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[Abstract:0659] OP-001 [Accepted:Oral Presentation] [Energy System Transition » Electricity]

Latin America can dispatch 100% renewable electricity by 2050 – the Colombian case

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Overview:The global transition towards 100% renewable electricity supply is easiest for Latin America. Though a big number of countries world round are committed to achieving net-zero carbon emissions in the energy sector by 2050 not many are pursuing full renewable-electricity dispatch. Latin America is mostly hydroelectric-based and could largely make this happen in the mid-term. However, it will be complex to sustain green-only power supply over the long run as the current hydroelectric facilities (with reservoirs) will be insufficient to take care of the intermittency of enormous amount wind and solar resources that will be in place in the future to come. As the learning curve of batteries is steep, these technologies will come to help. Moreover, some geothermal and biomass – more 'secure' supply sources – could complement the less intermittent sources available for more reliable electricity supply. A specific Latin America country may serve as an example for assessing the hypothesis of 100% clean power in the long run. This paper evaluates the feasibility of achieving a wholly green electricity supply in Colombia by 2050, considering: exchanges between energy regions, transmission infrastructure and the inclusion of a variety of new clean technologies such as geothermal, biomass and storage facilities. To investigate this, the manuscript presents a simulation model that captures the most relevant characteristics of the Colombian power system. The key finding of this paper is that, under alternative scenarios, some sources, intermittent or not, can provide cost-effective and secure 100% renewable electricity supply by 2050.
Methods:Scenarios, modelling and simulation
Results:The key finding of this paper is that, under alternative scenarios, some sources, intermittent or not, can provide cost-effective and secure 100% renewable electricity supply by 2050.
Conclusions:Energy transition towards 100% reneables is feasible in Latin America by 2050
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Keywords: Energy transition, modelling, renewables, Latin America

[Abstract:0304] OP-002 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Regional Analysis (South America)]

The Crossroads of Change: Latin America's Energy Dynamics and Global Impact

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Overview:In this concurrent session on Latin America energy issues, I will present a detailed exploration of Latin America's energy sector. The session is set to unravel the complex energy landscape of the region, focusing on its multifaceted challenges and pivotal role in the global shift towards sustainable energy. The presentation offers a comprehensive analysis of Latin America's current energy state, characterized by a unique amalgamation of vast renewable resources and significant fossil fuel reserves. This distinctive energy composition not only defines the regional energy strategy but also positions Latin America as a crucial influencer in global energy dynamics.

The presentation will delve into the critical economic, political, and technological factors shaping energy policies across Latin American countries. These include the impact of economic variances,

political transitions, and advancements in energy technologies on the sector's stability and growth. Further, it will explore potential pathways towards a more sustainable and resilient energy infrastructure within the region. Key aspects of this exploration include an assessment of ongoing renewable energy initiatives, the integration of advanced technologies, and strategies for enhancing regional cooperation and fostering international partnerships.

Moreover, the presentation will underscore the intricate interplay between local energy initiatives in Latin America and broader global energy trends. My aim is to illuminate the manner in which Latin America's energy decisions contribute to and influence the worldwide pursuit of a sustainable and environmentally responsible energy future.

The presentation is designed to provide attendees, including academics, industry professionals, policymakers, and energy enthusiasts, with a thorough understanding of Latin America's critical role in the global energy landscape. It seeks to foster a deeper appreciation of the region's unique challenges and opportunities, offering a nuanced perspective on its contribution to the global energy transition. The insights and discussions presented promise to be invaluable for those interested in the future trajectory of global energy policies and practices.
Methods:1.- Data Collection: Comprehensive gathering of recent data from various sources including energy production and consumption statistics, policy documents, and economic reports from Latin American countries.
2.- Comparative Analysis: Analyzing Latin American energy data in relation to global energy trends to understand regional peculiarities and impacts.
3.- Policy and Economic Analysis: Evaluating energy policies and economic factors in Latin America, including government regulations, market dynamics, and investment patterns.
4.- Technological Review: Investigating the adoption and impact of new energy technologies in the region.
5.- Stakeholder Interviews and Case Studies: Incorporating insights from key industry experts, policymakers, and case studies of specific energy projects in Latin America.
Results:1.- Energy Profile: Detailed characterization of Latin America’s energy mix, highlighting the proportion of renewable vs. non-renewable energy sources.
2.- Policy Impact: Analysis of how different policy frameworks across countries have shaped energy markets and technology adoption.
3.- Economic and Political Dynamics: Insights into how economic trends and political shifts are influencing energy stability and investments in the region.
4.- Technological Advancements: Assessing the progress and impact of new technologies in enhancing energy efficiency and sustainability in Latin America.
5.- Regional vs. Global Impact: Comparative analysis showing Latin America's energy decisions in the context of global energy trends.
Conclusions:Strategic Position of Latin America in Global Energy Transition: The presentation concludes that Latin America holds a strategic position in the global energy landscape due to its rich endowment of renewable resources and significant fossil fuel reserves. This unique energy mix offers both challenges and opportunities in the context of global energy sustainability.

Interplay of Economic, Political, and Technological Factors: The analysis emphasizes the profound impact of economic fluctuations, political stability, and technological advancements on the region's energy policies. These factors are crucial in shaping the future of Latin America's energy sector, influencing both regional and global energy markets.

Potential for Renewable Energy Development: The presentation highlights the substantial potential of Latin America in harnessing renewable energy sources. The region's progress in renewable energy projects, especially in solar, wind, H2 and hydroelectric power, is pivotal for global sustainability efforts.

Regional Integration and International Collaboration: Enhanced regional integration and international cooperation are vital for Latin America's energy sector to overcome existing challenges and fully realize its potential. This includes sharing best practices, collaborative investments, and technology transfers.

Recommendations for Sustainable Growth: Fostering stable, long-term energy policies, encouraging investment in energy infrastructure, and promoting research and development in renewable energy technologies as keys to sustainable growth.

Latin America's Role in the Future of Energy: Finally, the presentation posits that Latin America is not just a participant but a key contributor to the global energy transition, capable of influencing global energy dynamics through its decisions and developments. References:This presentation on Latin America's energy landscape draws on a diverse range of sources to provide a comprehensive and multi-faceted analysis. Key institutional sources include reports and datasets from major international and regional organizations such as the International Energy Agency (IEA), the United Nations, the Latin American Energy Organization (OLADE), the Economic Commission for Latin America and the Caribbean (ECLAC), and the International Renewable Energy Agency (IRENA). These organizations provide valuable data, policy analysis, and insights into energy trends and sustainability initiatives. Specialized literature, including academic journals, offers in-depth research and scholarly perspectives on energy economics, policy, and technological advancements in the Latin American region. Additionally, insights and current developments are supplemented by articles from reputable press and media outlets that cover the global energy sector, offering up-to-date information on political, economic, and environmental aspects affecting the region's energy dynamics. This amalgamation of institutional reports, academic research, and journalistic coverage ensures a well-rounded and informed view of the energy challenges and opportunities in Latin America, reflecting the latest developments and scholarly discourse in the field.

Keywords: Latin American Energy, Sustainable Development, Renewable Resources, Policy Dynamics, Global Impact

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[Abstract:0590] OP-003 [Accepted:Oral Presentation] [Energy System Transition » Investment Financing]

Decarbonization in the Brazilian Amazon: a roadmap for energy transition in remote communities

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Overview:According to the United Nations (2023), about 660 million people live without access to electricity, and close to 2 billion people do not have access to clean cooking. The challenge of achieving universal access becomes even more significant in the current context of climate change and the global rise in energy prices, impacting not only productive processes and service provision but also undermining user affordability. In this context, the International Energy Agency (IEA, 2023) projects that the achievement of universal access to modern energy by 2030, as established by Sustainable Development Goal (SDG) No. 7, would require US$ 30 billion per year in investments.

Specifically, SDG 7 aims to "ensure access to affordable, reliable, sustainable, and renewable energy for all." This goal qualifies access to energy in economic, technological, and energy efficiency terms. The importance of the quality of access to energy services is recognized in determining the conditions under which universal access should be achieved by 2030. However, this likely implies that the number of people lacking access to energy is even greater than the reported figures mentioned above.

Climate change further complicates the challenges of achieving universal access, requiring sustainable and renewable solutions. The rising prices of electricity pose additional hurdles, affecting the affordability of energy.

The Brazilian Amazon finds itself lagging in the pathway to a decarbonized economy. More than 200 remote communities are not connected to the main grid and are predominantly supplied by fossil fuel generation (EPE, 2023). In 2023, the total cost of using fossil fuels for power generation in remote communities reached approximately US$ 2.4 billion (ANEEL, 2023).

The use of diesel generators goes against the core principles of decarbonization efforts. Therefore, there is a pressing need for targeted interventions and user focused sustainable solutions that include productive uses of energy (World Bank, 2022).

To close the access gap in the Amazon, the Brazilian government launched the "More Light for the Amazon" (MLA) Program in 2020. Initially, the goal was to bring clean and renewable electricity to about 220,000 families by 2022. However, by 2023, less than 5% of families had access to clean energy (IEMA, 2023). Besides the limited success of government policies, the current scenario is plagued with subsidies.

In a recent effort to overcome these challenges, in August 2023, the federal administration combined the MLA and Light for All Programs, launched in 2003, and established December 2028 as the new deadline for reaching universal access in the Amazon region. The government's plans aim to not only connect remote communities but also to promote solutions to phase down fossil fuel or enhance efficiency in generation for communities that currently lack a connection or where it is economically and financially unfeasible.

Another important initiative towards universal access in the Amazon area relates to the legal commitment of Eletrobras, the largest Brazilian power company, to contribute US$ 500 million over 10 years to the Pro-Amazon Legal Fund. The fund's stated goal is to finance structural changes such as promoting clean energy for decarbonization and cost reduction of generation in remote areas.

In line with the investment commitment, Eletrobras, along with the Brazilian Economic and Social Development Bank (BNDES) submitted a United Nations Energy Compact in September 2021. The goal is to collaborate in solutions that promote the generation of renewable energy in the Amazon as a strategy to decarbonize the power matrix of Amazon's remote communities.

The existing policies and initiatives, while sharing common goals, lack a prioritization strategy for remote areas. These regions demand a targeted approach that recognizes their distinct circumstances. The absence of a specific ranking methodology or set of criteria for prioritization further compounds the challenge. Without a transparent framework, decision-makers may encounter difficulties in determining which remote areas should be addressed first.

To contribute to overcoming this challenge, the goal of this study is to propose a data-driven methodology to prioritize investments and to inform the design of a roadmap to fossil fuel phase-out in remote communities in the Brazilian Amazon. Following the literature on energy planning, as pointed out by Estevez et al (2021), our paper develops a multi-criteria decision analysis (MCDA) to address the challenges of selecting priority remote areas for investment.
Methods:In the paper we develop a prioritization strategy for decarbonization investments in the Amazon remote areas. The MCDA model is developed based on the following steps:

• Understanding the energy supply and demand scenarios in Amazon's remote areas considering economic, social, and environmental dimensions, as well as existing technical constraints.
• Identifying, listing, and assigning weights to the relevant criteria for investment prioritization.
• Collecting and integrating the most recent data across the selected dimensions.
• Developing an MCDA and assessing the robustness of results to changes in criteria weights and data.
• Ranking the Amazon remote areas for investment prioritization, considering the implications and limitations of the decision-making process.
• Validating and reviewing the results with stakeholders.
• The model outcomes will feed into an interactive dashboard to inform a prioritization strategy for investment in targeted Brazilian Amazon remote communities.

The modeling strategy and the dashboard development will make use of a set of databases that include socioeconomic microdata from surveys run by the Brazilian Institute of Geography and Statistics (IBGE), including the Brazilian Census, National Household Sample Survey (PNAD), and the Consumer Expenditure Survey (POF); energy sector information from Brazil's Energy Research Office (EPE), the Brazilian Electricity Regulatory Agency (ANEEL), and the Operator of the National Electricity System (ONS).

Results:Due to this study, the prioritization model and the dashboard will play a critical role in informing and guiding an investment strategy for decarbonization in remote Amazon communities. This tool will allow policymakers and investors to assess the resources required for each feasible alternative of a sustainable energy solution, considering the risk associated with each one and its contribution to closing the access gap.
Conclusions:To decarbonize remote communities in the Amazon, it is crucial not only to evaluate the resources required and the risks associated with diverse energy solutions developing a roadmap that delineates priority areas and their respective timelines. The dashboard proposed in this study aims to help policymakers and investors with a data-driven and strategic decision-making tool. This approach's purpose is to guide investments toward more impactful and sustainable initiatives to achieve universal energy access.

Finally, bridging the access gap in the Brazilian Amazon is also intricately linked to socio-economic development objectives. Access to reliable and clean energy can catalyze improvements in education, healthcare, and overall quality of life. Therefore, efforts to decarbonize the Brazilian Amazon should be viewed not only as an environmental imperative but also to promote social equity and sustainable development.

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Keywords: Energy transition, Decarbonization, Brazilian Amazon, Remote Communities

[Abstract:0164] OP-004 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Resource Endowments and Economic Performance]

The impact of critical minerals endowment on green economic growth in Latin America

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Overview:Achieving carbon neutrality by 2050 emerges as an urgent issue facing our planet to avoid the irreversible consequences of climate change and global warming. However, reaching this goal requires a profound structural transformation of the current global energy system, which is still heavily reliant on fossil fuels, towards clean and renewable energy. This is critical to green economy since energy-related greenhouse gas emissions, especially carbon dioxide, account for two-thirds of global greenhouse gas emissions (Srivastava and Kumar, 2022). Nevertheless, transitioning to a low-carbon economy demands a large amount of critical minerals necessary for producing clean energy equipment and technologies, such as solar PV, wind turbines, fuel cells, and storage technology (IEA, 2021; Zhu et al., 2022). This presents significant opportunities and challenges for mineral-rich developing countries such as Latin America (LA). On the one hand, abundant critical mineral endowment positions the LA region a potential global hub for manufacturing clean energy technologies (Katz, 2015; IEA, 2023b). On the other hand, given extractive industries' energy- and pollution-intensive nature, accelerated mineral production could lead to severe environmental degradation and adversely affect the well-being of local communities and inhabitants, ultimately threatening sustainable development (Papyrakis and Pellegrini, 2019).
Considering the factors discussed above, this study examines the effect of critical mineral abundance on green economic growth within the resource curse framework context. The contributions of this study are highlighted as follows: Firstly, the study is distinctive in its focus on analyzing the effect of critical mineral abundance on green economic growth, specifically in the LA region. Unlike most previous studies on the resource curse hypothesis, which predominantly focused on the effects of fossil fuel resource wealth (particularly oil) or mineral resource wealth without differentiating conventional minerals (like gold, silver, and iron ores) from critical minerals, this study distinctively focuses on the latter, which are essential for clean energy transition. Moreover, per capita green GDP is incorporated in this study as a proxy for green economic growth to explain more relevantly the negative externalities of environmental degradation. Secondly, the impact of critical mineral abundance on green economic growth was analyzed separately according to the specific types of critical minerals. Given its significant repercussions in promoting green economic growth, the results can provide valuable insights for policymakers in the LA region on which critical mineral production should be prioritized. Then, this study examined the threshold effect of mineral abundance on green economic growth to determine the conditions under which critical minerals can have favorable or detrimental effect on green economic growth. Lastly, this study identified the main mechanisms by which critical mineral abundance affects green economic growth. Understanding these mechanisms is crucial to working out effective strategies to harness the region's competitive advantages in critical mineral wealth for green economic growth in the region, which provides policymakers in the LA region with valuable insights on how to enhance or mitigate various transmission channels to achieve green economic growth.
Methods:Based on the resource curse hypothesis, the effects of critical minerals (copper, lithium, cobalt, and nickel) on green economic growth are examined in 10 mineral-rich Latin American countries from 2000 to 2020. Firstly, the effect of critical minerals on green economic growth is analyzed in disaggregated and aggregated terms. Subsequently, the moderating role of institutional quality is examined for influencing the effect of critical mineral abundance on green growth performance in these countries. After then, the non-linear effect of critical mineral abundance on green growth is analyzed, conditioned on the values of low-carbon technology exports as a percentage of GDP, fiscal balance, number of patents, non-conventional renewable energy capacity, and Gini Index using panel fixed-effect threshold regression. Lastly, the primary channels by which critical mineral abundance affects green growth in the Latin American region are identified using panel mediation analysis.
Results:The findings from our estimates are highlighted as follows: 1) In aggregate terms, critical mineral abundance contributes to increasing green growth, but its effect varies significantly depending on the type of each critical mineral. 2) when combined with critical mineral abundance, institutional quality is found to have no significant effect on green growth. 3) The effect of critical mineral abundance differs significantly depending on the values of each threshold variable. 4) Critical mineral abundance influences green economic growth through five channels in this study: exchange rate, renewable energy share in electricity capacity, fossil fuel dependency, government debt, and economic complexity.

Conclusions:In this study, a panel dataset of ten critical mineral-rich Latin American countries from 2000 to 2020 was used to analyze the impact of critical mineral abundance on green economic growth, based on the resource curse hypothesis. This study is the first to attempt to examine the impact of each critical mineral, separately—copper, lithium, cobalt, and nickel—to determine their individual effects on green growth. Then, the impact of aggregated critical minerals was examined to assess their joint contribution to green growth. The findings indicate that lithium and nickel significantly promote green growth, confirming a resource blessing in these cases. However, a non-significant or negative impact is observed for copper and cobalt, indicating a resource curse, particularly for cobalt. When considering the combined impact of all critical minerals, it positively influence green growth in the LA region, affirming the resource-blessing effect. Interestingly, the study could not find a moderating effect of institutional quality on the relationship between (aggregated) critical mineral abundance and green growth. However, it was found in this study that institutional quality itself significantly enhances green growth in the region. According to the fixed effect threshold regressions, the impact of critical mineral abundance on green growth is not linear or symmetric across countries. Instead, it varies significantly depending on variables such as each country's export share of low-carbon technology in total GDP, fiscal balance, innovation capacity (measured by the number of patent applications), non-conventional renewable energy capacity per capita, and level of inequality (measured by Gini Index). Specifically, countries with a high export share of low-carbon technology, better fiscal balance, and a high level of inequality are those where the abundance of critical minerals has a more substantial positive effect on green growth in the LA region. Conversely, countries with lower innovation capacity and non-conventional renewable energy capacity per capita are those where the positive impact of critical mineral abundance on green growth is more pronounced. Regarding panel mediation analysis, the results indicate that the primary mechanisms through which critical mineral abundance affects green growth are: exchange rate, renewable energy share in total electricity capacity, fossil fuel dependence (measured by fossil fuel rents), government debt, and economic complexity. Specifically, the exchange rate positively mediates between critical mineral abundance and green growth. This implies that indirect effect fully absorbs the direct positive impact of critical minerals via the exchange rate. In the case of fossil fuel dependence, a partial positive mediation effect is observed, reinforcing the direct positive impact of critical mineral abundance on green growth. Concerning the renewable energy share of total electricity capacity, government debt, and economic complexity, the estimates indicate a partial negative mediation effect for each variable, meaning that the variables partially offset the direct positive effect of critical mineral abundance on green growth. Despite the significant contributions of this study, there remain more rooms for further researches. Specifically, a more comprehensive measure of green growth is necessary, given that only economic and environmental dimensions are considered in calculating green growth using per capita Green GDP in this study. Future research can incorporate the social dimension into the calculation of green growth, emphasizing aspects such as equitable income distribution and inclusiveness. Additionally, the scope of environmental externalities could be expanded through further studies with more factors like the costs associated with natural disasters and water pollution. The period and the number of countries for the study need to be enlarged to include a broader range of critical mineral abundance on green economic growth. Lastly, the scope of further research on the roles of the digital economy and the circular economy need to be expanded to explore the potential mediation effects on the nexus between critical minerals and green economic growth. This is because their growing significance in green economic growth is expected to be considerable in the coming decades, mainly due to their potential to boost productivity and enhance material and resource efficiency (recycling of critical minerals).

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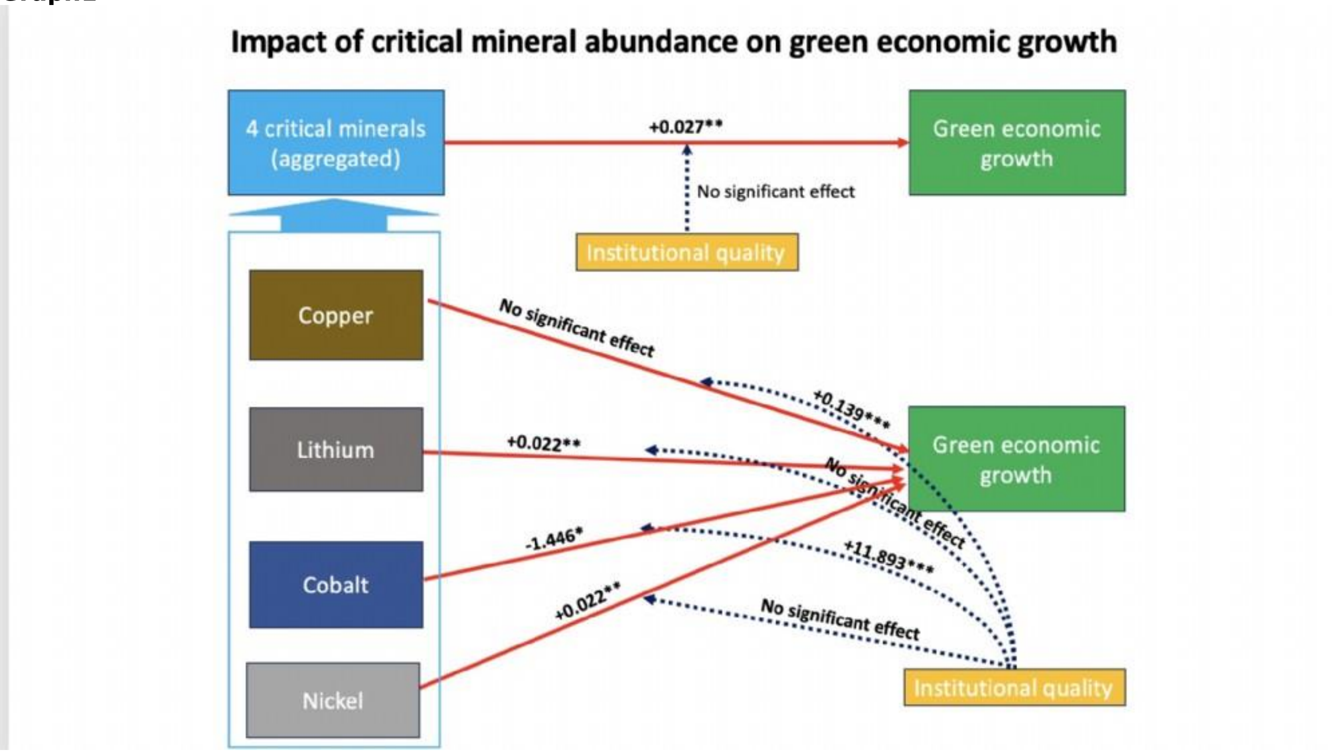
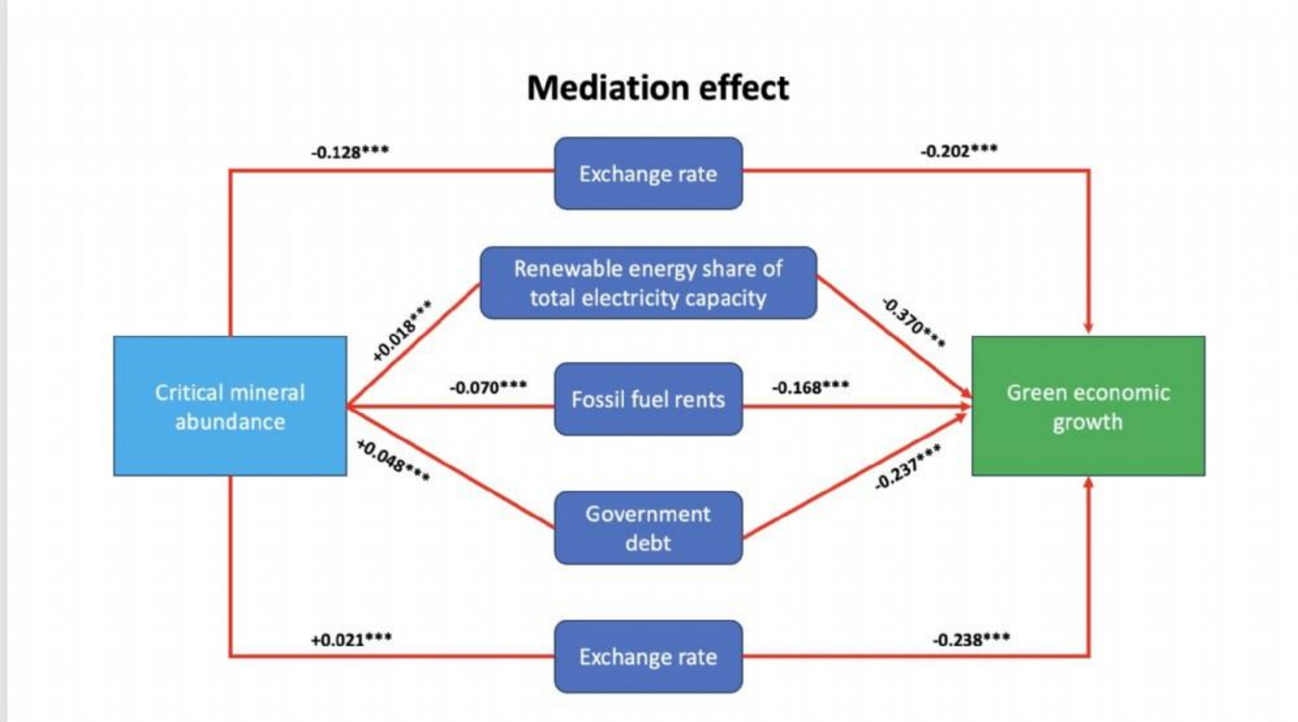
Keywords: Critical minerals, Green growth, Latin America, Resource curse, Mediation effect, Threshold effect

Graph1



Graph2



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[Abstract:0004] OP-005 [Accepted:Oral Presentation] [Hydrogen » R&D and Emerging Technologies]

Energy policy pathways to inform climate policy in Saudi Arabia

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Overview:At the 21st Conference of Parties (COP), 196 countries adopted a treaty to keep the average global temperature rise below 2 oC compared to pre-industrial levels. The temperature of interest is defined as the combined surface air and sea surface temperature averaged globally over a 30-year period. Modeled global greenhouse gas (GHG) pathways assessed by the Inter-governmental Panel on Climate Change (IPCC) (2022) imply global GHG reductions of 0.0 to 0.7 gigatons of CO_2 equivalent (CO_2e) per year on average from 2020 to 2030, and 1.4 to 2.0 gigatons of CO_2e per year between 2030 and 2050. For its part, Saudi Arabia announced its latest nationally determined contribution (NDC) to reduce GHG emissions in 2021.

In this work, we aim to show that a GHG emissions trajectory does not necessarily have to come about from prescribed energy policy that removes the use of fossil fuels in the energy system. It explores future energy policy pathways for Saudi Arabia and how they may further affect climate policy.
Methods:The KAPSARC Energy Model (KEM) is used to explore energy use in Saudi Arabia from 2019 to 2045. KEM is an equilibrium model that outputs least-cost or highest-profit decisions for various sectors in the energy system (KAPSARC, 2016). The decisions pertain to how the sectors meet their products' demands given a wide array of technological and fuel options. They may be broken down

into decisions on operations and investments. As a result of those decisions, the model will help us determine sectoral CO2 and CH4 emissions pathways.

We assess three main scenarios using a bottom-up energy system model developed for the Kingdom. First, a Baseline scenario is established as a reference for how sectoral activities and emissions will evolve over time considering no policy changes. Alternative scenarios are then compared to the Baseline. Scenario B examines the effects of the displacement of liquid fuels and renewable technology deployment in the electricity sector, in addition to fuel price reform that affects all sectors equally. These are two policies envisaged by the Kingdom. Scenario C takes the Baseline scenario and applies the energy-system-wide CO2 emissions that are estimated in Scenario B as a cap. Results:The total CO2 and CH4 emissions for the KEM sectors in the baseline scenario rises gradually from 415 million tons of CO2e in 2019 to 624 million tons in 2045. In 2030, the year of the NDC, 130 million tons of CO2e could be reduced through the implementation of the policies of Scenario B or through the imposition of the CO2 emissions cap in Scenario C. That is about half of the commitment made by Saudi Arabia. Baseline CO2 and CH4 emissions are the greatest for electricity, petrochemicals, and fertilizer production.

$50 billion in lower costs are exhibited by oil refineries and electricity utilities in Scenario C compared to Scenario B. The use of fuel oil for power generation in Scenario C declines by 85% by 2030 to 111 trillion BTU, compared to being fully phased out in Scenario B. This higher demand for refined products warrants more crude oil to be processed – and thus higher operational costs – in Scenario C. Still, the costs of the oil refining sector are higher in Scenario B due to higher imports of petroleum coke, a fuel that is demanded for cement manufacturing. Considering the lower use of fuel oil by domestic sectors in Scenario B because of raising fuel prices, operating the deep conversion units of refineries only to produce petroleum coke becomes less attractive. This is contrasted with no fuel price reform in Scenario C.
Conclusions:Our analysis produces three key takeaways:

One, the energy system can contribute 130 million tons of CO2e by 2030. This around half of the total NDC committed by the Saudi government. In Scenario B, the policy levers that result in this reduction are imposed on the energy system. In Scenario C, the differentiating actions compared to Scenario B include building out CCS-equipped combined-cycle power plants, more reverse osmosis desalination plants, and lower petrochemicals and fertilizers exports.

Second, a non-prescriptive scenario that caps energy-system CO2 emissions produces the same emissions reductions at a lower cost. The present cost by 2030 is reduced by $72 billion compared to Scenario B. The primary reasons for the cost reduction in Scenario C are that fuel prices are maintained at their 2019 levels, investment in the electricity sector is lowered by $25 billion in annualized terms, and less activity by petrochemicals and fertilizers plants.

Third, the value attributed to CO2 approaches 35 $ per ton of CO2 by 2045. This value helps the Kingdom attain the NDC target and beyond without facing the higher costs of the electricity generation targets and fuel price reform that are in Scenario B.
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Keywords: Energy policy, Saudi Arabia, energy systems modeling, greenhouse gases, CO2, power system

AuthorToEditor: Dear Scientific Committe for the 2024 IAEE International Conference, Thank you for considering our submission. Best, Walid

[Abstract:0050] OP-006 [Accepted:Oral Presentation] [Hydrogen » Policy and Regulation]

Mapping China's Hydrogen Energy City Clusters: Old and New Synergistic Effects

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Overview:With the growing energy crisis and environmental problems, all countries around the world are actively seeking sustainable energy sources in the future. Hydrogen, as a renewable energy, foster the progress of clean energy transitions due to its unique feature such as cleanliness and abundance (Ren et al., 2020; Zhang et al., 2016). Today, hydrogen is produced from a variety of energy sources, including two main categories: fossil fuels (i.e., coal and oil) and renewable energy sources (i.e., wind and solar) (Blanchette, 2008; Rosen and Koohi-Fayegh, 2016). Furthermore, the application of hydrogen is versatile and plentiful due to its high conversion efficiency, such as Hydrogen fuel-cell vehicles (FCVs) (Ren et al., 2020). Therefore, many countries are engaged in the development of hydrogen energy, with the main goal of achieving a leading position in hydrogen technology and facilitating environmental impact and the energy transition.
Globally, several countries have invested significant funds and resources in hydrogen research and development while implementing a range of public policies to promote the development and application of hydrogen energy. For example, the US Department of Energy (DOE) established a new specialized office to promote the development of hydrogen energy by integrating cross-sectoral and cross-application cooperation in 2002 (Solomon and Banerjee, 2006). In 2003, the U.S. government allocated $32 million for hydrogen generation research (Hoffmann, 2003).
Governments adopt cluster policy to promote innovation and productivity, thereby contributing to technological development and economic growth (Wolman and Hincapie, 2015). Typically, clusters are formed by the geographical proximity of cities (Acs et al., 2013). For example, Silicon Valley, as a successful geographic cluster, has become the center of high-tech innovation and development in the world. To take the lead in the race to commercialize hydrogen energy, the Chinese government approved five city clusters for hydrogen fuel cell vehicle demonstration in 2021 to foster the development of hydrogen industry and technological innovation. Over the past decades, China has invested significant efforts to develop and support clusters to promote national economic growth or facilitate the development of particular industries. For example, in order to promote the development of the national economy and urbanization, the central government approved the formation of three city clusters in the coastal areas due to their geographical proximity, including the Beijing-Tianjin-Hebei, the Yangtze River Delta and the Pearl River Delta regions. Moreover, the Chinese government approved 9 pilot city clusters to promote the dissemination of new energy vehicles (NEVs) and the development of new energy industry and innovation. This study intends to examine the synergies between old and new city clusters in China. In other words, we focus on how the previous geographically based and industrial city clusters have shaped the development trajectory of the policy of city clusters for hydrogen fuel cell vehicles.
Methods:social network analysis (SNA) and exponential random graph models (ERGM).
Results:We conducted a comprehensive analysis by collecting data on three types of city clusters: hydrogen city clusters, new-energy vehicle (NEV) city clusters, and city clusters based on geographic location. Our findings reveal that 22 out of 53 cities in the hydrogen city cluster also appear in previous geolocation-based city clusters. Meanwhile, we identified 6 cities in the Guangdong hydrogen city cluster that are also part of the Guangdong NEV city cluster, and another 6 cities that are part of both the Hebei hydrogen city cluster and the Hebei NEV city cluster. This is first likely due to the industrial facilities and infrastructure available in Guangdong and Hebei provinces, which provide an advantage for hydrogen technology development. Moreover, the distribution of the industry chain and industrial ecosystems in these provinces is conducive to boost the mobility sector and transportation industry, thus creating sufficient demand and key end-application scenarios for hydrogen. Interestingly, we found that 11 hydrogen cities are not part of either the geographical or the NEV city group. One possible explanation for their inclusion in the hydrogen city cluster is their leading yet unique strengths in the hydrogen industry chain. For instance, some cities excel across the entire industry chain (e.g., Zibo), while others specialize in specific aspects such as production,

storage, or distribution (e.g., Wuhai).

A further examination suggests that not all hydrogen city clusters are built on past geographically or NEV city clusters. We identified two distinct of cluster patterns. In some cases, hydrogen city clusters comprise a combination of member cities from previous clusters and new cities with complementary resources, allowing for full coverage of the industry chain. In contrast, other hydrogen city clusters are built around core cities that promote the development of the entire hydrogen industry chain by leveraging the unique strengths of each member city in terms of resources, technological innovation, production and distribution capabilities, and markets.

Conclusions:Given the significant status of hydrogen in response to climate change and energy crisis, this study provides a systematic analysis of hydrogen city clusters in China. Specifically, we analyze the formation of hydrogen city clusters while revealing how past city clusters have contributed to the development trajectory of hydrogen city clusters. This study aims to advance the understanding of cluster policy research by revealing how China's hydrogen city clusters were built on pre-existing geographic and industrial proximity between cities within the clusters while pursuing synergistic effects with less-connected cities.

Our analysis of three different types of city clusters and heterogeneous city networks reveals hydrogen city clusters that are formed based on hydrogen resource and innovation complementarity rather than pure geographic proximity or previous collaborations. The patterns of hydrogen city clusters exhibit features that are distinct from prior geographically based and industrial city clusters. While some of the cities within hydrogen city clusters are part of past city clusters, some smaller cities and remote districts are emerging in hydrogen city clusters as well. In some cases, full coverage of the industry chain could not be achieved even if member cities from previous clusters had established networks and accumulated experience of collaboration. Therefore, some hydrogen city clusters involve new cities with complementary resources to compensate for the shortage of hydrogen resources and technological innovations.

In addition, the outcome of the development trajectory of hydrogen city clusters reveals that core cities committed to the development of the entire hydrogen industry chain play a dominant role in the formation of hydrogen city clusters. Some hydrogen cities were established around core cities to facilitate the development of the whole hydrogen industry chain by integrating member cities' strengths in hydrogen resources, R&D and innovation, hydrogen equipment manufacturing, and the application market. These hydrogen city clusters can tackle the mismatch between hydrogen resources supply and demand by establishing inter-city supply chain infrastructure networks and promoting the spillover of hydrogen technology. Therefore, it is imperative for governments pursuing cluster policies to promote industrial development to rethink the development of cluster policies on the basis of uneven distribution of resources and different levels of scientific and technological development.

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Keywords: cluster, renewable energy policy, hydrogen, social network analysis, exponential random graph models

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[Abstract:0575] OP-007 [Accepted:Oral Presentation] [Hydrogen » Policy and Regulation]

Lifecycle GHG emissions assessment for ammonia production in the US, China, and Saudi Arabia

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Overview:There will be a significant market change for ammonia in the context of clean energy transition. IEA's projection under the 2050 net-zero target shows about 266 Mt of ammonia could be used for power generation and transportation (IEA 2021). IRENA's projection under the 1.5 °C scenario shows that 227 Mt of ammonia will be used for maritime transportation and stationary power, and 127 Mt of ammonia as a hydrogen carrier (IRENA 2022). The future demand for ammonia as a fuel and hydrogen carrier could be larger than the current market for ammonia combined, which reached 185 Mt in 2020 and around 70 percent of the ammonia is for fertilizers.
Hydrogen trade flows also raise new strategic considerations. The European hydrogen strategy and the targets of many EU member states are geared to place most of their support on renewable hydrogen production, while countries such as China, Korea, and Japan are supporting other low-carbon hydrogen routes as well. Countries with abundant renewable and/or fossil and CCS resources are looking to optimize the value of these attributes in destination markets. New hydrogen production centers and shipping routes are in the process of development, which will increasingly shape the geopolitics of energy transformation.
As the global energy transition deepens, rising concerns about embedded GHG emissions along the supply chain have sparked interest in using the lifecycle assessment (LCA) approach to track the carbon footprint and sustainability impact of hydrogen and ammonia.
Methods:To understand the impact of climate policies, such as the EU's CBAM, on major ammonia-producing economies, it is important to assess the differences in lifecycle GHG emissions of ammonia production. In this study, three countries are selected for case studies and comparisons, including the US, Saudi Arabia, and China.
Calculating lifecycle GHG emissions across supply chains is complicated and requires an unprecedented understanding of data needs, data availability, and data quality. To the extent possible, this study attempts to shed light on the potential magnitude of impact, however, it is not a detailed and comprehensive LCA study.

The technology and feedstock options for hydrogen production are the major driving factors for GHG emissions in ammonia production. To make the calculation and comparison simple, this study narrows the production processes to natural gas-steam methane reforming technology. We adopt "the point of production" method to define the system boundary. It includes the upstream segment associated with the natural gas extraction, processing, storage, and transport to the SMR plant, and the production segment ending at the stage that is ready for delivery to the customer. This is different from "the point of use" method, which considers downstream emissions such as storage, transportation, loading and unloading, conversion and supply.
Results:Based on the lifecycle assessment, the result shows that 2.22 tCO2e of GHG emissions are generated for one ton of ammonia produced in the US, 2.33 tCO2e for Saudi Arabia, and 2.88 tCO2e for China.
• China has the highest emissions in upstream natural gas extraction and processing, almost 4 times of Saudi Arabia. Ongoing efforts to reduce methane flaring and leaking have made Saudi Arabia the lowest in upstream GHG emissions. This leads to the major differences in lifecycle GHG emission assessment among the three countries.
• The US has the best energy efficiency performance in ammonia production. It only generates 1.82 tCO2e/tNH3, which is about 11% lower than China and Saudi Arabia. This can be explained by much less natural gas used as feedstock and fuel in comparison with China and Saudi Arabia.
• The carbon intensity of electricity has a modest contribution to overall lifecycle GHG emissions as the share of electricity in total energy consumption is not very significant. However, the impact of electricity consumption could become significant if carbon capture, utilization, and storage (CCUS) technology is included in the assessment.
Conclusions:Preparing domestic ammonia industries for calculating and reporting lifecycle GHG emissions is a forward-looking industrial strategy. Data availability and quality have been the major challenges for lifecycle GHG emission assessment. Continued research and data collection on emissions related to natural gas extraction and processing, electricity production, and ammonia production process is needed to improve the accuracy and reliability.
Near-zero-emission production methods are emerging, including electrolysis, methane pyrolysis, and fossil-based routes with carbon capture and storage (CCS). Analyzing and comparing the production cost of these options against the intervention of carbon tax would provide insights into the economic implications of global ammonia trading.
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Keywords: ammonia, lifecycle assessment, GHG emissions

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Emerging Energy Economics and Policy Research Priorities for Enabling the Hydrogen Sector

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Overview:-

We highlight key emerging research priorities for enabling the hydrogen sector using a three-pronged approach. It includes examining journalistic reports from a research perspective, corroborating the determined research priorities with recent literature, and consulting a diverse group of experts in policy, energy, economics, and industrial applications fields. We delineate nine overarching themes that correspond to distinct research challenges and prospects. Specific emerging research issues related to – (i) an analysis of the varied incentives and policy actions implemented by governments within the hydrogen industry; (ii) a comparative study of hydrogen applications across sectors such as hard-to-abate industries, power generation, and energy storage; and (iii) an examination of the strategies employed by developed nations to invest in hydrogen in developing countries – received particularly high scores, computed by integrating expert ratings on importance in enabling the hydrogen sector, novelty and feasibility using a multi-criteria decision-making framework. Pursuing this new research agenda should help inform policymakers, and industry decision makers to ensure a smooth ride towards hydrogen enablement.

Methods:-

We first derive overarching themes by summarizing and categorizing the wide-ranging scope of recent media investigations pertaining to the hydrogen sector reported in Bloomberg New Energy Finance (BNEF) news between March 2023 and August 2023. We start off with media reports as they frequently shed light on nascent industry, energy economics, policy, and sustainability issues before they are thoroughly examined in scholarly literature. This can be attributed to the delays inherent in securing research funding and the time-consuming peer-review process that characterizes academic publishing. Furthermore, media reports frequently incorporate perspectives from non-academic stakeholders, often underrepresented in scholarly articles. Finally, we delineate specific research challenges and priorities that require more thorough consideration by applying an energy economics and policy research lens (including academic and industrial) on the formulated emerging themes.

We solicit expert opinions to prioritize the identified research challenges surveying a diverse group of international experts in policy, energy, economics, and industrial applications fields. The participants were asked to evaluate the identified research challenges and opportunities using a Likert-type (one to five) scale, assessing their importance, novelty, and feasibility. The respondents were also asked to rate the significance of each criterion, i.e., importance, novelty, and feasibility, relative to one another. Furthermore, data was gathered pertaining to the professionals' affiliations with either non-profit or for-profit entities, their educational credentials, years of experience in the hydrogen sector, and their level of familiarity with the research subjects under examination in this survey.

The expert survey results were analyzed using a multi-criteria decision making (MCDM) framework. AHP (Analytic Hierarchy Process) (Saaty 1988) was used to calculate the weight scores for the three criteria – importance, novelty and feasibility – by having respondents make a series of pairwise comparisons. TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) (Hwang et al. 1981) was used to rank the different alternatives based on their normalized scores – a measure of the extent of similarity between alternatives and the hypothetical ideal solution (with importance, novelty and feasibility ratings of five each) - considering AHP-based criteria weights. Given the subjective nature of the expert survey, it would have been better to use AHP for both deriving weights for criteria and ranking alternatives. From a time perspective, however, requiring respondents to make pairwise comparisons between twelve alternatives appeared impractical. A sensitivity analysis was performed using three different schemes to calculate the weighted average of the ratings given by the experts for use in the TOPSIS framework, including: (i) equal weighting, (ii) experience-based weighting, and (iii) familiarity-based weighting.

Results:-

Table 1 displays the identified set of contemporary research challenges, their respective rankings based on the normalized AHP-TOPSIS scores, and the sensitivity of these rankings to the selected weighting scheme. Bold ranks indicate issues that scored the highest. Overall, the results are fairly robust as 3 out of 9 alternatives encounter a maximum change of two ranks only across three weighting schemes.

"Table 1 comes here"

Conclusions:-

This work systematically explores the multifaceted challenges and emerging research priorities pivotal for enabling the hydrogen sector. By delving into diverse themes, it provides a comprehensive analysis of the current state and future directions of research.

By employing three distinct respondent weighting schemes within the AHP-TOPSIS framework, we identify key emerging issues in enabling the hydrogen sector that are critical in terms of importance, novelty, and feasibility. Among the high-ranking research challenges that merit in-depth exploration include – (i) governments' incentive comparisons and actions in hydrogen industry; (ii) comparative analysis of hydrogen applications in industry, power generation and energy storage; (iii) developed nations' hydrogen investment strategies in developing nations.

While this study offers a broad overview of the issues at hand, it acknowledges certain limitations. The rapidly evolving nature of emerging issues in hydrogen sector implies that findings might require continual updates. Moreover, the reliance on expert inputs, although valuable, may not fully capture the diversity of perspectives in this global industry.

This work contributes to the field by offering a structured framework to analyze and prioritize research areas in the hydrogen sector. It bridges the gap between academic discourse and practical application. In particular, the delineated priorities could serve as a potential roadmap for guiding forthcoming research endeavors within both the industrial and academic domains. Research findings from such initiatives may yield practical recommendations for policymakers and industry stakeholders, consequently fostering the formulation of strategies aimed at expediting the emergence of a resilient hydrogen sector. In conclusion, the emerging issues identified through journalistic reports, a review of published literature, and expert consultations provide a solid foundation for identifying the imperative research priorities required to facilitate a robust hydrogen sector.

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Keywords: Hydrogen, Policy, Demand

Table 1: Expert ratings-based ranking of potential research challenges, considering 3 cases: (a) equal weights, (b) respondent experience-based weights, and (c) respondent familiarity-based weights. The rankings were obtained using the combined AHP-TOPSIS

Alternatives	Equal weights	Experience based weights	Familiarity based weights

Government Incentives and Actions in Hydrogen Development • Comparison of incentives across different countries and potential implications for competitiveness, investment attractiveness, and cost-effectiveness • How government actions can address European manufacturers' barriers to long-term hydrogen offtake agreements • Government targets for domestic net-zero technology manufacturing capacity, including electrolyzer production, and their potential impact on hydrogen competitiveness and investment attractiveness	3	3	1
Hydrogen Investments in Developing Nations: Developed Nations' Strategies • Funding mechanisms established by developed nations' state-backed firms to support hydrogen projects in Africa and Latin America to facilitate exports to developed nations and energy transition in the host countries • Cost, return on investment, and risk assessment for developed nation investors considering hydrogen projects in developing nations with high renewable energy potential • Impact of corporate governance scrutiny and rising global interest rates on clean-energy investments, particularly in developing regions like India, and the potential implications of these factors on the flow of investments in the hydrogen sector	1	2	3
Hydrogen Investment Trends, Valuations, and Funding Mechanisms • Trends and drivers of hydrogen project investment, and the types of financial instruments used like IPOs, equity, debt financing structures, and investment funds • Valuations and market dynamics of companies involved in hydrogen production, including IPOs, partnership agreements, and investment strategies	7	8	8
Global Hydrogen Trade: Opportunities, Dynamics, and Implications • Potential and opportunities for different countries to become major exporters of hydrogen and related products, including global competitiveness, renewable energy resources, and local and regional demand • Implications of importing hydrogen for countries like Germany and Japan, including the potential impact on energy security and energy prices • Market dynamics of the global hydrogen trade, including price fluctuations, market power of importing and exporting countries, and international agreements and partnerships	6	6	7
Hydrogen-Powered Vehicles: Policies and Strategies • How policies may affect the deployment of hydrogen combustion engine vehicles compared to battery electric trucks, given their tailpipe GHG and non-GHG emissions regardless of green hydrogen being carbon-neutral • China, Japan, EU, U.S., and industry players' strategies towards hydrogen combustion engine, fuel cell, and battery electric trucks and their effects on market growth and technology advancement • Techno-economic analysis of hydrogen-based shipping	5	4	5

fuels relative to other alternative fuels and CCS-coupled conventional fuels: production costs, infrastructure needs, and scale economies			
Hydrogen Transport Infrastructure: Pipelines and Seaports • Investment plans and financing options for the hydrogen cross-border pipelines, including the role of public and private funding, and the potential for European Union aid and incentives • African hydrogen seaport infrastructure: Cost benefit assessment for Africa and beyond, including the potential for increased trade and hydrogen integration into the global energy landscape	9	9	9
Assessing Hydrogen Potential for Industry, Power Generation, and Energy Storage • Comparative techno-economic performance and scalability of pilot-scale hydrogen testing compared to electrification or CCS-enabled fossil use in hard-to-decarbonize industries, identifying sector-specific challenges and opportunities • Benefits and risks of combustible hydrogen-fueled power generation, including the potential change in GHG emissions and air pollutants compared to (i) traditional fossil fuel-based power generation and (ii) renewable energy with other forms of energy storage, including the possibility of co-firing hydrogen and ammonia with fossil fuels for stand-alone or backup to renewable power generation • Techno-economic feasibility of hydrogen for energy storage, including the costs involved, the potential returns on investment, and the competitiveness of hydrogen in the broader energy storage landscape	2	1	2
Crafting Effective Hydrogen Policy • Cost-benefit analysis of limiting the proposed U.S. IRA hydrogen tax credit to hydrogen production from new, clean power sources only • Compare different countries' approaches to clean-energy tax breaks considering spending and debt constraints, analyzing the variations in policy design, effectiveness, and economic outcomes • Hydrogen policy design, including effects of prioritizing use in energy storage, heavy industry, and transport over heating homes and the proposed UK hydrogen levy on household energy bills to fund the hydrogen industry • Potential impacts of including hydrogen produced using nuclear energy in the EU's 2030 renewable energy targets, considering both the arguments for slowing solar and wind deployment and the benefits of nuclear power's emissions-free nature and stability	4	5	4
Electrolyzer Market Trends and Policy Impact on Manufacturing Landscape • Market trends and competitive landscape of electrolyzer production and deployment, including company and country involvement and global electrolyzer shipments • Policy role in shaping electrolyzer manufacturing landscape - incentives to attract private investment and trade policies' impact on domestic and international manufacturers' competitiveness	8	7	6

[Abstract:0543] OP-009 [Accepted:Oral Presentation] [Hydrogen » Policy and Regulation]

Optimal trajectories of low-carbon fuels within development versus deployment debate: the case of hydrogen

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Overview:The transition to low-carbon fossil fuels requires additional investments on the supply-side to reduce costs (the development phase) and also investments in infrastructure for usage renewal on the demand-side (the deployment phase). This paper analyses the impact of the infrastructure trajectory on the supply path of a low-carbon fuel, which substitutes fossil fuels already in use (e.g. thermal vehicle). By means of an analytical model of optimal control, the paper explores the price trend of a low-carbon resource subject to climate policies constraining the use of fossil fuels. The model brings insights into the necessary conditions of the timing when the infrastructure triggers supply in the most cost-effective way by enhancing cost reduction through learning-by-doing compared to the cost of the fossil-fuel usage. The cost of the new low-carbon fuel usage will be composed of the production cost and the distribution cost that will both determine the path of deployment of the low-carbon resource. The findings on the critical time-periods of deployment of the infrastructure can contribute to defining the optimal State support for network planning that will allow accelerating decarbonization.

The case study of the hydrogen economy is relevant to this topic. Transition towards hydrogen economy raises challenges especially in the transport sector. First issue, the total cost of ownership for fuel cell electric vehicles is higher than for conventional thermal vehicles; nevertheless, researchers expect large cost reduction for both vehicle and hydrogen production, triggered by the demand growth, through learning effects (Ruffini and Weil (2017), Gim and Yoon (2012)). Secondly, hydrogen deployment in the transport sector is subject to a classical chicken-and-egg problem. Utilization of fuel cell electric vehicles requires refueling station network whereas investment in this infrastructure is dependent on fuel cell fleet magnitude. This paper addresses the two issues, of production and infrastructure cost, to analyze the coordination pathway between fuel cell vehicle fleet increase and refueling station deployment. I relate to a recent literature raising the question of decarbonized economy through low-carbon hydrogen development (Creti et al. (2017), Alhage (2023), Kasser et al. (2023)).
Methods:A dynamic model is built based on Chakravorty et al. (2006, 2012), composed of two goods: fossil fuel-based vehicles (FFBV), xf, and fuel cell electric vehicles (FCEV), yh, perfectly substitutable. The total cost of ownership (TCO) of FFBV, cf, including purchasing cost and fuel cost, is supposed to be constant. Thermal direct carbon emissions accumulate in the atmosphere, at rate αxf, and their concentration Zt must not overshoot some critical ceiling cap, $\bar{Z}$. TCO of FCEV is composed of the sum of two elements: unit production cost ch(Yh) and unit cost of refueling chk(Kt). Production cost benefit from learning-by-doing and decreases with past production Yh. An indirect effect is then introduced, from the network deployment, by assuming that refueling cost is decreasing with the total number (Kt) of refueling stations (Meunier and Ponssard (2020). Finally, the unit cost of a refueling station cf is constant. The social planner program then writes in the following way:

Equation 1 (here)
Results:The model explores the speed at which FCEV can substitute to FFBV along the carbon price pathway, with multiple trajectories resulting from the evolution of FCEV production cost and refueling cost. The trade-off between investing in car manufacturing industry first and in infrastructure thereafter is here subject to a constant amount of subsidy. Methodologically, the impact of the infrastructure network is investigated by comparing FCEV transition path with the commonly used model without the indirect effect of the network. Empirically, the network effect slows-down or

accelerates the FCEV transition depending on the parameters of cost functions, which are key to set conditions of the optimal development of cars and the deployment of refueling stations. Some simulations considered at Figure 1 show that the highest cost reduction is attained by a policy of early network deployment (starting with 2025), yet the effects of this policy are more important than investing in car development starting with 2035 only; in the transition period 2025-2035, the effects are similar among the two policies, which might defend the preference of some governments to massively invest on the supply-side first and wait for the infrastructure in case of successful manufacturing policy. Interestingly, a similar effect is obtained in 2050 if we invest in car manufacturing only or investing in network in 2035 with lower subsidies remaining for car manufacturing, yet volumes are much lower than investing in network earlier. When infrastructure develops later (curve FCEV T2035), there are few substitutions of fossil-fuel cars by hydrogen-fueled cars, and the carbon emission cap is reached earlier than the network deployment initiated in 2025 (trajectory FCEV T2025 at Fig.1).

Fig. 1. Evolution of the unit cost of vehicles over time, function of the trade-off of investment in network or car building (here)

Conclusions:Low-carbon hydrogen being at an early stage of deployment, it is difficult to predict if it will become a general-purpose energy source for the transportation sector. Major physical and economic barriers to mass deployment of fuel cell hydrogen cars might persist over the coming decade, and could result in still small share in the sector energy consumption by 2040 (IEA, 2023). Therefore, it is essential to anticipate the possible emergence of low-carbon hydrogen for the vehicle market, such as to design the network deployment that will largely modify the refueling station infrastructure. Battery electric vehicles alone cannot decarbonize the transportation sector due to raw material scarcity, hence alternative ways investigated in this study are needed to revisiting car policy planning; this suggested to add to the traditional cost-reduction on the supply-side modeling the cumulative volume effect on the demand-side. The establishment of a robust dynamic hydrogen infrastructure will be crucial for its widespread adoption.

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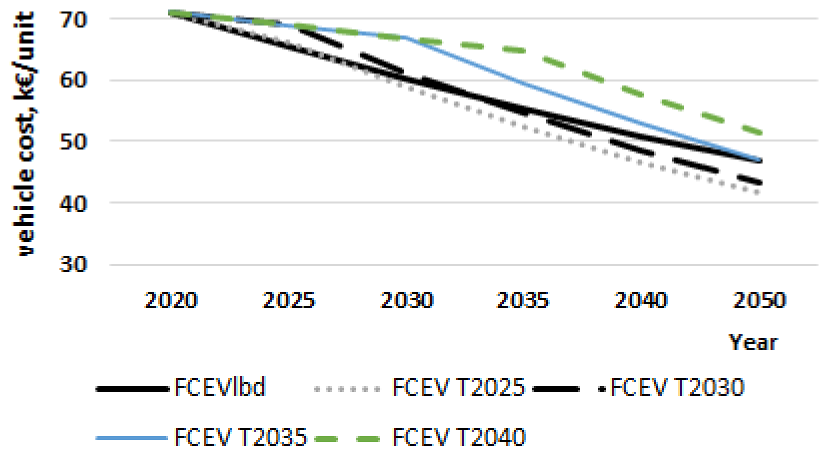
Keywords: Hydrogen, Fuel Cell Vehicles,Learning by doing, Network

Equation 1

$$\max_{\{x_f, y_h, k_t\}} \int_0^{+\infty} \left\{ u\left(x_{f,t} + y_{h,t}\right) - c_f x_{f,t} - \left(c_h\left(Y_{h,t}\right) + c_{hk}\left(K_t\right)\right) y_{h,t} - c_k k_t \right\} e^{-\rho t}\, dt$$

$$s.c.\ \ Y_{h,t} = \int_0^t y_{h,\tau}\ d\tau,\ K_t = \int_0^t k_\tau\ d\tau,\ \dot{Z}_t = \alpha x_{f,t},\ \bar{Z} - Z_t \geq 0$$

Fig. 1



[Page: 10]

[Abstract:0581] OP-010 [Accepted:Oral Presentation] [Energy Modeling » Other Econometric Techniques]

Optimizing the distribution of hydrogen production: Evaluation of centralized vs. decentralized approaches from an energy system perspective based on the case of Germany

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Workgroup for Economic and Infrastructure Policy, Technische Universität Berlin, Berlin, Germany

Overview:As a crucial element for the energy transition - especially in hard-to decarbonize sectors, hydrogen will most likely hold a key role in the European energy system [1]. With the REPowerEU plan aiming for a domestic hydrogen production of 10 Mt by 2030, member states are preparing for their own national hydrogen strategies [2]. Regarding the optimal distribution of hydrogen production sites however, discussion around centralized or decentralized production arises. Central production of hydrogen can benefit from i.e. high potentials of offshore wind energy. Furthermore, electrolysers can be used as a flexibility option, when electricity would otherwise be curtailed, especially in close vicinity to offshore wind power, where high wind speeds yield high capacity factors [3]. Decentral production close to demand sites on the other hand can reduce transportation costs of hydrogen substantially. Moreover, waste heat from electrolysers can be directly used in low-temperature industry processes or district heating for buildings [4]. In this paper, the influence of multiple techno-economic factors on the balance between central and decentral hydrogen production is to be analyzed with Germany as an exemplary case study. The results shall give insight into key indicators to decide whether a centralized or decentralized hydrogen production is more beneficial to the overall energy system and serve as a guideline for policymakers and stakeholders around Europe.
Methods:For this paper, the newest version of the Global Energy System Model (GENeSYS-MOD) is used for the optimization of the German energy system and the distribution of hydrogen production within the country. GENeSYS-MOD is a linear open-source energy system model minimizing costs to analyze low-carbon energy transition pathways. To represent a sector coupled energy system and reach deep decarbonization, the model considers the four sectors electricity, buildings, industry,

transport, and their interdependencies. A stylized version of the model's structure can be found in Figure 1.

As a setting and to follow the current hydrogen expansion plans of the EU, the most recent German policy developments, such as the Osterpaket and the coal and nuclear exit, are incorporated into the model, aiming to reach net-zero emissions by 2045. Furthermore, expansion plans for offshore wind capacities are included to enable the potential for centralized hydrogen production in the North and Baltic Sea. Germany is divided into its 16 federal states to take into account regional industrial demand sites and thoroughly analyze the distribution of electrolysers. To achieve a distinct representation of possible centralized hydrogen production, two offshore nodes (North Sea and Baltic Sea) are implemented in the model. This enables the assignment of specific time series, especially for offshore wind potential, whereas the potential of coastal federal states could be reduced in order to not overestimate the overall offshore wind potential. Furthermore, the two nodes are only able to build offshore wind and electrolyser capacities to analyze potential influences on the optimal distribution of hydrogen production. Sensitivity analyses in regard to transport costs of hydrogen and electricity as well as capital costs of electrolyers shall give more insights into the decision of the production sites.

Results:Preliminary model results favor a central production of hydrogen from an economic perspective, leveraging wind-power in the North and Baltic Sea. Hydrogen is then distributed across Germany via the existing gas-pipelines and towards 2050 increasingly via dedicated hydrogen pipelines. This is however to a great degree dependent on the chosen cost assumptions for the technologies and fuels. Production moves closer to the location of use (often regions with high industrial demand) when advancements, such as usage of heat from electrolysers, are added to the model. Sensitivity analyses further show an increasing decentralization with lower capital costs for electrolysers. However, more sensitivities on the transport costs of electricity and hydrogen are necessary to conclude the analysis.

Conclusions:We are expecting to see a change in the production distribution based on cost assumptions for transport of electricity and hydrogen, as well as capital costs of electrolysers. With the analysis of the sensitivities, specific break points in the cost assumptions are to be extracted and different price combinations are to be determined to give a first evaluation of when a central or decentral hydrogen production is most beneficial for the energy system. While a first estimate can be made however, more factors such as the distribution of industrial sites and overall renewable potential can be influential for the decision. Thus, further research on different regional cases is necessary. Furthermore, transnational hydrogen trade and production can greatly influence findings and should be carefully evaluated and researched in future efforts.

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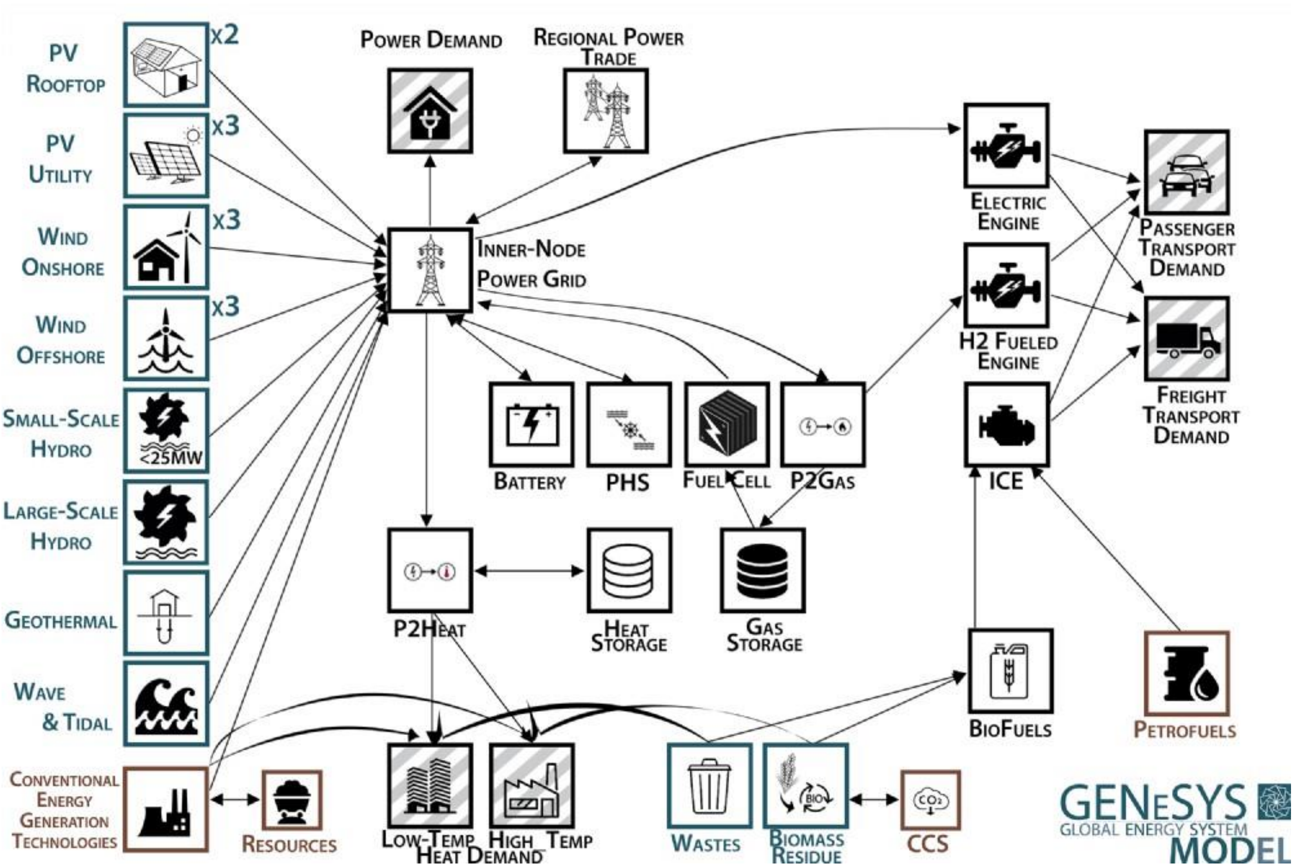
Keywords: Energy System Modeling, Hydrogen, Decarbonization, Energy Infrastructure, Electrolysis, Energy Policy

Stylized illustration of GENeSYS-MOD's structure



[Page: 11]

[Abstract:0156] OP-011 [Accepted:Oral Presentation] [Natural Gas » Policy and Regulation]

Charting the Path for European Biogas and Biomethane: A Comparative Policy Analysis

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Overview:The European Union's ambitious goal of achieving carbon neutrality by 2050, outlined in the 2019 EU Green Deal, requires a substantial overhaul of the energy system. While the primary focus is on increased electrification through renewables like wind and solar, biofuels and hydrogen also play crucial roles, especially in challenging sectors dependent on fossil hydrocarbon resources. The academic literature has predominantly explored hydrogen over the decarbonization potentials of biogas and biomethane. The REPowerEU Plan of 2022 emphasizes not only renewables but also renewable gases like hydrogen and biomethane, marking the need to increase their share in the EU's energy landscape. However, scaling up biomethane production faces challenges, requiring

investments, market access facilitation, grid connection, price signal improvement, EU-wide Guarantee of Origin system implementation, and sustainable feedstock mobilization [1,2].
The study evaluates European national policies supporting renewable gases, specifically biomethane and biogas, through a retrospective comparison of policies in Germany, Denmark, and Italy over a decade. It aims to identify effective policy designs and instrument combinations that promote low-carbon and renewable gases, aligning with the EU's decarbonization goals. The analysis explores whether renewable gas can benefit from regulatory approaches that have successfully reduced the cost of renewable electricity. Emphasizing the complexity of supporting biogas, the study underscores the need to consider the intrinsic nature of the energy vector and incorporate demand-side subsidies.
The research introduces a unique database from primary sources, offering an original perspective on country-specific biogas and biomethane production, filling a gap in the detailed analysis of the relationship between support schemes and deployment for biogas and biomethane [3,4,5].
The historical analysis of EU renewable gas policies from 2009 to 2019 reveals a significant focus on financial support for renewable energy in electricity generation. Despite historical gaps in support for developing renewable gases, particularly biogas and biomethane, beyond electricity production, the increasing number of operating plants highlights their potential role in the energy transition, aligned with the REPower EU plan [6,7].
Two streams of literature are identified in renewable energy policy development. One emphasizes economic efficiency and cost-effectiveness, primarily within a techno-economic framework, while the other, dedicated to optimal renewable energy policy design, underscores carbon pricing and subsidies as effective regulatory strategies supporting renewable energy sources (RES). In particular, existing literature on biomethane and renewable gas policies covers various areas, such as implications for biomethane production, single-country or sector policies, socio-economic assessments, and the effectiveness of supporting mechanisms in decarbonizing the energy sector across EU Member States. Other topics include supply chain dynamics, spatial planning's impact, heat utilization optimization, infrastructure competition, and potential hazards of promoting biogas. A broader study examines the evolution and balance of policy mixes over time. Despite the multitude of proposed strategies at both national and EU levels, the review highlights a lack of comprehensive understanding regarding the dimensions of biogas policies and their specific influence on production and usage, to create a robust market driver for renewable gases [8-15].
The paper highlights a gap in understanding the complexities arising from implementing a mix of policies and emphasizes the need for a multifaceted approach beyond technologies, considering infrastructures, market arrangements, and social practices. The study introduces a comprehensive framework for evaluating policy impacts on biogas and biomethane support trends, bridging the knowledge gap and assessing scheme performance in the context of public policy objectives and broader policy and economic frameworks.
Methods:The research employs Gustafsson and Anderberg's model as a guiding framework to critically appraise the evolution of biogas and biomethane policies [16]. The study delves into the dimensions and characteristics of European biogas policies through an extensive review of policy overviews, literature, and documents. A harmonized database with historical data from 2010 to 2019 is created to trace the evolution of the domestic biogas and biomethane sector. The evaluation extends beyond production metrics, encompassing a comparative examination of national biogas policies and their developmental trajectories. This approach is then utilized to analyze various biogas and biomethane policies and support trends in three Member States selected based on their established biogas production and recent policy developments.

The chosen countries, among the top biomethane producers in the EU, are Germany, Denmark, and Italy. The analysis focuses on their evolution in the context of policy support, aiming to understand the interplay between policy frameworks and the observed developments in the biogas and biomethane sectors. The study justifies the selection criteria, considering not only market maturity but also diversity in production levels and feedstock utilization. Other developed markets like the UK, France, Sweden, and the Netherlands are excluded as case studies due to reasons such as the absence of biomethane targets, less dynamic development expectations, specific market characteristics, or highly favorable support in Italy's case. The data collection involves an in-depth analysis of policy evolution and the creation of a harmonized database from publicly and non-publicly available sources, ensuring precision, coherence, and timeliness aligned with the study's objectives.
Results:Until the early 2000s, the sector primarily relied on biogas from energy crops, high feed-in tariffs (FIT), and electricity generation via combined heat and power (CHP) units. However, a shift has occurred towards a model emphasizing biogas upgrading to biomethane injected into the grid, diversification of feedstocks, and subsidy reduction. The transition from FIT to feed-in premiums (FIP) and from CHP to grid injection aims to create a more competitive market and broaden the utilization of renewable gases. The policy approach reveals fluctuations in market development, with Germany experiencing a stall from 2012 to 2014, Denmark facing a downturn since 2015, and Italy encountering a stall since 2013, with a timid uptake of biomethane post-2018 Biomethane Decree.

A comparative analysis across the three countries shows a transition from FIT to FIP and then to auctions and tenders as supporting schemes for biogas and biomethane. The findings indicate that providing incentives on the supply side effectively reduces risks linked to initial investments and market establishment, as the installed capacity of biogas and biomethane responded positively to increased policy support and declined when support decreased. However, they also underscore disparities among countries in incorporating demand and end-use considerations into their policies and the need for a strategic, long-term vision and a flexible policy ecosystem to effectively navigate the dynamic landscape of renewable gas markets. To this end, Denmark and Italy are highlighted as positive models with clear strategic visions, championing the use of biogas for waste management and transportation, showcasing the importance of aligning policies with overarching goals, and adapting to changing market conditions. Additionally, the results emphasize the impact of factors such as feedstock availability, along with the geographic and economic structure of a country, on shaping the development of a market for renewable gases. Conclusions:The study delves into the dynamics of policy support and deployment efficiency for biogas, biomethane, and renewable energy sources, focusing on the electricity production sector. It identifies a lack of comprehensive support, market perspectives, and policy frameworks, hindering the establishment of a harmonious EU-wide framework for biogas and biomethane deployment beyond electricity production. Challenges such as production costs, competition with cheaper natural gas, and lower economic support compared to other renewable energy sources impede the sector's development. The findings stress the importance of considering the entire value chain and end-use applications, subsidizing demand-side initiatives, acknowledging varying Member State approaches, and adopting flexible policies to address evolving market conditions.

The retrospective comparative analysis covering the period 2010–2019 reveals a connection between policy changes and the success or setbacks in biogas/biomethane evolution among Member States. Successful deployment is associated with a holistic approach, emphasizing end-use applications, and subsidizing demand-side initiatives to synergize and extend benefits beyond decarbonizing electricity production. The study identifies similarities in supply-side incentives across Member States, particularly in risk reduction for initial investments and market creation. However, differences emerge in creating self-standing markets, especially in accounting for demand and end-uses. The research emphasizes the influence of geographic and economic structures, feedstock availability, and the need for a more comprehensive policy approach that considers both production and end-use perspectives in the development of renewable gas within the EU energy system. Sustainable production, incentive gain sharing, renewable portfolio standards, Guarantee of Origin, and the role of biogas and biomethane in the circular economy, especially amid the evolving energy landscape following the conflict in Ukraine, are all under-researched issues that demand attention.
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Keywords: renewable gas, biomethane, biogas, policy mix, subsidies, comparative analysis

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[Abstract:0187] OP-012 [Accepted:Oral Presentation] [Natural Gas » Policy and Regulation]

Assessment of the Local Content and Local Participation Around the Natural Gas Discoveries in Tanzania: A case Study of Songosongo and Mnazi Bay

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Overview:Most of the current developmental projects in Tanzania on natural resources has been established basing on their national/macro-economic impacts and environmental impacts with little attention to the understanding of the nature/ways of lives of the local community. We understand that lately there has been a movement of resource rich countries to incorporate local content component in their policies so that local people can really benefit from the sector. Tanzania is not an exception following its local content policy as featuring in the Petroleum Act of 2015, which put forward that; a maximum engagement of local content and local participation in the development of the oil and gas industry is important to ensure optimum benefits to Tanzanians. The major gas developments involves offshore platforms, a substantial supply to send materials to the platforms, a terminal to receive the gas, and an LNG plan with export facility. These are all large projects with local content implications at the construction stage and the ongoing operations stage. Methods:Descriptive and Inferential Analysis with the objective of this study is to find ways in which Local community can benefit from the opportunity offered by their natural resources in this case the Oil and Gas (as stipulated by the Tanzania natural gas policy, 2013).

The study was conducted in three districts in Lindi and Mtwara Regions. The districts are Kilwa and Mtwara Rural in which the Songosongo and Mnazi Bay Natural Gas projects have been established. A baseline survey is planned in each of the study area, one in Kilwa for Songosongo and the second one in Mtwara Rural for the Mnazi Bay natural gas project.

The data collection was done in ten (10) villages in Mtwara and Lindi Regions, within two (2) districts, namely Mtwara Rural and Kilwa Districts. In each of the ten villages, a random sample of 20 households were subjected to a questionnaire, making a total of about 207 households. The household were sampled from the list of households available at the villages and were evenly distributed within the 20 subvillages that were covered. In view of this, the sample was representative enough.

Results:The following findings are worth noting:

i) The household head has been predominantly male with most of the household heads emanating from the villages. Migration and emigration seem to be insignificant in the study area with acceptance to both seems to be 30 and 10 percent respectively. This indicates the stability of the population composition.

ii) Fishing and agriculture are still and by far the dominant economic activities in the oil and gas discoveries sites. Both agriculture and fishing are for subsistence (50.7 percent) and for sale (49.3 percent).

iii) Local participation on average is only about 17 percent, with over 80 percent who do not participate on oil and gas activities. The potential and significant local participation is impeded by lack of qualification. Most of the villagers are involved in the most casual duties. While the primary school enrolment is on the rise, very few proceeded with the secondary education. Majority seems to remain in the street, casual labour or household chores for the girls (VEO, Mtawanya Village). Most of the villages do not possess the required qualification to be directly employed in the oil and gas project.

iv) There is Social Corporate Responsibilities (SCR) by oil and gas companies. However, these differs diversely between Mnazi Bay and SongoSongo discoveries sites. These leaves much room for complaints between these two major gas discoveries in Tanzania.

v) The perceptions and expectation of the local people was very high at the onset of the discoveries. However, the study found that they have been met only by 8 percent while over 80 percent are unmet.

vi) The promotion of local capability by the oil and gas companies is also very low. While many reasons could explain this, but significantly, it is due to the initial conditions in which the oil and gas companies found it difficult to promote ownership, participation, financing etc. It is only about 2.4 percent who have received training of any form by the oil and gas companies.

vii) There have been some steps taken by villages to promote entrepreneurship for the villages. In some villages groups were formed, and proposals were written to TPDC to solicit funds, but none of these have been funded (VEO, Mangamba Chini)

viii) The amount given to support the villages on the maintenance of the pipeline is small given the work that is involved.

ix) There is a need for the training on the administration of funds given to the villages for the maintenance of the pipeline by TPDC.

x) There is also a need for intervention on training on possible supporting activities such as mechanics, plumbing for the villagers in order to be assured on direct employment at the oil and gas industries as supporting staff.

xi) There are some unfulfilled promises. Example, in Msimbati they were told electricity would be free like in SongoSongo, but currently they are paying for electricity.

xii) There is lack of required skills in Mtwara to take advantage of the jobs advertised in the oil and gas industries and the related industries such as DANGOTE Cement Industry.

Conclusions:The Natural Gas Policy 2013 defines local content as "value added brought to Tanzanians through activities of natural gas industry. These may be measured and undertaken through employment and training of local workforce; investments in developing supplies and services locally; and procuring supplies of services locally". Additionally, Tanzania Petroleum Act, 2015 and National energy policy 2015, have provided a more specific definition of local content as "the quantum of composite value added to, or created in, the economy of Tanzania through deliberate utilization of Tanzanian human and material resources and services in the petroleum operations in order to stimulate the development of capabilities indigenous of Tanzania and encourage local investments and participation".

It has been observed that most of the current developmental projects in Tanzania on natural resources has been established basing on their national/macro-economic impacts and environmental impacts with little attention to the understanding of the nature/ways of lives of the local community. The main motivation of the study was the desire to come up with baseline information on local communities around the gas discovery areas for the local content provisions under the Petroleum Act 2015, the Energy Policy 2015 and the Natural Gas Policy 2013 among others to be achieved. A total of ten (10) villages selected purposively in Mtwara and Lindi Regions, within two (2) districts, namely Mtwara Rural and Kilwa Districts was used. In each of the ten villages, a random sample of 20 households was subjected to a questionnaire, making a total of about 207 households. The

household were sampled from the list of households available at the villages and were evenly distributed within the 20 sub villages that were covered. Qualitative and quantitative research designs were employed to generate data.
The study has found out among others that, the local participation and local capability on average is very low with the former being only about 17 percent. This calls for immediate intervention on enhancing these attributes as they are the core for a successful local content. Only 8% of people's perceptions and expectations were met. Government needs to come up with ways of managing people's expectations to avoid possible conflicts as the one that happened in 2012 in Mtwara region. The Social Corporate Responsibility (SCR) by the oil and gas companies seems to be very diverse between Mnazi Bay and SongoSongo. It was further discovered that fishing and agriculture are still the dominant economic activities in the area despite the oil and gas operations. However, none of these seems to supply the output to the oil and gas related industries. Few local businesses that are linked to the gas companies indicates inadequate capacity of these businesses to supply local goods and services in the petroleum subsector

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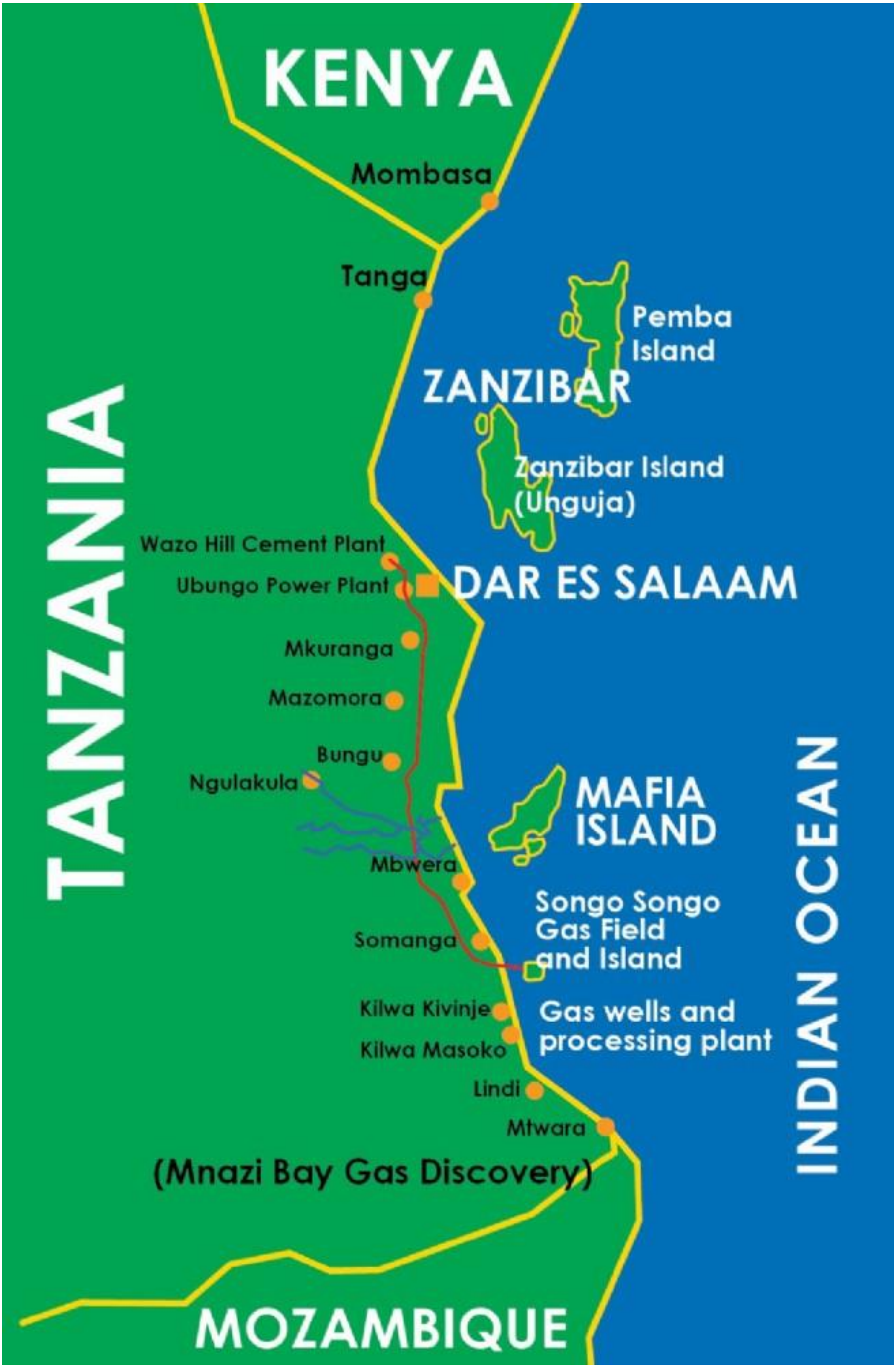
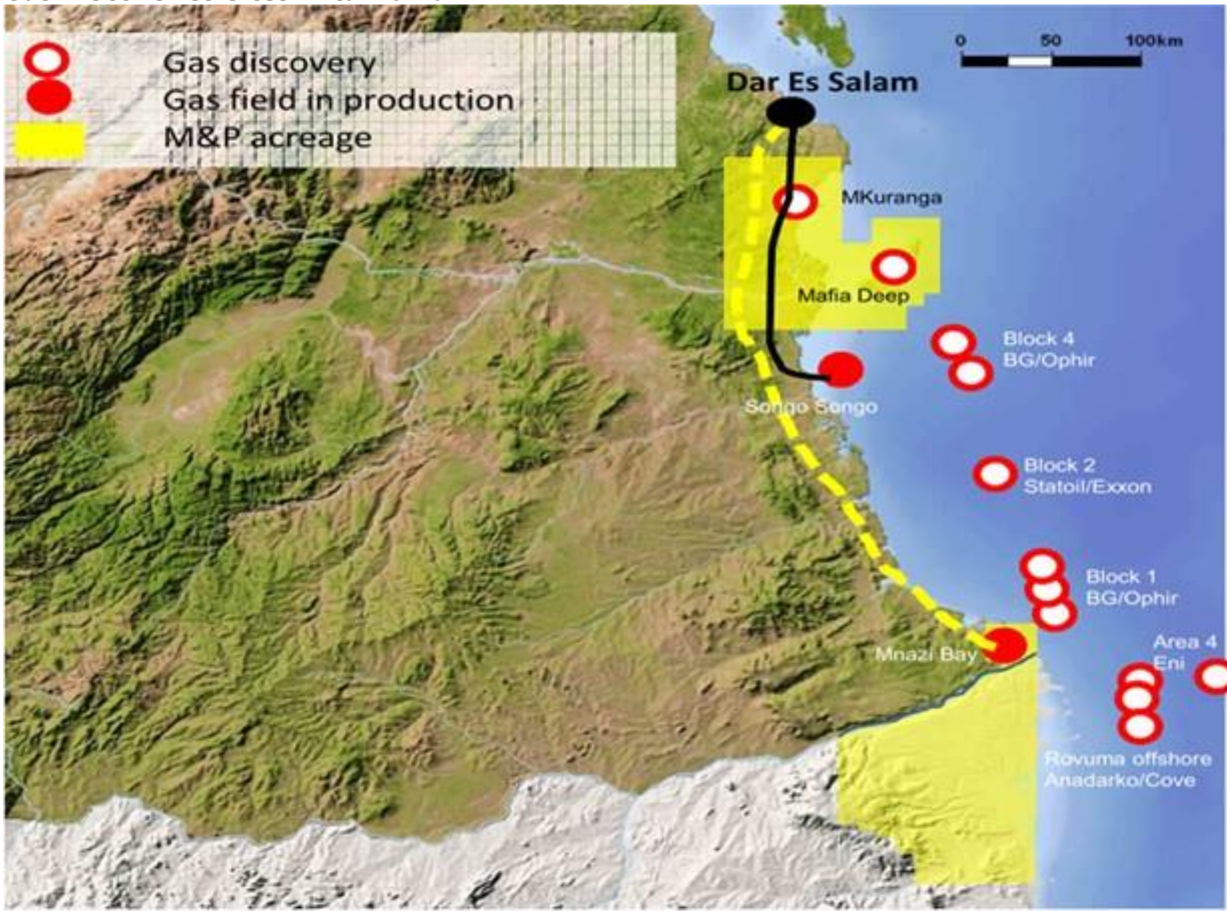
Keywords: Local Content, Local Participation, Local Capability and Local Capacity

Gas Discoveries Sites in Areas


KENYA
Mombasa
Tanga
Pemba Island
ZANZIBAR
Zanzibar Island (Unguja)
TANZANIA
Wazo Hill Cement Plant
Ubungo Power Plant
DAR ES SALAAM
Mkuranga
Mazomora
Bungu
Ngulakula
MAFIA ISLAND
Mbwera
Songo Songo Gas Field and Island
Somanga
Kilwa Kivinje
Kilwa Masoko
Gas wells and processing plant
Lindi
Mtwara
(Mnazi Bay Gas Discovery)
INDIAN OCEAN
MOZAMBIQUE

Gas Discoveries Sites in tanzania



[Page: 13]

[Abstract:0507] OP-013 [Accepted:Oral Presentation] [Natural Gas » Policy and Regulation]

Joint gas purchasing in Europe: How could it change the market competitive forces?

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Overview:The European Union has adopted the joint purchasing of gas to mitigate the risk of security of supply and lower gas prices and volatility, exacerbated by the Russia-Ukraine conflict. The major focus of the initiative is to reinforce the buying conditions of European gas buyers by pooling their gas demand. The European Commission announced that the initiative underpinned by the establishment of an aggregation platform ("Aggregate EU") delivered very good results, after four tendering rounds in 2023. The Aggregate EU platform allowed to aggregate and match more than 43 bcm of gas, based on the most competitive offers from suppliers (European Commission, 2024). Despite this matching, the negotiations between buyers and sellers and the resulting gas transactions

are conducted outside the Aggregate EU platform. The joint gas purchasing remains on a voluntary basis. So far, there is a lack of transparency and feedback on the contracts concretely signed after the negotiation process, as well as on the impacts of this mechanism on the prices (Barnes, 233; S&P Global, 2023).

In this context, this paper scrutinizes the potential implications of the joint gas purchasing on the market forces by considering not only the buying conditions of buyers but also other factors that shape the European gas market structure and affect prices. These factors are analyzed based on Porter's five-forces framework, which argues that market structure and the level of prices and benefits that suppliers can reap are shaped by five competitive forces: i) barriers for new entrants to the market; ii) power of suppliers; iii) power of buyers; iv) threat of substitutes and v) intensity of the rivalry between existing competitors (Porter, 2008)

Methods:Porter's Five-Forces framework has been largely applied to assess the competitive environment of a specific industry and evaluate the threats and opportunities for a player in the market, including in the oil and gas business (Ali et al. 2017; Yunna, and Yisheng 2014; Hokroh 2014).

In this paper, the Porter's Five-Forces framework is used first, to analyze the structure of the European gas market, with regards to the Porter's Five-Forces. Afterwards, it is applied to assess how the joint gas purchasing can act on these forces, and potentially affect gas prices.

Results:The analysis showed that the European gas market is still largely affected by the forces that enable sellers to achieve high prices, particularly the high power of suppliers, the low power of buyers, and the moderate intensity of rivalry between suppliers.

The joint purchasing mechanism would reduce the power of suppliers and increase competition between them by attracting new and additional supplies and offering sales opportunities through demand aggregation. But this effect will largely depend on the response of suppliers, their contracting approaches, and the volume of gas purchased through the mechanism, given its voluntary nature.

Furthermore, the joint purchasing mechanism would improve the market power of buyers, but to the extent to which buyers are willing to cooperate amid their perceptions of the complexity of implementing the mechanism, its impact on their gas operations and existing contracts, and the compliance with competition rules.

Conclusions:he application of Porter's five-forces framework showed that the assessment of the various forces shaping the European gas market structure is critical in appreciating the implications of the joint gas purchasing mechanism. Although the mechanism's core objective is to enhance the power of buyers through demand pooling and joint purchasing of gas, its success will depend on how it will influence other market forces in Porter's framework.

In general, the mechanism can affect the various market forces to achieve lower gas prices, but this will depend on the complexity of its implementation, the concrete volumes that can be aggregated and purchased through it, and the behaviors of both buyers and suppliers, particularly in the context of tight gas market conditions.

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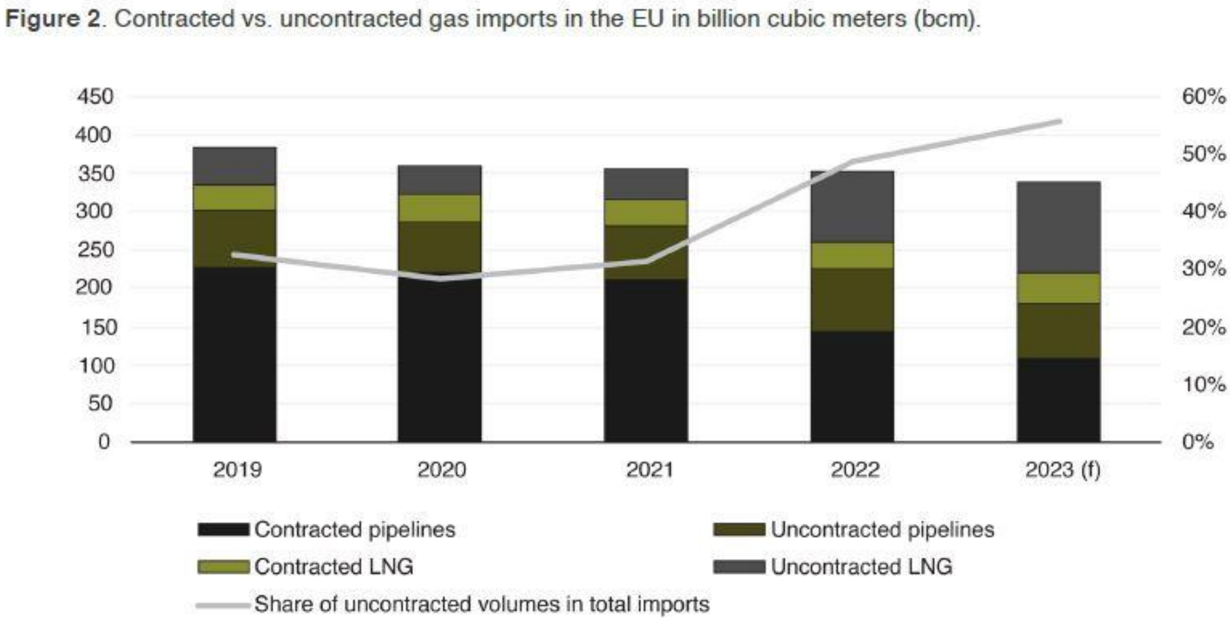
Keywords: Natural gas, joint purchasing, Europe energy security, competitive environment, Porter's five force

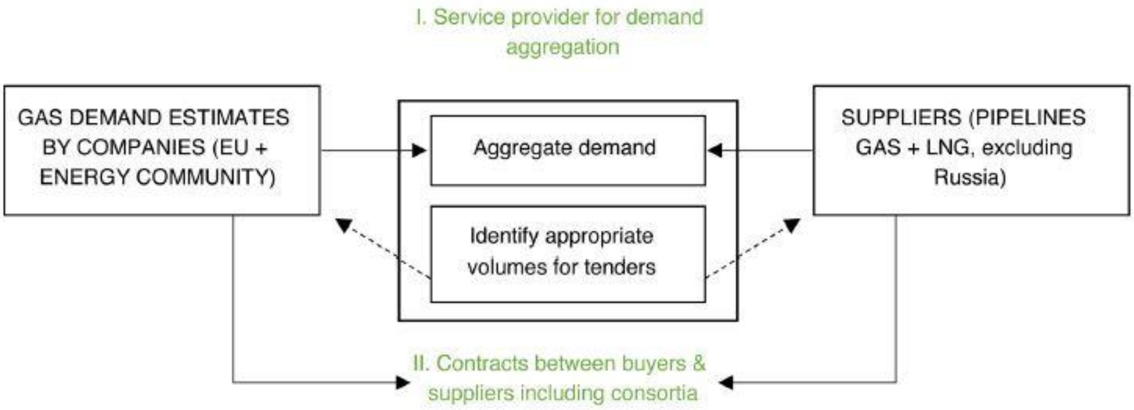
Figure 2. Contracted vs. uncontracted gas imports in the EU in billion cubic meters (bcm).



Assessing the market barriers is a critical step in the Porter's framework. One indicator of the decrease of the market barriers is the increased flexibility on European gas markets reflected in the share of uncontracted import volumes (volumes not associated with firm medium-or long-term contracts and purchased on a spot/short-term basis), in European gas imports.

How Does Joint Gas Purchasing Work?

Figure 1. Demand aggregation and joint gas purchasing.



Source: European Commission 2022d.

The figure explains how does the joint gas purchasing works? There are two main steps through which the proposed mechanism is implemented. First, gas demand is aggregated from buyers in the EU and Energy Community countries (e.g., Albania, Ukraine) through a service provider contracted by the European Commission. This demand is matched with offers from suppliers (excluding Russia) responding to gas procurement tenders organized by the service provider. Second, gas buyers conclude purchasing contracts, individually or in a coordinated manner, with the suppliers having submitted their offers to match the aggregated demand. Negotiating and contracting with suppliers are carried out separately outside the platform.

AuthorToEditor: Please find below a summary of my background. I'm a Fellow in the Oil and Gas program at Kapsarc with two decades of experience in the oil and gas industry. Before joining Kapsarc, I worked as Energy Policy and Environment Analyst at the Gas Exporting Countries Forum. I have been monitoring energy policies and environmental developments worldwide and evaluating their impacts on energy prospects. I also worked at a major Oil and Gas Company, where I have been delivering strategic analyses and insights; evaluating business opportunities and supporting the strategic planning process of the company. My areas of expertise include: gas market developments; energy modelling; assessing policy impacts; strategic analyses and business evaluations for oil and gas projects. Among my main interests is assessing energy market developments and the role of hydrocarbons in the energy transition. I hold a Bachelor in industrial Engineering and a Master’s in Energy Economics. I also have an MBA in Energy and Sustainability.

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[Abstract:0350] OP-014 [Accepted:Oral Presentation] [Natural Gas » Other]

The role of natural gas in the transition to low-carbon and reliable power generation

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Overview:The power generation sector is a strategically important area for natural gas as it accounts for around 35% of the total natural gas demand. In the global power generation mix, this fuel is the second largest source: while the share of coal has decreased from 41% in 2013 to 36% in 2022, natural gas has remained stable in the 22-23% range since 2008. At the same time, the role of gas-fired power generation varies significantly at a regional level. Making up over 70% share on average in the Middle East, natural gas supplies only 11% of electricity in Asia Pacific. In this context, natural gas offers a strong opportunity to accelerate the energy transition in this region.

Natural gas is expected to be favoured in many countries when it comes to power generation due to the rise in electricity demand as well as government policies and regulatory initiatives to phase out coal-fired capacity. Increasing penetration of natural gas against coal can be optimal CO2 mitigation option because it allows to reduce emissions in competitive and sustainable ways. Moreover, the expansion of gas-fired power generation is a good response to the rising requirements for power system flexibility and backup support amid the emphatic development of variable renewables.
Methods:This study reflects the GECF Global Gas Outlook 2050 reference case scenario and highlights the evolution of the global primary energy mix and global power generation mix, taking into account current energy policies, technology developments and the potential introduction of new policies that are likely to materialise throughout the period to 2050 (1). All the projections are carried out in the sophisticated modelling tool GECF Global Gas Model – a hybrid model that utilizes econometric and linear programming techniques using time series dating back to 1990.

With the main goal to assess the potential of natural gas demand growth in the power generation sector through to 2050, this study will also examine long-term electricity demand perspectives, the future power generation mix in different regions as well as main determinants, specifically the costs of generating electricity as well as energy policies adopted in key markets. Additional attention in the study will be paid to CO2 emissions perspectives from power generation.
Results:Natural gas continues to receive a high level of policy support. The share of this fuel in the global primary energy mix is projected to increase from 23% today to 26% in 2050. This ascending trend is mainly thanks to the rise in natural gas demand in the power generation sector, driven by strong growth in electricity needs and policies to phase down coal-fired power generation capacity. At the regional level, the biggest contribution to gas-in-power demand increase is expected to come from Asia Pacific where coal-fired power generation currently dominates, and Africa where energy poverty is still high.

In line with projected growth of the final electricity demand, global electricity generation is set to increase almost 1.8-fold from 28,890 TWh in 2022 to over 50,600 TWh. Concurrently, the global power generation landscape is on the cusp of a profound transformation as it shifts towards low-carbon energy sources. The combination of natural gas and renewables is set to account for the most to the total electricity supply by 2050.

The need for flexibility mounts amid the rapid deployment of solar and wind capacity, and natural gas-fired power generation is expected to play a growing role in helping to balance variable renewables, and ensuring stability of power grid systems. It provides a backup when hydropower supply faces drought-induced shortages. The demand for natural gas as a flexible and dispatchable source is forecast to persist across all regions, even considering anticipated progress in storage technologies.

Furthermore, carbon capture, utilisation, and storage (CCUS) technologies are poised to gain momentum, with natural gas-fired power plants expected to be equipped with CCUS, primarily after 2030, contributing to low-emission electricity.
Conclusions:The electrification of the global energy system is poised to become a prominent trend in the ongoing energy transitions. Simultaneously, the power generation sector will continue to be at the forefront of CO2 mitigation efforts. This can be tapped through the switching to less carbon intensive fuels, improving energy efficiency of power plants or the deployment of renewables. Natural gas as the cleanest burning hydrocarbon can support both anticipated electricity demand growth and decarbonising the power generation sector.

With the increasing integration of intermittent wind and solar energy sources, the importance of flexibility has grown significantly in ensuring the security of electricity supply. This flexibility can be sourced from various options, including conventional power plants, enhanced grid infrastructure and cross-border connections between countries and regions, advanced energy storage technologies and demand-side response measures. While battery capacities are expected to experience substantial growth and can contribute to flexibility to some extent, they are less suitable for addressing seasonal and long-duration storage requirements.

Given these considerations, dispatchable, low-emission generating capacities are anticipated to play a central role in providing the necessary system flexibility. Among these options, natural gas-fired power generation is expected to maintain its position as the primary choice. It is poised to serve as a vital partner to renewables, ensuring the stability of power supply in many countries.

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Keywords: Gas-fired power generation, natural gas demand, coal-to-gas switching, decarbonising the power sector, power generation, CCGT

[Abstract:0646] OP-015 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Energy Security]

The EU's vulnerability to gas price and supply shocks: The role of mismatches between policy beliefs and changing global gas markets

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Overview:Agencies and researchers have attributed the unprecedented surge in EU gas prices to a temporary convergence of exogenous shocks, especially the post-Covid economic recovery and the war in Ukraine. This paper argues that deeper issues are also in play, which go beyond the current conjuncture: the "policy beliefs" underlying its energy policy have made the EU unable to swiftly change policy approach in the face of rapid structural changes in international gas markets. By adopting the Latent Dirichlet Allocation (LDA) model, the paper extracts thematic information from EU legislation and executive acts and shows evidence that domestic market competition still dominates the EU energy policy agenda over energy security, making the EU unable to address the recent phase of shortage in international gas markets. The paper shows how EU gas markets have changed in recent years, also as a result of EU liberalization policies, and how international markets have changed. It emerges that European markets have lost their previous advantages in terms of security of supply and stability of price, while other international importers are now able to secure greater gas volumes, making the EU increasingly vulnerable to price and supply shocks. This vulnerability is interpreted as deriving from the contractual and infrastructure flexibility that was introduced by liberalization policies to increase market competition, which proved beneficial for EU importers in the previous phase of abundance (2014-2020), but that is contributing to destabilize EU gas markets in the current phase of scarcity (2021-2023). Methods:We utilized the Latent Dirichlet Allocation (LDA) algorithm (Blei, 2012; Blei et al., 2003) to identify topics within our dataset. The latter is made of EU legislative and executive acts collected on EUR-Lex, the official database of EU legal documents. LDA is a general topic modeling method, a Bayesian statistical algorithm for extracting thematic information from textual data. Topic modeling originates from machine learning research and could be characterized as principal component analysis for text. It is a probabilistic topic model capable of analysing extensive text datasets that would be impractical for manual review by researchers. It effectively distils large blocks of text into coherent topics, each associated with a set of specific terms. As such the LDA is ideally suited to automatically identify the topics in our set of documents. It treats each document as a mixture of topics and allows ordering the documents in decreasing order by the proportion of document containing a specific topic. This feature allows us to identify the documents with highest proportion of specific topic. The search yielded 389 documents, which were downloaded in PDF format. Each document was then screened to manually exclude those that (i) were not relevant to natural gas, such as those which refer to other kinds of gas (such as regulations concerning manual lighter gas, greenhouse gas thresholds, components of motor vehicles using compressed natural gas), or

concerned aspects of natural gas that are not relevant to this paper (such as safety of offshore oil and gas operations); or (ii) had no substantive content (such as public calls for tenders for selection of gas suppliers, or notices of application for a licence to prospect for oil and gas). 148 documents remained, on which the textual analysis was performed.
Results:From the textual analysis, it emerges that the categories (1) Market competition, and (3) Internal market, dominate EU energy policy. By contrast, categories (2) Energy security, and (4) Import market, are not emphasized as much. While energy security has received slightly more attention over time, the tools conceived to tackle it are once again all internal to the EU and its Member States. In addition, they are inspired by the principles of market competition or minimal public intervention in the economy. Therefore, strategies to intervene on the import markets, from which 97% of supplies reach the EU, have been very limited, and when developed, they were inspired once again by the principle of market competition. For example, the promotion of LNG at the expense of import pipelines, and the incentive to shift import pricing to the floating hub-indexation at the expense of fixed pricing, were an attempt to reduce market power of traditional non-EU exporters and increase competition among them.
Conclusions:By conducting a textual analysis through the Latent Dirichlet Allocation (LDA) algorithm, we have analyzed the EU legislation and executive acts of the last 25 years. We find that the liberalization of the domestic market has been the main priority, while energy security and the external dimension of the import market have received limited attention. The paper suggests that liberalization policy, and more generally the EU policy approach, has left the EU vulnerable to changes in energy markets, and especially international trends of increasing demand and decreasing supply of natural gas.

This was done through an analysis, supported by data extracted from leading databases, on the implications of gradually replacing fixed-price long-term import contracts with hub-indexed spot prices, and of promoting LNG at the expense of pipelines as import infrastructure. The analysis suggests that contractual and infrastructural flexibility has enhanced domestic market competition and has succeeded in reducing final energy prices in the previous phase of international abundance (2015-2020). However, with the advent of shortage in 2021, contractual and infrastructural flexibility has exposed the EU to global competition for energy procurement, as previously secured volumes and prices started to be put into question by the demand from other consumers, particularly in Asia, causing record-high prices.

This suggests that regulation should be rethought to some extent to suit periods of abundance as well as periods of scarcity (Cardinale, 2019; 2023). And yet, despite the current situation of emergency, and although the need for a major change has been strongly advocated by industry and citizens, this is occurring to a limited extent. For example, the latest measures adopted to contain the crisis do not reflect substantial changes as compared to previous approaches, nor do they show full awareness of the domestic and global causes of the crisis.

In our interpretation, the consolidation of beliefs that reinforced a policy paradigm emphasizing domestic market competition at the expense of energy security was made possible by the persistence for decades of international conditions of stability, which are now coming to an end (Cardinale and Landesmann, 2022). In other words, the EU is now challenged by some emerging economies whose path to industrialization has recently led them to become major gas consumers, and thus EU competitors on the market for gas import. The abandonment of long-term contracts, vertical integration, and energy diplomacy shows that energy security was taken for granted and no major global transformations were envisaged. This miscalculation is exposing the EU energy sector to a condition of vulnerability.

Reconciling the objectives of market competition and energy security can be challenging, as the two can often stand in a trade-off with each other. This is especially true in import-dependent countries and in periods of shortage, while constraints are loosened in periods of abundance. The reconciliation of these objectives becomes even more challenging in a context of governance in which EU's and Member States' jurisdictions over the market for gas import overlap, with each expressing sometime divergent policy approaches and interests in the energy market. The development of a coherent and effective EU energy diplomacy may be an initial step in the process of EU multilevel governance harmonization. However, this is challenging as it requires reconciling procurement needs, degrees of vulnerability, and foreign energy policy approaches of Member States first, while also considering the diversity of principles and interests between the EU and non-EU producing countries. And yet, the benefits would be systemic, as diplomacy's very aim is to align cross-country interests, and this can help achieve long-term gains in periods of stability and reduce losses in periods of crisis. Understanding the complexity of these issues would require extensive further research.

Lastly, if the EU is to acquire full jurisdiction on foreign energy policy, it should develop a strategy of energy diplomacy that considers the economic, political, and cultural differences of non-EU counterparts, which often do not share the same interests and approaches to regulation as the EU. Understanding their viewpoints without giving up domestic interests would potentially create the conditions for the EU to regain its recently deteriorated advantages in international gas markets. This would in turn contribute to reduce cost competitiveness gaps vis-à-vis major industrial competitors such as China and the US, who benefit from lower energy prices.

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Keywords: Energy security, Energy crisis, Liquefied Natural Gas, Pipeline gas, Long-term contracts, EU energy policy beliefs

AuthorToEditor: The paper is under revise & resubmit (minor revisions) by the journal Energy Economics, and has attracted interest among policymakers and in the energy industry for its policy relevance and the insights on how to potentially change the course of the EU energy crisis, by tackling its deep causes. In light of the nature of this contribution, and the potential interest by a wider audience of academics, policymakers and industry leaders, I will be keen to present the research results or discuss them in one of the Conference's general sessions (if this fits also the vision and interest of the conference's organisers)

[Abstract:0627] OP-016 [Accepted:Oral Presentation] [Energy Modeling » Energy Supply]

Probabilistic analysis of power generation costs for 2050 carbon neutrality in the power sector of South Korea

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Overview:In December 2020, South Korea declared its 2050 carbon neutrality goal and by October 2021, it established the 2030 National Greenhouse Gas Reduction Target (NDC), aiming for a 40% reduction in emissions by 2030 to achieve this objective. This study focuses on the power sector, highlighting the need for significant changes in the energy sector, as emphasized by the Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report (AR6). In Korea, the energy sector accounted for 87.2% of total emissions in 2019, with power and heat generation contributing 41%. The 2050 carbon neutrality scenarios propose two paths: Scenario A aims for maximum emission reduction including the cessation of thermal power generation, while Scenario B incorporates carbon capture, utilization, and storage (CCUS) technologies. Both scenarios anticipate a substantial increase in renewable energy generation to meet the rising electricity demand due to electrification across various sectors. The study aims to project generation mix, energy consumption, greenhouse gas emissions, and generation costs for the years leading up to 2030 and 2050 using

our internally developed METER-POWER model. It also explores an alternative scenario involving an increased share of nuclear power, considering its potential role in achieving carbon neutrality. The study intends to provide a quantitative analysis of generation costs under different carbon neutrality scenarios, incorporating deterministic and probabilistic approaches to address uncertainties in cost factors.
Methods:This research employs the METER (Model for Energy Transition and Emission Reduction) model, specifically its power sector model, which is a partial equilibrium hybrid model targeting the energy supply and consumption sectors. Developed using the General Algebraic Modeling System (GAMS), the METER model simulates repetitive market settlements in the energy market until an equilibrium of electricity production costs and prices in the power sector, and demand in sectors like industrial, transport, commercial, and residential, is achieved.
The power sector component of METER is designed to satisfy externally set electricity demands, such as those outlined in the Basic Plan for Power Supply and Demand, while optimizing facility investments, generation by different sources, fuel usage, and greenhouse gas emissions for the lowest total system cost from 2017 to 2050, within specific technical and policy limits. This is executed via a bottom-up linear cost optimization approach. The Reference Energy System (RES) in the power sector is a process where electricity is produced from fuel inputs through power generation facilities. The model includes various technologies like traditional and renewable energy, retrofit generators, Carbon Capture and Storage (CCS), and Energy Storage Systems (ESS).
The greenhouse gas reduction aim for the power sector in accordance with the 2030 Nationally Determined Contribution (NDC) is to cut emissions by 44.4% from 2018 levels, targeting emissions of 145.9 million tons post-reduction. This goal is incorporated only in scenarios A and B among three carbon neutrality scenarios, with scenario C calculating the maximum emission reduction potential by easing 2030 constraints.
Scenarios A and B in the 2050 carbon neutrality outlook both significantly cut back on fossil fuel-based power, expanding renewable and hydrogen power generation. The primary distinction is that scenario A completely stops fossil fuel power for zero emissions in the power sector, whereas scenario B retains some fossil fuel power (LNG), allowing for some emissions. Scenario C extends from scenario B's main assumptions, incorporating increased nuclear power capacity and usage. The 2030 power generation composition in scenarios A and B adheres to the latest Basic Plan for Power Supply and Demand, while scenario C is determined by cost optimization, with no specific constraints for 2030 except those related to nuclear power.
Initially, a deterministic evaluation of the generation mix, facility mix, energy usage, and emission trajectories for scenarios A, B, and C is carried out. Then, a selection of uncertain parameters from the deterministic model is used for random number generation in Monte Carlo simulations. The probabilistic assessment involves methods to either retain or reestablish carbon neutrality pathways based on the deterministic model. In maintaining pathways, the deterministic model’s power generation technology traits and the generation mix and emission trajectories for scenarios A, B, and C are kept constant, while random numbers are generated for uncertain CAPEX and fuel costs to derive distributions of total generation costs and average generation prices over 10,000 runs. For renewable energy and new technology CAPEX, annual predictions are used due to limited historical data, whereas fuel costs are based on a single forecast from a chosen optimal probability distribution, given extensive historical data.
When redrawing carbon neutrality pathways, the deterministic model's power generation technology features, the premises of scenarios A, B, and C, and the 2050 greenhouse gas reduction goals are kept. However, each scenario's cumulative emissions from 2023 to 2050 are set as constraints, with 3,285 MtCO2eq for scenario A and 3,103 MtCO2eq for B and C. By altering CAPEX and fuel cost inputs to generated random values, diverse carbon neutrality pathways are developed through cost optimization. The study presents a variety of system cost and average generation price pathways, determined after more than 100 iterations.
Results:In a deterministic model, the energy mix, consumption, capacity, and greenhouse gas emissions for carbon-neutral scenarios A, B, and C were analyzed, along with total generation costs and their breakdown. Initially, fuel costs dominate until 2030 (2034), but later CAPEX becomes more significant due to a shift from traditional thermal to renewable energy sources. In scenario A, using LNG without CCS, carbon costs peak in 2040, while in scenarios B and C, which retain LNG emissions, costs persist until 2050. Cumulatively, from 2021 to 2050, scenario A incurs the highest costs, followed by B and C, with about a 10.7% cost difference between A and C.
Annual costs also follow the A > B > C pattern, with A and B diverging post-mid-2030s and C remaining the cheapest. The average cost per unit of electricity increases until around 2030 for A and B, peaks around 2040, and then decreases, while scenario C remains lower even in 2040.
The study also included a Monte Carlo simulation with 10,000 runs using fixed trajectories and uncertain variables, showing that scenarios A and B's costs gradually decrease towards 2050, while C's costs consistently rise. All scenarios show a cost spike around 2030, likely due to increased ammonia fuel costs with ammonia co-firing.

The distribution width of average generation costs widens by 2050 for all scenarios, reflecting increased uncertainty and volatility in CAPEX, especially for renewables and new technologies. By 2050, the differences between scenarios A and B grow due to diverging energy mixes, while scenario C remains the most cost-effective.
Redrawing carbon-neutral pathways for the scenarios 100 times with random input parameters showed lower average generation costs in the 2030s but within the same range by the 2040s and 2050s. This suggests that selecting cost-minimizing technologies annually can better control input parameter uncertainties over the modeling period.
Conclusions:This research employed the METER21 model, a bottom-up linear cost optimization approach, to assess generation sources, energy use, greenhouse gas emissions, and infrastructure development paths under the 2030 NDC and 2050 carbon neutrality goals, examining the impact on generation expenses and average generation prices per scenario. The findings show a gradual annual increase in average generation prices since 2019, contradicting the common belief that transitioning to carbon neutrality will necessitate significant yearly increases in electricity prices. Analysis using both deterministic and probabilistic methods revealed that Scenario C presents less fluctuation in average generation costs compared to Scenarios A and B. This indicates that enhancing the use and extending the operational life of existing nuclear plants, along with restarting paused nuclear projects, can mitigate the impact of CAPEX and fuel cost variability while working towards carbon neutrality. Scenario C also showed the lowest average generation costs during the study period, attributed to its lower CAPEX and fuel expenses. This study uniquely illustrates the effects of augmenting nuclear power on generation costs amidst the shift to carbon neutrality, offering valuable insights for policymaking. Nevertheless, it notes the unavoidable uncertainty in choosing probability distributions for ambiguous parameters in the Monte Carlo simulation, partially addressed by incorporating expert opinions and estimates from credible sources.
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Keywords: power sector, carbon neutrality, bottom-up model, energy system model, probabilistic analysis, power generation cost

[Abstract:0181] OP-017 [Accepted:Oral Presentation] [Energy Modeling » Energy Demand]

Impact of electrification and smart energy management on grid infrastructure

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Overview:Increased electrification of heating systems in the residential sector will lead to an increase in electricity demand, which will most likely necessitate additional investments into grid infrastructure. In this work, a 2 case studies of an urban area are conducted where the energy demand of each building is modeled. By developing scenarios on the uptake of electrified heating systems, PV installations, battery storage, and smart energy management systems, potential necessary investments into the grid infrastructure are calculated. This is done by a two-stage modeling approach. First, the heating, cooling, and electricity demand of all residential buildings in the respective area are calculated. Then, the electricity demand is provided to a second model, calculating the necessary distribution grid infrastructure to support this demand on a granular spatial level. Results will show how the increase of heat pumps and PV systems can put additional stress on the electric grid and how smart energy management devices at the single household level could help alleviate some of this stress.
Methods:First the information of buildings and the grid layout in the area is collected using Open Street Maps (OSM) [1] and open building Databases (eg. URBAN3R [2] and 3Dbag [3]). The information of building location and adjacent wall area and ground floor area is calculated using the shapefiles from OSM while information on building age and height is obtained open building Databases. Industrial buildings, Sport centres and other large buildings not marked as such in either of the datasets are manually removed from the dataset. Sheds and other non-residential very small buildings are excluded by excluding buildings with a ground floor area less than 45m2. For the remaining buildings data on the building properties is mapped from a national building database underlying in Invert/EE-Lab building stock model. This is done using the building age and

classification such as single-family building, row house or apartment block. In a next step, the electricity demand of all buildings is modelled with different appliances installed. Appliances include photovoltaic installations, battery storage, domestic hot water storage, heating system, air conditioning systems and a smart energy management system. To save computational recourses it was decided to cluster the buildings (using K-means++) within the area into representative buildings using the thermodynamic properties of each building together with its floor area. Each building is simulated and optimized once using the 5R1C approach described in the DIN ISO 13790. The objective function of the optimization is to reduce energy cost of the building, increasing possible PV self-consumption and given a variable electricity tariff, also reacting to the electricity price by using the electrified heating system and thermal storages as well as the thermal mass of the building. The use of the smart energy management system transforms normal consumers or prosumers into so called prosumagers (households that consume, produce and manage their electricity consumption).
Results:Results will show how the uptake of single technologies can impact the necessary investment costs on the grid. While storage applications and PV installations will reduce demand derived from the grid, electrified heating systems will increase it. At the same time extensive uptake of PV can lead to grid congestion due to higher loads of exports from the building to the grid. Prosumagers can both increase and alleviate grid stress, depending on the detailed settings and frameworks incentivizing different investments and operational behaviour. Also the impact of different technology usage on future grid investments is climate dependent which will be shown in the difference between the two case studies which are situated in the south of spain and in the north of the netherlands.
Conclusions:Electrification of heating systems will impose a challenge on the future electricity grid. By incentivizing consumers to shift load with automated heating systems the stress on the electrical grid can be lowered. With an increase in photovoltaic installations smart energy management becomes even more important.

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Keywords: demand response, heat pumps, electrification, buildings, optimization

[Abstract:0341] OP-018 [Accepted:Oral Presentation] [Energy Modeling » Energy Demand]

Evaluating Building Decarbonization Pathways: A Comparative Multi-Model Analysis in the EU Context

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Overview:Forecasting potential future energy carrier compositions and consumption levels in buildings is essential for understanding and formulating decarbonization strategies. It's critical to

compare the results from diverse models to grasp their distinct characteristics and confirm an impartial analysis. Nevertheless, this comparison can be challenging due to the lack of standardized scenario specifications. Addressing this, the ECEMF project initiated a comprehensive scenario specification and model run task, outlining seven distinct scenarios that depict a range of high to low demand and various technological focuses. [1]. This paper utilizes a suite of building stock models, including Invert/EELab [2], Invert/Opt [2], FORECAST-Buildings [3], PRIMES-Buildings [4], and REMIND-Buildings [5], to simulate these scenarios. Through this comparative analysis, a stronger understanding of the potential decarbonization pathways for the building sector's energy is sought. Additionally, this study's core aim is to scrutinize and evaluate the alternatives for decarbonizing building energy, with a focus on the comparison between electrification and other potential strategies.

The research questions addressed are: What are the main contributors to the differences observed among the models' decarbonization scenarios for the EU building sector? What consistent insights and robust results can be drawn from the scenarios reviewed?

Methods:The methodology of this study involved curating a series of scenarios that reflect different intensities of energy demand and supply-side strategies, such as:

1. High Electrification|Efficiency Moderate
2. High Electrification|Efficiency High
3. High Electrification|Lifestyle and Behavioral Change
4. High H2/e-fuels|Efficiency Moderate
5. High H2/e-fuels|Efficiency High
6. High District Heating|Efficiency Moderate
7. High District Heating|Efficiency High

As previously elucidated, this study incorporates five distinct building stock models. Invert/EELab is a techno-socio-economic bottom-up simulation model that employs a logit approach, representing building owners as agents with distinct decision-making parameters [2]. Invert/Opt, on the other hand, is an economic bottom-up optimization model that seeks to derive the most cost-effective combination of renovation measures and technology choices for a specified target year [2]. FORECAST-Buildings, a bottom-up simulation model, takes into account the dynamics of technologies and socioeconomic drivers to project future energy demand in the buildings sector [3]. PRIMES-Buildings, a hybrid economic-engineering optimization model, is grounded in microeconomic theory and endeavors to capture consumer behaviors while incorporating engineering constraints [4]. Lastly, REMIND-Buildings integrates an energy-economy general equilibrium model with a bottom-up engineering-based energy system model.

The complete conference contribution will provide in-depth fundamental information regarding the modeling structure, algorithms, and other pertinent details for each model, including a comparative analysis of the models' approaches. Furthermore, comprehensive reporting will be conducted on the general scenario specifications and internal assumptions for each model. To ensure uniformity in data formats, definitions, and structure, the results have been uploaded to IIASA's Scenario Explorer tool [6], facilitating the necessary visualizations. In the results section, the outcomes of the comprehensive analysis will be presented and scrutinized for each scenario and model, enabling the identification of variations within scenarios as well as across different models. Subsequently, an extensive examination of these results will be undertaken to clarify the potential factors responsible for these observed deviations. Particularly, emphasis will be placed on comparing the effectiveness of electrification against alternative approaches in the context of decarbonizing building stock.

Results:We will deliver the results in terms of:

1. Total final energy consumption in the residential and commercial sectors,
2. Total final energy consumption by energy carriers in the residential and commercial sectors,
3. Total final energy consumption by end-use in the residential and commercial sectors.

Figure 1 provides a visual representation of the final energy consumption with the energy carrier mix within the building sector for each model and scenario, specifically focusing on the year 2050. It is worth noting that when considering the absolute magnitude of energy demand within this sector in the baseline year of 2020 (measured at 15.47 EJ), the overall deviations observed between the models are deemed to be of a moderate nature [7]. However, notable disparities become more pronounced, particularly between the high and moderate scenarios, as exemplified by the contrast between the Forecast and Primes models. These variations underscore the significance of scenario specifications and modeling approaches in influencing the outcomes related to energy consumption reduction targets within the building sector.

Figure 2 presents the distribution of direct electrification shares across the EU27 region, as assessed with each scenario and model. Additionally, in Figure 3, the installed capacities of heat pumps are provided. The outcomes demonstrate a wide-ranging spectrum of changes in the proportion of direct electrification, spanning from 43% to 90%. Notably, the REMIND model emerges with the highest

levels of electrification, primarily attributable to the prominent utilization of heat pump technologies within its framework. Differences in electrification shares do not only result in different assumptions of heat pump penetration but also in technology settings for competing technologies such as biomass-based heating systems or district heating. Also, the share of appliances in total energy demand and – related to it – the achieved energy savings through building renovation have an impact on the share of electrification in this sector. These findings provide insights into the slight variations observed in the degree of direct electrification across different scenarios and models, which hold substantial importance for policymakers and stakeholders engaged in decision-making about the imperative transition towards sustainable energy systems. By comprehensively evaluating these outcomes, this study contributes to the body of knowledge essential for shaping effective strategies and policies in achieving sustainable and decarbonized building energy systems. Reasons for these deviations include different model dynamics and also differences in the detailed scenarios specifications.
Conclusions:The following key learnings can be derived as common learning from all models: (1) Substantial enhancement of building renovation and related improvement of the building envelope is key for a decarbonised building stock. (2) Heat pumps play a crucial role in the supply mix of all scenarios, even in scenarios with a focus on other technologies such as H2 and e-fuels or district heating. (3) H2 and e-fuels do not turn out to be an efficient and economically viable solution in any of the models, even not in the dedicated H2/e-fuels scenarios. (4) District heating is important for decarbonisation, but models lead to different intensities of district heating expansion. In the full paper, we will further expand on these insights and also discuss the reasons for deviations.

In the expanded conclusion section, the paper will delve deeper into evaluating the robustness of electrification as a primary strategy compared to the use of hydrogen and synthetic gases (H2/e-gases). We will analyze the potential for energy savings and performance enhancements through increased efficiency measures. The scenarios will be meticulously cost-ranked to identify the most economically viable pathways. A thorough assessment of the role of district heating systems in the energy mix will be conducted, considering their potential to contribute to the decarbonization efforts. The discussion will critically examine how regulatory policies, especially those involving prohibitive measures, are central to achieving decarbonization targets. We will underscore that the attainment of these goals hinges on the implementation of certain bans, suggesting that policy enforcement is as crucial as technological innovation in the transition to a low-carbon future. This comprehensive examination aims to provide stakeholders with actionable insights for strategic planning and policy development.
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Keywords: building stock modeling, demand side building stock modeling, model comparison, scenario design

Figure 1 Energy carrier demand by energy carrier in buildings in 2020 and 2050 in different scenarios and models (EU27)

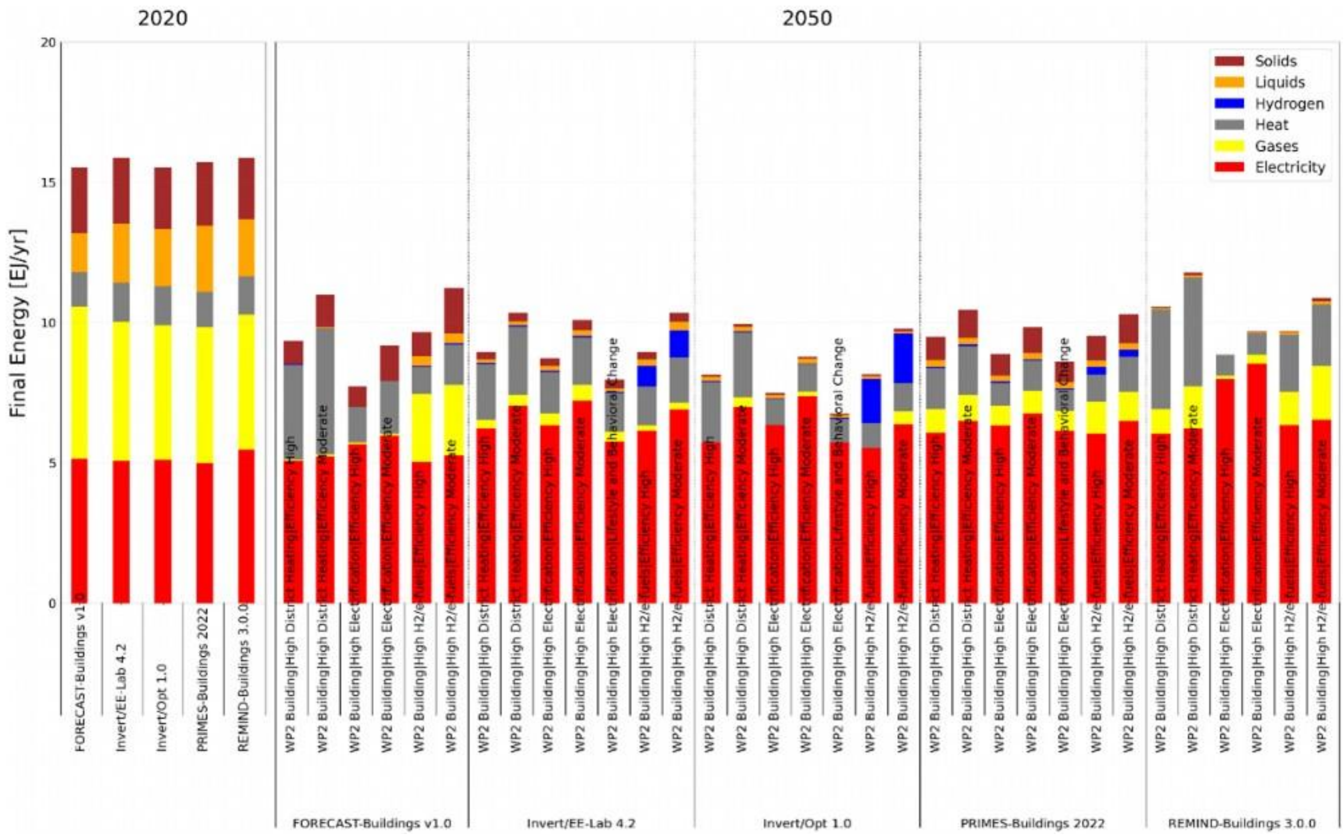


Figure 2 Share of direct electrification in buildings' final energy consumption, 2020 - 2050 (EU27)

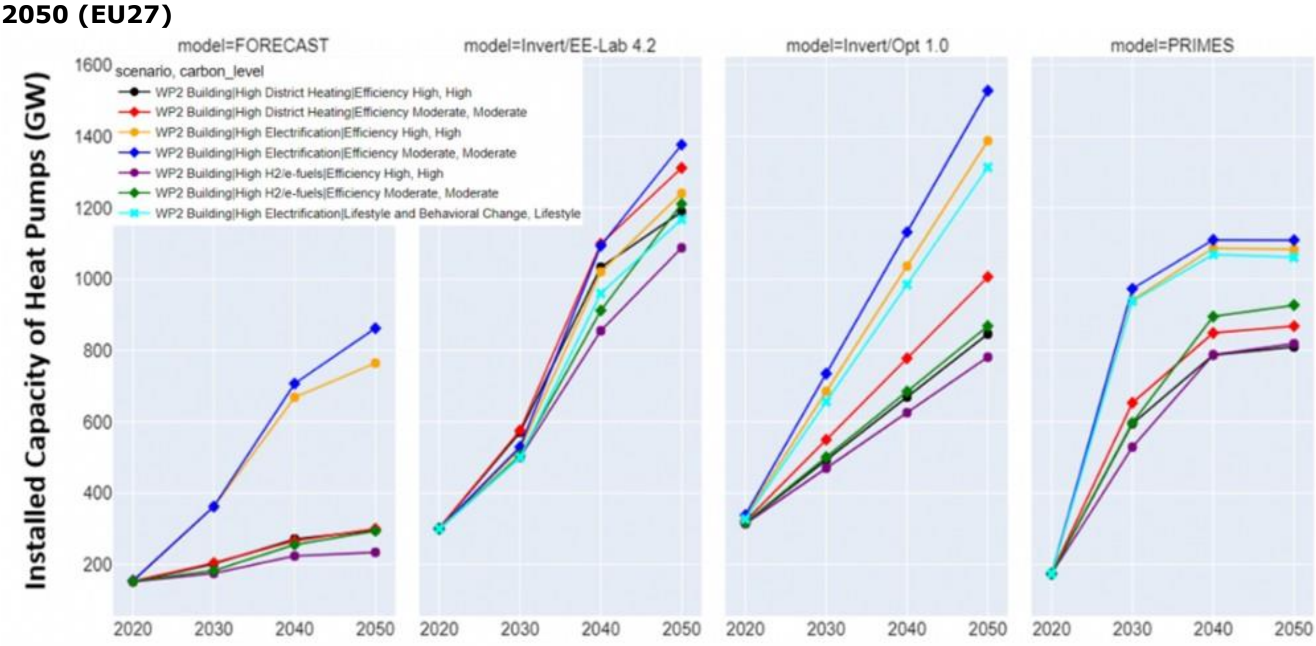
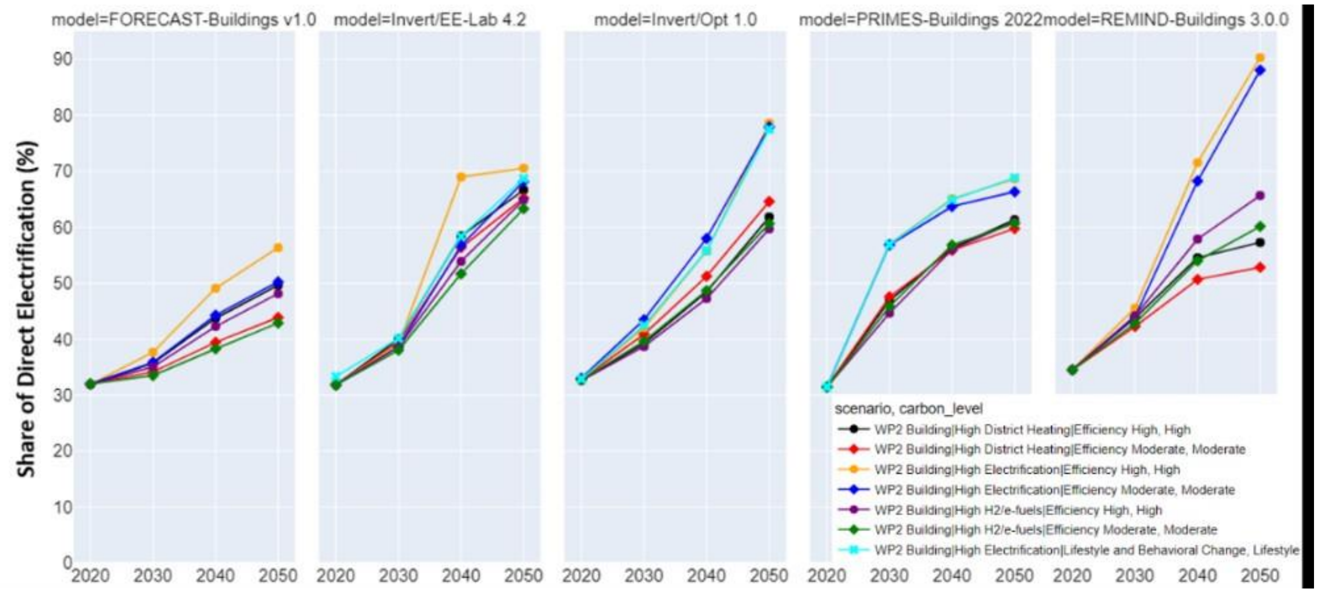


Figure 3 Installed capacity of heat pumps in the residential and commercial sector, 2020 – 2050 (EU27)



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[Abstract:0372] OP-019 [Accepted:Oral Presentation] [Energy Modeling » Market Equilibrium]

Interfuel Elasticities in the OECD: Regional Variations and their Evolution

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Overview:Climate change has forced countries worldwide to re-evaluate their energy consumption patterns to reduce the primary driver of global warming, CO2 emissions. This emission reduction is often achieved by switching from highly polluting fuels, such as coal, to lower carbon alternatives like renewable power. Depending on the availability of inputs and fuel prices, regions respond differently to the challenges associated with emission reduction through fuel-switching. Moreover, changes in the energy mix, capacity portfolios, and fuel (technology) preferences also affect the country's reaction to energy price changes. Interfuel elasticities of substitution (ES) are a powerful tool to measure and evaluate this reaction to prices, influencing the energy transition. Methods:The purpose of our study is twofold. First, we aim to estimate and compare the interfuel elasticity of substitution (ES) in the OECD, measuring how the relative fuel consumption changes in response to changes in relative energy prices. Second, using the past three decades' energy price and consumption data, we examine the evolution of ES values. Computing the ES values and tracking their dynamics helps shed light on the progress of the energy transition. Notably, we intend to verify whether the fuels with higher carbon content became weaker substitutes for the low-carbon energy sources.

In the past, studies on interfuel elasticity have been limited by the challenge of estimating ES under technological bias or asymmetric changes in fuel efficiencies. However, recent advances in econometric methods have provided a more accurate approach, allowing us to calculate ES for various fuel pairs. Building on the work of Gatscher & Ikonnikova (2024), who analyzed ES changes in the U.S. power sector, we expand our analysis to investigate ES dynamics in different regions of the OECD.

Results:To perform the envisaged analysis, we compile a database including variables such as generation efficiencies, individual fuel consumption (as input factor), and energy commodity prices for selected countries in North America, Europe, and the Asia-Pacific Regions. We adapt and implement the procedure developed by León-Ledesma et al. (2010) to estimate regional elasticities of substitution. Using historical data and applying a "moving time window" routine, we derive how ES values have changed over time.
Conclusions:To interpret our results, we turn to the decarbonization context. We confirm that countries in some regions favor "cleaner" fuels, supporting the path into the future of carbon-neutral energy. In contrast, the others remain reasonably conservative in their transition, hardly changing their fuel substitutability. Alternatively, our results can be interpreted concerning fuel "security" and supply availability (domestic versus import) and, possibly, capacity constraints.
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Keywords: Interfuel competition, elasticity, electricity generation, energy transition

[Page: 20]

[Abstract:0384] OP-020 [Accepted:Oral Presentation] [Energy Modeling » Market Equilibrium]

Navigating the Future: Assessing Long-Term Global Copper Supply Sustainability Amidst Ambitious Energy Transition Goals

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Overview:As nations and industries pivot towards renewable energy sources, electric mobility, and green infrastructures, the demand for metals is expected to surge to unprecedented levels. This article relies on the theoretical modelling of metal markets in the long term to simulate the potential impacts of energy transitions policies on the price dynamics of copper on global markets. We use a framework based on the Cumulative Availability Curve (CAC) approach and incorporate demand-side factors such as the level of development and green transition goals. Results suggest that a) energy transition policies, especially those aiming for net- zero emissions, frontload the surge in demand for copper, yet b) over the next few decades the world demand for copper could also be driven by the unimpeded economic growth outside of energy transition considerations in major demographic regions, and c) around 2050, the world price of copper is expected to be quite comparable in both scenarios, and high by historical standards. In summary, this suggests that the sustainability of the demand for copper may be preserved although at a high price. Recycling and/or technological progress hold the potential to mitigate these sharp price increases.
Methods:This article relies on the theoretical modelling of metal markets in the long term in order to simulate the possible impacts of energy transition goals on the price dynamics of some metal commodities.

On the supply side, we build on the Cumulative Availability Curve (CAC) approach (Tilton et Lagos, 2007; Tilton et al. 2018): the CAC of an exhaustible natural resource is the graph of the function that relates a given price of this resource to the total world stock economically exploitable at this price. The CAC differs from the traditional supply curve in economics textbooks, which describes the flow of goods offered on the market for a given period (usually one year) as a function of price. The CAC corresponds not to a flow over a given period, but to a global stock available for the future. It shows the total quantity of natural resource recoverable in the economic sense of the term as a function of the price level. However, like the traditional supply curve, the Cumulative Availability Curve assumes that apart from price all other determinants of metal availability are fixed (including exploration and production costs, and technological level).

The CAC distinguishes the economic effects of three types of factors that influence the sustainability of global metal demand, namely:
1) Factors determining the shape of the CAC mainly reflect geological phenomena (ore content, depth, etc.) that affect future extraction costs.
2) Demand factors shifting the market equilibrium point are mainly linked to economic phenomena, such as global per capita growth, the level of industrial development of emerging countries, the metal intensity of low-carbon and digital transitions, and the effect of government policies in favour of metal recycling.
3) Mechanisms shifting the CAC to the right, such as technological progress which reduces the cost of metal extraction and production.

On the demand side, we determine the exogenous global demand levels for metals. These demands levels are driven by two main phenomena: i) the energy transition goals, and ii) the economic development of demographic powers.

Regarding the first aspect, we begin by defining energy transition scenarios, following the International Energy Agency's (IEA) nomenclature: Stated Policies Scenarios (STEPS), Sustainable Development Scenario (SDS), and Net Zero Emission by 2050 (NZE). We also consider a benchmark scenario that does not include any energy transition goals. Then each of these scenarios entail annual targets in the deployment of a wide range of clean energy technologies, among which low-carbon power generation technologies (solar photovoltaic panels, wind turbines, hydrogen electrolysers and fuel cells), electricity networks, electric vehicles, and battery storage. Finally, for each of the clean energy technologies, the overall mineral demand is derived using four main variables: clean energy deployment trends, sub-technology shares within each technology area, mineral intensity of each sub-technology, and mineral intensity improvements. Projected mineral demand levels are highly dependent on the stringency of climate policies reflected in the different scenarios as well as potential technology development pathways.

Regarding the second aspect, for countries in the process of industrial take-off (Lewis, 1954) the construction of infrastructures in the heavy industry, housing, transport and communications sectors implies a surge in the consumption of metal ores (in particular so-called structural metals iron, aluminium, and copper). It is therefore expected that demand for structural metals will be significantly sustained by large demographic powers (such as Indonesia, India, Pakistan, and the currently most rural Chinese provinces) that have not reached the Lewis point, i.e a wealth level estimated at $15,000 Gross Domestic Product (GDP) per capita (Vidal 2018). As a consequence, we assume increasing metal content of per capita GDP for developing countries until they reach the Lewis point, after which the metal content of per capital GDP is assumed to be decreasing (Malenbaum 1978, Bringezu et al. 2009, Jia et al. 2021).

From the Cumulative Availability Curve (linking market price of the metal commodity to supplied volumes) and the computed exogenous demand levels driven by energy transition and economic growth, we derive a sequence of price-quantity pairs for all annual periods on a 2020 to 2050 horizon. The demand adjustment to market price is computed using the US Bureau of Mines's lagged demand curve (MIDAS-II model), which matches demanded quantity to price while taking into account short-term and long-term price elasticities.

Finally, our theoretical model is calibrated for copper, a significant metal in the energy transition. Copper not only plays a crucial role in the transition to renewable energy but also provides reliable and readily available time series data over a satisfyingly long time interval.

For the calibration: GDP and population growth projections are derived from the OECD Economic Outlook, demand price-elasticities are taken from Fernandez (2018), data for copper consumption,

production, reserves, and resources are USGS estimates, and 2020-2050 demand estimates are from the IEA's 2021 report The Role of Critical Minerals in Clean Energy Transitions.
Results:The results of the numerical calibration for copper highlight how this metal can be identified as a potential bottleneck in the context of the energy transition. The more ambitious the energy transition scenario is, the stronger the bottleneck on metal supply becomes. In a net-zero emission scenario long run equilibrium prices of copper may increase significantly — by around 60% in the next decade — reaching historical highs and persisting at elevated levels over a decade, which is significantly longer than observed in previous peak periods. The price peaks, primarily occurring around 2030, are caused by two key factors. Firstly, the surge in demand is front-loaded in the net-zero emissions scenario, where renewable energy production requires substantial metal inputs upfront for infrastructures like wind turbines and batteries. Secondly, the initial price boom triggers a supply response, mitigating market tightness after 2030.

Results also suggest a demand for copper primarily driven by unimpeded economic growth in major demographic regions globally. Unlike green energy production, which necessitates upfront metal usage, the continuous expansion of these economies itself becomes a driving force for copper demand across various industrial and infrastructural applications. Therefore, even in the absence of initiatives promoting sustainable energies the demand for copper remains significant due to the ongoing economic dynamism.

This highlights the necessity of considering not only factors associated with the energy transition but also the direct influence of economic growth on metal consumption.
Conclusions:The results bring about several policy implications. Given the uncertainty surrounding the energy transition there is a risk of delayed metal production investments without timely supply adjustments. A globally coordinated climate policy in order to signal gradual commitments could avert cost hikes in low-carbon technologies.

Expanding the model to incorporate secondary supply through improved recycling rates has the potential to alleviate the prevailing supply constraints and foster a more sustainable equilibrium. Acknowledging the potentially circular nature of metallic commodities by enhancing the efficiency of recycling processes would not only contribute to resource conservation but also serve as a strategic lever for easing the strain on primary metal production.

From the public decision maker's perspective, addressing the introduction of a tax fostering intergenerational equity in metal consumption could be a further extension to the model. Departing from the utilitarian framework of intertemporal utility maximisation, such a tax mechanism would serve as a dynamic instrument to potentially help smoothing the demand and supply curves over the horizon. In particular, the generated revenue could be strategically directed towards preventing demand destruction in the face of soaring metal prices, potentially hindering and delaying the green transition schedule.
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Keywords: metals, minerals, transition, copper, peak, sustainability

[Abstract:0506] OP-021 [Accepted:Oral Presentation] [Energy Modeling » Energy Demand]

Analyzing the effect of implementing CCS facility by using EnergyPlan

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Overview:Amidst escalating concerns about climate change, nations worldwide are actively striving towards carbon neutrality as a paramount goal in collective endeavors to address and mitigate the profound impacts of carbon emissions. South Korea has also announced plans to achieve carbon neutrality by 2050[1]. To achieve carbon neutrality, the integration of the energy system and the implementation of technologies that reduce carbon emissions are essential, and energy system integration using sector coupling has become a global trend. Like other major countries, South Korea is actively conducting research and demonstration to develop mitigation technologies such as CCUS and sector coupling technologies such as Power-to-X (P2X) and Vehicle-to-Grid (V2G).
This research analyzes the effect of implementing CCS facility using EnergyPLAN, energy system analysis computer model, focusing on P2X[2]. Based on two Net Zero 2050 scenario of Korea, integrating demand and supply of electricity, heating, cooling, industry and fuel, and transportation sectors. EnergyPLAN model can analyze the energy, environmental and economic impacts of different energy strategies. Rather than finding a single optimal energy system, the focus of this model is to compare different energy system strategies. Therefore, instead of presenting a single answer for an energy system, the model suggests several alternatives for comparison.
We derive the additional power capacity required to operate a CCS facility by comparing scenarios. To meet the target of the scenarios, 194MW of additional power plant capacity is required for scenario A (100% carbon emission reduction) and 299MW for scenario B (92% carbon emission reduction).
Methods:The EnergyPLAN model is a deterministic energy system analysis model in an input-output format. When the energy supply structure at the national or regional level is input, the model is constructed on a time unit basis. It balances the energy flows in each demand and supply sector of the model and returns the total annual energy supply and the time-optimized energy system as outputs. The input data consists of three main sectors: energy demand, energy supply, and energy storage and balancing. The energy demand sector is further subdivided into electricity, heating, cooling, industrial and other fuel use, transportation, and desalination. After entering all the input data, the researcher can choose a simulation strategy based on his objectives. Simulation strategies are broadly categorized into technical simulation and market economic simulation.
This research analyzes the effect of implementing CCUS facility under net zero 2050 scenario of Korea, which is to reduce carbon emission in CCS field by 3.88Mt in scenario A and 5.96Mt in scenario B. The main input data of demand is 1,322TWh/year in electricity sector, 350TWh/year in heating sector, 103.5TWh/year in cooling sector. The total power plant capacity is 71,675 MW, and additional power capacity for CCS plant operation is added based on each scenario.

Results:The demand for district heating during the winter season is sufficient; however, there is a shortage of power supply due to the power consumption of individual electric boilers and heat pumps used for individual heating. To meet the power supply shortage during the winter season, an additional capacity of 12,207 MW is required for thermal power plants.
An additional 194 MW of power plant would be required to capture 3.88 Mt of carbon in Scenario A and 299 MW of power plant would be required to capture 5.96 Mt of carbon in Scenario B. However, the operation of the CCUS facility will consume more electricity and emit 0.97 Mt of carbon in Scenario A and 1.49 Mt of carbon in Scenario B.
Conclusions:The implementation of CCS in the power generation sector requires a review of additional capacity expansions compared to existing plant plans. Additional capacity expansion requires a review of costs and siting. If additional capacity is added with a CCS power plant, the carbon emissions generated by the power consumption must be considered for carbon capture. The results of the capacity analysis for additional power generation and renewable energy could be a useful reference for future consideration when implementing a CCS facility.
There are several technologies to reduce carbon emission, and this research focused on CCS to derive additional power consumption and combined cycle power plant capacity to achieve the target amount of carbon capture under the net zero 2050 scenario of Korea. For further research, the implementation of carbon utilization is added, which target is 1.63Mt of carbon in scenario A and 2.5Mt of carbon in scenario B.
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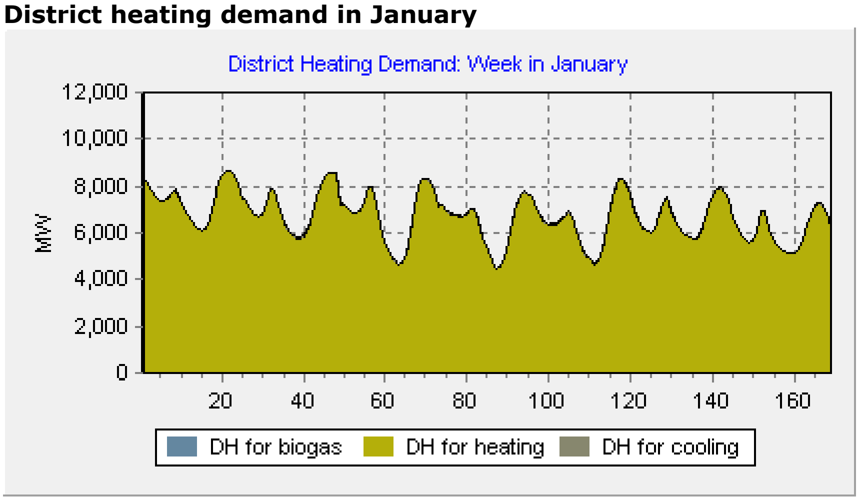
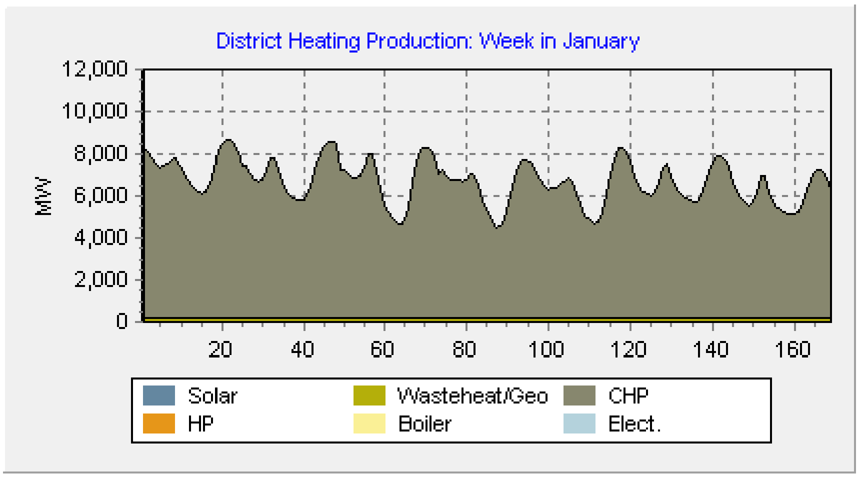
Keywords: Carbon capture and storage, Sector coupling, Energy system

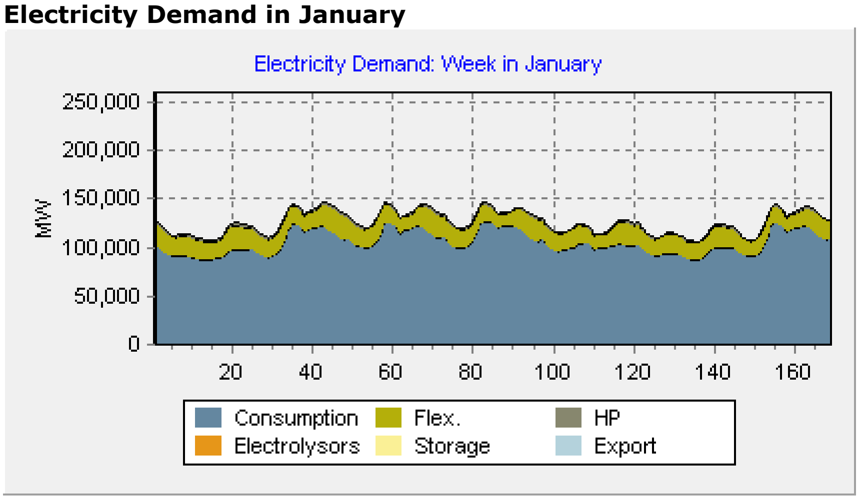
District heating demand in January



District heating production in January



Electricity Demand in January



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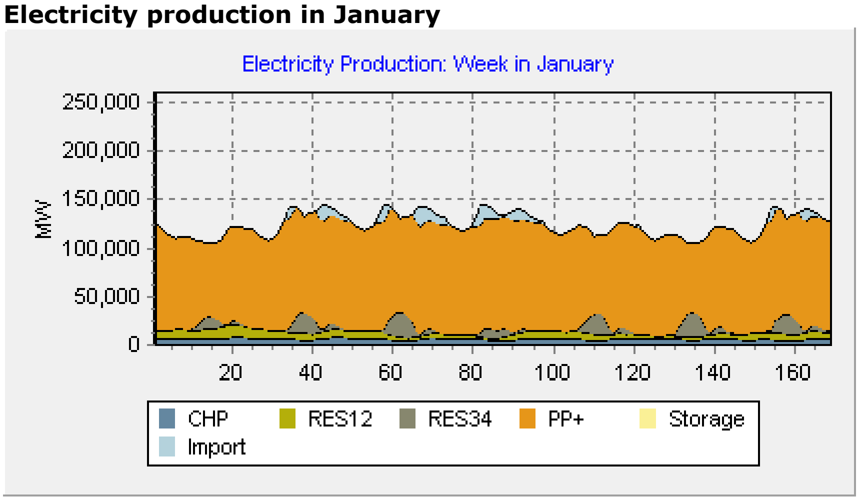

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[Abstract:0313] OP-022 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Electricity price formation schemes: a novel categorization of bid-based and cost-based market designs

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Overview:Since a first wave of electricity market liberalizations in the 1990s, an increasing number of countries and jurisdictions have adopted a wholesale liberalization paradigm in their electricity market structure – a practice that, at its core, involves the introduction of a marginal price signal for the purchase and selling of electricity, in line with microeconomic principles for maximizing welfare and fostering competition. Despite these common goals and core similarities, in practice there are a number of underlying assumptions and design choices that must be woven into the implementation of an electricity market in practice, which tend to create interesting contrasts and distinctions between different countries.

In particular, a distinction that has been explored in the literature is between the market model typically adopted by "European" markets (which relies more on self-dispatch, zonal market clearing, and power exchanges) and one commonly adopted by "North American" markets (which relies on mandatory deep pools, nodal market clearing, and physical representation of the entire grid). This dichotomy, however, leaves out not only a large portion of the world, but also a large portion of the space of possibilities that can be explored in an electricity market design.

In the present paper, we propose a broader, more thorough taxonomy for classifying international electricity markets, which allows us to more clearly describe points of similarity and dissimilarity involving countries that do not neatly fit into the "European" or in the "North American" clusters, as well as proposing new clusters. One particular component of this market design classification which emerges in this work is the distinction between "bid-based markets" in which electricity sector participants have a large amount of freedom to submit their information, VS "cost-based markets" in which the system operator retains information on individual units' physical and economic parameters and use these primarily as an input for electricity dispatch and price formation.

Methods:The methodology of this analysis is broken down into two parts. The first part is the construction of the characterization methodology itself, which involved the consolidation of the key distinguishing features of different electricity market designs; and the second part is the literature review itself, categorizing individual countries' experiences into this common structure.

For the construction of the classification structure, a key insight is the relationship between the model used for electricity market clearing and price formation, and the model used for physical validation of the network flows and operational limits. Most often, both of these tasks are carried out using optimization models, and sometimes the same model is used for both tasks (either using the same exact formulation or slightly different execution options or input parameters). Usually, "financial" representations of the electricity system are more relevant at longer timescales (as contracts can be negotiated on a month-ahead basis), and "physical" representations are more relevant at extremely short timescales (with the system operator sometimes taking action taking into account minute-by-minute views of the system) – but there is a significant overlap, with the "day-ahead" timescale being relevant for both. We argue that the differentiation between these representations at different time scales is an important distinguishing feature of electricity market designs.

Knowing that a large number of market design implementations rely on optimization models for dispatch decisions and price formation, the key distinction between the "bid-based" and the "cost-

based” market paradigms is whether agents have flexibility to make their bids however they wish. In practice, however, this flexibility often comes with some types of caveats, which are also explored in the paper’s classification: (i) there is often flexibility to submit information on some parameters but not others (for example, if ramping parameters are pre-calculated by the system operator and cannot be adjusted freely at the time of bidding), (ii) it is possible that bidders will be able to submit new parameters, but only within some limited range of possible values, and (iii) it is possible that the flexibility to bid new parameters varies per technology.
For the international review, the researches selected a broad range of countries, encompassing not only Europe (UK, Norway, Spain) and North America (PJM, Texas, California), but also Latin America (Brazil, Colombia, Chile, Mexico, El Salvador) and Asia-Pacific (Vietnam, New Zealand, South Korea).
Results:By classifying the various market designs according to the aforementioned categories, it was possible to identify different “clusters” of implementation design that do not fit exactly in the classic “European” and “North American” paradigms. In particular, the electricity markets in Colombia and New Zealand, both of which adopt a “bid-based” scheme allowing a high degree of flexibility to the agents when submitting their offers, are characterized by a mix of features (some of which are more common in “European” markets and others in “North American” ones), thus evidencing the need for a more thorough classification.
Most of the other countries evaluated can be classified as “cost-based” markets, as the chief element that drives the inputs to the optimization model used for electricity dispatch and price formation are the centrally-estimated generation costs of each agent, rather than decentralized bids. However, even in this case there are distinctions and caveats that are worth exploring. In particular, it is interesting to note that countries such as Mexico, South Korea, and Vietnam do have a communications channel for agents to systematically submit information to the system operator for usage in the dispatch and price formation processes – although these countries can still be categorized as “cost-based markets” since, unless their bids is within a narrow range of centrally-estimated parameters, they will simply be discarded. While El Salvador, Chile, and Brazil have adopted a more “inherently” cost-based structure, without a systematic process for incorporating agents’ decentralized information, these paradigms have been evolving are exceptions – in the case of the Chilean market for reserves and the representation of operational constraints of thermal power plants in Brazil, for example, routes have been created to take into account parameters declared by the agents.
Conclusions:Broad trends in electricity systems worldwide have been imposing novel strains on existing market designs, processes, and institutions – due to the increasing role of variable renewable energy and decentralized contributors such as distributed energy resources, prosumers and aggregators. In this context, it is important to clearly understand and analyze the various types of market design that have been implemented at various jurisdictions (as well as theoretical models that have not yet been attempted). This paper proposes a framework for such an analysis, which can be used to critically assess the level of readiness of different market designs for the expected transformations to come.
The paper concludes with such a critical assessment, making considerations on desirable elements for electricity markets going forward in an energy transition context and discussing how synergies can be exploited to the maximum.
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Keywords: electricity market design, electricity price formation, bid-based markets, cost-based markets, electricity market liberalization

[Abstract:0348] OP-023 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Uncertainty on renewable energies (wind and solar) generation forecasts and impact on energy prices in France

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Overview:Renewable energies (RES) play an important role in the supply of clean, sustainable electricity. The European Union encourages RES while ensuring affordable energy prices. In France, the government aims to decarbonize its energy system by 2050, which means more RES in the energy mix. However, integrating these energies into the power system presents challenges, mainly due to their uncertain and intermittent nature. This can affect the energy market, influencing prices and the prioritization of certain sources. In addition, with the rise of new means of mobility such as electric vehicles, demand for these renewable energies is increasing. Existing literature (Würzburg et al., 2013; Cludius et al., 2014; Zipp, 2017) has discussed the effect of RES on price based on their zero marginal cost, omitting the impact of other characteristics: intermittency and uncertainty (real-time forecast error). To date, only two studies have focused on the long-term impact of RES on prices. The first, conducted by Weber and Matt (2022) demonstrated a twofold effect of wind on market prices in Texas. The second study, the most recent by Hosius et al. (2023), analyzes the impact of offshore wind power on energy prices in Germany, western Denmark, and Great Britain.

This paper analyzes the impact of wind and solar uncertainty on prices in France between 2015 and 2018 by using fixed effect regression. Particular attention is given to the residual demand variation in relation to price change. The choice of France for this study is significant because existing literature on the subject highlights the crucial role of the energy mix (De Miera, G. S. et al.,2008; Jónsson, T. et al., 2010) and France is one of the countries with a 50% dominance of nuclear energy in its mix, which has high fixed costs as a base load energy source. Furthermore, in France, RES impact are mostly addressed from a legal (Darson, A.,2015) or technical standpoint by sciences (Haessig, P.,2011), and to a lesser extent, from an economic standpoint (González-Aparicio, I., & Zucker, A., 2015).
Methods:To do so, we gathered data from two distinct and reputable sources. Firstly, we obtained essential information from the Eco2mix platform, operated by RTE, the French electricity transmission system operator (TSO), covering the period from 2015 to 2018. This platform offers comprehensive hourly data on electricity demand, renewable energy generation (particularly wind and solar), as well as forecasts of renewable energy. Secondly, we acquired price data from the EPEX SPOT exchange, renowned for its reliability and accuracy in capturing market trends. Because of the COVID-19 and high prices observed during this period, we have not included recent data in our analysis to avoid biasing our results.

After statistically analyzing the collected data, specifically focusing on intermittency and uncertainty, we performed a fixed-effect regression to measure their influence on prices. Additionally, another aim of this study is to examine how prices vary with an increase in residual demand. To achieve this, we segmented our dataset into percentiles based on residual demand and conducted a regression analysis to explore the relationship between price changes and the rise in residual demand.
Results:The results indicate that wind uncertainty and solar intermittency significantly affect prices on the intraday market, more so than production forecasts. Price fluctuations depend not only on residual demand levels, but also on the merit order curve's shape. On the other hand, demand uncertainty and intermittency are better managed than those of RES. In addition, interconnection and the conventional generation mix play an essential role in stabilizing prices during peak-hour uncertainty.

Conclusions:In summary, three key conclusions emerge regarding the intraday market. Firstly, a country's existing conventional energy mix plays a crucial role in managing the uncertainties associated with renewable generation. In addition, interconnection contributes to price stability and ensures a secure energy supply. Finally, investment in demand response could mitigate the impact of uncertainty.

In the future, our research aims to investigate how demand flexibility could offset the costs of uncertainty and manage congestion in less interconnected regions, particularly in Brittany and south-east France. The results will help determine whether the development of demand response and interconnection can facilitate the integration of RES

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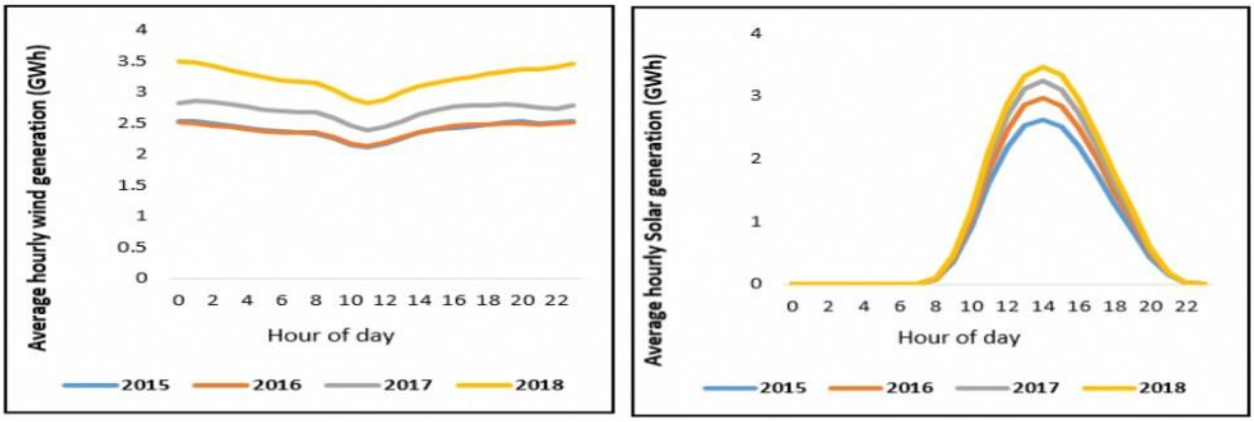
Keywords: Wholesale electricity market, Electricity price volatility, Renewables Uncertainty/ Intermittency, Residual electricity demand, Isolated / interconnected markets, Conventional generation.

Average hourly renewable generation in France by year



(a) Wind generation (b) Solar generation

Figure 1: **Average hourly renewable generation in France by year**

Solar and wind generation are the exogenous variables in our study. We study them in order to determine their variation over the studied period. Figures 1a and 1b depict the annual wind energy and solar power generated in France from 2015 to 2018, respectively. Solar generation experienced significant growth during the studied period, amounting to an increase of 3.1 TWh, with an average annual hourly increase of 1 GWh. Similarly, wind generation demonstrated a substantial increase of 7 TWh over the same timeframe, exhibiting a nearly consistent annual average hourly growth of approximately 2 to 3 GWh.

EPEX Hourly Prices in France

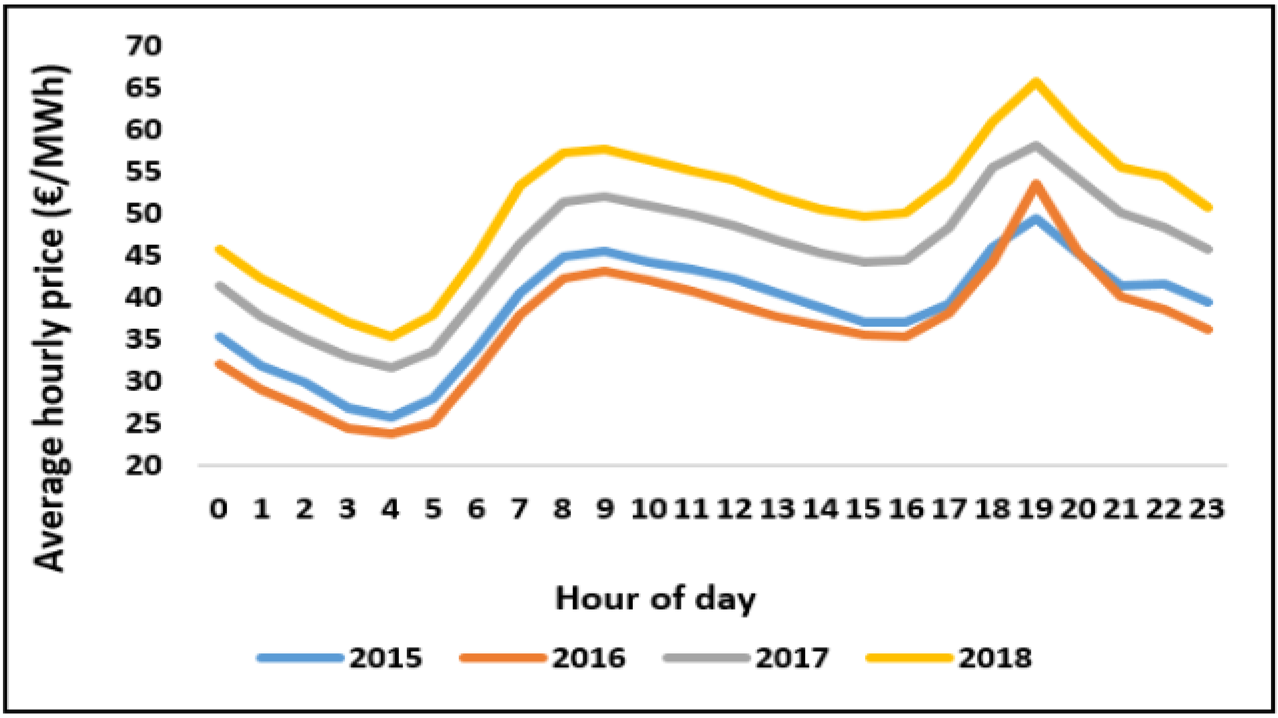


Figure 5: **EPEX Hourly Prices in France**

The main variable of interest in this study is the price change upon the entry of renewable energy generation.Figure 5 plots the average hourly wholesale price between 2015 and 2018. Hourly prices range from €(20 - 70) depending on the period. The graph shows a low period between 00:00 am – 6:00 am. With a recovery of activities from 07:00 am, this resumption increases the consumption, which reaches a first peak between 10:00 am – 13:00 pm before starting a new downturn for a second low period around 14:00 pm. From 7:00 pm, a second peak period, the most important of the day, lasts until 10:00 pm. Finally, consumption falls back down to reach a third off-peak period. The maximum prices are reached during the two daily peak periods and the minimum price during the off-peak periods.Moreover, figure 5 also shows that energy price on EPEX Spot Exchange gradually increase over years. During peak periods, high average prices are reached in 2018 (approximately €/MWh 70) and low average price are reached in 2015-2016 and are less than €/MWh 60. We also see that price did not follow the *same trend as wind and solar, meaning that renewable energy resources' impact on the electricity price in France is a complex and multifaceted issue that depends on several factors. The price change can be explained by several factors related to the characteristics of renewable energies, demand, the price of other resources like fuel, gas etc....In general, renewable energy sources, including wind and solar, can have a downward impact on the price of electricity by reducing the need for expensive fossil fuels and increasing competition in the energy market.*

France Merit-order curve of January 16, 2018 at 1 p.m

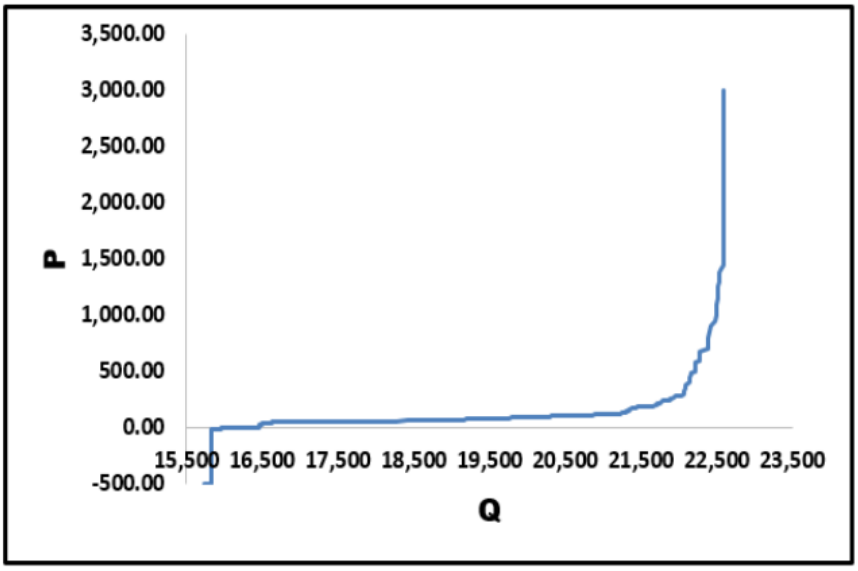


Figure 6: **France Merit-order curve of January 16, 2018 at 1 p.m**

This figure shows in part why the impact of uncertainty linked to production proves to be so significant. We observe minimal price variation when supply is in the MWh(16500 - 21500) range. In this interval, the energies called are relatively cheaper, and any additional demand or renewable generation on the market has a negligible influence on price. This pattern is evident in the results of table 1 when residual demand is between (25-99)th%. Conversely, between MWh(21500 - 22500), supply has increased by 1 GWh, leading to an exponential increase in price. Consequently, any excess demand or additional renewable generation has a similar impact on price. This trend is also observed in our regression when residual demand exceeds 99th%, resulting in a price reduction of over 250% compared to when residual demand is below 99th%, as marginally expensive energies will be excluded from the market.

Net Interconnection data analysis

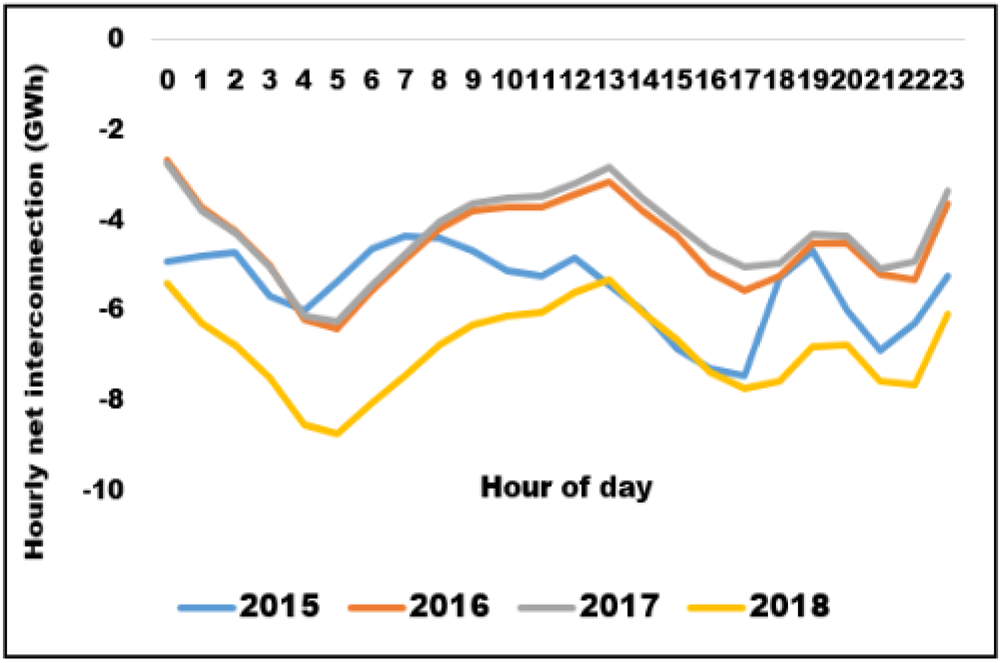
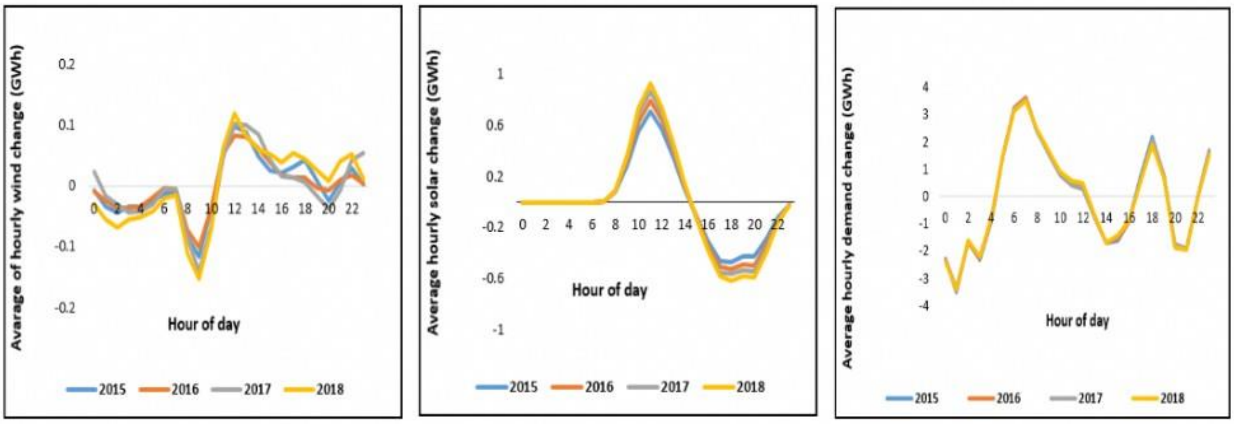


Figure 7: France Net interconnection over years

Here, we attempted to understand why the impact of intermittency and uncertainty in Table 2 on prices does not exhibit an exponential increase with the rise in residual demand, as observed in the case of Texas. This figure illustrates that France exports energy during the studied period, indicating that it produces more than it consumes. We then regressed this data, with net interconnection as the variable of interest and demand and renewable production as exogenous variables. We also focused on the production of conventional generators, which showed the role of conventional generation on price levels during uncertainty. These results were further discussed in the subsequent sections of the study.

RES and demand intermittency in France over time

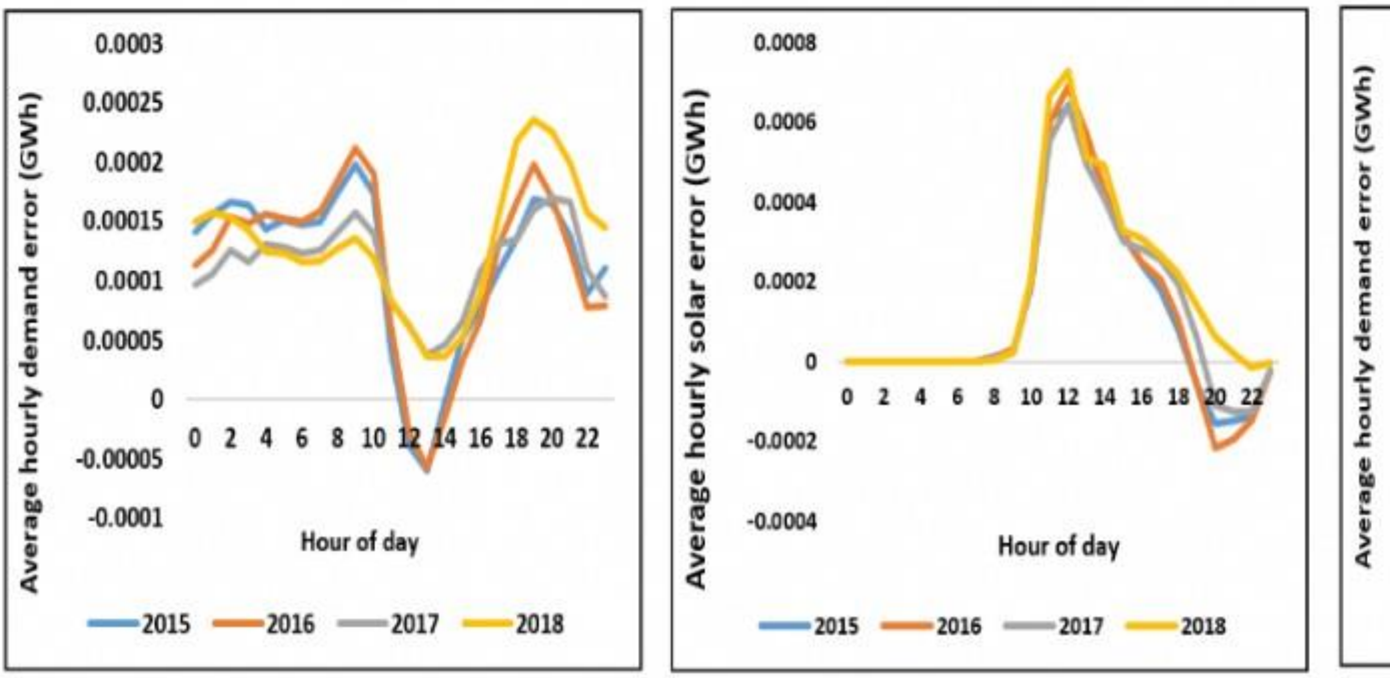


(a) Wind Intermittency (b) Solar Intermittency (c) Demand Intermittency

Figure 2: RES and demand intermittency in France over time

Temporary variation (intermittency), in our case study, refers to the difference between hourly electricity generation / demand at hours h and (h-1) within the same day as depicted in figure 2. The hourly variations observed in wind and solar generation surpass the percentage variations in demand, indicating a higher level of variability in renewable energy generation. Despite the fact that demand in France consistently remains five to six times higher than the generation from renewable sources, it exhibits minimal variation over the years. This can potentially be attributed to predictable consumption patterns facilitated by advanced technologies and energy efficiency measures. However, renewable energy sources demonstrate several factors contributing to their instability. Firstly, during the morning hours, figure 2a displays a decrease in wind generation leading up to the midday peak, while figure fig2b exhibits an increase in solar generation. This can be attributed to the wind speeds (Studies show a correlation between temperature and wind speed. As temperature rises, wind speed is likely to increase. At night, temperatures are generally low), which tend to be lower in the morning, as reported by the \href{https://meteofrance.com/}{French weather *agency}. Simultaneously, this period coincides with the onset of sunlight and the resumption of economic activities, explaining the opposite effect observed for solar power and demand. Secondly, the first peak in electricity demand usually occurs around mid-day when solar generation reaches its maximum, and wind power contributes significantly to the grid\footnote{France is a well interconnected country and receive wind energy from neighbours countries, especially Germany. Conversely, during the second peak, renewable energy generation is lower due to decreased wind speeds and the absence of sunlight. Additionally, when analyzing the overall intermittency pattern of RES, it becomes evident that wind intermittency is more unstable in the evening over the four-year period, as depicted in figure 2a, compared to solar intermittency in figure 2b. However, the midday period remains the most crucial in terms of solar intermittency*

RES and Demand Uncertainty (forecast error) in France



(a) **Wind Error** (b) **Solar Error**

Figure 3: **RES and Demand Uncertainty (foreca**

Uncertainty represents forecast error and is equal to the differencebetween the generation in hour h and its forecast in (h-1). Figure 3a clearly demonstrates that during the initial peak hours, wind hour-ahead forecasts decrease, especially in 2015 and 2016 and increase during the second peak (the presence of negative values in figures indicates that the hour-ahead forecasts exceed the power generation and corresponds to an over-forecast, while a positive sign indicates under-forecast of generation). In contrast to wind error, as shown in figure 3b, solar error increase during the first peak and then decrease for the rest of the day (the first peak corresponds to the solar production peak, contributing to an increase in the solar error. Thereafter, as solar energy becomes less available, its production decreases, reaching the lowest point and explaining the observed decrease in its error.) Figure 3c reveals a higher degree of demand flexibility throughout the study period because electricity demand rarely exceeds its hour-ahead forecasts, suggesting effective control over demand and a good understanding of the factors that influence it. This control and understanding contribute to the efficient operation of the power system and guarantee its reliability. This control can also make the demand a means of slowing down the effects of RES.

Full decomposition of price effect

	All	< 25th %	25-75th %	> 75th %
Variables	(1)	(2)	(3)	(4)
Wind forecast in previous hour(GWh)	-2.12*** (0.06)	-2.24*** (0.06)	-2.14*** (0.05)	-1.76*** (0.13)
Wind forecast hourly change (GWh)	-2.36** (0.49)	-1.75*** (0.59)	-0.90 (0.54)	-1.97*** (0.59)
Wind error (GWh)	-4.92*** (0.09)	-4.90*** (0.08)	-3.81*** (0.05)	-6.51*** (0.14)

Wind error hourly change (GWh)	-3.54*** (0.49)	-2.65*** (0.40)	-2.35** (0.49)	-4.25 (0.80)
Solar forecast in previous hour(GWh)	-3.18*** (0.37)	-3.81*** (0.26)	-2.45*** (0.24)	-2.02 (1.22)
Solar forecast hourly change (GWh)	-8.57*** (1.00)	-9.17*** (1.64)	-6.78*** (0.97)	-7.02* (2.42)
Solar error (GWh)	-0.52** (0.21)	-0.84** (0.40)	-0.22** (0.23)	-0.11 (0.38)
Solar error hourly change (GWh)	-1.83** (0.76)	-2.80*** (0.67)	-1.80** (0.86)	-2.08 (1.87)
Demand forecast in previous hour(GWh)	1.69*** (0.04)	1.89*** (0.09)	1.36*** (0.04)	1.48*** (0.08)
Demand forecast hourly change (GWh)	2.03*** (0.22)	3.53*** (0.55)	1.81*** (0.24)	1.68*** (0.34)
Demand error (GWh)	1.66*** (0.05)	0.16 (0.30)	1.30*** (0.06)	1.51*** (0.10)
Demand error hourly change (GWh)	1.37** (0.58)	0.56 (0.78)	1.40*** (0.37)	1.48 (0.91)
Observations	34,871	8,716	17,438	5,230
R-squared	0.61	0.69	0.67	0.58

This table shows the effects of intermittency and uncertainty on prices.The results show that the uncertainty associated with wind power, in the case of an additional 1 GWh of wind power, has a larger effect on the price than wind forecast. The wind error in the third row leads to a price reduction of €4.92 per MWh, while its hourly change in the fourth row contributed to a price decrease of €3.54 per MWh. Both impacts are higher than the influence of wind forecast and its hourly change on the price, which are €2.12 and €2.36 per MWh, respectively, as indicated in the first two rows. The reason behind this greater effect of error on price is that, in the event of one-hour uncertainty, additional unplanned renewable generation is injected into the grid, reducing residual demand. In this case, conventional generators have to reduce their output to cope with the reduction in residual demand. Some are shut down and excluded from the market. Other generators are unable to stop during this hour and continue to produce at a lower price, which changes the slope of the supply curve and lowers the market price. Similarly, uncertainty can lead to a reduction in renewable generation, increasing residual demand. In this case, planned production is not injected into the grid, and conventional generators must respond within the hour to this excess residual demand. Some power plants cannot start up in time, and others will incur start-up costs. This will change the slope of supply curve and increase the market price. This also applies to unplanned additional demand.

AuthorToEditor: The figures and tables provided offer insights into the main objective of the study and do not represent the complete set included in the paper. As a doctoral candidate, I would also appreciate it if my application could be considered for Poster presentation, with the understanding that Oral presentation remains my preferred option.

[Abstract:0368] OP-024 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

On Some Advantages of Convex Hull Pricing for the European Electricity Auction

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Overview:Since the liberalization of the power sector and the creation of wholesale electricity markets, the question of how to price the non-convexities that are present in the market has attracted the interest of both academics and practitioners. Power auctions are notably characterized by the presence of non-convexities. In the US, these non-convexities emerge from the so-called unit commitment model, which has been run in control rooms since before the liberalization of the power sector took place. Although some economists have argued for simpler—convex—market models (cf. the arguments covered by Stoft (2002)), unit commitment has prevailed in many US auctions. In Europe, despite the fact that the market model is different, it also includes non-convex bids (the so-called "block orders" being the simplest example). As in the case of unit commitment models, they aim at providing the suppliers with the flexibility of representing the complex constraints of power generation directly into the auction. The main drawback of non-convexities is that they impede the existence of a competitive equilibrium. The absence of equilibrium prices has resulted in various and evolving pricing practices among the US and EU markets.

Over the years, US markets have studied and adopted different and evolving pricing rules. Since the "Trilateral Market Coupling" (2006), the European day-ahead market has opted for a notably different pricing rule. Recently, EU stakeholders have undertaken research to reform it, and have indicated an interest for some approaches that are discussed in the other side of the Atlantic. Our paper aims at contributing to the debate. We critically compare the pricing methods that have been adopted in US and EU along the years and their institutional motivations. We highlights the main flaws present in the EU pricing rule. Given the willingness of EU stakeholder to reform the current pricing rule, we then introduce, in total, six pricing methods that have been discussed in the US and that we cross-compare their drawbacks and benefits for the EU market. Our analysis is based on both analytical results and numerical simulations. Both theoretical and numerical evidences that are gathered in our paper point towards the advantages of convex hull pricing.

More specifically, the contributions of the work are threefold. Firstly, we perform a cross-comparison of six different pricing approaches. Several properties are formalized mathematically on the same model, in order to allow for a rigorous comparison of the alternative prices. Our endeavor aims at addressing the urge for a better understanding of various pricing candidates, as called upon by EPRI (2019). To some extent, we pursue the pioneering works of Schiro et al. (2015) and Liberopoulos and Andrianesis (2016). While Schiro et al. (2015) focuses solely on Convex Hull Pricing, we discuss it in comparison with other approaches to better grasp their relative benefits and drawbacks. While Liberopoulos and Andrianesis (2016) study some properties on a "two-suppliers" model, we rather analyse other properties on a general market model.
Secondly, the theoretical properties are supported by numerical simulations on realistic systems. This is a novelty compared to both Schiro et al. (2015) and Liberopoulos and Andrianesis (2016). In particular, studying Convex Hull Pricing (CHP) on realistic instances is an effort that has not been widely undertaken in the literature. Thanks to recent algorithmic progresses (Stevens and Papavasiliou, 2022) we are able to compute exact CHP on realistic instances. This enables an accurate numerical comparison. More specifically, we illustrate and study the properties of the four pricing approaches on two different datasets: the "FERC dataset" (public data, but without a network) and the "CWE dataset" (non-public data, but including a network).
Finally, we particularly include the pricing method proposed by Madani and Papavasiliou (2022) referred to as "Minimal Make-Whole Payment" (MMWP) pricing in our comparison. This novel approach is representative of various recent proposals that have appeared in the literature, which have not been critically assessed so far. We notably implement three alternative versions of MMWP, and we discuss their relative advantages.
Methods:In total, six pricing methods are compared: the—classical—marginal pricing approach, convex hull pricing (CHP), extended location marginal pricing (ELMP) and three variants of pricing methods that aim at "minimizing the make-whole payments" (MMWP). We provide a model of a typical electricity auction and we formalize the six pricing methods on this model. Then, they are compared with respect to two main metrics: the so-called "lost opportunity costs" (LOC) and the "revenue shortfall" (RS). The main issue with non-convexities is that a competitive equilibrium does not exist. The lost opportunity cost measures the financial incentives that each profit-maximizing agent has for deviating from the allocation decided by the auctioneer—it measures how far we stand from an equilibrium. The revenue shortfall, on the other hand, measures the financial exposure of the market participants. Our analysis relies on analytical results—a series of Propositions that compare the six pricing methods—that we discuss alongside with numerical simulations. We use two different datasets, each having their merits for the properties we seek to illustrate. The first "FERC dataset" is based on public data. The underlying unit commitment model is sophisticated and the data gathers almost 1000 power units, but has no network. The second dataset is based on non-public data assembled by our team but it includes a network of 30 bidding zones and 74 power units.
Results:The analysis is conducted in five parts:

1. Agents' incentives, a distributional analysis: we compare the pricing methods with respect to the LOC and how the LOC is split between the market agents. CHP allows to reach the smallest LOC while also limiting the number of suppliers affected.
2. LOC vs make-whole payments controversy: we compare the pricing methods with respect to the RS and we show how minimizing the RS may backfire and leads to extravagant LOC.
3. The limits of approximating CHP: we analyse how CHP comes along remarkable theoretical guarantees that disappear when opting for an approximation of CHP such as ELMP.
4. Minimizing the costs or the LOC: we analyse how the pricing schemes may lead to monotonic or non-monotonic behaviour with respect the LOC when the cost is minimized. In particular, while CHP and ELMP preserve a monotonic behaviour, marginal pricing and MMWP do not.
5. The curse or blessing of market size: we analyse how the size of the auction may affect the LOC. Interestingly, the effect is significantly different depending on the pricing scheme. Under CHP or ELMP, the LOC are bounded while it is not true under marginal pricing and MMWP.

Conclusions:Marginal pricing could be an upgrade as compared to the current European pricing rule, given the likely improvement in both welfare and scalability. Nonetheless, the fact that many US markets have exhibited the tendency to move away from marginal pricing during the last ten years is something that stakeholders may wish to pay attention to in Europe, given the favourable alternatives that are on the table. In our work, we have attempted to highlight some of the advantages of convex hull pricing over several dimensions. With respect to marginal pricing, the fact that CHP incorporates the lumpy costs in the price signal improves significantly the incentives faced by the market agents. CHP is also accompanied by appealing theoretical guarantees, both in terms of consistency between cost and LOC minimization as well as in terms of the bound it ensures on the LOC. While ELMP would be a significant first step in the direction of CHP—a step that several US ISO have made—we have tried to highlight some limits of this approximation. In particular, ELMP does not safeguard all the theoretical guarantees of CHP, nor does it achieve the same performance in terms of LOC minimization. Finally, while minimizing the revenue shortfall—or "make-whole payments"—may sound like a reasonable target, we have shown that it may also result in unbearable (and unbounded) lost opportunity costs.

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Keywords: Convex hull pricing, Non-uniform pricing, Non-convexities, European electricity market

[Abstract:0399] OP-025 [Accepted:Oral Presentation] [Electricity » Transmission and Networks]

Incentives to withhold cross-border network capacity in the European electricity market

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Overview: A long-standing ambition of the European Union (EU) has been to create an internal market for electricity. This will enable member states to harvest gains from exploitation of comparative advantage and from increased competition. Market integration also serves to increase the overall reliability of the electricity system by making each individual country less dependent on the availability of domestic generation capacity for supply security.

Achieving an internal market has turned out to be challenging. A main reason is that the national transmission system operators (TSOs) that own and operate the national transmission networks and cross-border connections withhold capacity from the market. The Agency for the Cooperation of Energy Regulators considers "discrimination between electricity exchanges within and between bidding-zones" as one of the main obstacles to electricity market integration in the EU (ACER, 2019). But despite allegations that TSOs restrict trade to serve national interests, and the prevalence of transmission capacity restrictions compatible with such behavior, the role of TSOs for market integration has hardly received any attention in the literature.

One line of research uses power grid models to calculate efficiency gains of coordinating electricity redispatch, instead of solving these problems separately for each zone (e.g. Oggioni et al., 2012; Oggioni and Smeers, 2012, 2013; Kunz and Zerrahn 2015, 2016). Our paper differs from this literature by treating cross-border transmission capacity as endogenous. Glachant and Pignon (2005) and van Beesten and Hulshof (2023) consider the incentives of TSOs to supply transmission capacity to the market. The authors demonstrate by numerical examples how a TSO can earn congestion income and reduce redispatch cost, by inducing congestion on a cross-border interconnector to relieve internal congestion. Höffler and Wittmann (2007) identify an auction design that reduces the incentive to withhold capacity when an owner auctions off access to a cross-border interconnector.
Methods: We formalize a setting in which the electricity grids in two countries are interconnected through a transmission line. There is one TSO in each country. The two TSOs jointly own the cross-border connection.

Market interaction takes place in two stages. The first stage is a day-ahead market, which operates before electricity net demand is known. Retailers place price-dependent bids to purchase, and producers submit price-dependent offers to sell electricity in each country. Each TSO announces the maximal volume it is willing to transmit in each direction. The trading capacity in each direction is the minimum of the bids submitted the TSOs per direction. This procedure is known as a net transfer capacity (NTC) allocation. The market is cleared subject to the available transmission capacity. It is split into two price zones, one in each country, if the trading capacity is insufficient to sustain full day-ahead price equalization.

After gate closure of the day-ahead market, net demand is realized. A second-stage balancing market opens to enable redispatch of flexible generation to offset the variability in demand. This market is organized in accordance with the EU target model for an integrated balancing market. Retailers report their demand imbalances, flexible producers submit adjusted supply bids in the balancing market, and the TSOs submit adjusted capacity bids on the cross-border interconnector. The market is split into price zones if trading capacity is insufficient to sustain equal prices in the balancing market.

We assume that retailers and flexible producers are price-takers in both markets. Each TSO is assumed to maximize a weighted avererage of the private sector gains from electricity trade and congestion rent. These assumptions allow us to emphasize efficiency related to market power by TSOs, instead of distortions related to domestic governance problems or market performance in other dimensions.
Results: We establish fundamental efficiency properties of the balancing market. When the market opens, retailers and flexible producers have already made transactions in the day-ahead market, and these transactions and the transmission bids by the TSOs have generated a day-ahead trade flow between the countries. The subsequent bidding in the balancing market will in general depend on

the day-ahead trade flow, but actual production volumes and the balancing trade flow are determined through the transaction in the balancing market. With this setup, the day-ahead market is essentially a financial market.

The assumption that the allocated transmission capacity is the minimum of the capacity bid by the two TSOs---what we denote as the "Leontief" property---implies that a TSO can always reduce trade from a positive level by a unilateral reduction in its export or import capacity, but the TSO cannot always increase trade by a corresponding increase in capacity. Consequently, a necessary and sufficient condition for equilibrium in the capacity market is that no TSO can benefit from a unilateral reduction in trade. A first implication of this property is that zero trade always constitutes an equilibrium. A second implication is that equilibria with more trade Pareto dominate those with less trade. One would therefore expect TSOs to coordinate on equilibria that maximize trade. Even so, trade in the balancing market will be downward distorted in equilibrium.

The inefficiency of the balancing market is measured by the difference between balancing prices in the two countries. Its magnitude depends on the sensitivity of local prices to a marginal increase in output, multiplied by the difference in trade between the balancing and the day-ahead market. All of these entities can be directly estimated based on bid data.

Many of the properties of the balancing market are valid also for the day-ahead market, since the Leontief property also applies to capacities in this market. In particular, endogenous capacity constraints imply that trade is downward distorted also in this market. Still, the implied level of trade in the day-ahead market has a strategic effect on trade in the balancing market, similar to how forward trading has a pro-competitive effect on output under imperfect competition in the product market. Hence, the existence of the day-ahead market increases the joint welfare of the countries.

We conclude the analysis by proposing a balancing market design that implements efficient trade and production as the unique equilibrium outcome. This design deviates from the EU target model only with respect to how the balancing congestion rent is split among the TSOs. This rent measures the (positive or negative) gains from trade associated with a change in the volume of trade between the day-ahead and balancing market. Similar to the EU design, the two TSOs split this rent equally if they bid identical network capacities into the balancing market. However, any TSO that unilaterally creates or exacerbates congestion by setting a lower capacity that the other TSO, receives none of the congestion rent if it is positive and is financially responsible for the entire deficit if the rent is negative. The magnitude of the change in congestion rent associated with the unilateral capacity reduction is sufficient to cause the TSO to internalize the full consequences of its trade restriction.
Conclusions:Transmission system operators possess substantial market power in the European electricity market, but their incentives to exploit this market power has received very little interest compared to the behavior of generation owners. This paper provides a first step in the analysis of netowrk owners in the electricity market. Our apporach can be developed in many directions to develop a fuller understanding of the efficiency of the market also with respect to the allocation of network capacity.
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Keywords: International electricity market, transmission system operators, network congestion, network market power

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[Abstract:0408] OP-026 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Cost Effective Capacity Markets

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Overview:Capacity markets are designed to recover the difference between the investment costs that ensure resource adequacy and reliability in electric power systems, and the amount of revenue that investors earn through energy and ancillary services markets. We examine the relationship between energy market revenues, capacity market revenues, and investment in power generation resources, to highlight the importance of efficient resource accreditation—the amount that resources are compensated for the provision of reliability. We adapt a classical model of efficient investment and apply it to PJM, the largest wholesale electricity system operator in the United States. We find that heuristic approaches to accreditation that have been proposed or adopted by system operators may lead to significant inefficiencies: we estimate that improving system reliability using heuristics is up to 39 percent more costly than the first-best approach. Increasing the reliability target of a system may lead to more or less investment in a given resource type depending on the balance between energy and capacity market profits and the equilibrium response of the market. Increases in capacity market payments are somewhat offset by attendant reductions in energy market expenditures. We find that, using marginal ELCC for accreditation, 66 percent of the cost of additional capacity is offset by lower energy market expenditures at the margin.

Getting accreditation methodologies right is critical to the efficiency of wholesale electricity markets, as well as the efficient realization of decarbonization goals. Renewable resources provide significant reliability benefits, but with uncertainty due to intermittency of supply. Their reliability value also depends on the generation mix; a unit of solar power will add more reliability to a system without any existing solar than it will to one that is relatively saturated with solar power. Thermal energy resources such as natural gas-fired power plants generally have higher reliability value due to their ability to provide power on command, but system operators are reconsidering the value of these resources in light of recent performance failures from extreme weather and fuel supply disruptions. Moreover, economy-wide decarbonization policies call for electrification of large swaths of the economy, such as transportation and buildings, adding to the reliability challenges faced by system operators.

Our goal in this paper is to answer key questions pertaining to these challenges by examining how (1) the choice of accreditation factors, and (2) the stringency of the system's reliability target affects welfare outcomes at the margin.

We use a classical model of investment to develop the intuition behind efficient remuneration of generation resources for their reliability value. We derive optimal accreditation factors and show that they are equivalent in concept to marginal effective load carrying capability (ELCC), a commonly employed accreditation metric among system operators. We then use PJM data to econometrically

estimate marginal profit functions, which we use along with PJM ELCC simulation data to inform and apply our model. We measure welfare outcomes under counterfactual changes to the reliability target and under different approaches to accreditation.
Methods: We adapt the Boiteux-Turvey model (Boiteux (1960), Boiteux (1964), and Turvey (2017)) to derive efficient accreditation factors. This model assumes that competing technologies enter the market until profits to the marginal unit from the sum of electricity sales and capacity market payments are equal to marginal entry costs. Efficient accreditation factors reflect the probabilistic value a generator adds to the system, reflecting supply- and demand-side uncertainty.

Our empirical application of the model proceeds as follows: First, we econometrically estimate the effect of net load on profits to the marginal unit of three technology types—wind, solar, and natural gas combined cycle—using standard regression techniques, exploiting that consumer demand is inelastic in the short run. Second, we use PJM's ELCC simulation data to estimate capacity factors for renewables. We leverage the inverse relationship between net load and generation to produce estimates of marginal profits as a function of rival capacities. For example, our estimates allow inference of the effect of adding one unit of wind capacity on profits to the marginal solar plant. Finally, we use the PJM ELCC data to define different accreditation factors based on resources' contribution to system reliability, which we measure in expected unserved energy.

We use these inputs to inform the model and draw inferences about market equilibrium under different accreditation methods. We compute consumer welfare outcomes—expenditures on energy and capacity market payments—associated with four different accreditation factors. We choose factors based on methods proposed or implemented by various system operators in the United States. We compare outcomes when accreditation factors are defined using marginal ELCC with factors based on generator performance during the 30 highest-risk hours of the year, the 65 highest-risk hours of each season, and summer afternoon hours.

We construct our data set using data from PJM, the US Energy Information Administration (EIA), and the US Environmental Protection Agency (EPA). We use PJM's hourly load, generation, and real-time market price data from 2020-2023. These data allow us to construct an hourly net load variable (gross load net of generation from renewables), and hourly aggregate generation from wind and solar. We model generation from a representative sample of combined cycle plants using hourly heat input and generation data from EPA CEMS. We use daily Henry Hub natural gas spot prices, combined with the plant heat rate (mmBtu per net MWh) to compute marginal generation costs. We also use simulation data from PJM's reliability analysis to inform reliability value measures used in our analysis.
Results: Our results show that as the choice of accreditation method converges to the weighting reflected in the marginal ELCC, accreditation becomes more cost effective. Marginal ELCC is the most efficient both theoretically and in our empirical application. Using the 30 highest-risk hours for accreditation is not economically significantly different from using a marginal ELCC approach in our application, because equally weighting the 30 highest-risk hours approximately captures the marginal reliability value of resources. This result is somewhat incidental in nature: if the distribution of loss-of-load probability were to become less uniform across the 30 highest-risk hours, the 30-hour heuristic would become less efficient. Increasing the number of representative hours does not necessarily lead to efficiency gains—using the 65 highest-risk hours in each year implies a 39 percent increase in achieving an improvement in reliability, relative to marginal ELCC.

Results demonstrate the tradeoff in costs to consumers from capacity payments (which are typically allocated to consumers according to share of load), and energy market expenditures. An increase in the amount of capacity on the system causes electricity prices to decrease, benefitting consumers. We find that, using marginal ELCC for accreditation, 66 percent of the cost of additional capacity is offset by lower energy market expenditures at the margin.

Our analysis also brings to light, at a high-level, the trade-off between reliability and consumer welfare. We estimate that the last unit of reliability, measured as a one megawatt hour reduction in expected unserved energy, came at a cost to consumers of approximately $450,000 (this result is preliminary). This estimate is consistent with other estimates in the literature of the implicit value of lost load (see, e.g., Murphy et al. 2020), though it may be overstated as we do not include the value of reduced risk from a system-wide failure. We also limit our analysis to three technologies; accounting for competitive entry from demand response or other technologies may result in a lower estimate of the consumer cost of achieving reliability. Although our estimate of the implicit value of lost load is larger than estimates of the economic value of lost load, using our model we are able to map the relationship between expected lost load and consumer costs. This exercise shows that reducing the implicit value of lost load even slightly results in a significantly greater expected amount

of unserved energy.
Conclusions:Accurately accrediting generation resources is critically important. Through our analytical model, we present the economic principles of efficient accreditation, and demonstrate the equivalence to marginal ELCC. While certain heuristics can approximate the true value of reliability, the closeness of the approximation is an empirical question, and significant inefficiencies can arise if accreditation values are poorly defined. Pricing according to the marginal value of a resource requires a systems-level analysis. Seemingly small changes in the composition of a system, or in load or weather patterns, can lead to significant changes in resources' reliability value, warranting regular updates of accreditation.

Our analysis also suggests that policy makers should consider the welfare implications of market design holistically. While increasing reliability comes at a cost, the additional capacity also brings benefits in the form of lower energy prices. A better understanding of the distributional consequences of market design, unexplored in this paper, is an important avenue for further research. In particular, the heterogeneity across consumers of the value of lost load, and the distribution of cost burden from increased capacity market payments, could factor heavily into a more granular welfare analysis.
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Keywords: wholesale electricity market design, capacity markets, resource adequacy, reliability

[Abstract:0015] OP-027 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

The implication of digitalization on future electricity market design

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Overview:This paper explores the interplay between the decarbonization and digitalization of the electricity sector. While decarbonization has been studied extensively, there has been less attention paid to the digital transition. Not only can digital technologies improve efficiency and reduce operational costs, they also can enable new energy ecosystems, create new business models, and accelerate the energy transition.
The driving question of this paper is whether, and if so under which conditions, the economics of decarbonization and digitalization would make them converge and deliver synergies, or whether they could end up deterring each other's development. We provide insights to this question on three aspects: industry structure, ultimate products, and pricing. We use an inductive methodology to

develop four propositions and two corollaries that are the logical consequences of blending these economic characteristics. These are discussed in the context of electricity market design in the UK and the European Union.
Methods:This paper uses an inductive, theory-building methodology to develop propositions regarding the energy and digitalization transitions. Through a combination of observations, we launch propositions that are the logical consequences of blending the economic characteristics associated with digital technologies. These ideas could be tested in experiments in subsequent research.
We analyze interactions between decarbonization and digitalization by applying the work of David (1985), Arthur (1989), Unruh (2000), and Foxon (2011), whose common theme is co-evolution. A co-evolutionary approach seeks to identify causal interactions between evolving systems. While digitalization is mainly a technological and economic issue, decarbonization is driven primarily by government policies. This creates a complex set of tensions and interactions that require careful examination. There are various policy options available for decarbonizaton, but once a decision is made, for example to support intermittent renewables, both digitalization and decarbonization can be subject to the kind of analysis offered in this paper.
Results:We use an inductive methodology to develop four propositions and two corollaries that are the logical consequences of blending these economic characteristics.
On the impact of digitalization in electricity sector
Proposition 1. Digital transition will bring about a tension between fragmentation and aggregation in the value chain
Proposition 2. Digitalization can lead to a modular electricity sector versus economy of scale
Proposition 3. Zero marginal costs requires new ways to price electricity services
Proposition 4. Digitalization leads to unbundling of products and hyper-specialization

And 2 corollaries with respect to the Co-evolution of the digital and decarbonization transition:
Corollary 1. Transversal versus parallel sectors
Corollary 2. Hyper-specialization and non-zero marginal cost pricing
Conclusions:The future of the electricity sector will be characterized by complex and dynamic changes that will require innovative solutions. This paper seeks to conceptualize the interactions between the energy transition and the digital transition in the electricity sector. Overall, the digital transition will lead to a more efficient and flexible electricity sector, but will require careful consideration of its implications for the industry structure and pricing mechanisms. Digital technologies can also enable new energy ecosystems, help innovate business models, and accelerate the energy transition itself. Based on a transaction cost approach, we offer insights in three areas: industry structure, ultimate products, and pricing. The digital transition in the electricity sector will lead to a vertical fragmentation in the value chain, but also to horizontal integration with other sectors such as transport. While digitalization may increase fragmentation and market power in the value chain, it can also create new opportunities for smaller players, and reduce excess capacity. Additionally, new smaller players are expected to enter the market, competing in a modular fashion rather than based on scale. This may lead to competition in some segments, while others may be prone to increased market power. Digitalization can redefine the ultimate products of the electricity sector, launching new ones, but since some segments may have zero marginal costs, this would require a new approach to pricing and packaging.
Digitalization and decarbonization technologies can interact and co-evolve to create new systems that can further transform the energy sector. We use the framework of co-evolution to analyze the potential outcomes of this interaction, and suggest two corollaries. The first corollary discusses how the interaction between the two technologies can lead to the emergence of a transversal or parallel value chain structure. The second focuses on hyper-specialization and non-zero marginal cost pricing, and suggests that the zero marginal cost of renewable energy would require a new mechanism to capture scarcity sources.
This framework can help analyze relevant policy questions such as the consultation on electricity market design in the UK and EU. The framework aligns well with the proposal of a two-market approach that would encourage demand-side flexibility and incentivize firms to create hyper-specialized products.
This paper argues that digitalization has the potential to revolutionize the electricity sector by disrupting its existing industry structure, enabling new products, and ultimately improving overall industry performance. A pertinent question that needs to be addressed in future research is the reverse question: whether there are certain industry structures and legacies in terms of regulation and infrastructure that facilitate or hinder digitalization. As the electricity sector continues to evolve and integrate digital technologies, it is critical to consider how industry structures can either support or impede innovation.
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Keywords: Digitalization, Decarbonization, Electricity Markets Design, Co-evolution, Transaction Costs

[Abstract:0102] OP-028 [Accepted:Oral Presentation] [Electricity » Customer/Grid Interactions]

Reducing the need for grid expansion through variable electricity grid tariffs in households

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Overview:New incentive mechanisms are required to adapt to the increasingly volatile feed-in of renewable electricity generation plants and the changing consumption patterns in households, such as electromobility and heat pumps. Dynamic electricity grid tariffs at household level could offer an incentive solution to keep the electricity grids stable and potentially reduce the need for grid expansion. Thus, there is a need to design and test new tariffs that include incentives to shift energy consumption from high consumption periods to more desirable low consumption intervals (load shifting) and to avoid peaks altogether (peak shaving).

The amendment to the Electricity Industry and Organization Act in Austria introduced a regulatory sandbox provision in Section 58a, which allows deviations in grid tariffs to be tested in practice with the approval of the regulatory authority.

The national INNOnet project aims to investigate the incentive effect of load-dependent variable grid tariffs at household level in large-scale demos with over 1,000 participants. INNOnet also examines aspects of the practical implementation of these future tariff structures by grid operators and supports the development of a common position of the Austrian grid industry for a feasible and efficient design of future grid tariff structures in Austria.
Methods:In the INNOnet project, variable grid tariffs are being developed for 3 demo areas in Austria (Netz Oberösterreich, Linz Netz and Energienetze Steiermark). The process can be divided into four phases:

1) Development of the tariff schemes: Variable grid tariff schemes are developed specifically for the three selected areas.
2) Simulation and adjustment: The specific tariff levels are determined by simulating the tariff schemes with historical household data (load and generation).
3) Anticipatory grid simulation: The time slots for the tariff levels are determined based on daily running grid simulations for the following day.
4) Implementation and monitoring: The specific grid tariffs are made available to the participants in the demo areas daily via a specially developed app. This app enables participants to monitor their energy consumption and receive daily updates on the tariffs, which depend on the current grid utilization.

The demo participants can then respond to these tariff incentives manually (e.g. by charging their e-car in hours of low tariffs) or automatically via energy management systems. This project aims to evaluate the incentive effect of the test tariffs during the period of the demo, and draw recommendations for following policy/regulation actions.

It is planned that the grid tariffs will be approved by the Regulatory Commission in Q2 2024 via a regulatory sandbox application. A demonstration in the three demo areas is planned to be carried out over one year, starting from Q3 2024.
Results:The project is currently in the tariff development phase. Both energy price-based tariffs and power/capacity price-based tariff schemes (and variations/combinations thereof) are to be tested in the 3 demo areas. While energy price-based grid tariffs price consumption (e.g. variable over time) in cents per kilowatt hour, a power/capacity price-based grid tariff scheme prices the peak load (in kilowatts), e.g. of a day or month.

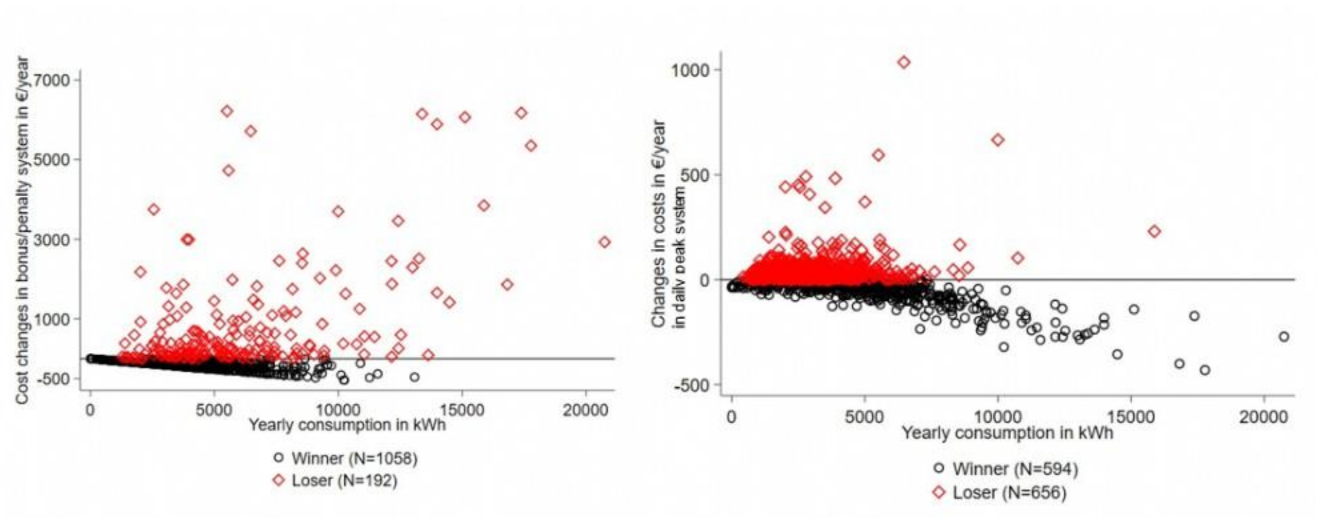
Initial simulations with household data from the Upper Austria grid area (data from 2017/18) show that with a pure bonus/malus tariff scheme, in which a basic fee is applied, and bonuses/penalties are paid out based on the load behavior of households, few households are confronted with very high grid tariffs. Therefore, this tariff scheme will also be provided with a consistent energy price. The purely power/capacity price-based tariff scheme, in which the peak of the day is priced, shows a more balanced picture between households that benefit from the tariff scheme and those that face additional costs. This tariff scheme will also be re-evaluated, and a possible basic fee or energy price will additionally be introduced.
Conclusions:Variable grid tariffs can be used to better adapt the electricity consumption behavior of households to renewable energy. The INNOnet project is developing 3 innovative, variable electricity grid tariff designs and will be testing them on a large scale in demos with over 1,000 participants from Q3 2024.

The initial simulations in the current tariff development phase have shown that grid tariffs (and their energy, power and/or flat-rate components) must be calibrated so as not to lead to extremely high-cost increases for individual households.

The next steps include the determination of tariff designs and their specific tariff levels by further simulations, the further development of the app for communicating with the demo participants, as well as the start of participants' acquisition via the grid operators. The actual demo participants will be determined by the end of Q1 2024 and analyses of the developed grid tariffs will be available based on the participants' historical load profile data.
References:Project homepage: https://www.ait.ac.at/themen/integratedenergysystems/projekte/innonet

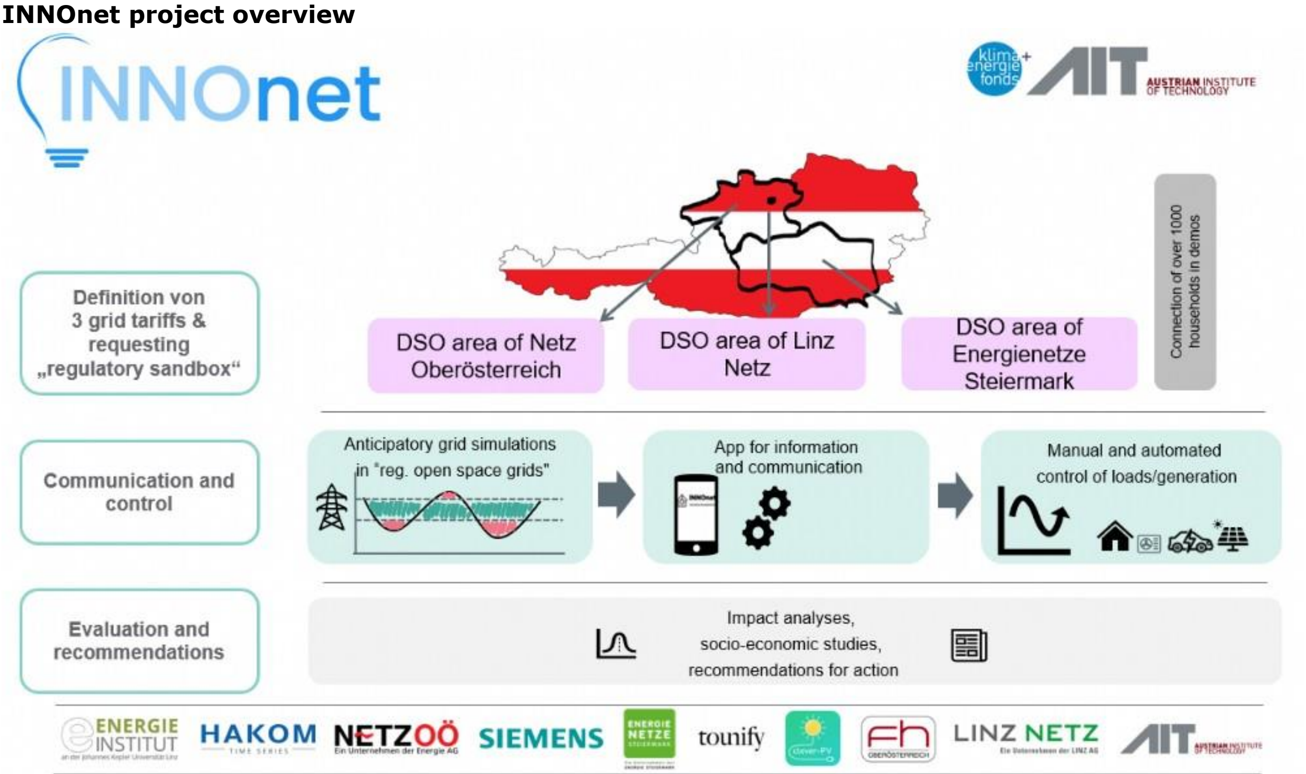
Keywords: electricity grid tariffs, distribution grid, variable pricing, demo project

First results tariff simulation (bonus/penalty system on the left, daily peak system on the right)



The figure shows first simulation results on winners and losers in different electricity network tariff schemes. The left (bonus/penalty scheme) shows more households that benefit from the tariff scheme, but fewer households that are confronted with very high network tariff charges. The right figure (daily peak scheme) shows a more even distribution between financial beneficiaries and the disadvantaged, however, few households are still confronted with rather high charges.

INNOnet project overview



The picture shows the phases of the national INNOnet project. In the first phase, grid tariffs are defined for the 3 demo regions in Austria and a regulatory sandbox is applied for at the Regulatory Authority. In a next phase, the daily grid simulations for the tariffs are prepared and a mobile app for communicating with the demo participants and to incentivize changes in their consumption/feed-in behavior is developed. In a final stage, impact analyses are done and recommendations are derived.

[Abstract:0124] OP-029 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

An incentive scheme for storage investments to help reduce carbon emissions

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Overview:SUMMARY

Transmission companies (TRANSCOs) can be induced to act in a way that serves the public interest through incentive regulation. Here, we show how recently proposed schemes for network expansion can be adapted to support investments in grid-scale energy storage performed by TRANSCOs, while steering their decision-making process towards the environmental goal of reducing carbon emissions. A bilevel program has been developed to test the proposed mechanism, where the upper level represents a TRANSCO's investment decision problem subject to incentive regulation, whereas the lower level is a wholesale market clearing problem. Results based on actual data from the Italian day-ahead market show that the proposed approach can significantly help improve carbon abatement, reaching 190 kgCO2 per MWh of energy storage capacity deployed.

INTRODUCTION

TRANSCOs can be subject to different incentive mechanisms and regulatory frameworks. In a centralised approach, an independent authority identifies system needs through cost-benefit analyses and informs TRANSCOs on how network capacity should be expanded. By contrast, in a merchant approach (Joskow & Tirole, 2005), a TRANSCO independently invest in network assets and is remunerated through transmission rights. One of the problems of the first approach is the asymmetry of information between the central planner and TRANSCOs, as the latter usually have better knowledge of technologies, market conditions and costs. By contrast, the merchant paradigm is subject to a significant conflict of interest, as TRANSCOs are private firms that pursue self-interests and, e.g., may withhold capacity to increase profit, while a central planner aims at public goals, such as the overall increase of social welfare. In addition, TRANSCOs usually are monopolistic firms, which makes the problem even more complex. An alternative approach to both centralised and merchant methods is incentive regulation (Vogelsang, 2020), in which a regulator tries to induce a monopolistic TRANSCO to use its superior information in a way that serves the public interest.

In the literature, the concept of incentive regulation can be traced back to Loeb & Magat, (1979) and Vogelsang & Finsinger, (1979). The former proposed an approach where monopolistic utilities receive a subsidy equal to the consumer surplus generated by their investments. The drawback of this approach is that a regulator has to estimate the demand for public utility services. Instead, Vogelsang & Finsinger, (1979) suggested constraining the firm's pricing such that it would break even if it sold the same quantities of output of the previous period, converging to Ramsey prices over time (Ramsey, 1927). The drawback of this method is that it can be severely exposed to strategic cost manipulations by the firm. A step forward was the introduction of the concept of a two-part tariff (Hogan et al., 2010; Vogelsang, 1989, 2001), where the revenues of a monopolistic TRANSCO depend on both a regulated fixed fee and usage charges. Recently, Hesamzadeh et al., (2018) extended this approach by proposing the HRGV model, where the fixed fee is a function of the surplus that the investment creates, while the usage fee depends on the merchandising surplus. The strength of this approach is that it does not rely on subsidies and the surplus can be directly inferred from the market. However, the drawback of this scheme is that it hands the whole benefit created by the TRANSCO investments to the TRANSCO itself, leaving consumers and producers at their original benefit level, which might be considered unfair from a distributional perspective.

The aim of this paper is to discuss a novel scheme, based on the HRGV model, to support grid-scale energy storage investments performed by TRANSCOs, while (i) trying to align their profit-driven self-interests with the public goal of reducing carbon emissions, and (ii) dealing with the fairness concern. The model is structured as a bilevel program, where the upper level represents a TRANSCO long-term investment problem subject to incentive regulation, whereas the lower level represents a wholesale market clearing performed by an independent system operator. Test cases based on actual data from the Italian day-ahead market show that the proposed approach can significantly help reduce carbon emissions.

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Methods:The HRGV model assumes the presence of a monopolistic TRANSCO that owns the transmission network and bears all investment costs. The TRANSCO's revenues are based on a two-part tariff scheme, with (i) a fixed fee subject to a regulatory constraint, and (ii) a usage fee equal to the merchandising surplus. Mathematically, the HRGV mechanism can be described through a bilevel model (omitted here due to space limit but will be mathematically detailed in the final conference paper)

The key property of the HRGV mechanism is that a monopolistic TRANSCO subject to the HRGV incentive regulation will aim at maximising the welfare in each period t>0 (as in a centralised optimal planning problem), which is a desirable property from the point of view of a regulator. However, this scheme has a fundamental drawback. Indeed, it transfers all consumers and producers surplus increase due to the TRANSCO investment to the TRANSCO itself through the new fixed fee, leaving consumers and producers at their initial benefit level. This means that consumers and producers do not harness any benefit from TRANSCO investments under the HRGV model.

To overcome this problem, we propose to limit the amount transferred by a percentage k. The parameter k represents a lever that regulators could use to tune this scheme according to their policy objectives. The Result section shows how it could be used to steer the TRANSCO investment decisions towards the public goal of reducing carbon emissions.

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Results:Preliminary results show that the introduction of the proposed tuning parameter can help steer investments in grid-scale energy storages, and the carbon emission reduction can be improved by up to 190 kgCO2 per MWh of energy storage capacity deployed.

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Conclusions:Incentive regulation can be an effective approach to steer the investment decision-making process of private transmission companies in a way that serves the public interest. This work discusses how this approach can be extended and adapted to incentivise grid-scale energy storage investments. In particular, we show how the HRGV model can be refined to help reduce carbon emissions while addressing fairness concerns in benefit allocation. Results based on actual data from the Italian day-ahead market show that the proposed mechanism can help decrease emissions by up to 190 kgCO2 per MWh of storage capacity installed. These findings highlight the importance of adequately designing incentive schemes, where relatively minor changes, such as the introduction of the proposed tuning parameter, can lead to a significant beneficial impact.

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Keywords: energy storage, investment, incentive regulation, carbon emission, bilevel program

[Abstract:0160] OP-030 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Decarbonization efforts hindered by uncleanness and inefficient utilization of transmission lines

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Overview:Power transmission lines play an important role in integrating variable renewable energy (VRE) and realizing the low-carbon transformation of power sector. In China, the early transmission lines especially UHV aimed to solve the demand shortage by transferring power from resource-enriched areas to the load-concentrated areas. It did not take improving the utilization rate of VRE as the main purpose. Under the low-carbon transformation of power sector, making better use of UHV transmission lines for integrating VRE to decarbonize power sector has become an important issue to be solved urgently. Based on the power market equilibrium model that includes independent system operators (ISO), producers, and consumers, this study finds that the existing transmission lines make no full use of their capacity to improve the utilization of renewable energy. Therefore, we propose two regulatory policies, volume-based and percentage-based, to improve renewable energy power transmission. The results show that (1) The regulatory policy can effectively promote interprovincial VRE transmission achieving the clean and efficient utilization of power transmission lines. (2) The regulatory policy can optimize the layout of newly installed VRE capacity, as well as significantly promote low-carbon transformation of power sector. (3) The volume-based policy is more effective in promoting carbon emission reduction in the power system than the percentage-based policy. Valuable implications for policymakers are concluded in the end.
Methods:We construct a national power market equilibrium model that includes independent system operators (ISO), producers, and consumers. The power transactions occur in the locational marginal price (LMP) power market. The objective of the ISO is to minimize the total system cost. We consider that there is only one state-owned company to manage market and power transmission as ISO does in China. We have divided key transmission nodes that include producers and consumers to simulate the real transaction. Transmission capacity bottlenecks the power exchanges between different nodes. The power flows can be adequately approximated by a linearized direct current DC flow that is governed by Kirchhoff's laws. Producers also known as generating firms own various types of power plants in different nodes. Based on the perfect competition hypothesis, we consider the firm as a price-taker. They sell power at an LMP-based power market. The power generated is delivered to the national transmission line network through the nearest transmission nodes. The LMP can effectively reflect the spatial value of power. It is adjustable to balance demand and supply at each node. It has higher prices in the areas with tight supply and demand. Their objective is to maximize the total profit by deciding their production and investment decision. In line with Kasina and Hobbs (2020), we assume that the power system operates after the investments come online without loss of generality. Consumers in different nodes include the power grid and end-users. Their demand is represented as their demand function.
Results:(1) Impact of regulatory policies on power system. The regulatory policy significantly reduces carbon emissions. The emission reduction effect of the volume-based policy is better than the percentage-based policy. It shows a better emission reduction effect as the policy intensity increases. It reduces carbon emissions by about 1.07 billion tons under the VOL-75% scenario compared with the BAU scenario. Regulatory policy has contributed to large-scale investments in VRE capacity. The

effect is particularly pronounced under the volume-based policy, with newly installed VRE capacity under the VOL-75% scenario being 17.7 times higher than the BAU. (2) Decomposing analysis of the emission reduction effect. The emission reduction effect is mainly attributed to VRE generation substitution. The emission reduction effect in the power sector is more dependent on newly installed VRE generation with the introduction of policies and increasing policy intensity. Wind power will play a greater role with its current lower prices and richer resource endowment. The increase in VRE power generation is concentrated at the exported end of power transmission lines. It particularly concentrates on the "three-north" regions. (3) Geographical distribution of generation and transmissions under 75% policy intensity scenario. The additional VRE capacity is characterized by a significant increase in the East and West and a relatively small increase in the Center. Among the newly installed VRE capacity, Southwest and Northeast China are dominated by wind power. Under the volume-based policy, interprovincial power transmission has become more frequent. It witnesses an aggravating trend "from West to East, from South to North". From the demand side, Shandong, Jiangsu, and Guangdong have the largest imported power from other provinces. Conclusions:This research highlights the following FINDINGS: (1) The regulatory policy can effectively promote interprovincial VRE transmission achieving the clean and efficient utilization of power transmission line. (2) The regulatory policy can optimize the layout of newly installed VRE capacity, as well as significantly promote low-carbon transformation of power sector. (3) The volume-based policy is more effective to promote carbon emission reduction in the power system than the percentage-based policy. These results can provide valuable implications for policymakers: (1) In addition to the planning for new UHV lines, high priority needs to be given to the efficient and clean utilization of existing transmission lines. (2) The newly installed VRE capacity should be firstly invested in provinces that has a high capacity to transmit power from UHV lines. (3) Compared to percentage-based policy regulation, stricter volume-based policy for regulating the UHV renewable energy transmission should be put in place to achieve better carbon emission reductions.
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Keywords: green power transmission policy, decarbonization of power sector, power market equilibrium model, UHV transmission lines

Fig 1. Scenario design

Scenario Setting	Scenario design	Description
Business as usual	BAU	Business as usual scenario with no VRE transmission policy
Percentage-based policy	PER-25%	VRE transmission is more than 25% of the total power transmission
	PER-50%	VRE transmission is more than 50% of the total power transmission
	PER-75%	VRE transmission is more than 75% of the total power transmission
Volume-based policy	VOL-25%	VRE transmission volume is more than 25% of the line capacity
	VOL-50%	VRE transmission volume is more than 50% of the line capacity
	VOL-75%	VRE transmission volume is more than 75% of the line capacity

Fig 2. Illustration of model formulation and variable transfer

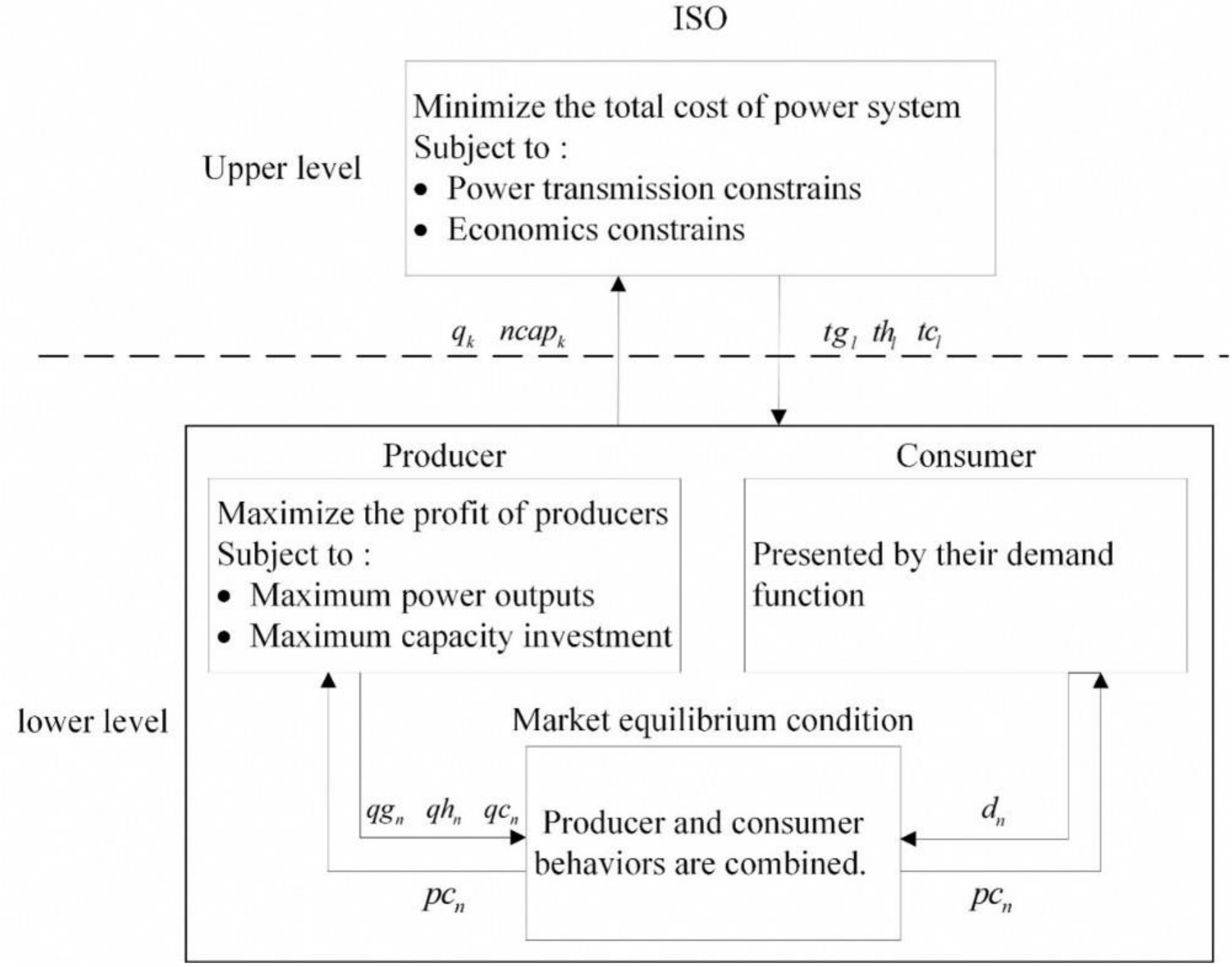


Fig 3. Carbon emission of power sector

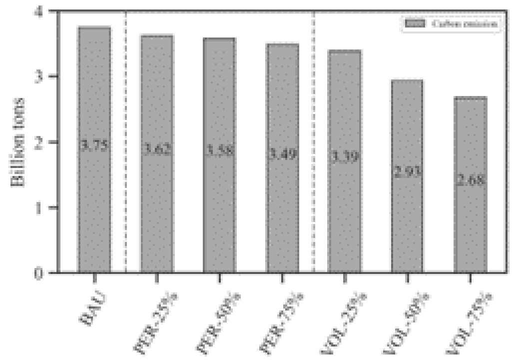


Fig 4. Newly installed VRE capacity

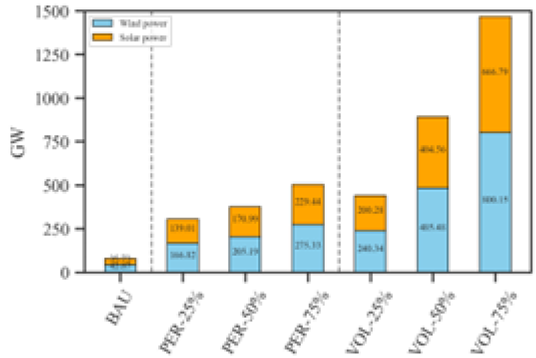


Fig 5. Power mix under different scenarios

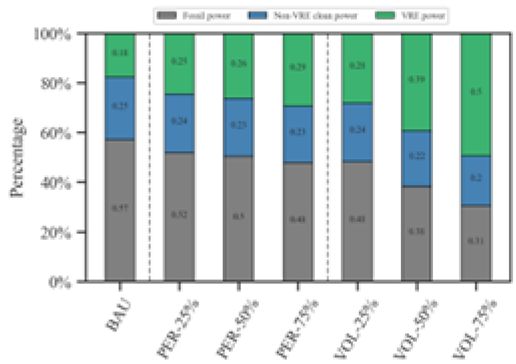


Fig 6. Interprovincial power transmission

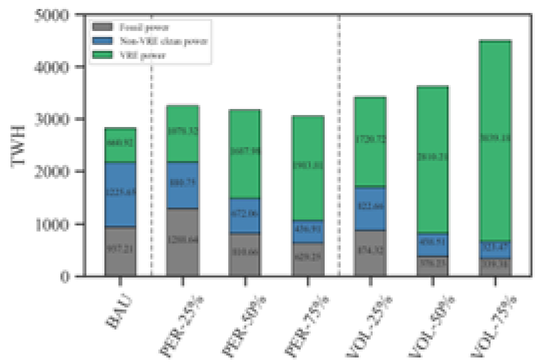


Fig 7. Emission reduction contribution under different scenarios

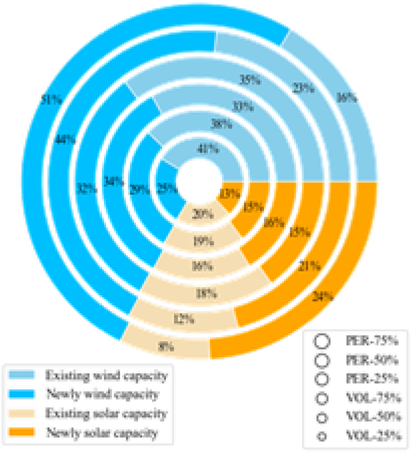


Fig 8. VRE generation compared to REF scenario

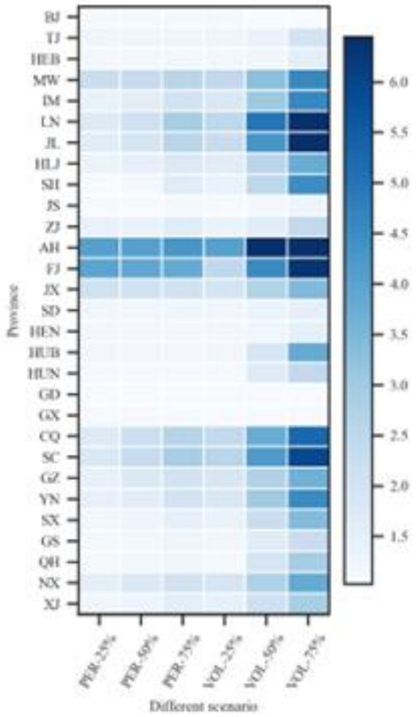


Fig 9. Provincial VRE ratio under different scenarios

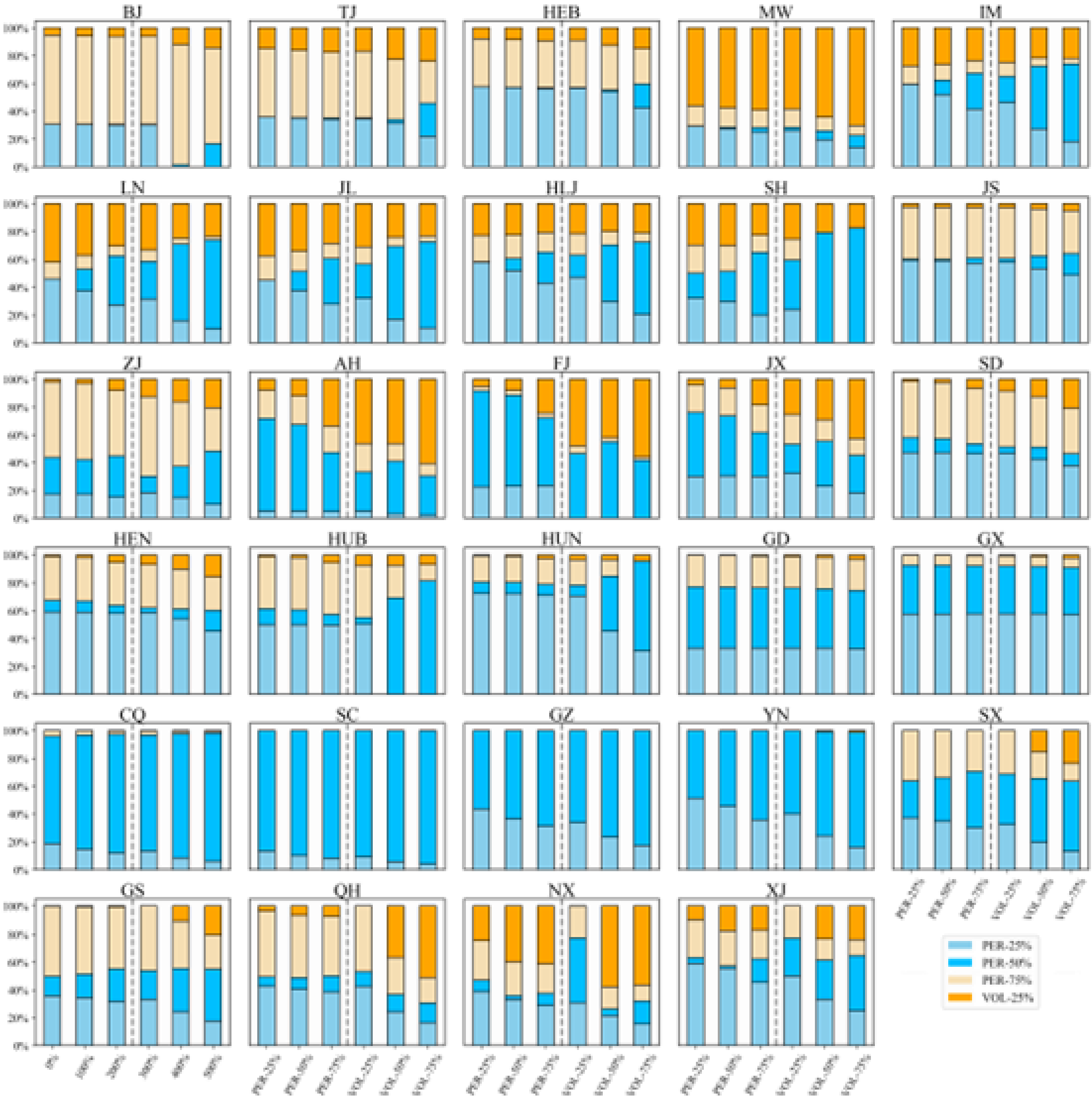
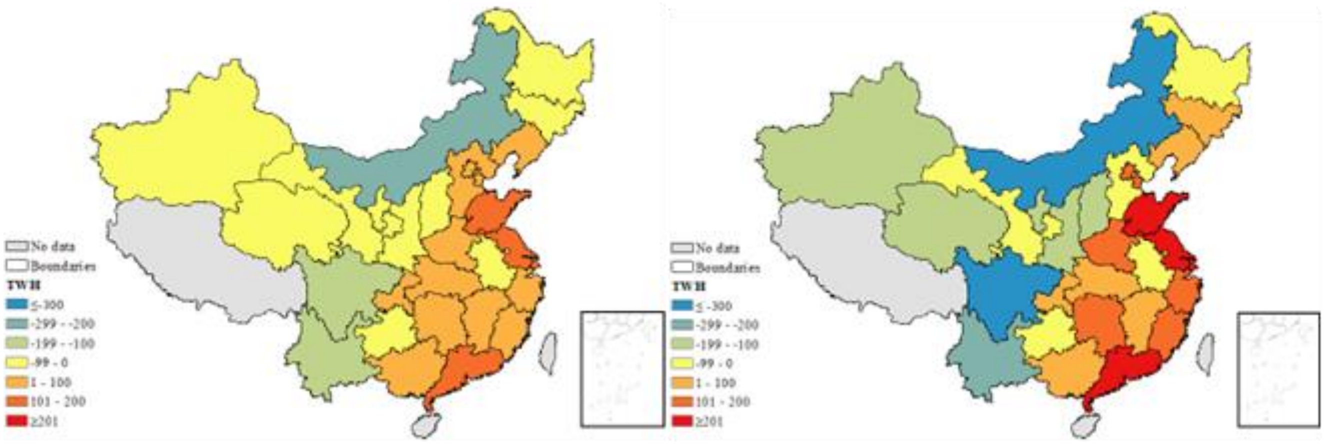


Fig 10. Net power transmission under PER-75% and VOL-75%



[Abstract:0224] OP-031 [Accepted:Oral Presentation] [Electricity » Demand]

Heterogeneous effects of government energy assistance programs: Covid-19 lockdowns in the Republic of Georgia

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Overview:At the beginning of April 2020, the government of the Republic of Georgia announced that it would pay the electricity bills of residential customers directly to the utility on their behalf—as long as electricity consumption was less than or exactly 200 kWh for the month. The policy would apply in April and May 2020, as well as retroactively for March 2020. Effectively, electricity would be free to consumers, as long their consumption levels would stay below or at 200 kWh. This decision was motivated by the desire to help households during the Covid-19 lockdowns—a period of extreme economic uncertainty—and came at a time when the electricity sector was experiencing generation difficulties, because of less abundant rainfall than usual and the upcoming temporary closure of the most important hydro power plant in Georgia for maintenance.

In August 2020, the government announced that the measure would be resumed in November and last until the end of February 2021. Officials at the national energy regulatory commission, GNERC, told us that virtually all of the consumers that contacted GNERC to make sure that they had fully understood the policy and its workings were residents of Tbilisi, the capital. One thus wonders whether somehow people elsewhere were unaware of the policy, and had perhaps failed to respond to it.

The purpose of this paper is to examine if and how people responded to the free electricity policy in the Republic of Georgia, and identify factors that affect the intensity of such response. Economic theory and common sense suggest that faced with the prospect of free electricity, low-volume consumers would increase their consumption—while trying to stay below the 200 kWh mark. Conversely, high-volume consumers would try to reduce usage to qualify for free electricity. Whether these two opposing responses resulted in an increase or decrease in electricity consumption, especially during lockdowns, when people are required to stay at home, is an empirical question, which we tackle in this paper. Understanding how people respond to strong price signals is of paramount importance when planning investment in generation, transmission and distribution, when seeking to reduce the negative externalities of electricity generation and use, and if carbon pricing is to be implemented.
Methods:We focus on the service territory of one of the two distribution utilities in Georgia—the one that serves the entire nation outside of the Tbilisi city limits. We have a 10% sample of its entire customer base, and conduct our analyses using a longitudinal dataset that follows these consumers every month from January 2017 to September 2021. This period covers revisions in the tariffs, the “emergency” free electricity policy during the pandemic lockdowns, and several months thereafter. Our analyses rely on econometric models with a rich set of fixed effects to account for household and dwelling unobserved characteristics, weather and nationwide trends in electricity usage, and take advantage of the intermittent nature of the free electricity policy. Our basic regression equation is

$$(1) \qquad \ln E_{imt}=\alpha_{im}+\tau_t+W_{imt}\beta+FREE\_ELEC_{mt}\cdot\gamma+\varepsilon_{imt}$$

where E is electricity consumption, W a vector of weather variables, FREE_ELEC is a dummy indicating if month m in year t is a free electricity month, and i denotes the household. We test specific hypotheses (see below) by interacting the FREE_ELEC dummy with either measures of distance from the capital (see figure 1) or with specific location dummies.
Results:The free electricity policy results in a 5% increase in electricity consumption during the lockdowns, which is modest when compared to estimates from the US (10% nationwide and 16% in

Texas: Cicala, 2020) and Spain (9%, see Bover et al., 2023). This figure however masks considerable heterogeneity across environments.

We formulate and empirically test a number of assumptions about the mechanisms that would result in heterogeneity. Briefly, we find no support for the hypothesis that knowledge of the policy, and hence presumably the responsiveness to it, decreases with the distance from the capital, Tbilisi. We find that rural areas experience a stronger percentage increase in electricity usage, whereas consumption is practically unchanged in urban areas, and even decreases by some 2% in the most urbanized of the urban areas. We had conjectured that the policy should have modest or no impacts in those areas where it represents just a minimal departure from the current situation (Chetty et al., 2009; Sallee, 2014). This would be the case, for example, in areas designated as "high mountain," where normally households receive a 50% discount in price if consumption is less than 200 kWh. Surprisingly, however, households residing in these areas actually exhibit the largest percentage point increase in their usage (almost 12%). We attribute this result to an increase from the very minimalistic baseline consumption, and to the possibility that households increased the use of electric heat.

Conclusions:We have examined household response to a policy that was in place—intermittently for a total of six months—in the Republic of Georgia in 2020 and early 2021, when lockdowns were ordered to help contain the spread of Covid-19. The government paid the electricity bills of residential customers directly to the utilities, as long as consumption for the month was less than or equal to 200 kWh. This effectively made electricity free to consumers below 200 kWh. The program effectively provided support at a time of high economic uncertainty due to the pandemic. For comparison, in other countries, including the United States, direct cash support was provided to households and businesses.

We found no evidence of "bunching" of the distribution of electricity consumption around the 200 kWh mark during the free electricity months. Yet, there was a meaningful response on the part of the consumers. The average household increased consumption by some 5%, but this figure masks considerable heterogeneity on the part of the consumers. We propose and empirically test a number of hypotheses about possible sources of heterogeneity.

One is that knowledge of the policy is inversely related to the distance from the capital, Tbilisi. We create concentric rings around the capital, but find that the effect of the free electricity policy is not monotonic in the distance from Tbilisi. It is possible that information about and awareness of the policy do not truly decay with the distance from the capital, or that they do but the net effect on electricity consumption does not match such decay, perhaps because of household income and habits, dwelling age and type and stock of appliances.

We suspected households in urban and rural environments to react differently to the policy, but did not have a clear a priori sense for the strength and direction of their responses. Households in urban settings are wealthier, live in smaller homes and use piped natural gas as their mean heating fuel, and may have more electric appliances. Homes are larges in rural areas but comparable in terms of age of the building. Piped natural gas makes a strong presence in rural areas as well, but income tends to be lower: Absolute poverty is dramatically higher—by 7-10 percentage points, especially in 2020—in rural areas (Geostat, 2023). We find that the households in rural areas increase electricity consumption by more, in percentage terms, than their urban counterparts, who exhibited either a negligible change or even a 2% reduction.

Finally, we had conjectured that the impact of the free electricity policy is likely to be lowest at locales where it poses the least amount of change compared to the existing tariffs. We identify such locales as those villages and areas with "high mountain" status designation, where, even before the pandemic, households already benefited from a 50% discount on the tariffs up to 200 kWh. Contrary to our expectations, the response of household in "high mountain" status areas is actually the strongest, in percentage terms.

A 2015 survey of residents in rural areas and mountain status areas in 12 municipalities indicates that despite the presence of gas lines at some locations, many households continue to use wood for cooking and heating, because it is cheaper than gas. Households members live confined to one or two heated rooms during the winter, and the rest of the home is not heated (Lekveishvili, 2015). It is possible and likely that these households chose to use more electricity and less wood during the free electricity months, since the former was, at their usage levels, free (Lekveishvili, 2015). Perusal of the data from the 2019-21 waves of the Household Budget Survey rules out purchases of appliances for these households or any other in our sample during the 2020 pandemic lockdowns. That the most pronounced electricity usage increases occur in comparatively poor areas bodes well in terms of progressivity of the program (Mastropietro et al., 2020; Berkhouwer et al., 2022; Alberini and Umapathi, 2024). That much of our sample reacted to the policy by increasing consumption has important implications in terms of GHG emissions. Assuming a "worst case scenario," namely that the increased demand was met using imports of natural gas fired electricity or domestically generated natural gas fired electricity, our sample alone would be responsible for an additional 2,028 tons of CO_2 emissions. In the larger cities, residential customers managed to reduce their consumption of electricity by 2%, and hence CO_2 emissions by 196 tons in our sample, despite spending more time at and/or working from home, which presumably would increase the demand for lighting, and electronics.

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Keywords: residential electricity consumption, increasing block rate (IBR) tariffs, salience, free electricity.

[Abstract:0190] OP-032 [Accepted:Oral Presentation] [Electricity » Customer/Grid Interactions]

Bargaining under non-cooperative trading for peer-to-peer energy communities

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Overview:Energy communities involve agents that trade the energy in surplus among members owning their power plants (prosumers). This paper analyses the relationship between power market prices, feed-in tariffs and individual preference for self-generated energy to solve the energy system sizing problem. Under the condition of neutrality of network charges, distributional issues are considered such as to limit the impact of community on the other consumers. We build a game theory frame with non-cooperative trade of the energy in surplus among two prosumers and extend the regular one-way trade of Nash bargaining framework to two-way trading: the prosumers are buyers and sellers in the same time over an extended period (one year). We connect the buying price to the selling price by weighting the bargaining power, the market prices and feed-in tariffs by the ratio of the quantities sold and bought, which gives the independence rate of prosumers into the community. Empirically, the model applies to a French household and another prosumer type (tertiary sector) installing solar power panels. We find that at low feed-in tariffs (< 0.05 €/kWh), the household solar panel size remains low (<3 kWp), which gives low to zero bargaining power to the household; this makes increasing community prices and reduces prosumer's motivation to engage in peer-to-peer trade. At the opposite, large solar panels (>7 kWp) give household price negotiation power and create trade opportunities; abnormal profits can be created, yet the social welfare is improved, as both prosumers are better-off than considered individually.
Methods:Individual self-consumption program. We assume a prosumer installing solar panels to consume in priority energy from panels and sell the electricity in surplus to the market. The power demand is made of the quantity of electricity withdrawn from the national market, Dm, and the electricity produced by the solar panel, Dp. The utility function is a monotonic convex combination of the two quantities, weighted by their preference parameters (b>a>0), with ɑ constant elasticity of substitution. The budget constraint is the total cost, CT, for installing the solar panel that produces a volume G at unit cost c, and for paying the energy bill for the electricity bought at the market price, pm. The total cost is net of revenues from selling the energy in surplus (G-Dp) at feed in tariff, f. The power self-consumed, Dp, is lower than the total power generation, G, and represents a given share into the total power generation, k, or the self-consumption rate (0<k<1). The market price, pm, and the solar panel unit cost, c, being exogenous, we solve the prosumer's market and solar power demand by performing a constrained optimisation problem of maximizing utility (see the Langrangian at eq. 1 in Appendix 1). After first order conditions and equation simplification we obtain the share of the electricity self-produced and consumed over the market power demand (eq. 2). The community program through Nash price bargaining with cost extension. We extend the one-way trade used in Castellini et al. (2021), at hourly time-step, to a larger time-period, so that the prosumer is buyer and seller at different time-steps at over that period. We look for the community price p* at which the prosumer i buys energy from the prosumer j (Dci) and the cost c* at which the prosumer sells energy to the same prosumer j (Sci). The trade-off implies that individual i improves utility if buying from individual j and selling to the individual j is better off than buying on the market at price pmi and selling at feed-in tariff fi (eq.3). Similarly, the individual j is better-off by trading in the community than on the market. The difference with one-way trade bargaining is that combined trade negotiation can lead to unprofitable buying situations that are offset by profitable selling opportunities.
We obtain the identity εUjc=(1-ε)Uic which gives the relationship between the buying cost and the selling price (eq. 5). The prosumer i links the buying price p* to the market price and also to the selling price difference between negotiated rate c*and the feed-in tariff, weighted by the bargaining power and by the quantity sold divided by the quantity bought (Sci/Dci). The latter represents the independence rate of prosumer i into the community or the rate of export to the community over

imports from the community.
Results:The case study applies to the French solar energy self-consumption for households trading with the tertiary sector. By means of the software GAMS, solver dnlp, we endogenize the capacity installed and obtain the demand self-generated and the market demand. Results show that maximum capacity of PV solar panel is attained at feed-in tariff rate of 0.15 €/kWh, such as a solar power system of 16 kWp, limited by the prosumer's contract powerg.
P2P community trade. The bargaining power of the household (i) depends on the ratio between self-surplus and demand bought from community, and on the magnitude of feed-in tariff (fi). A high feed-in tariff makes increasing the size of the solar panel and the surplus to trade with the community, which triggers-up the bargaining power of the prosumer. A prosumer j (tertiary sector) has necessarily a different consumption profile such as to absorb the surplus of prosumer i, and vice-versa to generate electricity when the prosumer i can consume.
Case 1. Low bargaining power of prosumer i. If no feed-in tariff policy applies, the solar panel of the individual i is rather low (3 kWp) which reduces the surplus to trade and hence, the bargaining power (ε=0.01). Figure 1a shows that potential prices for the prosumer i who buys energy from the community remain are high (p*>0.211 €/kWh), close to the market price; while the maximum price, c*, of selling energy to the community by the prosumer i is rather low (<0.04 €/kWh), below the cost of installing the solar panel (LCOE = 0.12 €/kWh). The bargaining power exerted by the prosumer j, by decreasing profit opportunities for the prosumer i, limits the interest of the later of trading within the community.
Case 2. Medium bargaining power. At feed-in tariff rate of 0.1 €/kWh (above the current level for similar sizes in France, e.g. 0.078 €/kWh), leads the prosumer i to high surplus (> 8.5 MWh/year) and a relatively high bargaining power (ε=0.55). The price of selling energy c* becomes higher, favour to prosumer i, while prices of buying energy from the prosumer j might attain negative values, e.g. p*=-0.03 €/kWh for c*=0 (Figure 1b).
Case 3. High bargaining power. At feed-in tariffs higher than 0.15 €/kWh, the maximum solar panel capacity is attained, with surplus higher than the demand addressed to the community. The bargaining power being high, the energy cost for the community that the prosumer i can request is high (c*>0.19), yet lower than the market price for the prosumer j (0.227), creating thus trade opportunities. Figure 1c shows a negotiation area which is favourable to the prosumer i with high selling prices and low to negative buying prices.
Conclusions:Panel sizing. Prosumer's investment cost is recovered by feed-in tariffs and bill savings. A low to zero feed-in tariff tends to encourage self-consumption maximization, yet leading to low solar equipment; the feed-in tariff, even at moderate levels (even lower than the average cost of the solar energy), incentivizes large solar generators, as long as power prices compensate this difference. The model shows that the decision to install the solar panel is not dependent on network fees avoiding. Numerically, taxes for individual self-consumption increase from the current 0.06 €/kWh up to 0.08 €/kWh for the energy withdrawn from the central network.
Trade bargaining rules. We obtain a set of solutions dependent on the size of the solar panel that endow the prosumer with negotiation power to set prices. Even if the French regulator designs self-consumption systems based on moderate returns on investment, peer-to-peer trading can lead to abnormal profits, function of the bargaining power. Some institutional considerations state that the rationality of communities is to renounce to market rules but not in favour to other merchandising opportunities, like community profits, yet, the individual rationality respect here the social welfare maximisation, for each and both prosumers.
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Keywords: self-consumption, peer-to-peer, bargaining power, non-cooperative trading, social welfare

[Abstract:0217] OP-033 [Accepted:Oral Presentation] [Electricity » Customer/Grid Interactions]

Evaluating the accuracy of standard load profiles in the era of energy communities: A Monte Carlo simulation-based approach

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Overview: Energy communities (ECs) are seen as a lever to increase participants' energy self-sufficiency, have potential to alleviate energy poverty, and are deemed a vital component in the transformation of the energy system towards increased sustainability. Even so, their effects on the electricity grid are still a matter of investigation in research. Energy suppliers currently use standard load profiles to estimate grid users' behavior and their resulting effect on the grid. With the continuously rising numbers of prosumers and ECs, as well as changes in consumption patterns due to the energy crisis, it can be expected that there exist significant differences between grid users' real load profiles and standard load profiles. In this work, we aim to quantify the impact of EC participation on the accuracy of using standard load profiles to predict grid users' behavior and the associated risks of misestimation through Monte Carlo simulation (MCS). Moreover, we present temporal correlations between the misestimations in the load profiles, allowing us to quantify currently existing structural errors in load profile estimation and the possible gains achievable through our proposed approach. We distinguish between different grid users, namely consumers, prosumers, and prosumers with access to a battery energy storage system (BESS), both as unaffiliated grid users and EC participants. In addition, we compare peak loads of these grid users. Furthermore, economic effects are reported through calculating levelized costs of electricity (LCOE) for all considered grid users.

Methods: To establish a default case to be compared to the EC case, we use measured data from real households to model a distribution for each timestep of a load profile for consumers and prosumers who own a rooftop photovoltaic (PV) generation plant that is dimensioned for on-balance annual self-sufficiency. We further consider two prosumer sub-cases: (1.1) prosumers without and (1.2) prosumers with a privately-owned BESS, dimensioned for optimal self-consumption of the available PV electricity.

For the EC case, we differentiate between two sub-cases: (2.1) EC without and (2.2) EC with a community-owned BESS, dimensioned for optimal self-consumption of the available PV generation within the EC. In both sub-cases, households with their own PV system consume as much as possible directly "behind the meter", before the surplus is made available to the EC. The surplus of PV-generated electricity is then shared among the EC participants using a dynamic allocation key, meaning each participant gets the share of the available PV electricity according to their fraction of the total demand at that time. In sub-case (2.2), the surplus PV-generation is first used to cover the immediate demand of the EC participants. Further surplus electricity is stored in the BESS and can be used to cover the demand at a later point in time, again using a dynamic allocation key.

For both the default and the EC case, we generate 10,000 load profiles using an in-house Python [1]-based MCS framework. The mix of consumers and prosumers in the load profiles corresponds to their respective shares in the current Austrian energy system. As a next step, we calculate the deviation of the MCS-generated load profiles from the standard load profiles in each time step for every load profile, allowing us to compare the generated profiles with the standard load profiles, both for EC participants and unaffiliated grid users.

We moreover derive the overall risk of misestimation through assessing how large the share of profiles differing 'significantly' from the standard load profile is. Here, 'significantly' is defined by a relative mean absolute error between a profile and the applicable standard load profile of at least five percent, calculated across a year in hourly resolution. We then compare the results for the default and the EC cases in terms of mean misestimation and risk of 'significant' misestimation. Furthermore, for both cases, we investigate the temporal correlation between misestimations at different points in the load profile. In a last step, we determine maximum peak loads and apply dynamic investment calculation to comupte LCOE for all considered grid users.

Results: Outcomes of our work are the mean misestimation caused by relying solely on standard load profiles for a default case of unaffiliated consumers and prosumers versus prosumers and consumers

belonging to an EC. Furthermore, the impact of a BESS used to optimize self-consumption on the deviation from standard load profiles is quantified. In addition, we report the risk of misestimation in all cases. Additionally, we present temporal correlation matrices for misestimations at different points in the load profiles. This allows us to differentiate between structural errors in the estimation approach and to-be-expected noise in the load estimation.

Moreover, peak loads for unaffiliated grid users versus EC members are quantified. This gives an indication of EC participants' impact on the grid and enables us to pinpoint levers for grid-friendly behavior incentivization.

Lastly, we present a distribution of possible LCOE for each grid user, consisting of the mean LCOE across a year for each load profile for every considered grid user. In this way, we can assess the economic impact of EC participation.
Conclusions:We conclude from our study that using standard load profiles to predict grid user behavior is no longer topical. This implies that energy suppliers should apply updated estimation methods for the loads caused by different grid users. Moreover, we deduce from our findings that EC participants have to be treated differently from ordinary grid users in terms of their impact on the grid, which is relevant for not only energy suppliers, but also grid operation. In addition, we draw the interference that the use of a BESS to optimize self-consumption is a lever for more grid-friendly behavior of prosumers and ECs, even though BESS have an adverse effect on profitability if they are only used in the capacity of self-consumption optimization. For that reason, we identify a need for further research on business models that ensure economic viability and simultaneous grid alleviation.
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Keywords: Monte Carlo simulation, energy communities, standard load profiles, load estimation

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[Abstract:0419] OP-034 [Accepted:Oral Presentation] [Electricity » Customer/Grid Interactions]

"Behind-the-meter" Estimation of solar self-consumption using machine learning and explainable AI

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Overview:As the adoption of renewable energy progresses, installing solar power systems for self-consumption, such as rooftop solar power, is also advancing. The phenomenon known as the "duck curve," which is characterized by a decline in daytime grid demand (demand minus self-consumption: net demand) due to increased self-consumption of solar power (solar self-consumption), has become more widely recognized in regions such as California, Australia, and Japan as the adoption of solar power increases. Solar self-consumption, often called "behind-the-meter," differs from the power supply from the grid and surplus solar power sell and is generally not metered. Solar self-consumption involves two aspects: the weather-dependent aspect of solar power generation and the behavioral aspect of the consumer's demand, making estimation challenging. This poses difficulties for power grid operators in predicting power demand and maintaining the supply-demand balance.

Especially in the evening, when both solar power generation and solar self-consumption decrease at the same time, flexibility is needed to ensure the stability of the power system. Additionally, for recent initiatives in demand-response (DR) and flexibility from the demand side, it is important to understand true demand (gross demand), including solar self-consumption. Several methods for estimating solar self-consumption have been proposed in existing literature (e.g., Cheung and Irwin (2023), Li et al. (2019)), addressing the growing complexity of customer demand patterns in the context of increasing distributed photovoltaic system (DPVS) adoption. The seminal work of Li et al. (2019) introduces a solar-demand decoupling framework that aims to separate the actual demand from the solar power generation for a more accurate customer baseline load, which is critical to the success of incentive-based DR programs. This framework hinges on the availability of historical solar power generation data, which presents a challenge as such data is often unattainable for small-scale DPVSs due to their 'behind-the-meter' placement. While Li et al. (2019) provide a machine learning solution to disaggregate individual DPVS output from net demand data, their approach primarily hinges on weather-based clustering, focusing on the discrepancy in demand between sunny and overcast or rainy conditions. Such a method may not fully capture the subtleties of temperature-driven demand, potentially overlooking the nuances in heating and cooling demand, which markedly affect power usage patterns. To circumvent this issue and streamline the estimation process, our study employs machine learning and SHapley Additive exPlanations (SHAP), known as the explainable AI (XAI) technique, using easily accessible data. Our approach offers an intuitive and more comprehensive annual estimation of solar self-consumption, leveraging readily available data. This methodology has been substantiated by three years of empirical data from Australia, ensuring robust validation beyond the short-term periods typically reported in current literature. Moreover, a case study in Japan’s Kyushu region—where solar power is gaining traction—demonstrates the method’s efficacy and reveals consumption trends that surpass the government's estimated values based on Feed-In Tariff (FIT) assumptions. This suggests a potential shift towards increased self-consumption, not just in residential sectors but also commercially and beyond.

Methods:The relationship between net demand, temperature, and solar radiation is illustrated in Figure 1. Net demand primarily fluctuates with temperature, which, in turn, is influenced by solar radiation. In the presence of solar self-consumption, net demand also varies with solar radiation. The observable variables are temperature, net demand, and solar radiation, while self-consumption is an unobserved variable. There is confounding between solar radiation and temperature. The impact of solar radiation on net demand (self-consumption) is consistently negative. In contrast, the impact of temperature on net demand rises with higher temperatures in summer and lower temperatures in winter. Therefore, the effects of solar radiation and temperature on net demand have opposite signs in summer and winter. Since electricity demand is nonlinear and influenced by multiple factors, machine learning is employed for prediction. Additionally, there are reports of factor analysis using SHAP. SHAP allows the decomposition of changes in the dependent variable into contributions from each explanatory variable. However, in the presence of confounding variables, SHAP may display values that differ from actual values (Heskes et al. (2020)). This study focuses on the seasonal variation in the impact of solar radiation and temperature on net demand (the effects are opposite between summer and winter, so the confounding is canceled out) and estimates solar self-consumption by extracting the influence of solar radiation on net demand using SHAP. For this research, the dataset used from 300 households with actual demand and solar power generation, publicly available from the Australian power utility Ausgrid, was employed. Among these 300 households, 92 had missing values for solar power generation. To address this, 208 households without missing values were considered as those with solar power self-consumption, while the remaining 92 households with missing values were regarded as households without solar power generation. The data were aggregated to simulate net demand. Sydney's temperature and global horizontal radiation (GHI) were used as meteorological information, and holiday flags and time-of-day (hour) flags were added. This analysis covered a period of three years, from July 2010 to June 2013, with hourly resolution. A predictive model was created using Python's XGBoost, with temperature, solar radiation, holidays, and hour as explanatory variables and net demand as the target variable. The predictive model was decomposed using SHAP, and the impact of GHI on net demand was further calculated using the SHAP interaction function, which removes the interaction of SHAP to extract the single effect.

Results:In the feature importance analysis of the machine learning model, the impact on net demand was most influenced by the hour, followed by GHI, temperature, and holidays in that order. The influence of GHI on net demand revealed an inverse relationship, where higher GHI corresponded to lower net demand. This indicates the impact of solar self-consumption. SHAP values from the individual effect of GHI exhibited negative values during the daytime and positive values at night. Since there is no solar self-consumption of solar power generation at night, the nighttime average of GHI SHAP value was used as the base value, and the base value was subtracted from GHI SHAP value to compare with actual solar self-consumption. The actual solar self-consumption over the three years and the estimated values are depicted in Figure 2. The three-year RMSE error is 13.4, and WAPE is 17.8%, indicating that the estimation is performed accurately throughout the year. However, on extremely hot days in the summer of 2011 and 2013, there is an underestimation. Figure 3 shows the estimation results for February 2012. Solar self-consumption estimates are highly accurate on both bad and good weather days. Based on these results, we believe that our proposed method is effective. Applying the same proposed methodology to estimate self-consumption in the Kyushu region of Japan revealed larger values than those anticipated by the government's assumed Feed-In Tariff (FIT) residential solar self-consumption. This suggests a growing trend of self-consumption beyond residential FIT installations, extending to commercial and other non-residential sectors.

Conclusions:Our innovative approach revolutionizes the estimation of solar self-consumption for systems of indeterminate capacity, harnessing readily available data to unveil the intricacies of solar power dynamics. Leveraging advanced machine learning algorithms alongside the interpretability prowess of SHAP, our methodology not only delivers precise, year-long predictions of self-consumption but also demystifies the consumption patterns hidden within. This breakthrough facilitates a deeper understanding of the actual energy demand, catalyzing more intelligent grid management, optimizing demand-supply equilibrium, and empowering robust demand response strategies.

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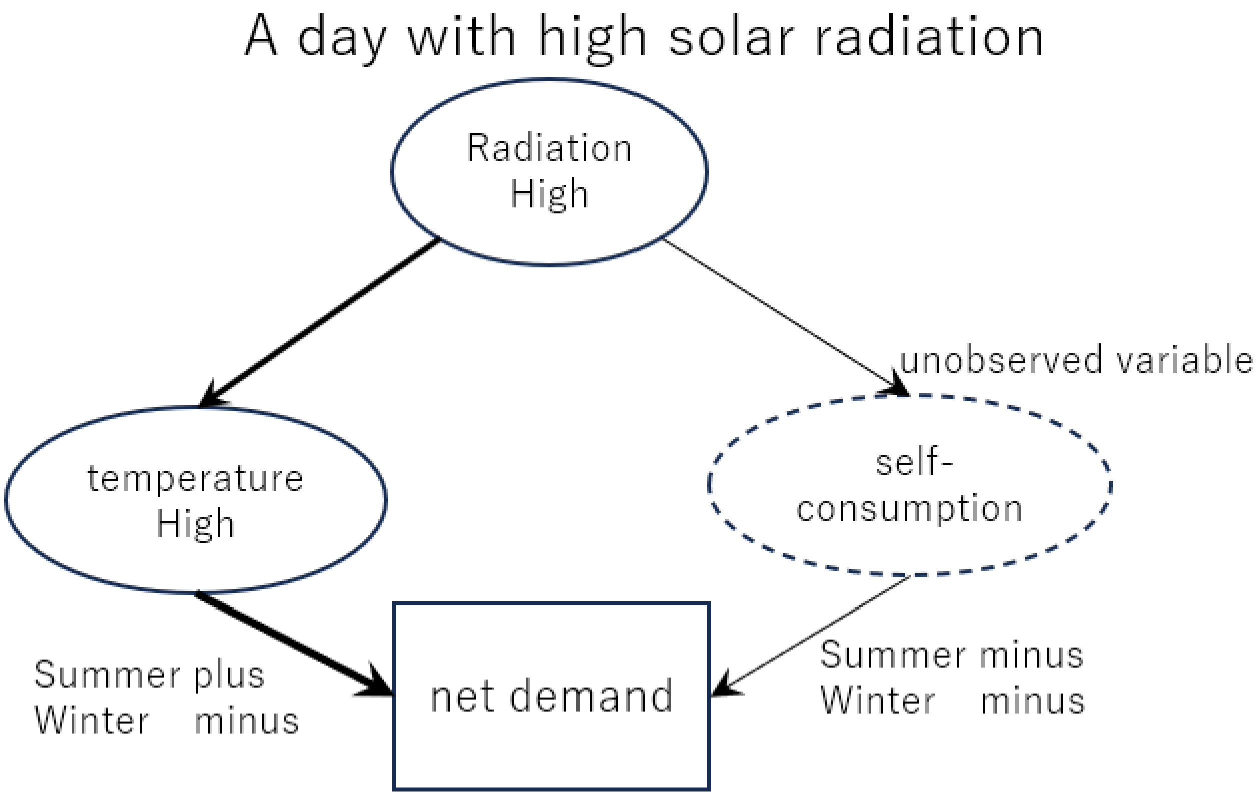
Keywords: behind-the-meter, solar self-consumption, renewable energy, distributed photovoltaic system, machine learning, XAI

Figure 1. Relationship between solar radiation, temperature, self-consumption, and net demand



Radiation, temperature, net demand are observable variables. Self-consumption is an unobserved variable.

Figure 2. Comparison of actual and estimated solar self-consumption from July 2010 to Jun 2013

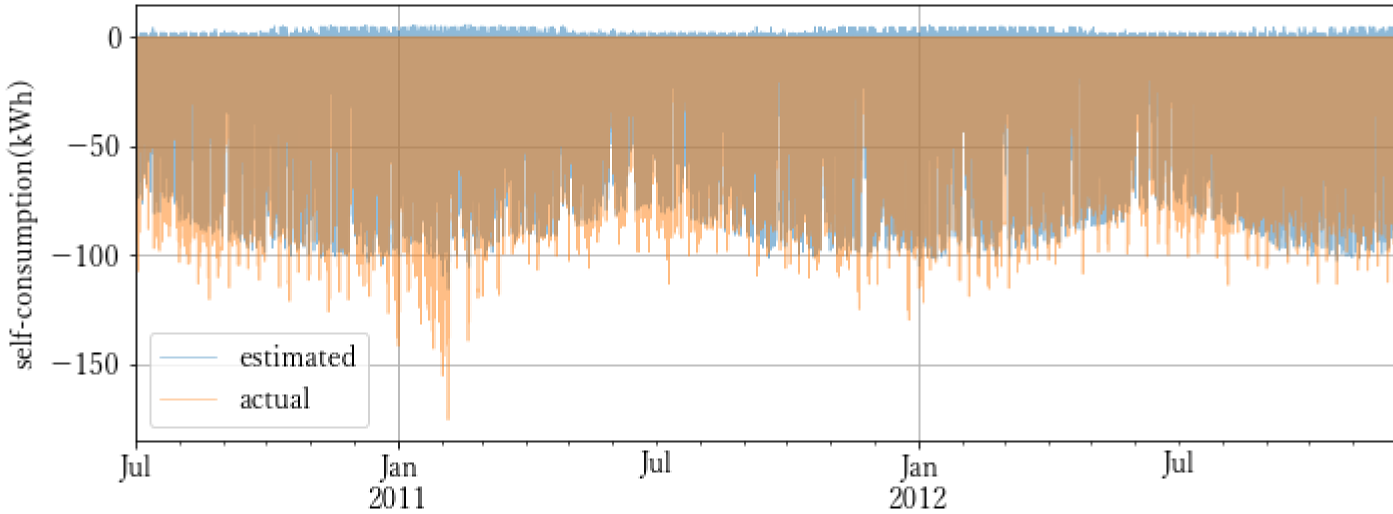
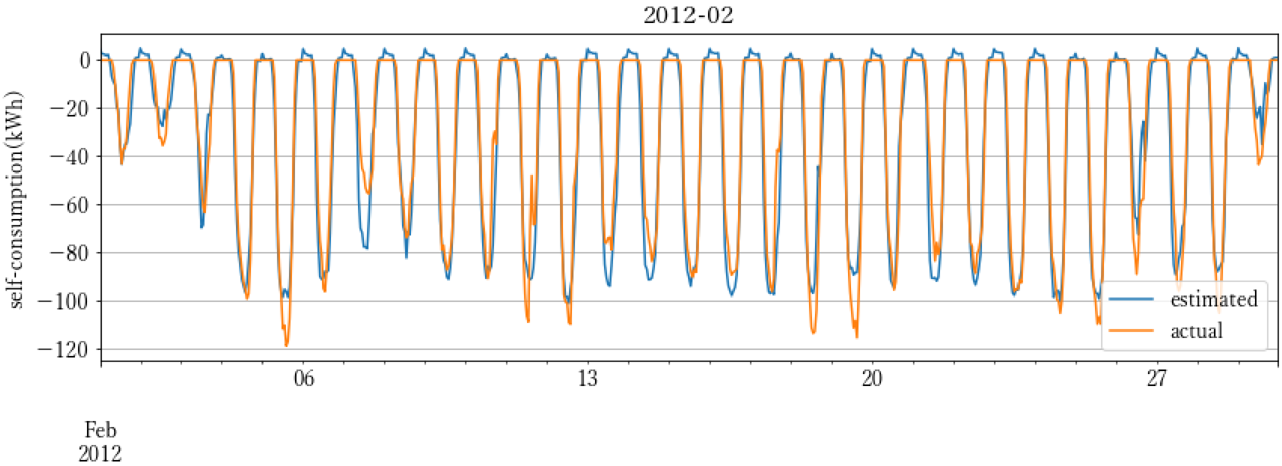


Figure 3. Comparison of actual and estimated solar self-consumption February 2012



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[Abstract:0278] OP-035 [Accepted:Oral Presentation] [Electricity » Customer/Grid Interactions]

Hedging households against extreme electricity prices

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Overview:Many economists emphasize the benefits of exposing households to dynamic electricity prices. Dynamic prices are linked to day-ahead electricity prices and fluctuate on a shortterm basis, e.g., every half hour. They incentivize households to reduce consumption during periods of high aggregate demand or scarce electricity supply.

A drawback of dynamic pricing is that it makes consumers vulnerable to extremely high prices when electricity is scarce. For example, during the winter storm in Texas in February 2021, a scarcity price of 9$/kWh was enforced for more than 64 hours over multiple days in response to a severe electricity shortage (ERCOT, 2022). As a result, the small minority of households exposed to dynamic prices received electricity bills exceeding $100 per day (EIA, 2022). These high bills sparked a public debate about whether dynamic pricing is suitable for households (McDonnel et al., 2021).

To address these concerns, economists proposed to complement dynamic prices with a forward hedge (Borenstein (2007), Schlecht et al. (2023)). The objective of the forward hedge is to protect households from high electricity prices while preserving incentives to reduce demand when needed most, namely during scarcity events (Bobbio et al., 2022). The German government recently introduced subsidized forward contracts known as gas and electricity price brakes to reduce consumers’ exposure to soaring energy prices while incentivizing them to save scarce energy (Dertwinkel-Kalt and Wey, 2022).

In this paper, I calculate household-specific optimal hedge shares, i.e., the optimal share of typical consumption that a household should buy forward. I simulate optimal shares for a dataset of 2,159 UK households that received half-hourly dynamic prices but no forward hedge. I study how optimal hedge shares are influenced by households’ price elasticity of demand, risk aversion, and ownership of technologies like electric heating and vehicles, and battery storage. To estimate welfare gains, I calculate the price premia households should be willing to pay for being optimally hedged.
Methods:To derive the optimal hedge shares for the households in my dataset, I solve a two-stage utility maximization model via backward induction. In the second stage, households do not face any uncertainty. They maximize their utility from electricity consumption and aggregate consumption of other goods. I assume a constant-elasticity-of-substitution utility function and exogeneously specify households’ elasticity of substitution and their coefficient of relative risk aversion.

In the first stage, households choose optimal hedge shares subject to stochastic electricity prices and quantity shocks. Quantity shocks capture all factors except prices that impact agents’ desire to consume electricity. For instance, the weather or a national holiday influence households’ desire to consume. The model allows deriving the unobservable quantity shocks as a residual of households’ observable unhedged electricity demand.

Based on the model, I can calculate optimal hedge shares for the 2,159 households in my sample given that the dataset contains each households’ half-hourly electricity consumption and dynamic prices from August 2020 to August 2021. Afterward, I simulate monthly electricity bills for unhedged households and optimally hedged households. This allows me to estimate how much the optimal hedge reduces the volatility of the monthly electricity bill.

Moreover, the model characterizes the risk premium households should be willing to pay for being optimally hedged. The risk premium is equivalent to the percentage change in the average electricity price that makes a household indifferent in expectation between the unhedged dynamic electricity tariff and the optimally hedged tariff. I also simulate how the risk premium changes when households are exposed to a Texas-style scarcity event by confronting households’ with manually set extremely high electricity prices over multiple days.
Results:My main contribution is to examine the interaction between price elasticity of demand and optimal hedging when agents face two volatile factors: Prices and quantity shocks. Previous literature analyzed how price elasticity affects optimal hedge shares when prices are the unique volatile factor (Moschini and Lapan (1992), Dionne and Santugini (2015)). They argue that optimal hedge shares decline if agents’ price elasticity increases. Priceelastic agents are less vulnerable to high prices because they can reduce demand when prices are high. Hence, price-elastic agents need to hedge less when prices are the unique volatile factor.

However, electricity consumers also face volatile quantity shocks. Their desire to consume electricity depends heavily on external shocks like extreme weather. Only a few authors consider how quantity shocks influence hedge shares (Losq (1982), Cowan (2004)). They find that optimal hedge shares increase if prices and quantity shocks are positively correlated.

My key result is that this correlation also determines how an increase in price elasticity affects hedge shares. When prices and quantity shocks are positively correlated, an increase in price elasticity raises hedge shares. Assume price elasticity increases for a household with electric heating. During a winter storm, the increased price elasticity induces this household to reduce consumption more strongly in response to high scarcity prices. However, reducing consumption during a winter storm causes large disutility for an electric heating owner since she needs electricity to heat her home. As a response, the more price-elastic electric heating owner increases her hedge share to reduce her exposure to spot prices. Lower spot price exposure allows her to maintain an acceptable level of consumption even during a winter storm when both prices and her desire to consume electricity are extremely high.

In contrast, when prices and quantity shocks are negatively correlated, an increase in price elasticity decreases hedge shares. In this case, responding more strongly to high prices causes small disutility because households desire to consume is low when prices are high. Hence, increasing price-elasticity makes households less vulnerable to high prices since they respond by reducing consumption without suffering large disutility. Therefore, they need to hedge less.

From these theoretical observations, I calculate optimal hedge shares for each household in my sample. The average optimal hedge share is 59% of households' typical consumption. Optimal hedge shares differ widely both between customers and by time of day. Ownership of low-carbon technologies partly explains the heterogeneity in hedge shares. Electric heating or electric vehicle owners have high average hedge shares of 77% and 69%, respectively. These technologies likely increase the positive correlation between prices and quantity shocks. On the other hand, solar PV owners hedge on average only 22% of their typical consumption, indicating that their electricity consumption from the grid is negatively correlated with prices. Battery storage ownership is also associated with a slightly lower mean hedge share of 52%.

An exogeneous increase in price elasticity of demand further amplifies the dispersion in hedge shares. Some households respond to higher price elasticity by reducing their hedge shares to exploit the negative correlation between prices and quantity shocks. Other households with a positive correlation increase hedge shares. On average, optimal hedge shares decline when price elasticity rises. In contrast, increasing risk aversion has a positive effect on hedge shares.

The optimal hedge is effective in reducing the volatility of monthly electricity bills. The optimally hedged tariff reduces households' coefficient of variation of monthly bills, on average, by 18% compared to an unhedged tariff. Hedging is particularly effective for households with large average hedge shares beyond 100% of their typical consumption. For these households, the hedge reduces their coefficient of bill volatility by 45%.

Optimal forward hedging results in tiny welfare gains for households during my sample period. Augmenting a dynamic tariff with a forward hedge leads to a welfare gain compared to an unhedged dynamic tariff that translates, on average, to a 0.3% reduction in mean electricity prices. The welfare gain from hedging increases to a more substantial 19% reduction in mean electricity prices when simulating a scarcity event like the Texas winter storm. Hedging is more valuable to consumers if they face worst-case events with extreme prices.
Conclusions:In this paper, I study how to augment dynamic electricity prices with a forward hedge. Using a utility maximization model, I simulate an average optimal hedge share of 59% for a dataset of 2,159 UK households.

Optimal hedging effectively reduces the volatility of monthly electricity bills by 18% on average. It also achieves significant welfare gains equivalent to a 19% reduction in mean electricity prices when households face a Texas-style scarcity event. Since extreme weather and price events will occur more often in the future, further research should analyze how to design optimal forward hedge tariffs that effectively protect against worst-case events.

In addition, the practical implementation of forward hedging requires further study. Most importantly, it needs to be tested whether domestic consumers understand how forward hedging works. Moreover, it is crucial to gain a better understanding how to determine households' baseline consumption levels, especially in the absence of historical consumption data. Despite all these challenges, forward contracts will play a vital role as a supplement to dynamic prices in the future energy transition.
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Keywords: Hedging, dynamic pricing, smart contracts, electricity demand, price elasticity

[Abstract:0062] OP-036 [Accepted:Oral Presentation] [Electricity » Storage]

How much electricity storage does the energy transition need? The critical role of hydro availability, demand flexibility, and regulation

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Overview:The need to decarbonize global energy systems, together with the already competitive cost of variable renewable energy (VRE) technologies such as solar photovoltaics or wind energy, is driving a very significant increase in the shares of these technologies in power systems across the world. However, managing a power system with such large shares of VRE presents many challenges, both technical and regulatory, that must be carefully addressed. From the technical point of view, the need to ensure that a variable, not-totally-predictable supply meets demand at every moment (from the very short term to the long term) requires deploying the right amount of flexibility in demand and non-VRE generation, as well as building storage or backup capacity if that flexibility is not enough. From a regulatory point of view, the right signals must be sent to ensure this deployment takes place.

Some have argued (e.g., Junge et al., 2022) that, with no price caps, electricity market prices might be able to provide the right incentives for investment in storage or demand flexibility. However, price

caps are quite widespread, and hence many markets will require some additional support to achieve the socially optimal amount of storage. Moreover, the existence in some systems of low VRE production periods, such as the dunkelflaute (Li et al., 2021), or the large annual variability in systems with hydro (e.g., in Spain, hydro production may vary up to 10% of the total annual generation), may demand additional instruments to ensure the correct sizing of the storage required to cover these infrequent periods.

This, in turn, requires estimating as precisely as possible the storage needs, which will depend on several factors: the profiles of demand or VRE (Ramsebner et al., 2021), the existence of alternative flexible generation technologies (such as storage hydro or thermal power plants), the responsiveness of demand, or the characteristics of the storage technologies available. In this regard, previous studies have shown that different storage technologies may be needed to match supply and demand at different time scales (e.g., Gabrielli et al., 2020), which will interact among themselves and with the rest of the flexibility options in non-evident ways (see Junge et al., 2022).

In this paper, we try to address most of the limitations of previous approaches: we use an open-source capacity, storage, and network expansion model (the openTEPES model, Ramos et al. (2022)) with large temporal (hourly) and geographical detail, able to represent most of the relevant features of power systems such as ramps, technical minima, etc.; we simulate both average and extreme years to determine the different storage needs and how they can recover their investment costs, implicitly identifying the fraction of those needs that may be provided by the market and the ones that must be achieved in other ways (administratively or through long-term instruments); we model hydro reservoirs as potential balancing sources, accounting for the constraints that may affect them; and we consider multiple flexibility options (including demand response, electric vehicles, exports to neighboring countries or hydrogen sector coupling) so that we can account for their interactions. We do this for 2050, assuming a fully-decarbonized power system, but also for 2030 to understand the role that storage may play during the transition.
Methods:Our assessment strategy is built upon the following stages:
- First, we determine the storage needs for a worst-case scenario (understanding as such a dry-hydro and low-wind year). For that, we run the openTEPES model (described below) in a generation and storage expansion mode, although we set the power installed in the system to the figures presented in the Spanish National Energy Plan. Therefore, we allow for investments in storage and also allow for increasing the installed capacity of VRE if there are non-supplied-energy issues in the system.
- Then, we fix the investment variables determined in the previous stage and run the model for an average hydro scenario, which allows us to represent the normal operation of the storage built in the previous stage (as well as of the generation fleet).
- Finally, we run some additional scenarios in which we vary hydro flexibility, demand response, or other parameters to test the robustness of the results and the implications of these alternative scenarios.

The Open Generation, Storage, and Transmission Operation and Expansion Planning Model with Renewable Energy Sources and Energy Storage Systems (openTEPES) (Ramos et al., 2022) determines the optimal investment mix for large-scale electricity systems considering new installations such as generators, energy storage systems, and transmission lines in order to meet the projected demand at the lowest possible cost.
The model formulates a two-stage stochastic optimization problem including generation, storage, and network binary investment/retirement decisions, generation operation decisions (commitment, startup, and shutdown decisions are also binary), and line-switching decisions. The capacity expansion considers adequacy system reserve margin constraints.

The model has hourly detail and accounts for the different technologies' startup, shutdown, and ramps; its outputs include costs, CO_2 emissions, locational short-run marginal costs, water energy value, or revenues from operation and operating reserves.
Results:The results obtained by running the reference case and alternative scenarios for 2030 and 2050 provide many interesting insights about the amount of storage needed along the energy transition, and also about the way to finance these investments.

The first interesting result is that the total storage to be installed in the system in 2030 amounts to 1,160 MW, most of it being pump storage (more costly in capital terms and with lower efficiency, but more flexible than batteries). This is much lower than the estimate of 20 GW provided by the Spanish Ministry in its Storage Strategy and also to the 6 GW included in the 2019 National Energy plan. It is also a very small amount compared to the 150 GW generation installed in the system.

However, storage never recovers it cost, under any of the scenarios. This of course derives from the fact that the amount of storage installed is not the optimal one under the average scenario (which, according to what Junge et al. (2022) explain would be sufficient for cost recovery). That is, there is an extra amount of storage that is installed under reliability concerns (in this case, an exceptionally dry year), and that must be paid through other mechanisms.

Results for 2050 are significantly different from those in 2030: in that year, the target year for net-zero, fossil fuels are not allowed by the system, so the backup capacity that CCGTs provided in 2030 is not available any more. Their place however cannot be taken up completely by batteries or pump storage, which are not able to provide the seasonal storage required by the system. Hence, the model installs hydrogen storage (we name as such electrolyzers plus hydrogen turbines) and also uses the flexible hydrogen final demand (for industry and transport) to accommodate VRE.

Compared to 2030, the amount of storage installed is significantly larger: two orders of magnitude larger for batteries, one order of magnitude larger for pump storage, and a very significant amount, under some scenarios, of H2 storage. Storage capacity is also 20 times larger than in 2030, for an electricity demand roughly double that of 2030. The total generation installed in 2050 is 180 GW, so now storage installed power amounts to 28% of that total generation (compared to 2% in 2030).

However, and in spite of the larger storage volumes required, again storage is not able to recover its installation cost. Economic losses for storage units are even larger than in 2030 (partly because of the lower, flatter prices observed in the market). Again, this raises the need to develop some kind of mechanism through which to pay for the storage needed.
Conclusions:This study has estimated storage needs for the Spanish power system in 2030 and 2050, a system that can be considered representative of many other regions with a current hydro-thermal power mix and significant renewable resource. Overcoming most of the limitations of previous approaches, we use an open-source capacity, storage and network expansion model, with large temporal and geographical detail; we simulate both average and extreme years to introduce reliability constraints and assess economic returns; and we consider multiple flexibility options, including demand response, electric vehicles, hydro reservoirs, or hydrogen sector coupling.

The major insights that can be derived from our results are, first, that demand and hydro flexibility reduce significantly the need for investment in storage. Second, that storage needs are quite small in 2030, even with an 80% share of variable renewables in the system, if thermal power plants can still contribute to providing flexibility; but are 20 times larger in 2050, and more importantly, require seasonal storage, which cannot be provided by batteries or pump storage. Smart vehicle charging or flexible hydrogen demand provide a very significant share of the flexibility required in 2050, which highlights the need to provide strong economic signals for this flexible demand (as well as for a more flexible hydro operation). The final, and very important, insight, is that the amount of storage required to provide reliability in dry years will not be able to recover its costs in the energy market: alternative remuneration mechanisms, which go beyond flexibility mechanisms, are required if the right amount of storage is to be installed. This should be included in the current or future electricity market reform proposals, such as the one recently approved in Europe.
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Keywords: electricity system, renewable energy, storage, energy transition

[Abstract:0241] OP-037 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

Imperfect information in car investment decisions: results from an online labelling experiment

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Overview: Electric vehicles (EV) are seen as one of the major pathways to reduce transport related greenhouse gas emissions. The decision to switch to an EV from a conventional internal combustion drivetrain involves complex trade-offs between multiple vehicle attributes and intertemporal costs. Inattention to, or a failure to take into account future energy costs is often cited as a major barrier to scaling up EV uptake (Gillingham et al., 2021; Andor et al., 2020; Allcott & Knittel, 2019; Turrentine & Kurani, 2007). This paper presents preliminary results from repeated surveys of the general public which study factors that influence electric vehicle (EV) adoption, including barriers, enablers and perceptions. An embedded car choice experiment explores how different fuel efficiency labels influence the switch to an EV, and how this has evolved over time given significant exogenous variation in fuel prices.
Methods: At the core of our survey is a discrete choice experiment (DCE) which presents respondents with hypothetical car choices (Figure 1). In the DCE, respondents first pick their preferred car type (one of six car classes), engine type and colour. We then present alternative EVs beside their benchmark internal combustion engine (ICE) vehicle which differ (to their benchmark) only in efficiency, price, range, charging speed and boot size, and explore if households would switch from their benchmark to the comparable EV. The DCE also changed the way energy efficiency was presented, with respondents randomly assigned into different informational frames (7 treatments and a control group) with alternative energy cost and carbon combinations. Central to the motivation of this labelling experiment is the assumption that there are various informational gaps and behavioural biases which could prevent some prospective car buyers from making accurate energy cost and/or emission comparisons at the point of purchase. We conducted the first wave of this DCE in 2020 with approximately 2000 respondents from the general public in the Republic of Ireland. The experiment will be repeated early in 2024 in order to gauge how preferences have evolved over time given rising global fuel costs and a changed EV purchase environment.
Results: Results from the first wave of the DCE suggest that both efficiency and non-efficiency attributes are important to consumers when considering the switch to an EV. Firstly, results for the non-efficiency/emissions attributes indicate that consumers are sensitive with respect to price, range, fast charging and the boot size of vehicles. For example, each €10,000 decrease in price is associated with an increase in EV adoption of 5.3 percentage points (PPs), while each 100km increase in range (holding price fixed) would increase adoption rates by 3.6 PPs. Furthermore, if the typical EV had ultra-fast charging and identically sized boot (to ICE), adoption rates would increase by about 10 PPs.

Second, there are likely a range of informational aspects which could be slowing EV adoption. The results from the labelling experiment demonstrate that framing the CO_2 and monetary benefits of switching to EV in terms of their long-run implications increases switch probability. For example, framing efficiency in terms of ten-year cost and carbon implication increases adoption by about 11 PPs relative to a simple CO_2/km (only) label.
Conclusions: This paper presents preliminary findings from repeated discrete choice experiments carried out in the Republic of Ireland which study consumer preferences for EV adoption. Results from the first wave of the study suggest that a range of attributes are important when consumers consider the switch to an EV, including price, range, charging speed and boot size. How energy savings and CO_2 emissions savings are framed is also important in encouraging the switch to an EV. A repeat wave of this experiment is currently underway which will allow us to study how preferences have evolved over time, and in particular following significant recent volatility in energy prices.

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Keywords: electric vehicles (EV), discrete choice experiment (DCE), information framing

Figure 1: Discrete choice experiment flowchart

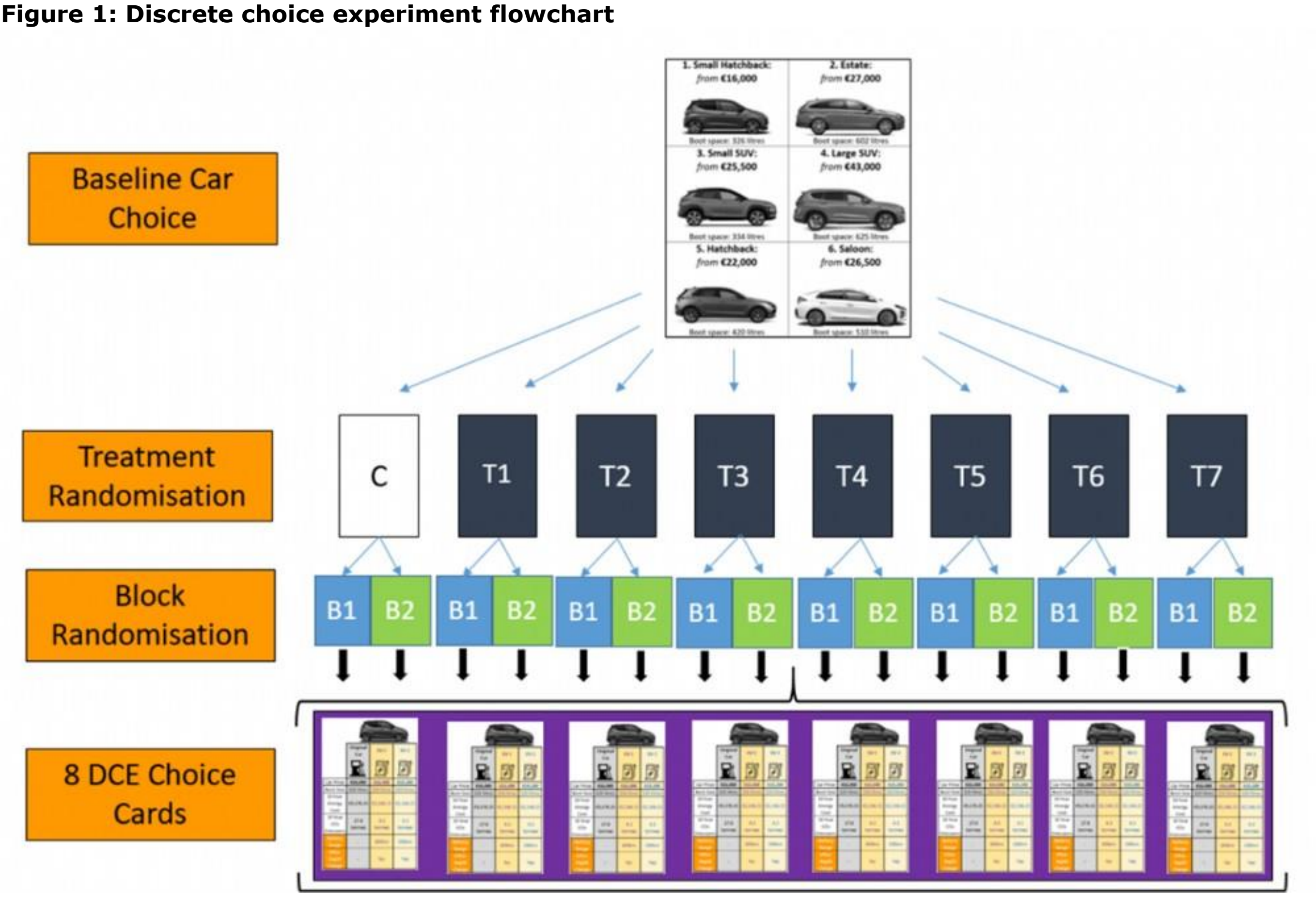
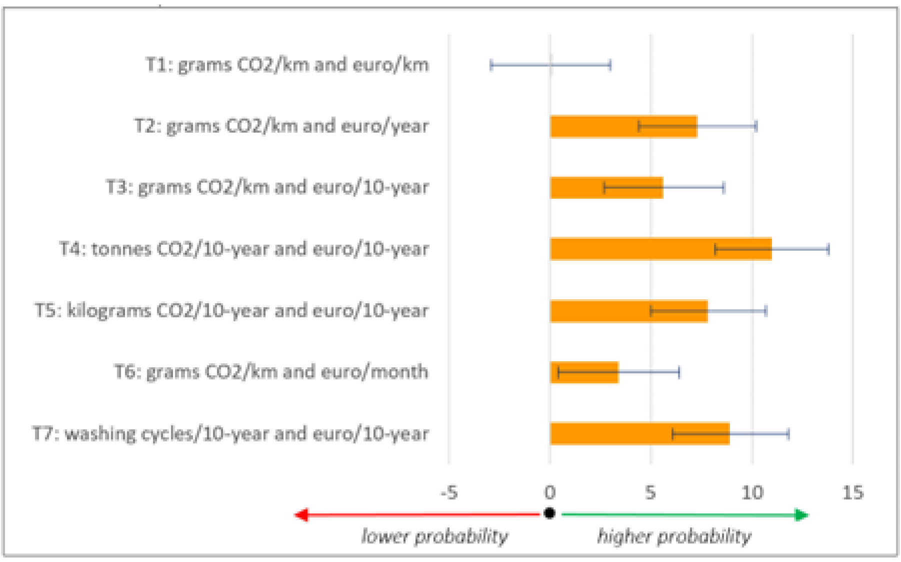


Figure 2: Treatment effects from information framing of energy cost and CO2 emissions



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[Abstract:0252] OP-038 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

The flexibility potential from smart charging of electric vehicles in Europe

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Overview:The registration of electric vehicles has increased significantly in most industrialised countries in the last few years as a result of the ambitious goals set by many national governments concerning the electrification of road transport. The growing number of electric vehicles is expected to increase the demand for electricity, which could pose a challenge to future energy systems. To ensure a smooth integration of the electricity demand from electric vehicles, it is essential to have a comprehensive understanding of its characteristics. Assuming a high share of electrification for future fleets, the scope of this study is to evaluate the demand-side flexibility potential of passenger transport in different European countries. Based on data from national travel surveys, i.e. country specific driving patterns, different vehicle fleet characteristics and grid infrastructure scenarios are evaluated to derive representative electric vehicle charging and flexibility profiles for European countries. Finally, the resulting profiles are used in an energy system optimisation model to assess their impact on the energy system design and operation for the case of a highly sector-coupled European energy system model.
Methods:Energy systems oprimisation models represent a widely used technique to determine decarbonisation pathways to assist policymakers in the definition of future energy systems. The REMix energy system modelling framework provides a linear framework with high spatial and temporal resolution to analyse energy system transition scenarios [1]. After initially being restricted to the power sector, the framework has progressively improved to incorporate the flexible coupling to the heating, industry and transportation sectors, through a multi-modal configuration that enables the use of electricity from variable renewable energy sources in all sectors. Considering boundary conditions, such as the development of demand or the flexibility of generators and consumers, REMix can be used to evaluate the interaction between all technologies in hourly resolution and to determine

the minimum-cost expansion and operation of the energy supply system under consideration (Figure 2). Numerous models of the German and European energy system with various foci have been modeled and examined in the past using the framework, as well as energy systems of other countries [3, 4, 5].

The venco.py model is used to derive characteristic electricity demand and charging profiles (uncontrolled and controlled charging). It is an open-source Python-based tool [2] that calculates boundary conditions for the charging behaviour and for vehicle-to-grid (V2G) potentials based on mobility data and techno-economic assumptions. This allows for the investigation of the electricity demand increase due to the electrification of passenger road transport. Figure 1 shows a schematic representation of the model building blocks.

Based on driving profiles, technical data and assumptions about BEVs, boundaries for minimum and maximum states of charge (SoC) of the vehicle batteries are calculated. From this, temporally resolved demands for uncontrolled charging as well as load shift potentials for controlled charging can be derived for different electric vehicle fleets. The venco.py model has been used in different projects. Among others, it was applied to the German transport survey "Mobility in Germany" to investigate the influence of electric vehicles on the future load shifting potential and its impact on the German power system [6]. Exemplary results of the framework include the distance travelled per hour, the connection availability, and the upper and lower limit for the batteries' state of charge.

By additionally including mobility datasets for additional European countries among the ones listed in Table 1, the tool capabilities are extended to these additional geographical scopes. A sensitivity analysis on different fleet characteristics and grid charging infrastructure deployment is carried out in order to analyse how these parameters infuence the charging operation of the vehicles and the resulting load profiles in the anaylsed countries.

Results:Growing BEV fleets can have substantial impacts on the power sector. On the one hand, they increase the electric load, on the other hand, they may also provide temporal demand-side flexibility, which can help in integrating variable renewable energy sources and thus in decarbonising the power sector. The venco.py results provide representative BEV load and flexibility profiles with customisable length and resolution for passenger fleets in Europe. Such profiles provide a necessary starting point for modelling BEVs in energy systems models or aggregators in electricity market models. The results from the energy system model on the other hand provide an assessment of how the representation of charging profiles and flexibility of BEVs might affect energy systems optimisation results.

Conclusions:Many model-based analyses to investigate potential power sector interactions of future BEV fleets depend on a realistic representation of mobility patterns of vehicle users. Yet such data are ofen not publicly available and in general empirical data are scarce. This work contributes, among others, to close the gap in BEV charging models to derive relevant timeseries in a flexible way, while including comprehensive documentation, transparency and reproducibility, providing thereby explicit technical flexibility potentials for passenger fleets in Europe depending on specific national mobility patterns and charging infrastructure deployment.

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Keywords: Electric vehicles, energy system optimisation model, charging flexibility

[Abstract:0418] OP-039 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

Unveiling preferences for smart electric-vehicle charging programs

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Overview:Large-scale charging of electric vehicles using limited and intermittent grid resources is an imminent problem. Smart electric vehicle charging programs offer a solution to alleviate peak demand pressures on the electrical grid, optimize renewable energy integration, enhance grid stability, and promote cost- effective, sustainable, and equitable electrified transportation solutions. Unidirectional smart charging (V1G) can effectively help to defer loads during critical periods (e.g., very hot summer afternoon), align EV charging with availability of renewable power, and shift demand to ultimately flatten loads. However, modeling demand response to smart EV charging requires a deep understanding of customer preferences for charging flexibility. In this paper, we leverage unique data from a recent market research study in the USA to examine how customers respond to smart EV charging programs aimed at better managing EV loads. Methods:Choice experiment microdata from 582 EV owners living in the United States are used in this paper. Respondents were recruited via PlugShare Research. Members of the PlugShare Research panel are users of the PlugShare app, which helps EV and PHEV owners find charging locations along their route. The choice experiments in the survey were designed specifically to assess customer response to possible features of smart EV charging programs. Bundles of V1G smart charging programs were built in the experiment pivoting around smart charging program type, namely: Demand response (DR): pause EV charging temporarily when the grid load is at its maximum; Managed charging (MC): charge EV with a cost or emissions optimized schedule based on the user's preferences and grid conditions (e.g., pricing and renewable energy content); and Fixed schedule (FS): charge EV at only certain times of the day, e.g., avoid charging during the peak hours of 5--7 p.m.Before completing the choice experiment tasks, each respondent was asked to answer 7 attitudinal questions, as well as 28 rating tasks to ensure the respondent understood the details of V1G programs.

Modeling: Discrete choice models based on random utility maximization are used to analyze the data. To increase modeling flexibility and to explicitly model attitudinal and other psychometric factors that affect decision making by consumers, more complex model structures have been proposed, such as hybrid choice models. The framework of HCMs expands on traditional discrete choice analysis in multiple dimensions. The core expansion is the consideration of an integrated choice and latent variables (ICLV) model, where multidimensional factors are summarized endogenously into latent variables (LVs) that enter the utility function of a discrete choice kernel. In this paper, a hybrid choice model is specified to analyze the effect on the choice of smart EV charging program with consideration of a latent variable that elicits attitudes toward decarbonization.

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Results:Overall, preferences are aligned with economic expectations. For example, a larger monetary bonus increases the likelihood of selecting a smart charging program. Furthermore, a $1 increase in an annual bonus has a larger probability marginal effect than a $1 increase in a sign-up bonus. No opt-outs allowed in a DR program actually decreases the probability of selecting such program. Whereas a $100 fast charge credit as enrollment perk is positively valued, other enrollment perks are either unattended (2-year roadside assistance, which is not significant at the 5\% level) or negatively perceived. We also analyzed the marginal rates of substitution (MRS) estimates with respect to (w.r.t.) annual bonus to give a better notion of the parameter signs and magnitudes. It is possible to draw some interesting insights from the MRS estimates, e.g., having no opt-outs corresponds to a notably high disutility, while allowing unlimited opt-outs is much more attractive than allowing only 5 or 10 opt-outs per year. For enrollment perks, $100 fast charge credit is the most appealing option, while $100 rideshare reimbursement is the least preferred. All types of

participation incentives and emissions reduction have positive MRS w.r.t. annual bonus, indicating their varying attractiveness to EV users. Among the incentives, $20 per month for not charging during 5--7 p.m. has the highest MRS, which implies the feasibility of shifting demand from peak to off-peak hours through this means. The effect of the latent variable representing attitudes toward decarbonization has a positive significant effect on a subset of attributes of the hypothetical smart EV charging bundles.

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Conclusions:Using logit-type discrete choice models integrated with a latent variable measuring decarbonization attitudes, we have evaluated EV users' valuation of features of demand response, managed charging, and fixed schedule programs for smart EV charging. Results indicate that EV users positively value emission reductions that are associated with decisions such as delaying when energy is delivered to the vehicles. We also find that scheduling EV charging to maximize renewable energy is more preferred than allowing priority charging in managed charging programs (with a rate of substitution of 1.597), further showing EV users' support of environmental protection. From the structural model of the latent variable, it is possible to extract clustering information representing the segment of EV owners with higher environmental concerns. For instance, women, those who are early adopters of EVs, and those having solar panels at home appear as having a higher valuation of decarbonization efforts and, consequently, exhibit a higher probability of adopting a smart EV charging program that emphasizes sustainability.

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Keywords: electric vehicles, smart charging, choice experiment, V1G charging

[Abstract:0496] OP-040 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

Reviving the Battery Life Cycle: Insights for Scaling Up EV Battery Recycling in Europe

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Overview:The imperative to decarbonize road transportation, coupled with a tenfold increase in European demand for electric vehicles (EVs) by 2030, will drive a substantial need for sustainable lithium-ion batteries (LIBs). At the same time, it is expected that substantial amounts of recyclable scrap will become available when several million of the EV batteries currently in operation reach their end-of-life and the commissioning of gigafactories leads to high waste volumes. Therefore, establishing circularity for batteries in Europe represents a considerable opportunity, fueled by several economic and ecological benefits – and required to comply with recent EU regulations. Existing literature predominantly addresses individual facets of lithium-ion battery (LIB) recycling, yet it needs a cohesive analysis for practical strategy development in Europe's evolving sector. Studies have concentrated on the technological nuances of various recycling methods, assessments against alternative end-of-life strategies, policy implications, and circular economy approaches derived from material flow modeling. However, there is a notable gap in integrating these elements – technological advancements, policy dynamics, and business model innovations – into actionable insights for stakeholders within the battery value chain. The question arises as to, *how can recycling players synergistically integrate advancements in battery technology, recycling infrastructure, and policy frameworks to optimize the European circular economy for lithium-ion batteries in electric vehicles?*
Methods:This paper employs an exploratory, inductive research approach through multiple cases. This approach is particularly suited to build strong theory and derive actionable insights about the under-explored phenomenon of battery recycling in Europe. Cases are selected by means of a theoretical sampling strategy which allows to focus on the phenomenon of integrated recycling strategies by excluding unsystematic heterogeneities. Polar sampling seems to be particularly suitable for identifying success factors. A balanced sample of 3 successful and 3 unsuccessful companies are selected based on the following performance indicators related to capacity, time until launch of operations, material recovery levels, and regulatory compliance. Primary sources of insight are semi-structured interviews with recycling player executives from different functions, which are cross-referenced with secondary data from company websites or press articles.
Results:Striving for an optimized European circular economy for EV LIBs, several implications emerge for recyclers and policymakers. The more advanced state of battery technology now requires recyclers to focus on process efficiency and scalability, mindful of uncertainties in future cell chemistry mixes. This development occurs alongside a strict regulatory landscape in the EU, which responsible entities must closely monitor. On the one side, companies benefit from a more secure investment climate. On the other side, excessive regulation puts global competitiveness at risk, and strict recycling quotas may inadvertently impede circular material flows and second-life applications. A balanced approach is essential to manage feedstock, avoiding overcapacity (as seen in China) while securing market shares. Promoting intra-EU material flows is crucial, involving facilitated transport logistics in a hub-and-spoke model and incentives for industrial use of both spent batteries and production waste. Lastly, the complexity of the Lithium-Ion Battery (LIB) value chain necessitates close cooperation among stakeholders to aim for a circular economy optimum. This includes integrating other elements of the waste hierarchy (e.g., re-use), which can positively impact CO_2 emissions and reduce the levelized cost of energy.
Conclusions:This study integrates academic and practical insights, highlighting the need for a sustainable circular economy in Europe's lithium-ion battery (LIB) sector. It emphasizes the importance for recyclers to adapt to evolving battery technologies and regulatory landscapes, balancing efficiency and scalability with market demands. Policymakers must ensure a level playing field for manufacturers and recyclers, promoting a circular economy that aligns with both economic and ecological objectives. The findings advocate targeted incentivization and enhanced collaboration along the value chain, avoiding the cannibalization of other second-life applications – often a more economically viable way to handle a retired battery.
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Keywords: battery recycling, electric vehicles, circular economy

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[Abstract:0501] OP-041 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

Shared Autonomous Electric Vehicles: Charging load profiles considering different charging strategies under given mobility demand and net load

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Overview:In 2022, the transportation sector contributed approximately 30% of global carbon dioxide (CO2) emissions, underscoring the urgency of reforming the transport industry. The shift to electric vehicles (EVs) as a key climate change mitigation measure puts significant stress on the electric power system due to the increase in electricity demand and its amplifying effect of existing demand peaks. However, empirical evidence, as presented by Milovanoff et al. (2020), suggests, that existing electrification targets alone fall short of meeting mitigation goals (shown using the United States as a case study), which are necessary to stay within an appropriate CO2 emission budget for light-duty

vehicles. Shared Autonomous Electric Vehicles (SAEVs) promise to address this issue by reducing the overall charging demand through increasing occupancy and improving flexibility with regards to charging timing. Autonomous vehicles are on the rise, though their impact on emissions remains uncertain due to the potential rebound effect stemming from increased travel demand due to reduced marginal cost of driving and travel time cost. Hence, this study seeks to investigate the environmental and energy advantages associated with SAEVs, highlighting their synergistic potential when integrated with all three technologies, as opposed to their separate application. SAEVs have the potential to mitigate emissions, but their effect highly depends on both operation and the size of the fleet as well as its interaction with the electric power system. Given the differentiating travel behavior between SAEVs and privately owned vehicles, the interaction between SAEVs and the electric power system must be investigated. These differences stem from variances in duty cycles, autonomous operation devoid of human involvement, independence from conventional working hours, and the capability of self-organized charging, distinguishing SAEVs from private vehicles. While literature comprehensively addresses the interaction between EVs and the electric power system, the existing body of SAEV literature predominantly focuses on their advantages, cost analyses, public acceptance, and environmental implications. Pruckner and Eckhoff (2020) have identified two research gaps: the modeling and simulation of SAEV travel demand based on individual mobility instead of traffic and the impact on grid load of applying different charging strategies to SAEVs. Further, there is limited data and understanding of this issue in the European context. Hence, this study focuses on Germany as the largest European economy in size and people. As a substantial market penetration of autonomous vehicles is expected after 2030, this research investigates the year 2035. Specifically, this paper addresses the following research question: What is the impact of Shared Autonomous Electric Vehicles (SAEVs) on electric load, and what charging strategies are suitable, considering given mobility demand and net load for the year 2035?
Methods:To investigate the effects of SAEVs on electric load, a two-step modeling approach is employed. Firstly, SAEV travel behavior is modeled, utilizing individual trip data. This enhances accuracy considering the fact that SAEVs are expected to replace both public and private modes of mobility, this seems more appropriate than traffic data used across most other studies. Subsequently, the simulated travel demand is used to estimate the SAEV charging load (electricity demand), and to generate hourly charging profiles. To construct scenarios regarding SAEV travel behavior, two modeling parameters are defined: the level of SAEV market penetration and the vehicle occupancy rate for shared rides. To derive the SAEV daily charging load, hourly aggregated travel behaviour is translated into energy consumption, based on the energy conversion efficiency rate of SAEV. Then the SAEV daily charging load is allocated into each hour of the day to form hourly charging profiles. Four charging strategies (night-time charging, uniform charging, charging inverse to ride requests, charging inverse to netload) are defined based on a synthesis of existing literature, observed SAEV travel patterns, real-world charging data, baseload demand data, and renewable generation data (obtained from previous grid simulations that do not factor in SAEV charging load). The different charging strategies serve as model parameters for scenario analysis. A comparable methodology, using data from established transportation network companies (TNCs), was applied by Li et al. (2022) in their case study of California in the year 2030.
Results:Generally, CO_2 emissions from SAEVs increase linearly with the expansion of the fleet and therefore market penetration. Charging inverse to netload as a charging strategy, offsets this impact of fleet expansion. Further, total CO_2 emissions are inversely correlated to the average occupancy rate of an SAEV fleet. With higher occupancy rates environmental benefits can be achieved most efficiently. This leads to the result that under the German power grid SAEVs can be less carbon intensive compared to EVs.
The employed analysis shows that the aggregated SAEV charging load is marginal compared with the baseload. The associated charging profiles exhibit different load peaks, which magnitude depends on the selected SAEV adoption level and occupancy rate. Charging inverse to ride requests peaks in the early morning hours (4-6 am), a lower peak during noon, and a rising demand after the rush hour in the late evening hours leading to the peak in the early morning hours. These fluctuations align with commuter patterns, reflecting heightened ride requests during morning and evening hours. The charging strategy inverse to ride requests schedules fewer charging activities during periods of peak ride requests, an approach expected to be advantageous for fleet operators. Meanwhile, charging inverse to netload shows a peak during the day (8 am-4 pm) which are intervals characterized by a high proportion of electricity generated by renewable sources within the energy system and low baseload. This charging pattern is anticipated to assist in utilizing surplus intermittent renewable energy and flatten the aggregated power system demand curve. Therefore, the results of this study demonstrate the potential for smart-charging strategies, where SAEVs charge in reaction to a received signal from the electric power system via vehicle-to-grid communication.
Conclusions:This paper contributes to existing research about the effect of SAEVs on the electric power system by providing insights on SAEV travel behavior and the associated charging load. It also explores the potential of SAEVs to contribute to decarbonizing the transportation sector. It

speaks to the existing academic literature while focusing on Germany. Similar to EVs, the environmental benefits of SAEVs strongly depend on the share of renewable energy sources within the power system. As the grid progressively adopts cleaner energy sources and SAEV adoption gains momentum, these emission benefits are expected to amplify.
The extent to which the charging strategy aligns with renewable power output plays a pivotal role in determining the environmental advantages associated with an SAEV fleet. The findings of this study have the potential emphasize the necessity of SAEVs to policymakers and the need to develop favorable policies to drive adoption. Further it provides valuable insights for SAEV operators to adopt environmentally friendly charging strategies. Furthermore, the results can be harnessed to investigate the impact of SAEVs on the German power market, utilizing the derived SAEV charging loads as inputs for a power system market model.
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Keywords: Electric Vehicles, Autonomous Vehicles, Shared Mobility, Decarbonization, Emissions

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Distributional impacts in an open economy of domestic and international climate policies

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Overview:Almost all countries in the world have pledged climate policy commitments for 2030 in the Paris Agreement, and during 2022 and 2023 many of the pledges (so-called Nationally Determined Contributions, NDCs) were updated. How binding, detailed and ambitious they are, varies significantly. The EU, in collaboration with Norway and Iceland, is among the frontrunners with legally binding emission caps set 55% below their respective 1990 emissions levels. In accordance with EU's Fit-For-55 strategy, which also applies to Norway and Iceland, separate targets are set for sectors covered by the EU Emissions Trading System, ETS, and the remaining, non-ETS, sectors. The ambitions will involve considerable costs in the years to come. Many European governments are experiencing public resistance against carbon pricing and regulations aimed at obtaining rapid and comprehensive transition of sectoral patterns, investments in new technologies and changes of lifestyles. The worry is that costs will be unfairly distributed.

The main objective of this paper is to generate new knowledge on the drivers and possible outcomes of the NDCs for countries that are highly exposed to international trade. For open economies, not only their own climate policies, but also those of the outside world, are likely to be influential. The prime focus of the paper is changes in income distribution, and we use the small, open Norwegian economy as an example. A recent experience that highlighted the policy-relevance of our research, is the extraordinarily high Norwegian energy price peaks during the worldwide energy crisis in the winter 2022/2023. The incidence mobilised large public resistance, not only against the perceived inequitable impacts of Norway's own domestic climate policies, but also of exposing the Norwegian power markets to international trade and price transmission.

Surveys and opinion polls commonly reflect a presumption that decarbonation policies, through raising energy prices, will aggregate an already skewed income distribution. The large number of such surveys stand in contrast to surprisingly little research on the factual distributional impacts. Thus, there is a danger that misconceptions exist. Our main research questions are: How and to what degree, will own, EU and the rest of the world's climate policy measures aimed at meeting the NDC targets for 2030 affect the Norwegian income distribution. The analysis includes a comparison of different polices, also including possible compensatory measures. Our approach is to use the global, multi-region CGE model SNOW that is equipped with a microsimulation module splitting the household sector into ten income deciles with empirically based budget shares of goods and source shares of income.

Undoubtedly, the EU's fit-for-55 strategy is a major candidate for influencing Norwegian households' goods prices and income: Not only does it affect Norway through higher allowance prices in the Emissions Trading System (ETS), the EU is also the major trade-partner of Norway. Inter alia, there are several power grid connections between Norway and EU member states, and Norway is a dominant natural gas supplier through pipelines to the European continent. In addition, Norway is a key exporter of petroleum and a supplier of energy-intensive manufacturing products to the world markets. The development in these global markets will also wash over the Norwegian economy. It is, thus, worth analysing to what extent the Norwegian economy is likely to be affected by policies in non-EU regions to meet their respective NDCs.

Many previous studies examine the distributional impacts of climate policies. Our contribution lies in the decomposition of the effects of domestic and international climate policies. For example, single-country impact analyses (e.g., Rausch et al. (2010) and Dissou (2015)) exclusively focus on domestic policies while overlooking any changes in international prices. On the other hand, some studies use a global multi-region model to assess the impacts of NDCs of all countries worldwide (e.g., Landis et al. (2021) and Chepeliev et al. (2021)). Although these studies account for changes in international prices, they do not break down the impacts of domestic versus international policies. For a small, open country the influence of global action like the Paris Agreement is likely to be of no less significance than domestic policies. A noteworthy exception is Bohringer et al. (2021), which explores the impact of domestic and international climate policies separately for the case of Germany.
Methods:The SNOW model is a conventional GTAP-based CGE model. The world is split into 16 regions, with Norway, the EU and UK as separate units. Production in each region takes place in 10 sectors; in Norway and the EU, 6 of these are covered by the common emissions trading system, while the remaining 4 along with the households, are not. The micro-simulation module in SNOW distinguishes households in terms of income levels, income sources (capital returns, wages, transfers) and consumption patterns (of the 10 goods). This framework is based on the one developed in Fæhn and Yonezawa (2021).

A benchmark scenario (BMK) reflects 2030 in case of no new climate policies. It is calibrated based on the projection in the Norwegian National Budget 2022 for Norway (Meld. St. 1, 2021) and EIA (2017) for the rest of the world. Substitution elasticities between electricity and fossil fuels are recalibrated to reflect expected improvements of electrification technologies in Norway and the EU.

Four different Climate Policy Scenarios are simulated and compared with the BMK:
- ROW: The rest of the world, except the EU fulfils their NDC through carbon pricing.

- EROW: The rest of the world + EU fulfils their NDCs. The EU implements its NDC as directed by the Fit-For-55 decisions, and full flexibility across EU borders are assumed both for ETS and non-ETS sectors, implying separate carbon prices in the region. We disregard LULUCF.

ALL: The rest of the world + EU + Norway fulfils their NDCs. Norway also participates in the Fit-For-55, however flexibility with the EU is only assumed for ETS; the non-ETS target is fulfilled domestically. Thus, one carbon price applies in the common ETS market, while EU and Norway have one carbon price each for non-ETS sectors. To allow for CCS, we reduce emissions coefficients in waste and certain manufacturing industries and add the corresponding abatement costs recursively to the computed costs.

ALL-2: The rest of the world + EU + Norway fulfils their Paris Agreement pledges. Norway also participates in the Fit-For-55, however purchase of allowances in the ETS is not allowed. This reflects a key ambition expressed by the Norwegian government. Consequently, the Norwegian ETS carbon price will normally deviate from that of the EU.

The first three scenarios enable us to decompose the impacts of the NDCs into those of other non-EU countries, of the EU and of Norway, respectively. The fourth reflects the ambition of the Norwegian government of not relying on ETS allowances for its Fit-For-55 implementation.

In a set of Compensatory Policy Scenarios, we plan to consider different ways in which the revenue from the Norwegian carbon pricing in the ALL-scenario is recycled to domestic households.
Results:Looking, first, at effects of NDCs of regions outside of Europe reveals that these have a progressive incidence on the Norwegian economy. Even though their NDCs are, in general, significantly weaker than those of European countries, the fact that their demand for petroleum, particularly for oil, drops affects the income of capital owners in oil companies negatively. Capital owners are clustered in the high-income households. Moreover, lower oil prices tend to favour the gas and diesel consumers, in particular the less wealthy households that use large budget shares on private transport in Norway.

Adding EU (and UK) climate policies, strengthens the progressive incidence from abroad significantly. Again, the major cause is, as for the rest of the world, reduced demand for petroleum, in particular gas, in the European markets. On the other hand, a significant increase of European electricity prices is partly transmitted to Norwegian electricity prices. This counteracts somewhat but does not offset the progressivity of the EU influence. Like gasoline and diesel, electricity constitutes higher budget shares for the lower the household income, so higher electricity prices contribute regressively.

The effect of the Norwegian climate policies in ALL is found to be neither progressive nor regressive. However, in ALL-2, where the government practises policies that prevent domestic firms from purchasing allowances in the ETS market, obtaining a 55% cut in domestic emissions turns progressive. The reason is that the abatement cost for the ETS-covered sector increases and capital-owners in these sectors suffer, which improves the distributional profile.

While the current result indicates the progressive incidence for the total effect of domestic and international climate policies, we plan to improve the way we allocate the income from crude oil sector. Then, the current incidence pattern might be overturned. In this case, the Compensatory Policy Scenarios would be more natural choice. We plan to explore them further.
Conclusions:Our study delves into the distributional impact of domestic and international climate policies for the case of Norway. The tentative finding is that while Norwegian domestic policies is neither progressive nor regressive, international climate policies have strong progressive incidence on Norwegian society.
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Keywords: Carbon policy, Distributional impact, Emission trading system, Trade and climate policy, Computable general equilibrium

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[Abstract:0089] OP-043 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Asymmetric effect of human capital on the ecological footprint within the EKC framework in Saudi Arabia

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Overview:In contrast with previous studies exploring the linear effect of increasingly educated human capital on environmental degradation, this study examined the non-linear relationship utilizing the Environmental Kuznets Curve (EKC) framework. It offers empirical evidence considering the developing and oil-rich economy of Saudi Arabia. The ARDL model was estimated, to reveal that the gross tertiary enrolment ratio has an inverse-U shaped relationship with ecological footprint. This is consistent with our assumption within EKC model, in that when schooling enrolment rates are low in the early stages of economic development, environmental degradation is augmented. However, after reaching the turning point in education, the increase in enrolment rates reduces degradation. This indicates that human capital can exert opposing effects on environmental quality, relative to level of economic development and expansion in education. The empirical findings suggest education is vital to reduce environmental degradation and upgrade energy efficiency and sustainability in the context of Saudi Arabia. The study suggests raising individuals' awareness, environmental education, and increasing knowledge concerning the significance of climate change actions must be integrated into environmental policies and strategic agendas.
Methods:In estimating the link between human capital and ecological footprint, the current research used the econometrics and analytical approach, in particular, the autoregressive distributed lag (ARDL) technique. According to Pesaran et al. (2001), the presence of different order of integration at level I (0) or first difference I (1) is possible with the ARDL approach, on the condition that there

is no variable is stationary at I (2); and also, it efficiently works with small datasets. These merits make such approach is more appeal and useful in the literature, in comparison with the other prevalent cointegration methods that frequently utilized in prior studies such as Johansen et al. (1990).

Results:The empirical findings for long-term estimates identified that enrolment rates at higher education have asymmetric impacts on ecological footprint. This is consistent with our assumption, in that when schooling enrolment rates are low in the early stages of economic development, environmental degradation is augmented

Conclusions:Given extremely the limited studies exploring the asymmetric impact of human capital on environmental degradation, our study examined this non-linear relationship as measured by the gross tertiary enrolment ratio, on ecological footprint, using the EKC model. The study considered oil intensive-based economy for the period of 1986 to 2017, utilizing the ARDL model. We followed Balaguer and Manuel Cantavella (2018(, in which education may have two opposite effects on environmental degradation, and accordingly assume the presence of an inverted U-shaped relationship between education and ecological footprint. The empirical findings for long-term estimates identified that enrolment rates at higher education have asymmetric impacts on ecological footprint. This is consistent with our assumption, in that when schooling enrolment rates are low in the early stages of economic development, environmental degradation is augmented. However, after reaching the turning point in education, the increase in enrolment rates reduces degradation. Concerning the other control variables, on per capita GDP coefficient and its squared were found to be insignificant, meaning the hypothesis of EKC in terms of income and environment is not proven. Additionally, the relationship between energy consumption and ecological footprint was positive but non-significant. However, trade openness and air transport are both associated positively and significantly with ecological footprint.

To conclude, the findings of study suggest human capital is a determinant of environmental quality with respect to level of economic development and the extent of expansion in education. It also provides a different analysis in which human capital can combine the opposite effects on ecological footprint in developing country, potentially reconciling the mixed results obtained in previous studies that consider the linear relationship.

In light of the empirical findings, this study has an important policy implication. Saudi vision 2030 places significant attention on both educational progress and advancing issues related to environmental sustainability. Accordingly, as Saudi Arabia has launched a series of initiatives and critical projects to combat climate change and improve environmental quality, the role of individuals' awareness has become more prominent. Certainly, environmental knowledge fostered by education must be increased to deliver better understanding of the adverse consequences to humanity, so as to realize the importance of climate change actions adopted globally. Arklof (2017) states that promoting awareness of the public as an end goal constitutes an essential policy for governments. The author also adds that fostering changes in education and improving values and mores at the level of society in the long-term will make it possible to make more cooperative environmental decisions, demonstrating the substantial role of raising awareness. Thus, this issue must be considered when environmental policies and growth strategies are intentionally integrated with existing initiatives relating to the environment. The existence of high human capital in the country may prove helpful in meeting those SDG goals that are relevant to climate change and the environment.

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Keywords: environmental degradation, ecological footprint, education; human capital, sustainable development,Saudi Arabia

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[Abstract:0165] OP-044 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Analysis of the relationship between carbon dioxide emissions, energy supply from fossil fuel, energy consumption and gdp: Nigerian case

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Overview:Human actions, like releasing greenhouse gases (GHGs) by burning fossil fuels, are the primary cause of global warming. Economic
Growth has had both positive and negative effects. Particularly in developing countries like Nigeria, economic growth has sometimes led to climate change and increased greenhouse gas emissions. Previous studies pointed out that because resources are limited, it is crucial to find alternative options to fossil fuels in order to stop global warming from worsening. The power sector is the most significant source of CO2 pollution in Nigeria. Accordingly, about 80% of the country's energy comes from the "off-grid" or "decentralized" system, driven by gasoline and diesel. This causes significant environmental pollution, and we need to think about our future energy needs and how to stop pollution. Through the lens of natural resources and environmental economics, this study looks at the links between economic growth, environmental pollution, and energy use. It also looks into the relationship between GDP and pollution, like CO2 emissions, and the relationship between economic expansion and energy use. In addition, it seeks to answer the question, "What is the relationship and the causal direction between carbon dioxide emissions, energy supply and demand, and economic growth?" and "What are the appropriate energy policies to attain the goal of greenhouse gas reduction in an economy mainly dependent on fossil fuel production and consumption?"
Methods:study uses Autoregressive Distributed Lag (ARDL) and a cointegration test on data from 1990 to 2020 to investigate how these relationships change over time. The International Energy Agency and the World Bank provided the study statistics on total energy use, energy supply from oil and gas, CO2 per person, and GDP per person.
Results:The results of the ARDL short-run model reveal that CO2 emissions in the past added to CO2 levels today. This suggests that activities that hurt the environment in the past play a significant role in climate change today. Moreover, oil and gas energy supply affected CO2 emissions because more energy is used. Furthermore, the results of our causality study show that using energy (especially oil and gas) makes a big difference in CO2 pollution. However, GDP does not make a big difference in CO2 pollution. Hence, the present study proposes changes to policies on energy and the environment, alternative energy, energy transition, decoupling, and green energy to simultaneously reduce CO2 emissions and boost economic growth.
Conclusions:Indeed, long-term plans for sustainable growth and strong political will are needed to switch from fossil fuels to renewable energy. Building the infrastructure necessary for an economy based on renewable energy takes longer than one term of a government's administration. Thus, to keep the energy transition plan going, a strong legal framework that is safe from the vested interests of politicians is
necessary. Additionally, people need to be committed to solving the short-term problems that arise during the shift to a low-carbon economy.
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Keywords: CO2, ARDL, Short-run, Causality, energy-environment-economic policies, Nigeria

AuthorToEditor: This research was carried out and defended as part of my graduation requirement at Seoul National University College of Engineering, Master of Engineering, as of August 2023. I hope it is allowed as a submission to this distinguished committee. Also, no. 3 on the author list is my professor, who supervised the work. All data was gotten from the World Bank and IEA, and the software used was for the school. I hope I will be able to show case my research and also show how policy implications were based on econometric analysis for the world, especially as CO2 emissions are a major emission in a developing country like Nigeria, where fossil fuels are both produced and consumed, and how we can find the best policies to mitigate or move away from emission-causing sources. thank you

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[Abstract:0194] OP-045 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Effect of a European Carbon Border Adjustment Mechanism on the APAC Region: A structural gravity analysis

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Overview:In an attempt to slow down climate change, policies aiming at taxing carbon emissions are gradually being implemented all around the world. Pioneering in this field, the European Union (EU) has introduced an emission trading scheme (EU ETS) in 2005, and has been recognized as the first cross-border cap-and-trade scheme of its kind. The EU ETS now boasts one of the highest carbon prices in the world, with estimated allowance price nearing 100 EUR/tCO2 in 2022.

A high allowance price brings concern over the competitiveness of the industry, as their production costs are expected to rise. Industrial relocation, coupled with higher demand for relatively cheaper foreign products, may lead to emission relocation to countries with lower or no carbon taxation, a phenomenon economists refer to as ‘carbon leakage’. Ever since the implementation of the EU ETS, studies tried to assess whether the introduction of the EU ETS resulted in this phenomenon. Even now, there is no academic consensus regarding the existence of such leakage (Böhringer et al., 2022). However, carbon leakage may occur, as the EU ETS price has increased rapidly in recent years.

In this context, the EU introduced a Carbon Border Adjustment Mechanism (CBAM) to tackle carbon leakage. This mechanism takes the form of an additional carbon price at the EU border, whose value is determined based on the difference between the carbon price paid by EU producers and foreign producers, for a given product. By doing so, the EU aims to ensure a level-playing field for its industry. Literature identified that carbon border adjustments are thought to be the most efficient instrument against carbon leakage, but many highlight that it may result in a decrease in exports, exacerbate regional inequalities between exporters and might be difficult to implement due to legal issues arising from WTO treaties (Böhringer et al., 2010; Böhringer et al., 2012; Fischer and Fox, 2012; Monjon and Quirion, 2011).

The EU CBAM is the first carbon border adjustment to be implemented, and thus, since its announcements, many studies have simulated its potential impact. A common trend emerging from

their findings is that CBAM would have a negligible effect on global welfare but a negative impact on exports (Korpar et al., 2023; Pyrka et al., 2020; Takeda and Arimura, 2023). Most importantly, CBAM is expected to have a small impact on emissions (Korpar et al., 2023; Zhong and Pei, 2022), despite the policy's main objective being to decrease global emissions.
Methods: Among studies that simulated the impact of CBAM on emissions, most only incorporate its effect on emissions from production. However, the effect of trade policies on emissions are often more complex, as they include change in emission from shipping or indirect effects of the policy on the demand for downstream products. We aim to include emission from shipping activities in addition to emission from production. We use a structural gravity model focused on trade to simulate the impact of CBAM with data from 2014. In addition, we also provide a case study of the policy's effects on Asia and the Pacific (APAC) region: comprising many large, developing economies, this region does not yet possess widespread carbon pricing and is expected to be the most vulnerable to the introduction of CBAM.
Results: Our analysis shows that the impact of CBAM on welfare is small, regardless of the region. Still, the policy is expected to reduce exports, with global declines ranging from -0.29% (metal products) to -1.49% (steel products). South and Central Asia would see the largest declines in exports, estimated at -10.52% for crude steel products in South Asia and -7.03% for chemical products in Central Asia. This particular result suggests that the CBAM would look like a protectionist policy. However, it would tackle carbon leakage effectively, as it is expected to bring back industrial production inside the EU. In EU countries, production is shown to experience a rebound, between 1.31% (nonferrous metals) and 5.24% (steel), and emissions from production will increase at a similar rate.

There are significant differences in vulnerability to this policy by level of development, which is exemplified by case studies from Asia and the Pacific. Middle-income economies are particularly affected by CBAM, with significant declines in exports, production, and emissions. To illustrate this point, Figures 1 and 2 show changes in steel exports from China and Japan, respectively. China, which is more emission-intensive in its production and did not introduce carbon pricing in 2014, would face relatively higher CBAM price. As a result, the simulation predicts a sharp decline in Chinese exports to the EU and a slight rebound effect in exports to Africa. In contrast, Japan is expected to face relatively low CBAM prices due to the high carbon efficiency of its energy-intensive products and the global warming tax. The simulation predicts that Japan and other high-income countries that gain a comparative advantage will increase their exports to the EU. Thus, this study suggests that this policy may contribute to the creation of a "climate club" of developed nations trading between each other and may increase global inequality among nations.

Table 1 contains the emissions calculations from CBAM. In addition to emissions from production, emissions from shipping activities are included. Globally, CBAM is expected to reduce emissions, but the majority of this reduction will come from shipping activities. This reduction is estimated to be approximately 770 mtCO2 if the policy had been implemented in 2014, and emissions from transportation activities and trade account for 73% of this reduction. There is a slight rebound effect in emissions from production activities (chemicals and non-ferrous metals), but this is generally offset by emissions from trade. The largest emission reductions come from the steel sector (-693 MtCO2), followed by the chemical sector (-132 MtCO2). The largest reductions are in the Asia-Pacific region (-768 MtCO2). Perhaps due to approximations in the calculation of sea distances and the choice of emission factors, the emission reductions may be overestimated, but it can still be concluded that CBAM is an effective policy to reduce CO2 emissions globally.
Conclusions: Our results show large differences in vulnerability to this policy depending on the level of development, and this is exemplified by our case studies of the Asia and the Pacific regions. Middle-income economies would be especially affected by CBAM, with larger decrease in exports, production and emissions. Thus, our study suggests that this policy may contribute to the creation of a 'carbon club' and might widen global inequalities between countries. One of our main findings, however, highlights that this rebound in production emission is offset by the large decrease in emission from shipping, mostly due to the fall in exports. Overall, we estimate that, if CBAM been introduced in 2014, 770MtCO2 could have been avoided, and that 73% of which are emission from shipping activities. Though we probably overestimate such emission reduction due to approximations in calculating sea distances, we can still conclude that CBAM is an effective policy to reduce CO2 emissions globally, although such reduction is mostly due to the decrease in exports.

As the policy provides discounts and exemptions for countries with CP, we also simulate the effect CBAM would have, if G20 were to introduce a CP rate as high as the EU, and become exempted from CBAM. In general, the expected impact of CBAM on G20 economies is limited, and the small changes are likely attributed to indirect effect of the policy on trade disruption. While this means that we expect a small reduction on emission reduction, we can infer that such a high carbon price in G20

economies would likely result in substantial domestic emission cuts, though we leave the modeling to further studies. Interestingly, a small disruption in global trade also means a reduced effect of CBAM on exports of non-exempted, middle-income economies. These results must be handled carefully, however, as the introduction of a CP rate as high as USD 87 among all G20 economies seems unrealistic in the next few years.
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Keywords: Carbon border taxes, Carbon tariffs, Structural Gravity, Asia and the Pacific, Transportation

Figure 1 Change in exports of iron and steel in China

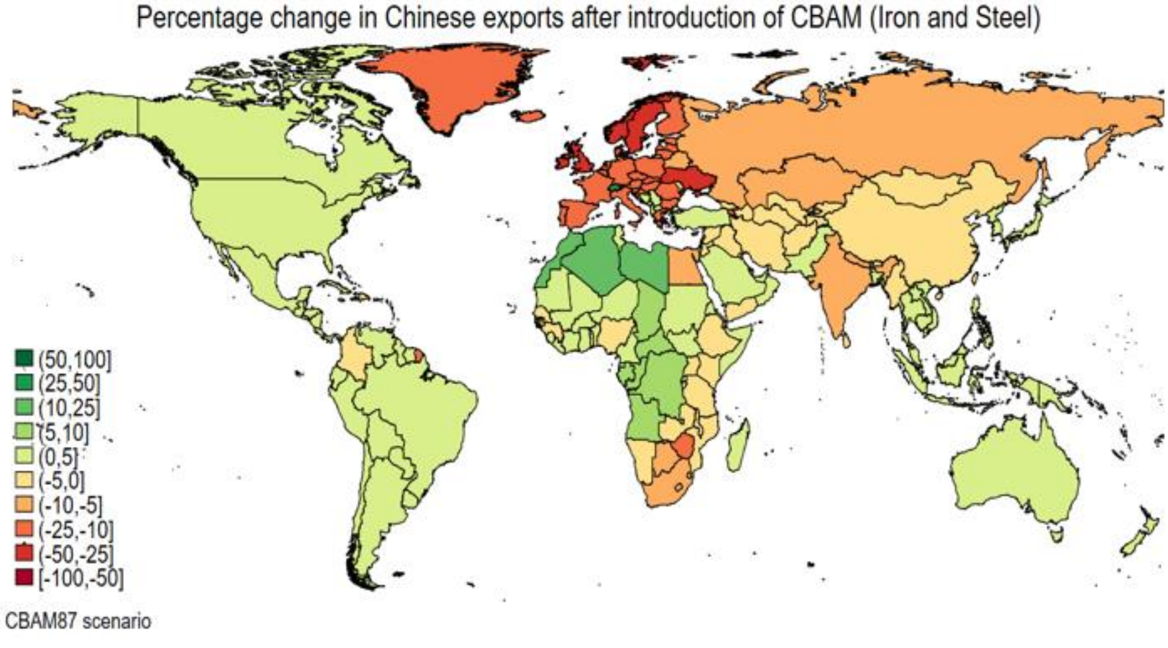

Figure2 Change in exports of iron and steel in Japan

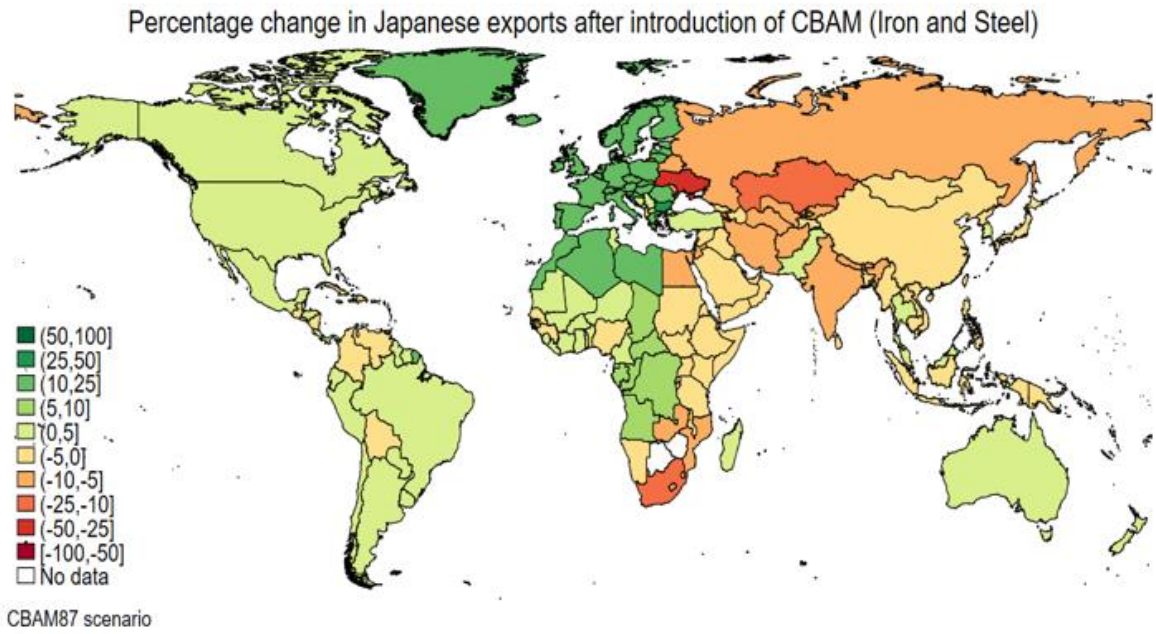

Table 1 Expected effects of CBAM on emissions

Unit: Mt CO2	Chemicals	Iron and Steel	Non-ferrous metal	Metal products	Total
APAC	-218.14	-543.76	-2.42	-3.58	-767.9
Other Asia	54.44	-289.73	12.27	-3.31	-226.33
EU31	-28.23	311.93	14.88	2.93	301.51
Other Europe	54.15	-128.37	3.04	0.38	-70.8
Rest of the World	5.86	-43.27	31.14	-0.1	-6.38
World	-131.92	-693.18	58.9	-3.7	-769.9

"EU31" refers to the European countries that will be implementing CBAM. It shoud be placed after the final paragrapn of the "resutls section"

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[Abstract:0213] OP-046 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Environmental Regulation and Innovation: An empirical analysis for group of EU Countries

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Overview:This paper seeks to explore the impact of environmental regulation, quantified through environmental protection expenditures (EPF), on innovation within a sample of EU countries. The

study is guided by four primary objectives. Firstly, it empirically assesses the collective influence of EPE—encompassing expenditures from government, corporations, and households—on innovation. Secondly, addressing an ongoing academic debate, the research considers whether patents or research and development (R&D) expenditures better capture innovation. Consequently, both R&D expenditures and patents are utilized as measures to conduct robustness checks. As the environmental protection expenditure (EPE) encompasses three distinct subsectors—government, corporations, and households—the third objective is to assess the impact of expenditure from each sector on innovation. Lastly, the paper investigates the diverse effects of EPE on innovation across countries with varying levels of climate performance, as determined by the Climate Change Performance Index (CCPI).
Methods:We collect information concerning innovation, environmental protection spending, and controlling factors (such as trade openness, financial development, labor force, and human capital) for a set of 32 primarily European nations spanning the period from 2006 to 2020. This data is assembled through an unbalanced panel approach. Our choice of time frame is primarily influenced by data accessibility from the main data source (Eurostat). For empirical estimation, we use panel fixed effect and system gmm for our core model. We also use other estimation techniques for robustness of our results.
Results:The study revelated that there is a positive impact of Environmental Protection Expenditure (EPE) on innovation. The findings remain robust even after accounting for the influence of trade, credit, education, and inflation on innovation. To mitigate endogeneity concerns, the study employs the System GMM estimator. Furthermore, the core results withstand scrutiny when alternative measures of innovation are considered, and alternative estimation techniques addressing endogeneity, such as the Hausman-Taylor estimators, Mundlak, and Lewbel 2SLS procedures are applied. The examination at the sectoral level reveals that the primary driver behind the positive influence of environmental protection expenditures on innovation is the government sector. Moreover, we note that the impact of environmental protection expenditures on innovation varies across countries depending on their effectiveness in addressing environmental issues, as measured by Climate Change Performance Index (CCPI).
Conclusions:In light of the aforementioned findings, several policy implications emerge. Firstly, given the ample resources at the disposal of the public sector, optimizing government spending on environmental protection can expedite the innovation process. Secondly, fostering public-private partnerships, especially those directed at environmental protection expenditures aimed at technological innovation, may yield significant impacts on both environmental sustainability and innovation. Thirdly, implementing targeted subsidies for local stakeholders and enterprises investing in environmentally friendly technology can provide additional support for innovation activities.
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Keywords: environmental protection expenditures, Innovation, Panel data, EU sample

[Abstract:0100] OP-047 [Accepted:Oral Presentation] [Energy and the Environment » Environmental Markets and Taxes]

""What drives emerging carbon credit markets – fact or fiction? An econometric analysis""

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Overview:Established in 2011 under the Australian Government's Carbon Farming Initiative (CFI), the Australian Carbon Credit Unit (ACCU) program sought to provide a robust mechanism for individuals and entities to generate tradable carbon credits by implementing projects that reduce or remove emissions. Each ACCU issued represents one tonne of carbon dioxide equivalent (tCO2-e) stored or avoided by a project. Regulated by the Clean Energy Regulator, the ACCU market encompasses a diverse range of participants, including farmers, landholders, businesses, and indigenous communities (Clean Energy Regulator, 2023). The issuance of ACCUs is undertaken as part of the Australian Government's Emissions Reduction Fund and involves a meticulous process, where projects are rigorously assessed against approved methodologies to ensure genuine emissions reduction or sequestration. These credits are then issued to project proponents, reflecting the quantified environmental benefits achieved. Other than being sold to the Commonwealth under a carbon abatement contract, the subsequent trade of ACCUs occurs in the secondary market and is influenced by various factors such as policy developments, market participants' behavior, and global events (Clean Energy Regulator, 2023).
This study delves into the dynamics of ACCU prices within the national carbon market. Employing various econometric models, we identify the key drivers of ACCU returns, offering valuable insights into potential policy implications. Our results reveal the profound influence of Australian environmental policies, market regulations, and events on the performance of the ACCU market. In other words, based on our analysis, the ACCU market's primary drivers are rooted in regulatory and policy frameworks established to address climate change, making it distinct from other conventional financial markets where factors like economic indicators, financial factors or monetary policy may hold more sway. Surprisingly, we identify a negative correlation between ACCU returns and European Union Allowances (EUA) during the investigated period. Our analysis finds no significant relationship between ACCU prices and other financial assets. Furthermore, our findings support the anticipated connection between macroeconomic variables and ACCU returns, indicating that economic growth may lead to higher returns, while higher interest rates correspond to lower prices. This research contributes to a comprehensive understanding of the intricate dynamics governing the ACCU market, facilitating more informed decision-making for all stakeholders.
Methods:This study pioneers an exploration into the factors influencing ACCU returns, marking a significant contribution to the existing literature. To unravel and quantify these factors, we employ rigorous econometric models. Our daily dataset spans from February 1, 2020, to June 30, 2023, capturing the dynamic nature of ACCU prices. Central to our investigation is the assumption that ACCU price fluctuations are maily tied to policy shifts, political events, and market dynamics that challenge its stability.
We conduct a comprehensive analysis by considering key factors, including financial assets, energy prices, macroeconomic indicators, and ACCU-specific variables. Our analytical approach involves employing various statistical methods aligned with our econometric specifications as outlined below.
In the preliminary stage, Model (1) exclusively incorporates policy, event, and regulation variables, revealing three significant events with noteworthy impacts on ACCU returns. Expanding our scope, Model (2) incorporates additional macroeconomic variables, such as interest rates, economic growth, and the Australian Industrial Production Index (API). Model (3) delves into supplementary financial variables, encompassing ASX 200, oil, coal, gas, and EUA returns. Further refinement is achieved in Model (4), which assesses ACCU-specific variables, including the number of transactions, new issuances, holdings, as well as voluntary and compliance cancellations.
In the final step, Model (5) employs a stepwise forward regression approach (α=0.10) to construct the most robust model, integrating variables from all categories—macroeconomic, financial, and ACCU-specific.
This research aims to deliver valuable insights, empowering stakeholders to navigate the intricacies of the Australian carbon market and emerging carbon markets more broadly. By identifying key drivers of ACCU returns, we aspire to facilitate informed decision-making in a landscape shaped by

policy dynamics, economic trends, and market-specific variables.
Results:Our findings demonstrate that the Australian Carbon Credit mark is mainly influenced by policy, regulation and events and they play a decisive role in explaining the dynamics of ACCU returns during the period examined. In other words, based on our analysis, the ACCU market's primary drivers are rooted in regulatory and policy frameworks established to address climate change, making it distinct from other conventional financial markets where factors like economic indicators, financial factors or monetary policy may hold more sway.
Notably, we identify a negative correlation between ACCU and EUA returns during the investigated period. This observed negative relationship would suggest a divergence in market dynamics, underscoring the distinct influences on these assets arising from regional policies, economic conditions, and environmental regulations. This finding can confirm that the performance of the ACCU market is just heavily linked to the Australian environmental policies. Conversely, the EUA market is tied to the broader regulatory framework and emissions reduction targets set by the European Union. This inherent regional specificity results in a complex interplay of factors, whereby changes in policy directions, economic trajectories, or global environmental events can exert varying pressures on each market, potentially leading to a negative correlation. Our analysis reveals no significant relationship between ACCU prices and other financial assets. Furthermore, our findings support the anticipated connection between macroeconomic variables and ACCU returns, indicating that economic growth may lead to higher returns, while higher interest rates correspond to lower prices.
Conclusions:In conclusion, our study on the dynamics of ACCU prices within the national carbon market offers crucial insights for policymakers, businesses, and households. Through the application of econometric models, we have identified the primary drivers of ACCU returns, shedding light on the interplay of environmental policies, market regulations, and events shaping the ACCU market. The identification of a negative correlation between ACCU returns and EUA underscores the unique regional influences on these carbon markets. Importantly, our findings reveal a lack of significant relationships between ACCU prices and other financial assets, emphasising the distinctive nature of carbon market dynamics in Australia. Additionally, our results highlight the expected relations between macroeconomic variables and ACCU returns, providing stakeholders with valuable foresight into potential market trends. These insights hold significant policy implications, suggesting the importance of aligning environmental policies with market dynamics to ensure a robust and sustainable carbon market. By integrating our findings, stakeholders can make more informed decisions, contributing to the effective implementation of environmentally conscious policies and fostering a resilient carbon market ecosystem.
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Keywords: Carbon Credit Unit, Carbon market, Climate Policy, Safeguard Mechanism

[Abstract:0184] OP-048 [Accepted:Oral Presentation] [Renewables » Solar]

Net Metering Scheme for Solar Energy: How Are Costs and Benefits Distributed Between Households With and Without Solar Panels?

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Overview: Solar panels are crucial in the transition from a fossil-based to a renewables-based energy system. A widespread policy to foster their adoption by households is net metering (Dufo-López and Bernal-Agustín, 2015). The latter scheme allows households with grid-connected solar panels to feed their excess electricity production to the grid at retail prices. Specifically, net metering usually involves one meter, and the electricity costs for the households are based on the yearly difference between consumption and own generation. This policy has been shown to be one of the most cost-effective (Darghouth et al., 2011; Londo et al., 2020) and easier to implement (Duke et al., 2005) measures to incentivize residential solar panel adoption.

The net metering scheme affects the electricity bill of households both directly and indirectly through the increase in residential solar panels. Indeed, this policy has a negative effect on electricity prices, because more production from renewables in a given hour implies a lower wholesale price of electricity in that hour (so-called merit order effect), as well as a positive effect, as retailers may charge more to offset the costs of supplying electricity to households with solar panels. Moreover, net metering implies that the burden of electricity bill levies is disproportionately larger for households without solar panels. Furthermore, this policy is associated with an increase in residential solar panels, which increases grid and balancing costs for distribution system operators (DSOs) and retailers. However, the distribution of these effects between households that install solar panels and those that do not has rarely been addressed in previous literature. To fill this gap, we develop a model to measure the effect of net metering on households statically and to capture the dynamic effects on the behaviour of retailer (i.e. retail tariff adaptation), government (i.e. tax rate design), and DSO (i.e. grid tariff adaptation). We evaluate this model based on historical province-level data for the Netherlands and conduct a sensitivity analysis on our results. We find that households that do not install solar panels face a higher electricity bill under the net metering scheme and that the largest part of this increase is related to an increase in the grid tariff. Ultimately, our study contributes to the small literature on the distributional effects of net metering and aids policymakers to evaluate and mitigate the inequality between households associated to this policy.
Methods: Previous literature has proposed different channels through which the net metering scheme may affect households' electricity bill. For instance, Mills et al. (2008) and Kim et al. (2023) show evidence of cross-subsidies from households without solar panels to those with solar panels through retail rates. Moreover, Pudjanto et al. (2013) and Gupta et al. (2021) find that grid costs increase as residential solar panels uptake increases. However, no paper has quantified the total effects of this policy on the household electricity bill and the distribution of costs and benefits between households with and without solar panels. We fill this gap by developing a model with four agents. Firstly, we model households' load and generation profiles. Secondly, we model how the retailer is affected by the net metering scheme through its electricity trading on the wholesale market, the merit order effect, the balancing costs and the feed-in fee that is used to compensate households for their excess generation. Thirdly, we model how the government responds to the decrease in the tax base caused by the net metering scheme. Lastly, we model how the costs faced by the grid operator change due to the scheme. On the basis of this model, we estimate the distribution of the net benefits of net metering between households with and without solar panels using historical public data for the Netherlands and we conduct a sensitivity analysis on the assumptions used in the model.
Results: We evaluate the effects of the net metering scheme on the household electricity bill using data for the Netherlands in 2019. We find that the retail cost component increases due to the feed-in fee and the higher balancing costs and decreases thanks to the commodity revenues and the merit order effect, leading to a lower retail tariff overall. Moreover, we find that the tax component increases modestly as a result of this policy, yet our sensitivity analysis shows that this increase worsens as more households install solar panels. The grid cost component also increases, yet the magnitude of this increase is approximated based on previous related literature. Overall, our results show that the net metering scheme is associated with an increase in the electricity bill for households without solar panels and with a decrease in the electricity bill for households with solar panels.

Conclusions: We evaluate the net metering scheme for Netherlands and find that it may have had a negative effect on the electricity bill of households that do not install solar panels. Hence, this policy may have negative implications for inequality and energy poverty and it may be recommended to improve the design of this policy to foster redistribution. For instance, the observed inequality would be reduced if netting for tax purposes was not allowed and if the grid cost increase associated with the higher number of solar panels would be paid by households with solar panels. Moreover, we show that the burden of this policy becomes even more unequally distributed as more households install solar panels. Our model can be extend to compare the effect of this policy in other countries that have adopted as well as to evaluate the distributional effects of possible alternative policy designs. Ultimately, this study aids policymakers in reducing the inequality across households caused by net metering and improving this policy's design, which is crucial to achieving a fair and sustainable energy transition.

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An analysis of regulatory, social and financial barriers to energy community roll-out and countermeasures

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Overview: With the recast of the Renewable Energy Directive [RED.2018] and the Electricity Market Directive [EMD.2019] (both parts of the Clean Energy for All Europeans Package of 2019), rules for the establishment of renewable energy communities (RECs) and citizen energy communities (CECs) were laid down at European level. European Union member states were required to transpose these supranational guidelines into national law within 1-2 years. In this respect, Austria acted as a fore-runner, having provided legislation for RECs and CECs since mid 2021. With the number of operating ECs increasing ever since (currently, more than 700 RECs and CECs have been established in total in Austria) the collection of practical experience grows and brings to light a number of barriers which need to be addressed in order to enable a successful smooth roll-out of RECs and CECs at a large scale.

Methods: In order to mitigate hurdles for a future roll-out of energy communities, barriers need to be specified and analysed in detail. Moreover, it is necessary to derive recommendations for action to support policy decision makers and aid a reasonable development of energy communities that is compatible with practical implementation.

SYSPEQ, an Austrian research project, funded by the Austrian Research Promotion Agency (FFG), focuses on research concerned with facilitating the planning, development, and implementation of energy communities. A comprehensive analysis conducted within this project revealed various barriers and gaps: Literature reviews and structured expert interviews have highlighted financial, regulatory, technical, and social obstacles encountered throughout the energy community planning, implementation and operation phases. Engaging a range of multidisciplinary stakeholders including financiers, non-profit housing developers, third-party service providers, researchers, and end-users reveals practical experiences that underscore the necessity of adapting regulatory frameworks for energy communities to enable and unlock this concept's full potential. The synthesis of the analysis of existing barriers and gaps in literature, complemented by practical insights from multidisciplinary stakeholders, using mixed methods (e.g. literature review and structured expert interviews), yields a set of recommendations for policymakers.

Results: Out of the results, preliminary findings emphasize the significance of regulatory complexities, financial constraints and social perspectives for the development of energy communities.

At the national level, Austria has already established a comprehensive legal framework for energy communities. However, certain legal obstacles hinder harvesting the full potential of energy communities, particularly concerning the engagement of non-profit housing developers in energy communities. Most non-profit housing developers are classified as large enterprises, who are forbidden to participate in RECs. Although their participation in CECs is basically possible, they are not allowed to exercise decision-making power. However, it is worth mentioning that the restriction of large enterprises (including non-profit housing developers) is not solely a problem in national legislation, but is a legal requirement given by EU directives.

Energy communities, by their nature, aim to enable collective and citizen-driven energy actions and support the clean energy transition based on inclusivity. This means that energy communities should especially address energy poverty, and support vulnerable citizens. With excluding or significantly constraining social housing developers' participation in energy communities, their residents – often being vulnerable and subject to limited financial means -- are deprived of their opportunity to actively participate in the energy transition through energy community initiatives. Thus, given the identified barrier to the restriction of the participation of large non-profit housing developers in energy communities it is recommended to reconsider and amend the legal framework at a European level, and consequently at a national level. Such adjustment would align with the inclusive purpose of energy communities and supports to overcoming barriers for a more equitable and accessible concept.

Energy communities are often organised as associations, and non-profit organisations, which are limited in their financing possibilities. Examining the financing perspectives and bankability of energy communities, the underlying legal personality significantly impact the bankability. This applies to consumer protection laws and tax-related questions, particularly in the involvement of non-profit limited liability companies.

The legal requirement of "non-profit orientation" for energy communities hinders the presentation of positive credit ratings, resulting in interest rate increases, and requires additional equity. In addition to that, there is a lack of awareness and challenges in navigating through federal or regional subsidies which affects the security of financing concepts. Moreover, ambiguities are encountered in presenting economic returns from volatile electricity trading transactions. All these issues impede energy communities from securing positive financing commitments from financial institutions, which would be important for larger investments in community assets, e.g. community battery storages.

Thus, the roll-out of energy communities could be enhanced by providing more awareness campaigns with the aim of clarifying subsidies, while banks should consider developing flexible financial models to support them. Additionally, funding institutions could play a crucial role by providing higher financial support, and local stakeholders should explore financing options based on the chosen implementation and operation model of an energy community. Addressing these aspects,

policymakers can contribute to the bankability, sustainability, and widespread participation of energy communities.
Further obstacles encompass heritage protection regulations (e.g. no possibility to mount PV systems on certain buildings), and existing tenancy laws hamper the participation of tenants and property owners in engaging with energy communities. Strict regulations (regarding the height of the rent, complexity of rent calculations, and consent of tenants) result in a lack of financial incentives for property owners to establish an energy community, install generation systems, and provide the resulting electricity to their tenants or a wider energy community.
From both the tenant's and property owner's perspectives, the extent of organisational effort is also crucial. The complexity involved in planning, setting up, and maintaining an energy community demands significant organisational effort, hindering citizens, and specific citizen groups, especially those with low financial capacity, from participating in energy communities. To address these issues, a review and revision of heritage protection regulations and tenancy laws are essential to identify areas hindering the establishment and participation in energy communities. Additionally, there is a need to develop financial incentives and support mechanisms for property owners, including tax credits, grants, or other financial incentives, to make investments in renewable energy projects more attractive. Simplifying and streamlining administrative processes, especially related to the planning, setup, and maintenance of energy communities, is crucial to making participation appealing to both tenants and property owners.
Conclusions:In conclusion, the analysis highlights various challenges in the implementation and operation of energy communities, encompassing regulatory barriers, financial constraints, spatial and social obstacles. Legal impediments hinder the involvement of large non-profit housing developers, which significantly constraints the chances of vulnerable citizens to become part of an EC. Financial obstacles, such as non-profit orientation requirements, limited awareness regarding support schemes, and variable economic returns underscore the necessity for awareness campaigns, and especially novel and innovative financial models of conventional credit institutions. Spatial and social barriers, including heritage protection regulations and organisational complexities underscore the importance of reviewing regulations and streamlining administrative procedures. Collaborative initiatives at the European level should focus on harmonising legal frameworks and encouraging participation, fostering a sustainable and inclusive rollout of energy communities.
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Keywords: energy communities, barriers, countermeasures,

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[Abstract:0349] OP-050 [Accepted:Oral Presentation] [Renewables » Policy and Regulation]

Understanding the behaviour of renewables under long term contracts – the case for power system management

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Overview: For many years, the development of renewable energy has been supported by the use of long-term contracts. Support schemes have been effective in driving down costs and helping to bring technologies to maturity (IRENA, 2023). However, over the years, historical support schemes contract design has shown limitations in terms of incentives that are well documented in the literature (Meus et al., 2021). As a result, in Europe, Member States have changed the design of contracts to converge mainly towards financial contracts for difference (CfDs).

Market incompleteness and soaring electricity prices in the last years led academics to argue for strengthening long-term contracts in power markets (Fabra, 2023; Keppler et al., 2021; Schittekatte and Batlle, 2023). A system based on well-established long-term contracts hedges against the volatility of electricity prices, protecting consumers and producers against price fluctuations. Although current support schemes decreased distortions, they still do not provide the right short-term incentives, and affect markets players behaviours.

While many authors have analysed the incentives for producers in the spot market and proposed adapted designed (Billimoria and Simshauser, 2023; Favre and Roques, 2023; Newbery, 2021; Schlecht et al., 2024), one remaining gap in the literature relates to the impact of long-term contracts for the management of the power system. This paper thus aims to investigate the impact of long term contracts on power system management and proposes an analysis of support schemes from a power system perspective.

Methods: In order to understand and analyse the effect of contracts already affecting markets, the paper focuses on the French electricity market under renewable energy support schemes.

As a first step, the paper recapitulates the design of CfDs, which varies widely across Europe depending on national policy choices. The analysis is based on a qualitative analysis of the national regulator's (NRA, CRE for France) call for tenders and the AURES II project database. This information is used to analyse contract design incentives theoretically in order to determine (i) incentives for market participation and bidding, and (ii) the volume of support schemes in the power system.

In a second step, theoretical incentives are compared with bids on market platforms. The analysis lies on the supply and demand curves of different market players to identify situations where renewables behave according to contract design rather than market incentives. As the contract design affects the financial settlement, market participants do not maximise revenues based on market incentives alone, but by crossing information between markets and contracts.

In a third and final step, to understand more precisely the impact of support schemes on power system management, identified behaviours are confronted with empirical data of the French power system for the period 2020 to 2023. As the paper is written from a power system point of view, the paper brings novelty in the fact that the analysis is not limited to the impact on the day-ahead markets, but also includes intraday (ID) and imbalance settlement (ISP) prices. A cross-analysis allows to quantify behaviour and highlight the complexity of power system management in predicting and managing market behaviour under long term contracts.

Results: The analysis shows that the French support schemes are currently Contracts for Difference, based on the difference between an electricity price and a market reference price for all injected energy. As acknowledged in the existing literature, such contracts provide incentives aligned with the contract rather than market signals.

In addition, the design of French contracts includes a premium if the assets do not produce in the event of negative spot market prices. This design is explained by the will to limit opportunity costs in the event of oversupply in the spot market. However, as a consequence, assets could have a strong incentive to stop production completely in such situations, or to produce fully when electricity prices are positive on the spot market, leading to a dual behaviour that does not provide an incentive to produce in shorter markets.

In situations of negative prices in the spot market, assets have no incentive to make their capacity available in shorter-term markets such as ID or balancing, even if they are available at almost zero cost due to the premium. As a result, more expensive assets are activated in these markets, resulting in higher costs for consumers.

Empirical analysis supports the estimation and shows a strong increase of these situations in the

power system for 2023. Situations where several GW reacts to negative prices in the spot market are increasingly present in term of frequency and volume, and creates complications for the operation of the power system.
Conclusions:The paper aims to understand and analysis long term contract under the perspective of the power system management. Transmission system operators are currently confronted with the complexity of managing the power system under higher uncertainty, associated with the increase of support schemes for renewable energy. The complexity is expected to increase in the future as more capacity is installed under support schemes.

Scholars have begun to propose adapted contracts to align incentives with short term markets. However, historical contracts already have implications for power system management that needs to be understood and analysed. The paper shows that it is crucial to focus on redesigning contracts in coherence with market incentives, as it already creates complexity for power system management. This realignment is essential to ensure that behaviour is consistent with short-term market incentives and to mitigate the impact on the power system.
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Keywords: renewables, support schemes, long term contracts, market design, power system management

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Empowering Progress: Global evidence on the link between women political empowerment and renewable electricity generation

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Overview:The sustained increase in renewable electricity generation (RES-E) is essential to reverse growing carbon emissions. In this sense, it is crucial to identify enabling and distorting factors of RES-E to achieve targets 7.1 and 7.2 (i.e. clean and affordable energy) of the United Nations Sustainable Development Goals (SDG) [22]. Next to economic, institutional and societal determinants, political factors are well studied in the literature. One political dimension which is significantly under-represented in the RES-E determinants literature is women's political empowerment (WPE). This is so even though research shows that women tend to exhibit more knowledge about climate change [15], environmental concerns [21], and pro-environmental behavior than men [13; 2]. Based in this environmental gender gap, the study derives and discusses direct and indirect conceptual mechanisms behind the relationship between WPE, and its dimensions, and RES-E deployment, and offers a new perspective on SDG 7 for policymakers by extending the discussion by the valuable gender equality (SDG 5) policy point of view.

A rich literature on the determinants of RES-E generation and consumption has flourished in recent years (see [7]). It has emphasized the role of determinants, such as Gross Domestic Product (GDP) (e.g. [18]), financial development (e.g. [14]), institutional quality (e.g. [10]) and human capital (e.g. [16]). Still, the empirical literature on the link between the political role of women and renewable energy outcomes is only very recent and rather sparse and partial. [17] analyzed the case of 36 African countries from 2000 to 2015 whereas [19] considered a global sample with 100 democracies from 1997 to 2017. Importantly, investigations so far focused on a single component of one of the dimensions related to WPE, namely the share of women in national parliaments.

In sharp contrast to the studies mentioned above, this study considers a comprehensive indicator of WPE based on [20]. The index not only accounts for direct political representation, but also includes civil and societal dimensions. Furthermore, the empirical analysis exploits a large panel dataset covering 128 developed and developing countries from 1990 to 2018. To account for the dynamic process of RES-E deployment, the impact of WPE on RES-E is estimated from a dynamic empirical specification that controls for time and country unobserved heterogeneity.

Estimates from a two-step system Generalized Method of Moments (GMM) estimator supports the hypothesis that further WPE increases the share of RES-E. The estimated effect, sizeable and highly significant, is consistent with the mechanisms identified in the study. Furthermore, results suggest that political participation is not the dimension driving the results. In fact, the estimated effect of political representation of women on RES-E is negligible and statistically insignificant. Additionally, the results reveal that the effect of WPE is stronger in countries with high human development index (HDI), which seem to drive the results of the global sample. The evidence obtained in the study has several implications, particularly considering that, despite the worldwide trend in recent decades towards more gender equality, there are still substantial differences between countries in the degree of WPE.

The study contributes to the literature in several ways. First, several mechanisms (direct/indirect) are conceptualized through which WPE potentially affects RES-E generation. Second, a more holistic measure for WPE is deployed, allowing a verification of the derived mechanisms. Finally, the study presents novel evidence for a large global sample with robust empirical approaches and new insights related to the WPE effect's heterogeneity.

Methods:The study deploys an unbalanced panel for 128 countries from 1990 to 2018. The outcome variable of the study is the percentage of electricity generated from renewable energy sources over the total electricity generation. The measure only includes electrical energy, referring to the crucial role of electrification in the energy transition [4], and does not include hydropower, as it is considered unsustainable due to serious social and environmental externalities [8; 18].

The main explanatory variable of the study is V-Dem's Women Political Empowerment index. The WPE index consists of three sub-indices, which are: The Women Civil Liberties index, the Women Civil Society Participation index, and the Women Political Participation index. The WPE index, and the three sub-indices, range from 0-1 (high empowerment). Details on the composition of the WPE indices are presented in Table 1 [20]. Additionally, the study includes a comprehensive set of controls considered by the literature, which are reported in Table 2.

Since RES-E generation is a dynamic process that is affected by past generation and potential feedback effects, the main analysis of the study is conducted by dynamic panel estimations. The econometric specification is:

$$logRES_{it}=\beta_0+\beta_1 \, logRES_{(it-1)}+\beta_2 \, WPE_{it}+Controls_{it} \, \gamma+\tau_t+\varepsilon_{(it)}$$

where $logRES_{it}$ denotes the share of RES-E in country i and year t. WPE_{it} represents the WPE index, $Controls_{it}$ refers to the control variables listed in Table 2, and τ_t depicts a set of time dummies. Finally, $\varepsilon_{it}=\mu_i+v_{it}$ constitutes the disturbance term, where μ_i denotes the country heterogeneity. The coefficient of interest is β_2, implying the short-run effect of WPE on RES-E generation. The long-run effect is $\beta_2^{(long\text{-}run)}=\beta_2/(1-\beta_1)$.

The inclusion of ($logRES_{(it-1)}$), which is not strictly exogenous, leads to problems of autocorrelation and endogeneity and thus to inconsistent estimates of standard panel-data estimators [11]. Therefore, the study deploys the two-step system GMM estimation technique which is robust to these problems [1; 5]. Next to mitigating issues of endogeneity (reverse causality and dynamic endogeneity), the GMM procedure allows consistent estimations in the presence of heteroscedasticity [23], serial correlation [3], omitted variables [12], and measurement errors [6]. To further strengthen the results, time fixed effects (τ_t) are included and robust two-step standard errors computed, following [24]. Finally, supplementary estimations are conducted with alternative key measures, estimation techniques and sample compositions – included in the main study.
Results:This section reports and discusses the highlights of the estimation of the effect of WPE on RES-E generation. The first column in Table 3 reports the estimation of the coefficients in a specification that includes the overall WPE index and suggests that an increase of one standard deviation in the WPE index would rise the share of RES-E by 20 percent, in the short-run, and 179 percent in the long-run, which is clearly statistically significant. This result confirms the main hypothesis of the study, in the sense that WPE encourages the deployment of RES-E. Furthermore, the estimates of columns (2) to (4) indicate that the effects of the three sub-indices of the WPE index, individually, are highly statistically significant as well as showing positive signs. In terms of magnitude, civil liberties and civil society participation seem to have the strongest effects. When included simultaneously, in column (5), the order of magnitude changes a bit. Civil society participation shows the largest coefficient, followed by civil liberties and political participation, although, civil society participation is only statistically significant at 10 percent level, and civil liberties is insignificant. The results highlight the relevance of all three dimensions of WPE and support the elaborated indirect mechanisms through which WPE affects RES-E generation. The coefficient of lower chamber female legislator, in column (6), shows a positive but smaller effect. Nevertheless, the effect is statistically insignificant, indicating that the direct mechanism might be less substantial, compared to the indirect ones.

As most of the research regarding the environmental gender gap considers developed countries and uncovered that this gap is moderated by income [9], the study conducts a heterogeneity analysis by splitting the sample based on HDI and income. Column (1) of Table 4 presents the global sample estimates, whereas columns (2) and (3), and columns (4) and (5) show estimates for HDI and income sub-samples, respectively. The latter do not show statistically significant estimates for WPE, although it is worth noting that the coefficient for high-income countries is relatively larger, compared to low-income countries. Regarding HDI, estimates in column (2) show a WPE coefficient larger than for the global sample, which is also statistically significant at 5 percent level. Opposingly, estimates in column (3) show a negative and statistically insignificant coefficient for WPE. Overall, the results might imply that countries with high HDI drive the global effect of WPE and that a certain threshold of human development is necessary for the mechanisms of WPE to fully unfold. Finally, results might imply that, rather than the level of income itself, the human development – additionally considering health and education dimensions – potentially better captures the found moderation of income of the environmental gender gap.
Conclusions:Regarding policy implications, the study enables policymakers to achieve clean energy targets (SDG 7.1/7.2) through WPE policies (SDG 5). Furthermore, it provides novel evidence that civil society participation could play a key role for RES-E deployment, even greater than women participation in political arena. This supports indirect mechanisms (e.g., corporate governance) which unleash economic forces rather than just political influence. Finally, Direct mechanisms might be not so effective as more seats occupied by women in parliaments not necessarily translate into political decisions that favor RES-E deployment.
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Keywords: women's political empowerment, renewable electricity generation, panel, GMM

Table 1

Table 1. Components and indicators entering V-Dem's Women Political Empowerment Index

Women Political Empowerment Index	
Women Civil Liberties Index	Freedom of domestic movement women
	Freedom from forced labor women
	Property rights women
	Access to justice women
Women Civil Society Participation Index	Freedom of discussion women
	CSO women's participation
	Percent female journalists
Women Political Participation Index	Power distributed by gender
	Lower chamber female legislators

Table 2

Table 2. Descriptive statistics.

Variable	Definition	Mean	Std. dev.	Min	Max
Log(%RES)	Electricity generated from renewable energy sources (% of total electricity generation)	0.922	1.046	0.000	4.904
Women political emp.	Women political empowerment index	0.720	0.192	0.102	0.965
Civil liberties	Women civil liberties index	0.712	0.222	0.014	0.983
Civil society part.	Women civil society participation index	0.694	0.199	0.054	0.941
Political part.	Women political participation index	0.768	0.226	0.062	1.000
(%) Lower chamber female	Lower chamber female legislators (% of total seats)	16.031	10.939	0.000	53.080
Quality of Government	Quality of Government Index	0.553	0.209	0.060	1.000
Democracy	Polity5 democracy index	4.367	6.126	-10.000	10.000
Log(GDP pc)	Gross Domestic Product per capita in constant 2015 $US	8.538	1.473	5.243	11.629
Financial development	Financial development index	0.326	0.236	0.000	1.000
Foreign direct investment	Foreign direct investment, net inflows (% of GDP)	4.258	11.236	-57.532	279.347
Human capital	Mean years of schooling	7.724	3.323	0.290	14.132

Table 3

Table 3. Baseline results.

	Two-step system GMM					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
L.Log(%RES)	0.883***	0.887***	0.892***	0.909***	0.891***	0.887***
	(0.0347)	(0.0348)	(0.0345)	(0.0305)	(0.0371)	(0.0304)
Women political emp.	1.093***					
	(0.271)					
Civil liberties		0.880***			0.397	
		(0.296)			(0.274)	
Civil society part.			0.800***		0.517*	
			(0.225)		(0.295)	
Political part.				0.463***	0.235**	
				(0.136)	(0.114)	
(%) Lower chamber female						0.00164
						(0.00174)
Quality of Government	0.643***	0.701***	0.562***	0.745***	0.524**	0.857***
	(0.132)	(0.134)	(0.132)	(0.149)	(0.207)	(0.163)
Democracy	0.00756**	0.0101**	0.00966***	0.0145***	0.00575	0.0273***
	(0.00376)	(0.00486)	(0.00365)	(0.00416)	(0.00418)	(0.00667)
Log(GDP pc)	0.0921	0.0347	0.101**	0.0527	0.113*	-0.0230
	(0.0583)	(0.0546)	(0.0486)	(0.0529)	(0.0575)	(0.0496)
Financial development	-0.198	-0.0864	-0.0996	-0.159	-0.172	0.0272
	(0.152)	(0.155)	(0.126)	(0.168)	(0.145)	(0.144)
Foreign direct investment	0.00161**	0.00178**	0.00147*	0.00164**	0.00158**	0.00174*
	(0.000805)	(0.000836)	(0.000807)	(0.000822)	(0.000797)	(0.000933)
Human capital	-0.0649**	-0.0492	-0.0645**	-0.0378	-0.0743**	-0.00693
	(0.0321)	(0.0304)	(0.0303)	(0.0262)	(0.0300)	(0.0262)
Constant	-1.239***	-0.657**	-0.980***	-0.762**	-1.275***	-0.129
	(0.366)	(0.302)	(0.299)	(0.304)	(0.370)	(0.265)
Observations	3,385	3,408	3,408	3,385	3,385	3,295
Number of countries	128	128	128	128	128	128
AR (1)	0.000	0.000	0.000	0.000	0.000	0.000
AR (2)	0.821	0.896	0.818	0.836	0.811	0.829
Hansen P-Value	0.498	0.463	0.593	0.450	0.973	0.396

Notes: The dependent variable is the share of renewable electricity generation as defined in the text. Women political emp. depicts the Women Political Empowerment Index. Civil liberties, Civil society part. and Political part. are the WPE sub-indices, Civil Liberties Index, Civil Society Participation Index and Political Participation Index, respectively. All estimates control for year fixed effects. Windmeijer robust standard errors are reported in brackets. ***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively.

Table 4

Table 4. Heterogeneity Analysis.

	Two-step system GMM				
	(1)	(2)	(3)	(4)	(5)
VARIABLES	GLOBAL SAMPLE	HDI HIGH	HDI LOW	INCOME HIGH	INCOME LOW
L.Log(%RES)	0.883***	0.821***	0.697***	0.862***	0.742***
	(0.0347)	(0.0647)	(0.130)	(0.0460)	(0.113)
Women political emp.	1.093***	1.922**	-0.146	0.485	-0.0215
	(0.271)	(0.948)	(0.821)	(0.632)	(0.862)
Quality of Government	0.643***	-0.618	0.689	-0.0989	0.768
	(0.132)	(0.735)	(1.085)	(0.312)	(1.245)
Democracy	0.00756**	0.00875	-0.000455	0.0260	0.00593
	(0.00376)	(0.0194)	(0.00640)	(0.0167)	(0.00521)
Log(GDP pc)	0.0921	0.305	-0.0745	0.0765	0.192
	(0.0583)	(0.223)	(0.341)	(0.0980)	(0.343)
Financial development Index	-0.198	-0.445	1.855	-0.0779	-0.340
	(0.152)	(0.434)	(1.541)	(0.194)	(1.965)
Foreign direct investment	0.00161**	0.00118	-0.000699	0.00164	-0.000328
	(0.000805)	(0.000864)	(0.00184)	(0.00107)	(0.00162)
Human capital	-0.0649**	-0.0396	-0.188*	0.0262	-0.139
	(0.0321)	(0.0503)	(0.104)	(0.0377)	(0.0895)
Constant	-1.239***	-3.165	1.709	-1.149	-0.431
	(0.366)	(1.986)	(2.242)	(0.766)	(2.585)
Observations	3,385	1,726	1,659	2,073	1,312
Number of countries	128	67	61	79	49
AR (1)	0.000	0.008	0.003	0.000	0.057
AR (2)	0.821	0.650	0.658	0.935	0.745
Hansen P-Value	0.498	0.999	0.999	0.939	0.993

Notes: The dependent variable is the share of renewable electricity generation as defined in the text. Women political emp. depicts the Women Political Empowerment Index. All estimates control for year fixed effects. HDI HIGH consists of countries with high average human development (average HDI >0.7), whereas HDI LOW consists of countries with medium and low average human development (average HDI <0.7). Countries are grouped by INCOME level, using the World Bank taxonomy, that is: high income, upper middle income, lower middle income and low income. Based on this classification, for the purposes of this study, countries are further grouped into HIGH-income countries, which consist of high- and upper-middle income economies, and LOW-income countries, which consist of low-income economies and low-middle income countries. Windmeijer robust standard errors are reported in brackets. ***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively.

[Abstract:0354] OP-052 [Accepted:Oral Presentation] [Renewables » Policy and Regulation]

Uzbekistan's energy transition: how to attract more investment in renewable energy

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Overview:The energy transition generation of renewables in Uzbekistan is going gradually developed year by year. To achieve Uzbekistan's target of 40% share of RE in energy sector by 2030, the country would need to invest in renewable every year to gain this aim. However, Uzbekistan began to sign agreements from different companies that construct the PV panels' plants and wind turbine station annually from 2021 to 2023. Through a comparative review of three key factors for attracting investment –energy targets, renewable energy legislation, and general conditions for investors – this study examines why the country's renewable energy sector has not attracted more capital. The contribution of the article consist of three parts of analysis concerning to attractiveness of business climate for renewable energy. First, it develops a new review model for assessing the business climate for renewable energy in Central Asian and even any countries. Second, it offers update and expand the answers how to work on targets in Uzbekistan. Third, taking into account international best practices, it identifies the obstacles and solutions to attracting investment in renewable energy in the country. The article finds that condition for investment for renewables has some limitations for investors and the share of renewables in the energy governance system needs to be increased.
Methods:We analyzed previous studies of scholars to drive our methodological approach. First, we develop a review model by chart (see Fig.1). Second, using the model, we study Uzbekistan's progress in attracting investment in renewables from 2016 to 2023. Then, we gave analysis for each review concerning to the business climate for renewable energy.
[Fig. 2 Review model for assessing the business climate]
[Fig. 2 Renewable energy generation, Uzbekistan]
We define the three targets of renewable energy step by step, review legislation and investment conditions in Uzbekistan. These three areas are major determinants of the ability to attract renewable energy investment.
Business climate for investors is the main indicator to contribute initial capital for renewable energy sector. In addition, FDI in renewable energy has positive effects in other fields, such as employment, problems with deficit energy, local air pollution, CO2 and greenhouse gas emissions. We also review the regulatory frameworks, legal and policy documents, and reports of the country. First, we assess the adoption and enforcement of renewable energy legislation and best policy practices, including regulatory policies, fiscal incentives, and public financing mechanisms. In review of renewable energy targets we examine the main targets of the country: carbon emissions reduction, energy efficiency and share of renewables in long run term. The next of review, we collecting all legislation documents upon development of renewable energy sources. Finally, we consider investment conditions for renewables by analyzing above two reviews.
Results:To create business climate for renewable energy, first of all, the country set up ambitious targets; carbon emissions reduction, energy efficiency and share of renewables in energy sector. In 2018, Uzbekistan ratified the Paris Agreement and adopted a national commitment to reduce GHG emissions per unit of GDP by 10% of the 2010 level by 2030. Still, the country has faced problems regarding with air pollutions (because of subsidy for fossil fuel and projects for renewables increase slowly the last five years), CO2 and other ecological problems (such as, sorting the rubbish, deficit of water, energy producing stations which works without filters etc,). There are many solutions to reduce GHG emissions from world experience: levy taxes for externalities, trade by auctions and others. In order to reduce air pollution, the volume of greenhouse gases from industrial enterprises is to be auctioned for sale to large producers. Adoption of this mechanism gives a significant result of the future environment of Uzbekistan.
Subsequently, in 2022, the President of the Republic of Uzbekistan approved the Decree No. PF-60 "New Uzbekistan development strategy for 2022-2026". According to the decree the efficiency of using energy has to increase 20% by 2026. The country put the aims to develop "green economy" by increase renewable energy projects, using EV cars, reconstructing infrastructure energy sector which remained Soviet Union and utilities. However, currently the efficiency of the energy is not significance that expected the government. The population of the country is increased year by year and lead among the Central Asian countries. Additionally, electricity and hydropower stations take a long run term to update in which had been constructed 70-50 year before. On the other hand,

Uzbekistan in a short time achieved to attract foreign investors in solar and wind energy projects. Solar PV projects are increased rapidly. By 2024, the construction of wind energy station will be given for exploitation as well.
Next target is the position of share of renewable energy in energy sector. The Presidential Decree No. PF-158, 2023, September 11, "Uzbekistan-2030", in goal 51, the share of renewable energy will reach 40% by 2030. The eve of the end of the year 2023, December 27, the President of the Republic of Uzbekistan Shavkat Mirziyayev addressed at the ceremony joint projects in the field of green economy. He emphasized that the next six years demand of electricity would be increased from 83 billion to 120 billion kilowatt hours that leading to cover through renewable energy and its active investment policy to increase the capacity of green energy sources to 27 gigawatts by 2030.
The second review gives hierarchical legislation on renewable energy sector of the Republic of Uzbekistan that reveal how governance reform. By 2023, Uzbekistan had adopted renewable energy regulations based on best practices in other parts of the world. Extensive information on renewable energy legislation is provided by international organizations. One reason Uzbekistan has adopted forward-looking renewable energy legislation and policies are that receive assistance from international organizations and donors, which often provide advice and help in designing regulatory measures such as, the Asian Development Bank, the World Bank, and others.
The last review is about investment conditions for renewables. Except to designing and adopting sound policies and increasing the share of renewables in the governance system, it is critical to improve the investment climate and communication. As part of their global decarbonisation and climate change strategies, many large international corporations and investors have been withdrawing their capital from countries and projects that rely on fossil fuels. However, the value of fossil fuel subsidy is very high in Uzbekistan. So, to boost attractiveness of investment on renewables government can involve providing subsidies for investors, tax credits, feed-in tariffs mechanism, or net metering schemes that make renewable energy more affordable and competitive.
Conclusions:Based on our analysis, we propose three policy measures to attract more investment in renewable energy in Uzbekistan. First, the country could continue to adopt best-practice policies and incentives—and put them into practice. In particular, they need to strengthen their practical experience of managing tenders, feed-in tariffs, and auctions. Renewable Portfolio Standards can also change the position and status of the country and push to develop of the prosperity investment conditions for renewables.
Second, Uzbekistan could reduce subsidy share for fossil fuel by increase the market electricity price step by step to transit to renewables. This indicator shows the lowest level attraction of investment for renewable as well. Therefore, government should refuse subsidies for fossil fuel gradually.
Third, Uzbekistan needs to improve its position in rankings of the renewable energy investment climate that leading to improve living standards of the country.
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Vakulchuk, Roman, Indra Overland, and Beni Suryadi. 2023. "ASEAN's Energy Transition: How to Attract More Investment in Renewable Energy." Energy, Ecology and Environment 8(1): 1–16. https://doi.org/10.1007/s40974-022-00261-6.

Keywords: Renewable energy, business climate, investment conditions, greenhouse gas, subsidy

Fig. 1 Review model for assessing the business climate

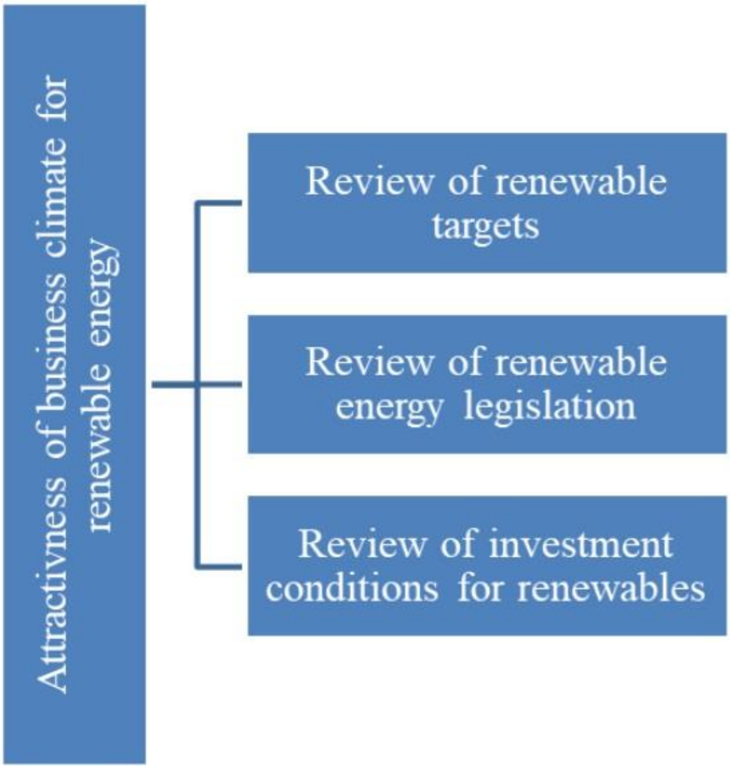
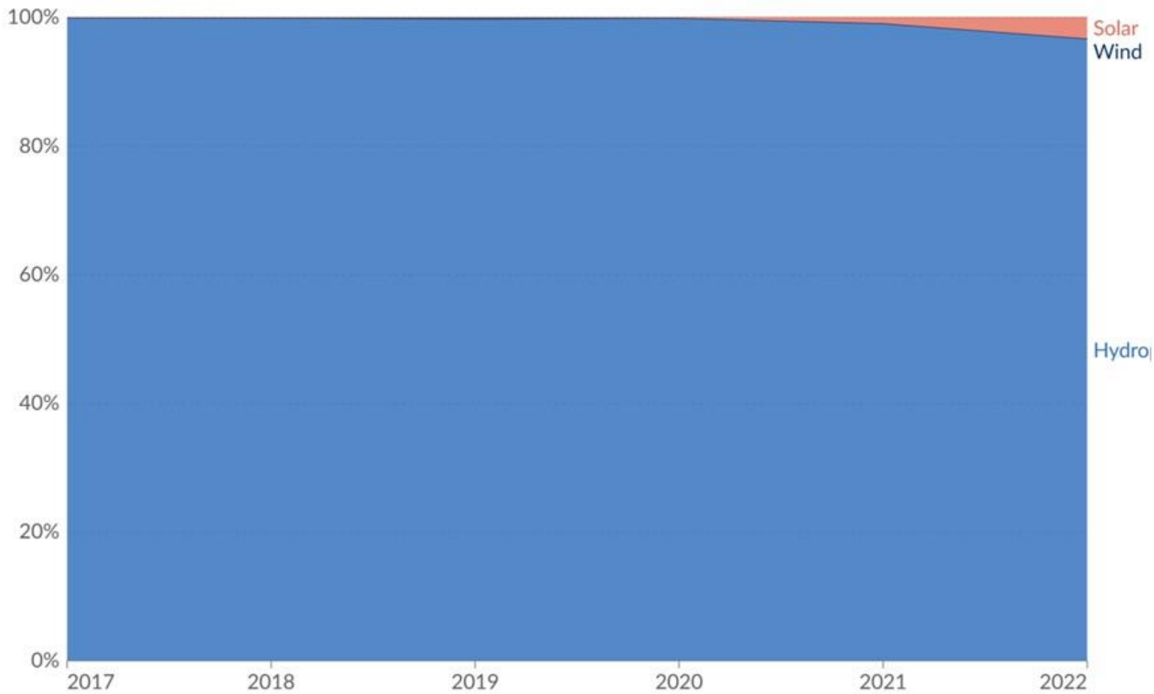


Fig. 2 Renewable energy generation, Uzbekistan



[Abstract:0396] OP-053 [Accepted:Oral Presentation] [Renewables » Policy and Regulation]

Incentivizing winter solar PV production in regions with seasonal weather patterns

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Overview:Solar photovoltaic (PV) technology is a critical component of future energy systems, offering advantages such as modularity, scalability and cost-competitiveness compared to traditional power generation [1–3]. However, in regions with temperate and continental climates, like parts of Europe and North America, where seasonal weather patterns are more pronounced, the annual energy output from PV plants varies significantly [4]. During winter, the reduction in solar irradiation reaching the PV panels lowers their capacity factors, often to far less than half of their summer values [5]. For these countries, this seasonal "winter gap" in solar energy production challenges their energy security, as it may necessitate fossil fuel-powered backup capacity or increase reliance on electricity imports, especially where wind energy potential to cover the winter production gap is missing.

The siting and angle of solar photovoltaic (PV) panels are critical in determining their annual generation [6]. Situating plants at higher altitudes with less cloud and fog cover and steeper PV panel angles could boost their electricity production in winter [7–9]. Nonetheless, such plants might incur additional costs due to accessibility challenges and complex racking and installation [10]. Policies could offset these higher costs; however, such measures are at present inexistent [11]. Moreover, the research that explored the impact of support schemes on the spatial distribution of renewables mainly focuses on onshore wind and remuneration scheme design [12–14], network charges [15,16], support bid adjustment to minimize systems costs and network constraints [17–19] and impacts of spatial planning policies [20]. There are no studies explicitly focusing on policies for winter PV electricity.

We address this gap and explore support policy designs to boost winter electricity production from rooftop PV systems. We focus on Switzerland, where winter irradiation varies significantly due to altitude differences between the Alpine and midland regions [7] and which heavily relies on electricity imports during winter. Although minimum tariffs are rarely used to support solar PV [21–23], their relevance in the Swiss context, with its 630 local electricity providers and individualized PV tariffs [24], makes them a compelling subject for analysis. To contrast the minimum tariff's effects, we assess a seasonally differentiated FIT, a more prevalent support mechanism in Europe for rooftop PV systems [25]. Additionally, we examine an investment subsidy for PV panels with a 60-degree inclination to cover the increased installation costs.
Methods:We evaluate these policies by measuring their impact on profitability and winter electricity production for rooftop PV in 2068 (97%) Swiss municipalities. Here, we define winter electricity as PV production from November to February. We employ a techno-economic model to assess the Internal Rates of Return (IRR) of a 12 kW PV system for a single-family household under different policy scenarios. Here, we account for the complex Swiss PV tariff system, determined individually by 630 utilities and other investment conditions such as various cantonal PV policies and taxation rules [26]. Furthermore, we apply a fine-grained solar irradiation dataset for 30- and 60-degree panel angles, including snow cover effects [7].

We carry out our analysis in several steps. First, we calculate the profitability of a 30-degree PV system in each municipality under the current Swiss investment environment to establish a baseline. Here, we divide between urban and non-urban municipalities with low and high winter electricity (more than 20% of yearly generation occurs in winter) to differentiate between their rooftop and winter electricity potential. Second, we estimate the IRR impacts of uniform (same for every municipality) and non-seasonal FIT and minimum tariffs. We then investigate seasonal, i.e., winter-

differentiated tariffs, assuming they remunerate at higher tariff rates between November and February. Third, we assess the same uniform and winter-differentiated tariffs for 60-degree PV systems. In addition to the winter tariffs, we investigate the impact of investment subsidies for PV systems with 60-degree panels. We estimate the effectiveness of these policies by measuring their ability to boost the IRR of the PV systems in the different municipalities above a 3% IRR profitability threshold and increase the correlation between IRR and winter electricity potential.
Results:Our analysis yields several key findings. First, we demonstrate the fragmentation and lack of tariff alignment in the current Swiss PV tariff landscape, leading to large profitability variations (Figure 1). Differences in cantonal PV policies and taxation rules further exacerbate the policy and profitability fragmentation. Most notably, in the context of our study, the current PV tariffs and policies do not incentivize winter PV production, as observed by the 17 pp correlation between winter electricity production and IRR in the baseline case.

Second, we show winter differentiated tariffs could improve the profitability of PV systems in municipalities with high winter electricity production, irrespective of tariff design: an 18 Rp/kWh winter minimum tariff and FIT increase IRRs for municipalities with high winter electricity by about 1.6 pp IRR (Figure 2; 100Rp=1CHF). However, compared to the minimum tariff, the winter-differentiated FIT results in a larger correlation between winter electricity and profitability: 66 pp for an 18 Rp/kWh winter FIT, compared to 34 pp for a 18 Rp/kWh minimum winter tariff. Moreover, the minimum tariff does not decrease the over-subsidization of some municipalities, which, under the 2022 PV tariffs, achieve IRRs amounting to up to 10%. The FIT clusters the IRR levels as it equalizes remuneration across Switzerland, unlike minimum tariffs that increase remuneration only for municipalities below the minimum tariff, leaving high PV tariffs unchanged.

Third, while winter-differentiated tariffs would impact the profitability and siting of PV installations, they would not change the PV production patterns of the individual plants. We subsequently show that installing PV panels at a 60-degree inclination increases winter PV production in every location, especially at higher altitudes. Moreover, steeper PV panel inclination would increase the number of municipalities with high winter electricity from 231 in the case of 30-degree panels to 947 or 45% of the total in a scenario with a 60-degree inclination. However, inclining the PV panels to steeper angles would cause an overall yearly production loss because of lower summer generation (Figure 3). The lower annual production and higher installation costs of 60-degree PV systems reduce profitability, which could be remedied through a policy mix of 18 Rp/kWh and a 10% investment subsidy for such PV systems to cover the additional capital expenditures (Figure 4).
Conclusions:Our study offers insight into the effectiveness of different policy measures to increase winter PV electricity by studying rooftop PV profitability and its winter production potential across 2068 (97%) Swiss municipalities. We find that FITs increase the correlation between profitability and winter electricity production more than minimum tariffs, or 66 pp compared to 34 pp, respectively, for an 18 Rp/kWh winter tariff. Furthermore, to boost winter PV electricity, it would be most effective to incentivize PV panels with steeper tilts, especially in higher-altitude locations. However, as this decreases the annual PV production and necessitates higher upfront investment into racking and installation, policymakers would need to bridge the profitability gap with a 10% investment subsidy in addition to an 18 Rp/kWh winter tariff.

Our findings offer several policy implications. First, we stress the importance of implementing uniform PV tariff rates in Switzerland to decrease profitability fragmentation and reduce transaction costs for solar PV developers [26]. Second, adopting winter-differentiated tariffs would boost winter PV electricity, as shown by our analysis, despite their design. Therefore, we would encourage policymakers to adjust PV support policies according to their existing policy instruments. Third, besides remuneration-based policies, policymakers should also implement incentives for PV systems with steeper panel angles, as this boosts winter electricity production the most, especially in higher-altitude locations. We show that single policy instruments are insufficient; instead, a policy mix [27] is required to boost winter PV electricity.

Although we analyze Switzerland and its specific regulatory and power market setup, our analysis is relevant to countries with similar PV production seasonality, especially those with geographical altitude differences. The entire Alpine area, including Northern Italy, Austria, and Southern France, has similar seasonal solar irradiation patterns, including locations with high shares of winter solar irradiation in yearly irradiation. None of the countries in question have active policies to stimulate winter electricity production from solar PV [11]. Nevertheless, such policies could decrease these countries' dependence on winter electricity imports or the need for backup plants, improving their energy security. They would also increase the value of solar electricity [28,29] by enhancing generation in winter when wholesale prices increase [30].
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Keywords: solar photovoltaics, tilt angle, winter electricity, policy support, profitability

Figure 1: Share of winter PV electricity production in annual PV output

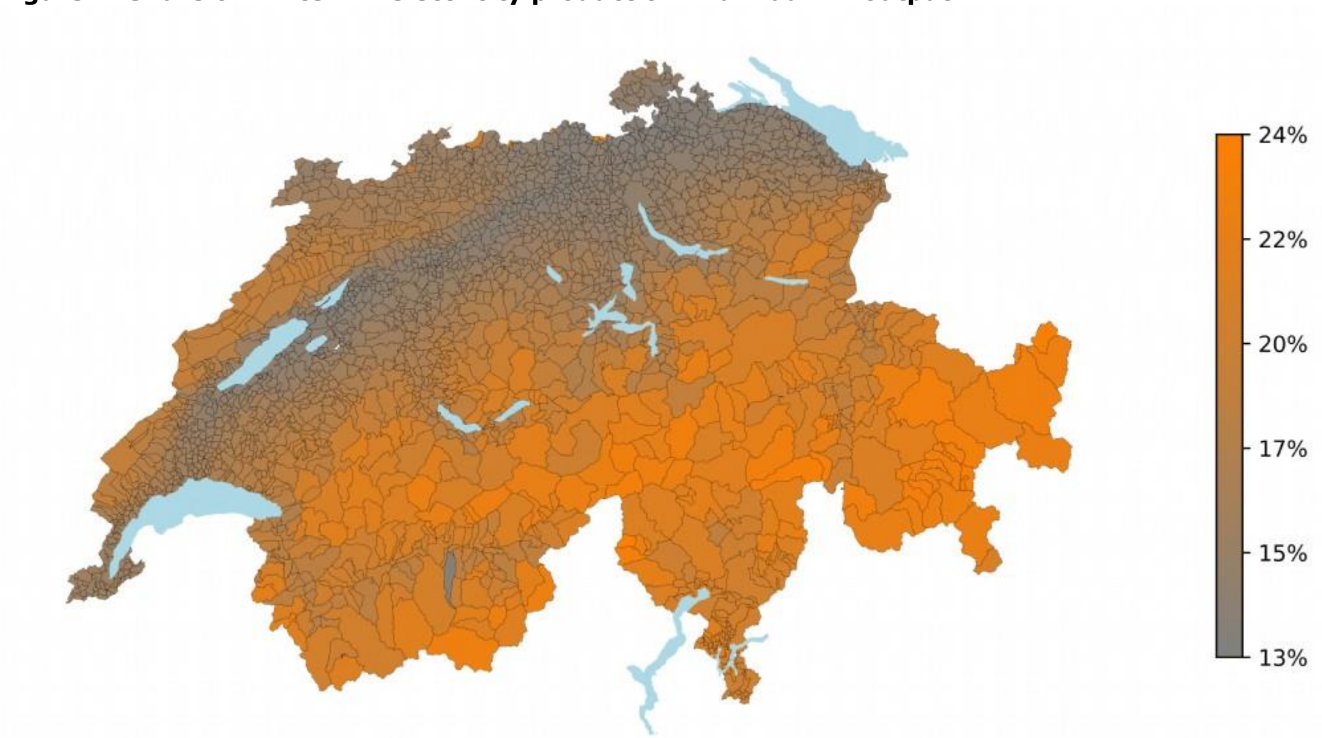


Figure 2: Baseline under current PV and electricity tariffs

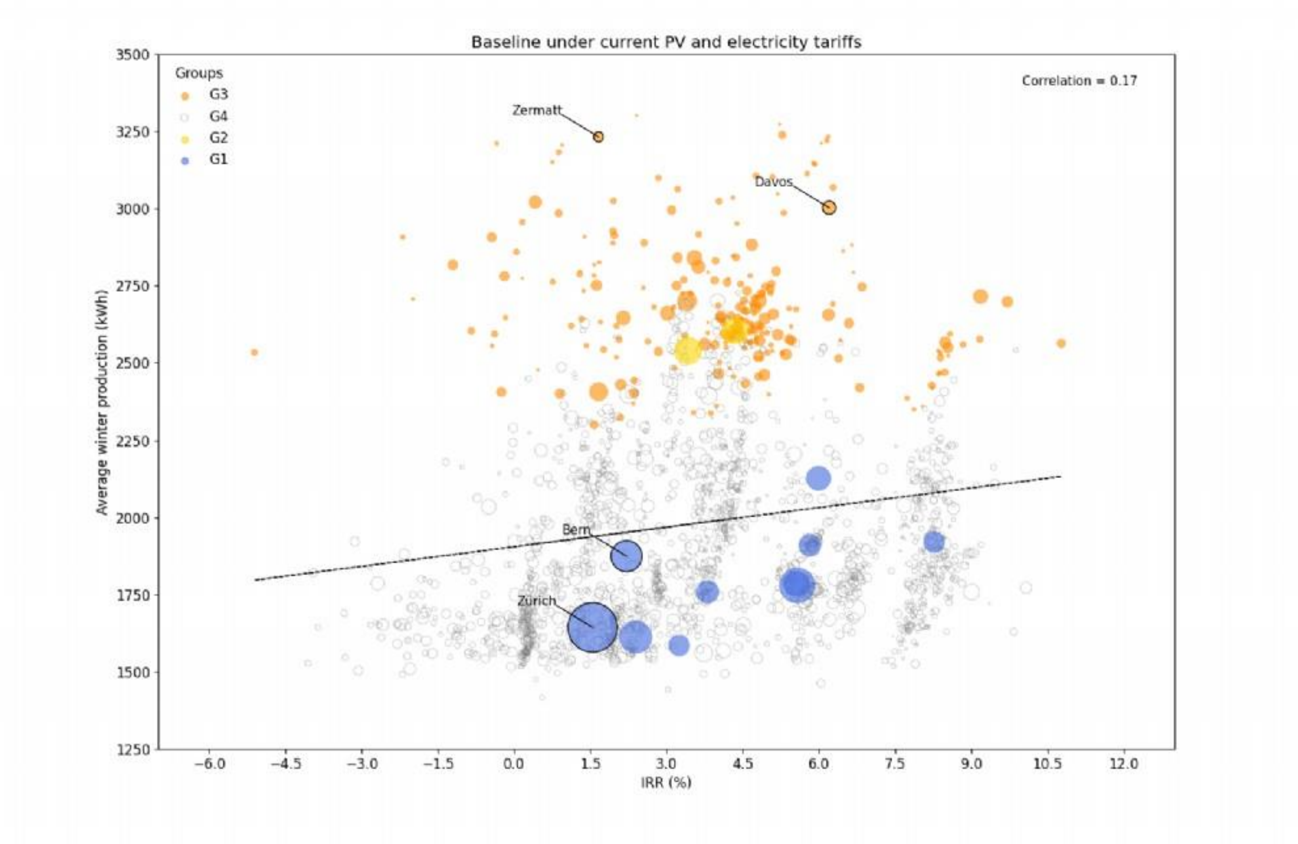
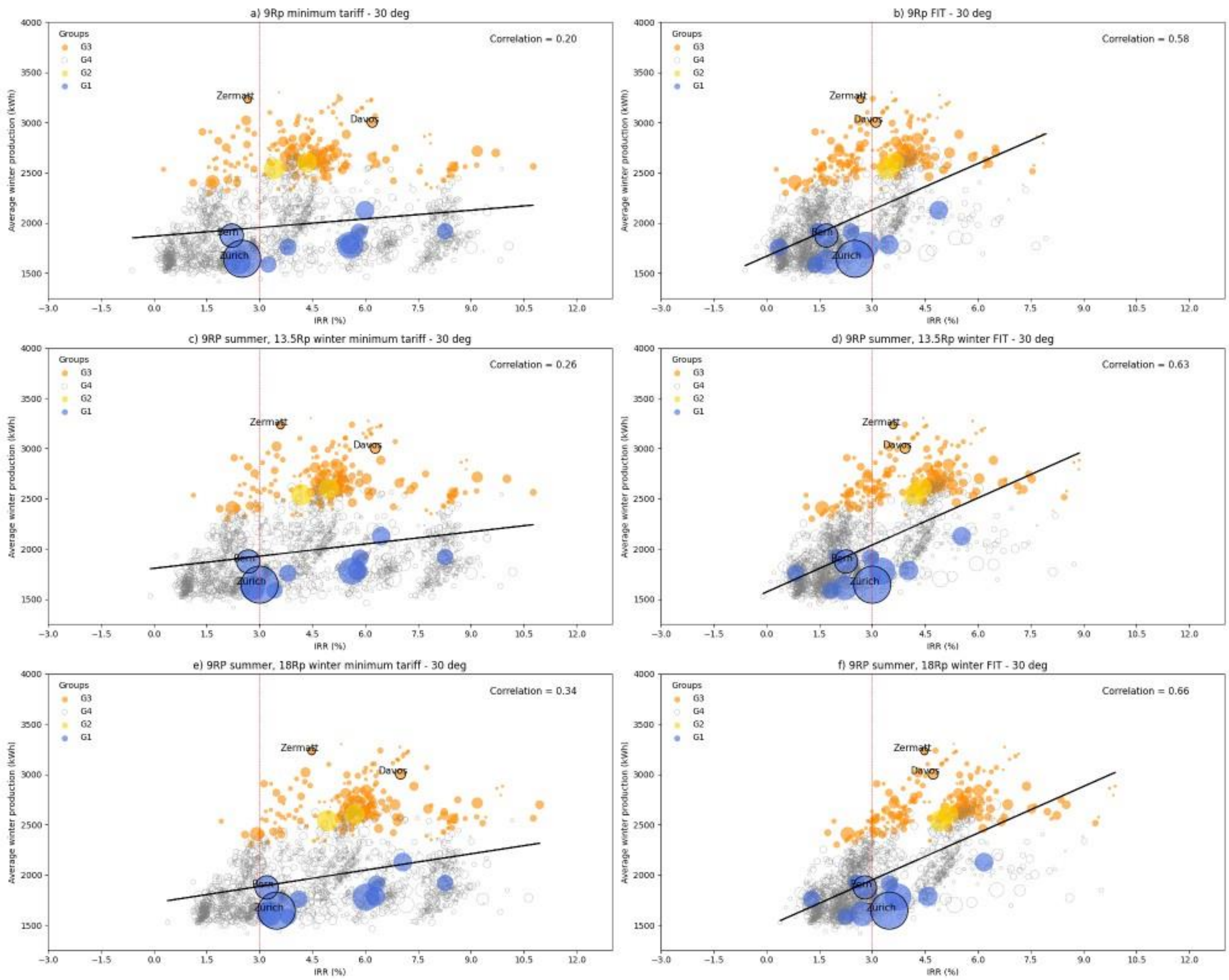


Figure 3: Effects of uniform and winter-differentiated minimum tariffs and FITs



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[Abstract:0060] OP-054 [Accepted:Oral Presentation] [Energy Finance and Trading » Market Design and Regulation]

Lessons from EU-ETS: Assessing Applicability in South Korea and Beyond

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Overview:As 2030 approaches, an increasing number of countries, regions, cities, and states have adopted carbon pricing policies for emissions reduction. According to the World Bank, as of April of 2023, 73 national or subnational carbon pricing policies are in effect, both in the format of carbon taxes or emission trading schemes (ETS). Many other countries have also indicated that they have their carbon pricing policies scheduled or under consideration (World Bank 2024). Despite this proliferation, lingering uncertainties persist regarding the efficacy of such policies and their potential

impact on economic growth. At the same time, although the carbon prices display an increasing trend, it is still argued that the carbon tax/ETS auction price is still less than the abatement cost for emissions (Bayer and Aklin 2020, Errendal, Ellis and Jeudy-Hugo 2023).
An emission trading scheme (ETS), or cap-and-trade, is a market-based carbon pricing policy featured by setting a cap on emissions and enables market participants to trade for the allowance to offset their emissions. The ETS of the European Union (EU-ETS) is the most representative one. With a long operation history dating back to its pilot phase in 2005 and formal launch in 2008, EU-ETS has achieved up to 34.6% of emissions reduction and plays a critical role in achieving the EU's climate-neutral targets (European Commission 2022).
Methods:A comprehensive global macroeconomic dataset at the country-year level was established, which includes (1) CO2 and greenhouse gas (GHG) emissions data collected from the climate watch; (2) macroeconomic indicators including GDP, economic structure, energy structure, urbanization level, etc, from the World Bank; (3) other environmental policy data collected from the governmental website of each country. We utilize the CO2/GHG emissions as our measurement of environmental effect and the GDP as a measurement of overall economic performance.
A matching difference-in-difference (DiD) method is applied to assess the environmental and economic impact of EU-ETS. We utilize the formal launch of EU-ETS in 2008 as our policy instrument. We keep the 18 EU-ETS participating countries in our treatment group, after ruling out those with additional carbon pricing policies. 30 out of 149 non-EU countries are selected as the control group though matching to satisfy the parallel trends assumption of the DiD (Imai, Kim and Wang 2023). Comparing the outcomes of the treatment group with the control group, we capture not only the cumulative impact but also the dynamic impact of the formal implementation of EU-ETS.
As a comparison, we conducted a synthetic control method (SCM) analysis for South Korea's ETS, which launched in 2015 (Abadie, Diamond and Hainmueller 2015). 4 countries are used to construct the synthetic South Korea. We assess the impact of Korea's ETS by comparing the outcome after the implementation of its ETS by comparing the real South Korea with the synthetic South Korea.
A key feature of the ETS market is to let the market itself determine the price of the allowance based on the dynamics of supply and demand. Another question we investigate is the price sensitivity of emission reduction and the economic performance of these two ETS markets. To do so, we conduct fixed effect regression separately for both markets based on the data that combines the emissions, GDP, and price of ETS auctioned allowance of the covered jurisdictions.
Results:We first confirm the effectiveness of the ETS for both the EU and South Korea in emission abatement. To be specific, compared with our control group (non-EU countries without any carbon pricing policies), the formal launch of EU-ETS induces 1.472 tCO2e per capita reduction for our treated EU countries, roughly 1/3 of the sample mean. Such a result is consistent with the findings of the EU carbon market report (European Commission 2022). Additionally, there were large emission reductions in later years, particularly after the year 2013 (phase III), possibly a result of stricter emission targets, and expanded sectoral and geographical coverage. Meanwhile, the implementation of the ETS induces a slight and non-significant impact on GDP. Specifically, a negative impact in the early years but a positive impact in the latter. For South Korea, the launch of ETS from 2015 to 2020 includes 0.5721 tCO2e per capita reduction, which slight negative but nonsignificant impact on GDP. Further, the emission reduction is large for the year 2018, when the pilot phase ended.
In terms of price sensitivity to emission reduction, we find that a 1-euro increment in the EU-ETS price induces 0.033 tCO2e per capita reduction, which is statistically significant at 95%. On the contract, we find that CO2 emission in South Korea is not sensitive to its allowance price. The low proportion of allowance auctioned and low ETS price in South Korea result in less regulatory power for the company's production emission. In the EU, up to 40% of the general sector allowance for Phase III (2013-2020) and 57% of the general sector allowance for Phase IV (2021-2028, separately 15% for the aviation sector) are based on the auction. However, only 10% of the allowance is under auction in Korea. Similarly, based on the data in 2022, the average EU-ETS allowance price is 83 USD, and that for South Korea is less than 20 USD.
Conclusions:To sum up, as an increasing number of countries start their carbon pricing policies, accurate evaluation and experience gathering from the existing market is virtually important. In this study, we empirically confirm the environmental effectiveness of the EU-ETS along with its non-impact on overall economic performance based on our matching DiD analysis. By conducting an SCM analysis on South Korea's ETS market, we confirm that the successful experience of the EU-ETS is possible to be applied to another jurisdiction.
On the other hand, countries need to exercise caution when adopting existing policy frameworks from others or establishing new policies. Regularly conducting effectiveness analyses and adjusting accordingly are crucial. The phased-in adjustments and expansions of the EU-ETS offer important lessons for other countries to learn from. For example, the Korean government is appropriately addressing the issue of price sensitivity by revising the proportion of allowances under auction to 20% starting in 2024.
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Keywords: Policy Evaluation, Carbon Pricing, Emission Abatement, DiD, SCM

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[Abstract:0236] OP-055 [Accepted:Oral Presentation] [Energy Finance and Trading » Market Design and Regulation]

Market-Linked Futures Contract: A Stackelberg Game Theoretic Approach

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Overview:The relationship between price volatility and energy derivatives is a complex one, with both driving and being driven by each other. The inelasticity of energy demand, coupled with the finite and geographically concentrated nature of resources, creates a market susceptible to price instability due to supply shocks or demand fluctuations. Financial instruments like futures, options, and swaps, known as energy derivatives, derive their value from the underlying prices of energy commodities such as oil, natural gas, and electricity. These financial instruments function as tools for companies and investors to hedge against volatility, aiming to mitigate the effects of unexpected price fluctuations.
Methods:Using the Stackelberg leader-follower game framework, we have developed a Market-Linked Futures Contract (MLFC) that incentivize both the buyer and the seller to adhere to their contractual obligations, even in scenarios marked by extreme price volatility. The proposed pricing mechanism within MLFC incorporates modifications in response to fluctuations in market prices. The interaction between the buyer and seller is represented as a Stackelberg game, and optimal contract parameters are determined through backward induction.
Results:The model affirms that there is no incentive to deviate from the MLFC. We have outlined the logical criteria that would incentivize both the buyer and seller to willingly participate in the MLFC. We conducted a sensitivity analysis to further enhance our comprehension of the implications associated with these criteria.
Conclusions:The proposed mechanism possesses the capacity to diminish market price volatility and uphold the significance of the market mechanism. According to the established model, adhering rigorously to the MLFC framework leads to an improved overall expected benefit for both the buyer and the seller. The proposed MLFC framework has the potential for deployment in various domains, including agriculture and dairy.
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Keywords: Energy Prices, Futures Contracts, Price Volatility, Stackelberg game

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[Abstract:0323] OP-056 [Accepted:Oral Presentation] [Energy Finance and Trading » Market Design and Regulation]

Improving market design flexibility: analyzing strategic behavior with deep reinforcement learning

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Overview:Recent developments in the European electricity market are characterized by an increasing share of renewables alongside progressive market integration. Consequently, there is a growing need and cost for congestion management solutions such as redispatch (RD). An alternative approach to costly grid expansion is to refine existing market designs to better address congestion issues. Enhancing procurement mechanisms can empower market players, allowing them to offer their goods more flexibly, increasing profitability for suppliers, and improving market liquidity.

However, introducing new market mechanisms without careful consideration may elevate socio-economic costs by creating opportunities for exploitation by market players. A well-known example is the emergence of inc-dec gaming in conjunction with market-based RD, where energy producers may manipulate their day-ahead (DA) offers to maximize profits by reselling volumes at higher prices in the RD market.

Our current understanding of these evolving dynamics is limited due to a lack of real-life experience and reliance on highly stylized models. While some researchers caution against the risks associated with such market designs [1,2], others emphasize potential opportunities [3,4]. To bring clarity to these discussions, we intend to examine the potential emergence of gaming within market-based RD and to investigate ways to enhance the interoperability of flexibilities between RD and balancing capacity (BC) markets.

In pursuit of this objective, we employ an innovative approach utilizing a combination of deep reinforcement learning (DRL) and mixed-integer linear programming (MILP). Our market model stands out, as it considers not only the DA market but also integrates BC and balancing energy (BE) markets, along with market-based RD procurement. Furthermore, our agent architecture enables the integration of joint bidding, covering both price and volume bids, resulting in a more accurate representation of potential inc-dec gaming.
The findings of this research are twofold: (1) to contribute to improved model design for analyzing emerging strategic behavior with market-based RD and (2) to highlight the benefits of increasing product flexibilities through coordinated procurement strategies of BC and RD.
Methods:The proposed approach integrates our novel DRL/MILP-based agents Agent-Class into a four-stage market environment Market-Class, to enhance the overall model's capabilities across all use cases.

Agent-Class:

Recent advancements in DRL have showcased its ability to navigate complex model environments and optimize strategic decisions, overcoming limitations of commonly used optimization algorithms [5]. Therefore, we integrate a state-of-the-art DRL algorithm to evolve strategic behavior in pricing decisions, in conjunction with utilizing MILP for optimal volume allocation.

While MILP struggles to analyze opportunities presented by diverse market prices, often relying on historical or predicted data forcast, DRL is designed to explore optimal actions *online* without pre-existing knowledge. We iteratively allow these two algorithms to determine volume and price bids, respectively, until convergence is achieved, identifying optimal strategic behavior. The agent, a fusion of DRL and MILP, is initialized with data grounded in basic economic theory decision-making, and anticipates elevated returns through the interaction of these two methods with the model environment during training. Moreover, this approach facilitates a direct comparison of the effectiveness of DRL in analyzing the potential emergence of gaming. The whole model is illustrated in Figure 1.

Model-Class:

The market model implements and depicts the BC, DA, RD, and BE markets. We assume that accepted BC bids are guaranteed to be available by transmitting the offers at the minimum price to the DA market. Moreover, our emphasis is on portfolio-based single bids for each hour across all markets, except for BC, where we aggregate the bids into six 4-hour blocks, following the common practice in European markets. However, it is crucial to emphasize that our primary focus is on potential interoperabilities between BC and RD, along with the potential emergence of inc-dec gaming due to market-based RD.
Results:In order to ascertain the robustness and reliability of our model, we conduct a thorough evaluation of the agent by comparing our findings with well-known examples from previous studies [2,3] that examined inc-dec gaming along with market-based RD. Therefore, we focus on a 2-stage market setup on a six-node grid, see Figure 2, enabling a more reliable comparison through the replication of identical model constraints.

Subsequently, the evaluated agent is integrated into our four-stage market model, which is deployed on a 23-bus system. The grid model incorporates aggregated real data from the DACH region, including Germany, Switzerland, and Austria. Notably, this model allows us to use real-world historic data on power flows and the occurrence of congestion in the Bavarian region, to further improve and validate our model. To better quantify the impact of the proposed combined BC and RD procurement strategy, along with exploring the role of inc-dec gaming, we define three indicators that will be evaluated:

1. Procurement deficit: Examining the impact of using BC for RD on BE procurement.
2. Economic impact: Assessing the effect of joint BC-RD procurement on overall socio-economic costs.
3.Impact of gaming: Investigating socio-economic costs with and without inc-dec gaming, which is achieved by (de-)activating the DRL component accordingly.

In order to investigate these indicators, we introduce parametric adjustments to the agent- as well as market-configuration. This allows the simulation of different use cases against an established baseline. Notably, employing an integrated agent architecture involving DRL and MILP enables us to assess the economic efficiency of the proposed use cases under different scenarios, with and without the presence of gaming dynamics. This approach allows for the analysis of a hypothetical scenario illustrating a regulated RD market without gaming incentives.
Conclusions:Recent developments, including the rise of renewables, progressive market integration, and slow grid expansion, increased the needs and costs for RD in most European countries. This highlights the urgency of adapting current market designs. In response, we propose an innovative agent-based model addressing common limitations, particularly in (1) assessing gaming emergence with market-based RD, and (2) exploring joint BC and RD flexibility procurement.

Despite potential risks of abusive strategic behavior, we expect this adapted market design to enhance flexibilities, increase profitability and liquidity, overall positively impacting socio-economic welfare. For the analysis we are combining Deep Reinforcement Learning and Mixed-Integer Linear Programming allowing joint-bidding and optimizing strategic decisions by capitalizing on market opportunities.

Model reliability is assessed by comparison with well-known examples from the literature. Subsequently, we implement this agent architecture in a four-stage market model on a 23-bus grid with aggregated data from the DACH (DE, AT, and CH) region. Evaluating three key indicators — "Procurement deficit," "Economic impact," and "Impact of gaming" — we aim to showcase the impact of the proposed modifications. Despite the risks linked to specific gaming opportunities, adapting market designs holds the potential to enhance efficiency. Therefore, our intention is to reinforce this observation by presenting quantitative evidence.

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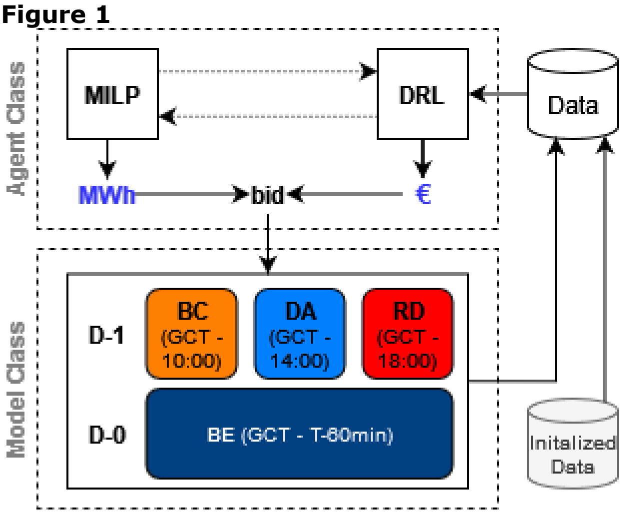
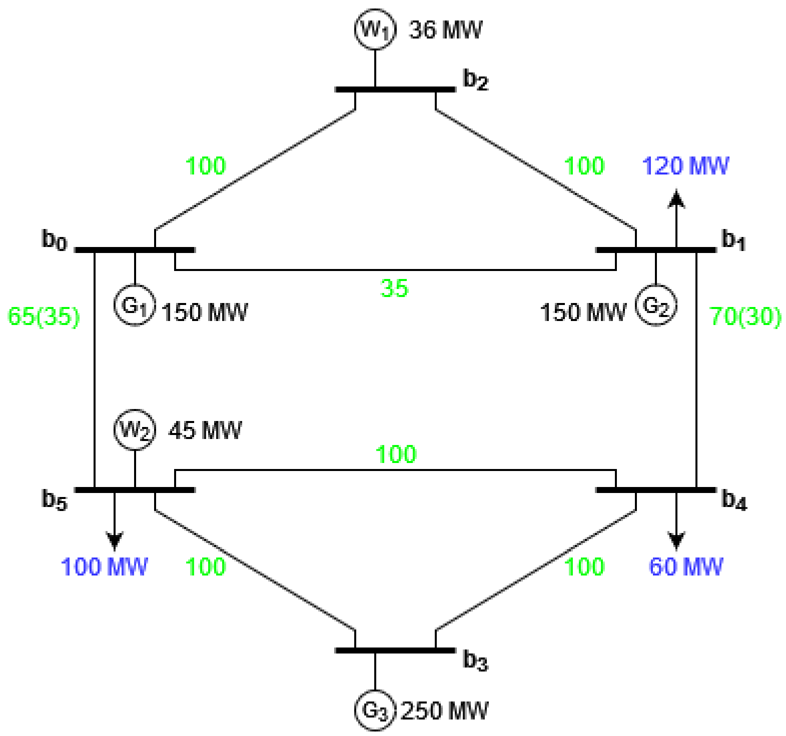
Keywords: Electricity Market Design, Strategic Bidding, Agent-Based Model, Reinforcement Learning, Flexibility Procurement

Figure 1



Four-stage market model with Deep Reinforcement Learning and Mixed Integer Linear Programming based agents.

Figure 2



Six node grid model based on the studies of Sarfati and Holmberg, 2020 and Midttun et al., 2022.

AuthorToEditor: The authors Viktor Zobernig and Stefan Strömer are also affiliated with 2; And the author Jochen Cremer is also affiliated with 1;

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[Abstract:0347] OP-057 [Accepted:Oral Presentation] [Energy Finance and Trading » Market Design and Regulation]

Optimal design of scoring auctions with divisible goods for the hydrogen generation market

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Overview:Hydrogen power has gained attention for its environmental advantages and its ability to overcome the intermittency of renewable energy sources. So far, hydrogen generation has relied on the Renewable Portfolio Standard (RPS) system, but unlike solar and wind power, it requires fuel costs, prompting continuous suggestions that a separate government support system is necessary. To deal with this problem, South Korea took a groundbreaking step in 2023 by establishing a bid market exclusively for long-term hydrogen power contracts. It aims to activate the hydrogen economy in Korea and drive down generation costs through competition between generators. Currently, the market and auction system for hydrogen power are operational only in South Korea. However, given the distinctive characteristics of hydrogen power compared to solar and wind energy, it is anticipated that similar hydrogen power bidding markets will be established internationally in the future. The current procurement auction scheme for long-term hydrogen power contracts in South Korea evaluates bids from power generators based on both price and non-price factors,

utilizing a predetermined scoring rule. Power generators with the highest scores within the specified quantity are awarded contracts in sequence. In addition, the contract is executed with the bid prices, quality, and capacity as submitted. However, under the current auction rule the bid price is evaluated as a ratio to the lowest bid price. Consequently, due to information asymmetry among participants, bidders encounter difficulties in determining their equilibrium bidding strategy. Also, the existence of a stable equilibrium becomes ambiguous. Therefore, it is not guaranteed whether the auction mechanism currently implemented in the hydrogen power bidding market maximizes the government's revenue.

In this regard, this study proposes a multi-attribute auction scheme for long-term hydrogen power generation contracts. The buyer (government) aims to procure a specified amount of power through the auction, while suppliers (power generators) intend to participate in the auction to supply the required power capacity reliably. Unlike many other auctions, it is essential to note that procurement competition for hydrogen power involves performance/quality dimensions other than price. This is due to the primary goal of the auction, which is to promote environmentally friendly hydrogen generation and foster diverse and innovative power generation technologies. Typically, suppliers specify not only the desired contract price and capacity but also promised technical characteristics, energy efficiency, and credit ratings during the bidding process. We collectively refer to these attributes as quality attributes.

Reflecting these realistic auction characteristics, this study designs a multi-attribute procurement auction where suppliers bid on price, quality, and capacity, and their bids are evaluated by a scoring rule pre-designed by the buyer. Specifically, the buyer is assumed to use a quasi-linear scoring rule, allowing bidders to precisely recognize the score they will receive based on their bids, enabling them to decide on their bidding strategy accordingly. The first issue in this context is to determine the optimal auction rule for the buyer. Therefore, this study designs an optimal scoring rule that maximizes the buyer's expected payoff during the contract period. Numerous studies have designed optimal scoring rules for multi-attribute cases [1-2]. However, research on multi-attribute auction design with optimal scoring rules, specifically for divisible goods such as hydrogen power, determining multi-winners, is lacking, and relevant discussions are limited. In this aspect, our study contributes to the existing literature. Additionally, we propose an efficient computation algorithm for implementing the auction. Lastly, we evaluate the performance of the proposed auction by analyzing the buyer's expected payoff through various simulations.

Methods:This study assumes that the auction consists of a buyer who is an auctioneer and suppliers. Each supplier has a two-dimensional type: one is about the generation inefficiency, and the other is about the capacity. Supplier's type is independent and identically distributed with commonly known distribution *F* and density *f*. The supplier's cost function increases in both his inefficiency type and quality. Suppliers bid on the monthly willingness to sell (WTS), single quality attribute, and capacity according to their types. Here, WTS and quality are determined based on the inefficiency type, and bidding capacity is dependent on the capacity type. Each supplier's bid is evaluated by a quasi-linear scoring rule: *S(p,q) = s(q)-alpha*p*. The alpha value varies depending on the region where the supplier generates power and the technology employed for power generation. It aims to reflect potential fluctuations in fuel costs during the contract period in the current bid price. This indicator is considered public information. We allocate the quantities in sequence to suppliers with the highest scores. Contracts are established based on suppliers' bid price, quality, and capacity.

In this study, we show that a multi-attribute auction for divisible goods with a proper scoring rule can implement the buyer's optimal direct mechanism. Analogous to the previous literature on multi-attribute auctions [1], we analyze the auction in three steps. First, we derive an equilibrium bidding strategy in a scoring auction. In this case, we assume symmetric suppliers. Second, we characterize optimal direct mechanism under the revelation principle. Lastly, we investigate how the buyer should design an optimal scoring rule to implement the optimal direct mechanism. Since the computation and implementation seem complex due to a two-dimensional type and divisible goods, we develop an effective computation algorithm for the auction. We will introduce a specific description of the proposed auction scheme in the full paper.

Results:Through our auction design and analysis, we propose Lemmas for proving equilibrium bidding strategy and optimal direct mechanism, and proposition for showing optimal scoring rule. Through various simulations and comparisons, we would like to conduct the following analysis.

1. Performance comparison in terms of the buyer's expected payoff relative to other scoring rules
2. Performance comparison in terms of social cost and expected procured power generation
3. Sensitivity analysis for the value of the alpha index
4. Comparison of the results for different type distributions

Conclusions:We conducted a study proposing an improved auction system for the world's first hydrogen power bidding market currently operational in South Korea. In this context, we proposed the optimal scoring auction design where suppliers bid on price, quality, and capacity. Specifically, our research analyzed a multi-attribute procurement auction for divisible goods, as observed in the case of hydrogen power generation. Our main results provide the form of the optimal scoring rule that the auctioneer should design to achieve the optimal expected payoff. Additionally, we present a computation algorithm for the efficient implementation of the auction. While our simulation results demonstrate comparable performance to other scoring rules in terms of social cost and expected procured power generation, they highlight superior performance in the buyer's expected payoff aspect.

This study is expected to make a significant contribution to the future hydrogen power market and the activation of the hydrogen economy. Moreover, the proposed auction mechanism is anticipated to contribute not only to hydrogen power bidding markets but also to markets that use scoring rule to evaluate the bidders and involve the distribution of divisible goods or the determination of multi-winners.

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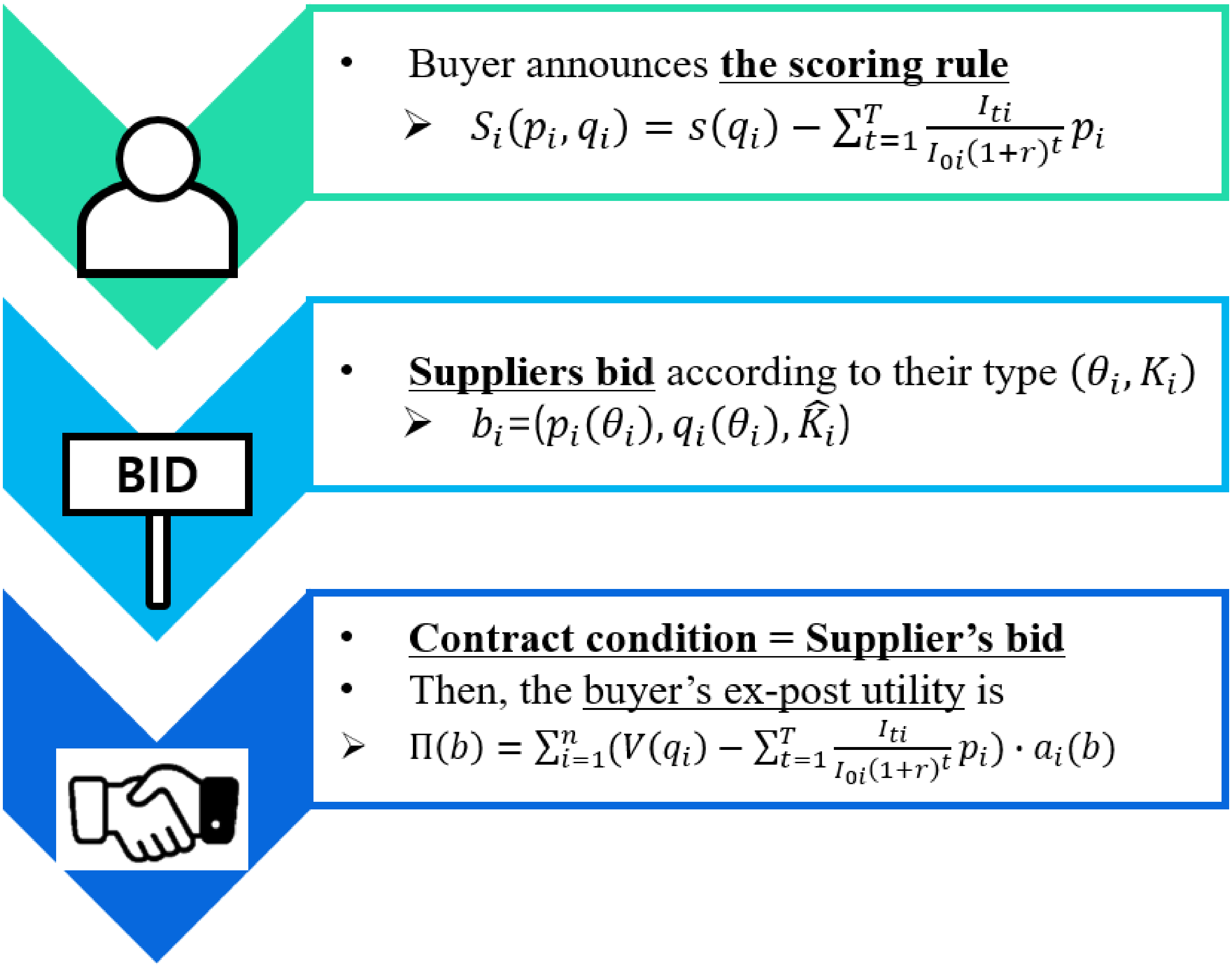
Keywords: Hydrogen generation, Long-term contract, Multi-attribute procurement auction, Scoring auction, Divisible goods

The flow of the multi-attribute auction



The auction process unfolds as follows: 1) The buyer announcement for the scoring rule, 2) Suppliers' bid submission, 3) Contract execution and calculation of the buyer's ex-post utility.

[Abstract:0404] OP-058 [Accepted:Oral Presentation] [Energy Finance and Trading » Market Design and Regulation]

Market Design for Renewable Energy Forecasting

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Overview:In response to global climate change, nations around the world have progressively dedicated efforts across various industrial sectors to transition towards a low-carbon society. A notable example among them is the energy industry, with substantial carbon emissions, transitioning from conventional fossil fuel-based generation to renewable energy sources such as solar and wind power. Renewable energy has contributed to carbon emission reduction, but the increasing share in the overall power generation has introduced supply uncertainties to the power grid. Due to the significant influence of environmental factors like weather, the generation of renewable energy is challenging to accurately guarantee.

Due to the uncertainty of renewable energy, complementary mechanisms such as demand response resources and day-ahead markets have become essential [1]. In Korea, specifically, a renewable energy generation forecasting system has been operational since 2021, with the government offering incentives for the accuracy of renewable generation forecasts. Hence, the imperative for forecasting renewable energy generation has spurred abundant research on models for predicting generation quantities [2,3]. In real world, Virtual Power Plant (VPP) operators are actively engaged in forecasting the aggregated renewable energy generation, and there has been a recent emergence of forecasting service providers utilizing artificial intelligence (AI) models to handle these predictions. Consequently, research has been conducted on data and information trading markets for renewable energy prediction [4-6].

Renewable energy prediction market research often designs optimal allocation problems based on auction mechanisms for pricing data or compensation systems for information provision [7-9]. However, a major drawback in existing literature is that prediction service providers(data brokers) disclose their actual prediction information (probability distribution of generation) when participating in auctions. Providing information about prediction accuracy or confidence levels during auctions, and supplying detailed prediction information after the auction and contract negotiation, is more desirable and practical in the renewable energy prediction market.

Therefore, in this paper, we conduct a pioneering study in the renewable energy prediction market where data brokers bid on the error distribution of predictions. Based solely on this information, renewable energy generator select the winner and enter into generation forecasting contract. We design a dominant strategy incentive mechanism using a penalty scheme based on realized prediction errors.
Methods:Consider a data market in Figure 1 consists of an information buyer and N data brokers (information sellers,i=1,…,N). The buyer wants to predict a future variable (stock price / semi-conductor market price) which directly influence the future profit. Each seller possesses own data asset and a prediction AI model so that sellers' forecasting performances are heterogeneous (Independence). In the market, sellers bid on the error distribution of prediction models, which signifies the accuracy of predictions.
The variable $X_i \in \Omega$, representing the error of each seller's model, is a random variable at the current moment and will be realized in the future. Then all the $\boldsymbol{X_i}$'s are independent. Assume there is a type space $\boldsymbol{\Theta}$ such that the distribution of $\boldsymbol{X_i}$ can be parameterized by a K-dimensional vector $\boldsymbol{\theta_i}=(\boldsymbol{\theta_i^1},\dots,\boldsymbol{\theta_i^k})\in\boldsymbol{\Theta}$ (i's type). Let $\boldsymbol{z}=(\boldsymbol{z_1},\dots,\boldsymbol{z_n})$ be an outcome vector and $z_i=1$ only if player i is a winner.

Market mechanism is defined in Figure 2.
The distribution of $\boldsymbol{X_i}$ is determined by reported type. The penalty function and the buyer's penalty

function are only affected on the realization.
Results:The main results are described in Figure 3.
In Theorem 1, we proved our proposed mechanism is dominant strategy incentive compatible with Assumption 1.
The proof of our main results is described in Figure 4.
Conclusions:In this study, we aimed to address the unrealistic assumption common in existing literature on renewable energy prediction markets, where data brokers preemptively bid on their actual predictions before being allocated and compensated in the market. We resolved this issue by having data brokers bid on the prediction error distribution of AI models representing the confidence level for their predictions. Furthermore, we designed a penalty scheme based on prediction errors, not just information prices, creating a market where all data brokers find it a dominant strategy to bid on their actual error distribution.
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Keywords: Renewable forecasting, forecasting market, market design, data broker, information market, data market

Figure 1. Renewable energy forecasting market overview

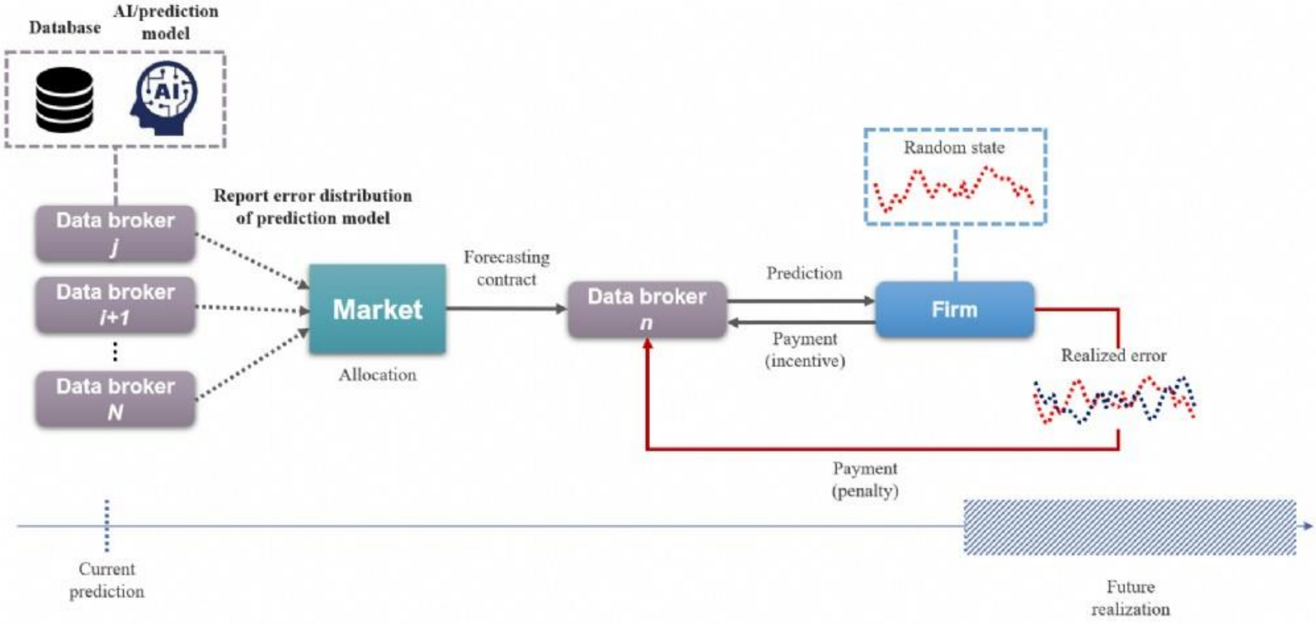

Figure 1. Renewable energy forecasting market overview

Figure 2. Market mechanism definition

- **Definition**

① Social choice function : $f: \Theta^N \rightarrow Z$

② Reported bids : $\hat{\theta} = (\hat{\theta}_1, \dots, \hat{\theta}_N)$

③ Distribution of X_i determined by θ_i : Left-folded error distribution $f_i(X_i)$ and corresponding $F_i(X_i)$, $\Omega = (-\infty, 0]$

- Distribution of absolute error
- $X_i \uparrow \rightarrow Prediction\ Accuracy \uparrow$

④ Realization : $\bar{X} = (\bar{X}_1, \dots, \bar{X}_N) \in \Omega^N$

⑤ Payment made by auctioneer to player i before the realization : $p_i: \Theta \rightarrow \mathbb{R}$

⑥ Penalty made by player i to the auctioneer after the realization : $q_i: \Theta \times \Omega^N \rightarrow \mathbb{R}$

⑦ Buyer's profit function (obtained by accurate forecasting) : $\pi: \Omega \rightarrow \mathbb{R}$

Figure 2. Market mechanism definition

Figure 3. Main results

- Buyer wants to maximize his profit
  - $\max E[\pi(X_i)] = \int \pi(x)\, d\widehat{F}_i(x)$
- Winner: n, marginal loser: $\tilde{n}$
  - $n \in \underset{i}{arg\ max} \int \pi(x)\, d\widehat{F}_i(x)$
  - $\tilde{n} \in \underset{i \neq n}{arg\ max} \int \pi(x)\, d\widehat{F}_i(x)$

- **Assumption 1 (Monotonic increasing)**
  - *The buyer's profit function π satisfies $\pi \geq 0, \pi(x) \leq \pi(y), \forall x \leq y$*

- **Theorem 1**
  - *For any π satisfies Assumption 1, the following mechanism is dominant strategy incentive compatible:*

$$p_n = \pi(0), \qquad q_n = \alpha[\pi(0) - \pi(X_n)], \qquad \alpha = \frac{\pi(0)}{\pi(0) - \int \pi(x) d\hat{F}_{\tilde{n}}(x)}$$

Figure 3. Main results

Figure 4. Proof of main results

- **Proof of Theorem 1**
  - We want to show that truth-telling is a dominant strategy equilibrium
  - Assumption 1 ensures that the penalty rate $\alpha \geq 1$
  - Fix a player i and suppose he is the winner with bid $\hat{\theta}_i = \theta_i$ (marginal loser is $\tilde{n}$)
  - $\mathbb{E}[U_i] = \pi(0) - \mathbb{E}\left[\alpha[\pi(0) - \pi(X_i)]\right]$

    $= \pi(0) - \alpha\left[\pi(0) - \int \pi(x)\, dF_i(x)\right]$

    $= \alpha\left[\int \pi(x)\, dF_i(x) - \int \pi(x)\, d\hat{F}_{\tilde{n}}(x)\right] \geq 0$
  - Suppose he is a loser with bid $\hat{\theta}_i = \theta_i$. If he changes his bid so that he outbids player n, his expected payoff is
  - $\mathbb{E}[U_i] = \alpha'\left[\int \pi(x)\, dF_i(x) - \int \pi(x)\, d\hat{F}_n(x)\right] \leq 0$ (where $\alpha' = \pi(0)/(\pi(0) - \int \pi(x)\, d\hat{F}_n(x))$)
  - Hence, he has no incentives to deviate

Figure 4. Proof of main results

[Abstract:0525] OP-059 [Accepted:Oral Presentation] [Energy Finance and Trading » Market Design and Regulation]

De-rating factors in regional capacity mechanisms with cross-border participation: the role of asymmetric national non-served energy values

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Overview:Capacity mechanisms (CMs) are regulatory frameworks often implemented to address market failures and ensure the long-term reliability of electricity supply. These mechanisms incentivize electricity generators based on their availability by providing financial rewards for producing electricity when needed and imposing penalties for failing to deliver with the committed supply [1]. In the context of regional markets, these mechanisms can maximize overall efficiency if they allow for the participation of cross-border generators.

When implementing national CMs, it is common to establish a methodology to determine the de-rating factors of the different resources participating in the scheme. The de-rating factors represent the effective contribution of generation resources in meeting adequacy requirements. If the objective is to allow the participation of cross-border resources in the national CM, it is also necessary to compute these de-rating factors to the generators located in the neighboring system. The literature on this topic is scarce.

This is the gap to which this paper aims to contribute. This paper extends the methodology proposed

in [2] to compute de-rating factors to the multi-area case. In addition, we explore how the non-served energy cost established by the countries sharing the common border can influence the results. This exploration is conducted through a comprehensive and stylized case study, shedding light on the potential consequences of the definition of the non-served energy cost on the performance and integration of new resources within CM.
Methods:We propose a four-step methodology based on [2] to compute local and cross-border de-rating factors for new resources. This approach involves comparing the contributions of each new resource to the reliability metric of each area implementing a CM with the contributions obtained in the same area by installing an ideal unit. The methodology can be summarized as follows:

Step 1: We run the dispatch model, including all the new capacities that would participate in CMs, to register the resulting reliability in the system.

Step 2: The installed capacity of one new resource is raised in a small quantity, and we run the model again. We assess the resulting changes in the reliability metric, calculated as the difference between the reliability metrics obtained in this step and the previous one for each area. This process is repeated for each resource participating in the CM. This step allows us to determine each generator's marginal contribution to each area's reliability metric.

Step 3: We determine the marginal contributions an "ideal" generator would have. This ideal generator is assumed to have zero operational costs, a capacity equal to the raised value used in the last step, and a one hundred percent availability rate.

Step 4: The marginal contribution of each new resource is compared with the marginal contributions of the "ideal" generator. The de-rating factor is precisely the ratio between both contributions. The de-rating factors of new resources closer to the "ideal" generator will approach one, while the farther will tend to zero.

Finally, we assess the influence of non-served energy cost on the calculation of de-rating factors through exhaustive simulations, i.e., steps 1 to 4 are repeated.
Results:We applied the previous methodology to a test system featuring two interconnected and fully competitive electricity markets, where Market 1 predominantly exports energy to Market 2.

We use a short-term cost-minimizing optimization model that simulates the behavior of a fully competitive regional spot market. Monte Carlo simulations have been conducted to model the uncertainty in the availability of new units participating in CMs for one year. Consequently, multiple simulation scenarios were solved, one for each availability path generated in the Monte Carlo simulation. In addition, the Expected Energy Not Served has been used as the adequacy metric to set long-term targets in implementing CMs.

As mentioned above, de-rating factors were computed by comparing the expected marginal contributions of new resources with those of "ideal" units for each area. The results highlight that non-served energy costs impact local and cross-border de-rating factors. Moreover, the results show that establishing different non-served energy costs between areas may have implications for the equitable treatment of participants within the CMs and introduces a layer of complexity in ensuring a reliable electricity supply for the whole electricity market.
Conclusions:This paper explores the influence of non-served energy costs on the recognition of de-rating factors for both local and cross-border new capacity resources. Specifically, we show that non-served energy costs have the potential to alter both local and cross-border de-rating factors within the CM. Additionally, our study provides evidence that the magnitude of these changes depends on the cost of energy not served in each electricity market. Consequently, our results indicate the necessity of incorporating considerations of differences in non-served energy costs between areas into the methodology used to calculate de-rating factors. This inclusion is crucial for ensuring fair competition within the framework of CMs with cross-border participation.
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Towards a resilient and cost-competitive global clean hydrogen market: future is green

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Overview:Limiting global warming to 1.5°C requires climate neutrality globally by 20501. The existing literature on decarbonisation of energy and industrial activities highlights the central role of electrification of end uses and large-scale renewable development to reach climate goals [2-7]. More sectoral studies on electricity systems [7-12] and the industry [13-16] and transport [17-19] sectors show that clean hydrogen and its derivative molecules can address the limits of electrification in hard-to-abate sectors, where electrification is difficult or impossible. The development of clean hydrogen entails both decarbonising the current production (above 90 MtH2[20]) and unlocking new end-uses such as clean steel production, industrial heating and the supply of synthetic molecules. Large uncertainties remain on which pathway the global value chain will follow, including technology options, production and consumption locations and trade patterns [21].
If the key issues of economic competitiveness of specific supply routes [22-25], transport options [26,27] and potential end-uses [28-31] have already been addressed by the literature, the focus is usually national and regional, or dedicated to a specific sector. The present paper aims at contributing to the literature by shedding light on the future clean hydrogen supply mix, associated trade routes, export revenues, investment needs and other economic and policy implications in the climate-neutrality context.
Methods:This study combines two modelling approaches: a mixed top-down and bottom-up hydrogen demand estimation model and a bottom-up global hydrogen trade optimisation model. Hydrogen demand estimation is based on the energy demand for different sectors, chosen in a top-down manner [32]. Using the final energy demand values in each sector, we identify the proportion of the demand that can be met by hydrogen. To do so, we first identify the energy and feedstock demands on a sector-by-sector basis, the part of the electrifiable demand and the demand that cannot be met by electrification or is very costly and difficult to electrify (such as feedstock demand, high temperature industrial heating and very long-haul heavy road transport). The demand that cannot be electrified is assumed to be met by hydrogen, synthetic fuels produced from hydrogen and bio-energies. Based on resource availability for bio-energies, the part of hydrogen and hydrogen-based synthetic fuels in each sector is identified. This assessment considers three types of calculation: energy replacement, feedstock replacement and process shift.
The hydrogen supply and delivery chain optimisation model (HyPE – Hydrogen Pathway Explorer) identifies the least-cost global hydrogen production mix and trade combination. The model features (i) clean hydrogen production via electrolysis based on wind and solar power or biomass gasification with CCS (green hydrogen), natural gas reformation with CCS (blue hydrogen) and pyrolysis of natural gas (turquoise hydrogen), (ii) technologies for the conversion, reconversion and transport of clean hydrogen and its derivative commodities, (iii) local specificities for hydrogen supply (e.g., weather conditions, financial costs, land availability), and (iv) a feasible network of trade routes to connect demand to potential supply centres. Hydrogen supply potentials and costs (hydrogen supply curves) were calculated for the entire globe within cells of 0.5° to 2° spatial resolution. It finds cost-efficient pathways to balance point-to-point hydrogen demand and supply and optimise transport between different regions over the period from 2025 to 2050. As such, it is also a global hydrogen trade optimisation model. By representing the competition between hydrogen production technologies, production locations, the costs incurred for transport and logistics, and other

abatement costs (i.e., CO2 and methane emission), the model finds cost-optimal investments in production technologies, use of resources, domestic supply and hydrogen trade flows [33].

Results:Following our analysis, achieving net-zero GHG emissions by 2050 entails the development of a 170 MtH2eq clean hydrogen market by 2030, growing to nearly 600 MtH2eq by 2050 (Figure 1). The modelling results show that green hydrogen from wind and solar power is the key clean hydrogen supply option (Figure 2), with a supply share growing from two thirds in 2030 (115 MtH2eq) to 85% in 2050 (more than 500 MtH2eq. The share of blue hydrogen remains relatively low (33% in 2030 and 15% in 2050) but appears as a component to build up the global hydrogen economy in the ramp-up phase. Its global production peaks in 2040 at almost 125 MtH2eq and it decreases to 92 MtH2eq by 2050.

Long-distance trade represents 20% of the clean hydrogen demand through the period between 2030 and 2050 (Figure 3). While China is the biggest green hydrogen producer over the whole outlook period, its huge demand requires 13 MtH2eq of imports in 2030 and 10.5 MtH2eq in 2050. Europe is the largest importer in 2050 (41 MtH2eq, 43% of its demand), and the second one in 2030 (10 MtH2eq) after China. Japan and Korea have the highest import dependency with 7.5 MtH2eq of imports in 2030 and 26 MtH2eq in 2050 (respectively 87% and 91% of their demand). While in 2030 India is nearly self-sufficient, by 2050, it becomes the third largest importer with 22 MtH2eq of imports (nearly a third of its demand). On the exports side, the Middle East is the largest exporter in 2030 thanks to its significant blue hydrogen potential, high solar irradiation and existing export infrastructure. Its exports account for 13 MtH2eq in 2030, remaining at the same level in 2050. North Africa, the second largest exporter in 2030 (7.5 MtH2eq), becomes the biggest clean hydrogen exporter by 2050 (44 MtH2eq). Leveraging on its high land availability and significant solar and wind potentials, this region exports 74% of its production in the long run. The Middle East and North Africa are ideally located between Europe and India, becoming the main providers of clean hydrogen to these two import hubs. North America becomes the second largest exporter in 2050 (24 MtH2eq) thanks to its existing natural gas reserves, export infrastructure and abundant renewable endowments. Using its Pacific and Atlantic export routes, it can serve diverse export destinations: Japan, Korea, China, and Europe.

The hydrogen market grows substantially from current US$ 160 billion market to more than US$ 640 billion in 2030 and US$ 1.4 trillion in 2050. The potential is largely located in Asia: the continent captures 55% of the value in 2030, driven by the large demand of China (the world's largest producer) and India. The largest exporters capture the biggest parts of the global clean hydrogen market revenues in US$ terms as well. While in the short run Middle East captures nearly half of the global trade market (US$ 83 billion), by 2050 Africa becomes the key winner of the clean hydrogen market, with export revenues exceeding 40% of the global market revenues (more than US$ 120 billion). Africa is followed by North America and Australia as two other key hydrogen exporters in the long run (Figure 4).

Conclusions:The findings of this study highlight the undisputable role of green hydrogen in the clean hydrogen value chain. While currently blue hydrogen seems a more viable production option at first from an economic perspective, it is associated with residual and indirect GHG emissions [33,34]. Moreover, leveraging economies of scale from the massive deployment of electrolyzers and wind and solar power, green hydrogen becomes in the long run not only more sustainable, but also more cost competitive. On the opposite, blue hydrogen has a limited window of opportunity, with environmental requirements that only tighten over time and increasing cost competitivity of green hydrogen. Its supply peaks in 2040 (at 125 MtH2eq) as the GHG-neutrality target is to be achieved in the second half of the century.

Global trade can spur economic development in the global South. Our results show that developing countries can capture almost 70% of the export revenues in 2050, if international efforts to channel financial resources and share knowledge are met. Moreover, global trade can become a key factor for cost reduction unlocking significant welfare gains by maximising the use of the best resources [35-37]. A sensitivity analysis with limited global trade reveals that reducing global trade to one fourth of the trade level in our central scenario can entail US$350 billion/year of extra costs in 2050, 25% of global market value. Imports are particularly crucial for land-constrained regions, especially Japan and Korea. Without imports, the residual demand can only be met either at a significantly higher domestic production cost, or by using fossil-based technologies. The modelling results suggest facilitation of free trade and proactive investments at least in the most robust trade routes, to keep in track with the energy transition at the lowest possible cost.

Finally, clean hydrogen is currently more expensive to produce and transport than its conventional counterparts [38]. According to our modelling results, the break-even point for clean hydrogen supply cannot be reached before 2035 (Figure 5). This is similar for ammonia (breakeven between 2030 and 2035), methanol (breakeven between 2040 and 2045) and e-kerosene (breakeven between 2045 and 2050). While green hydrogen is set to be cheaper in the long run, unlocking the economies of scale requires active financial/economic policy support at least until the projected breakeven dates for green hydrogen supply options.

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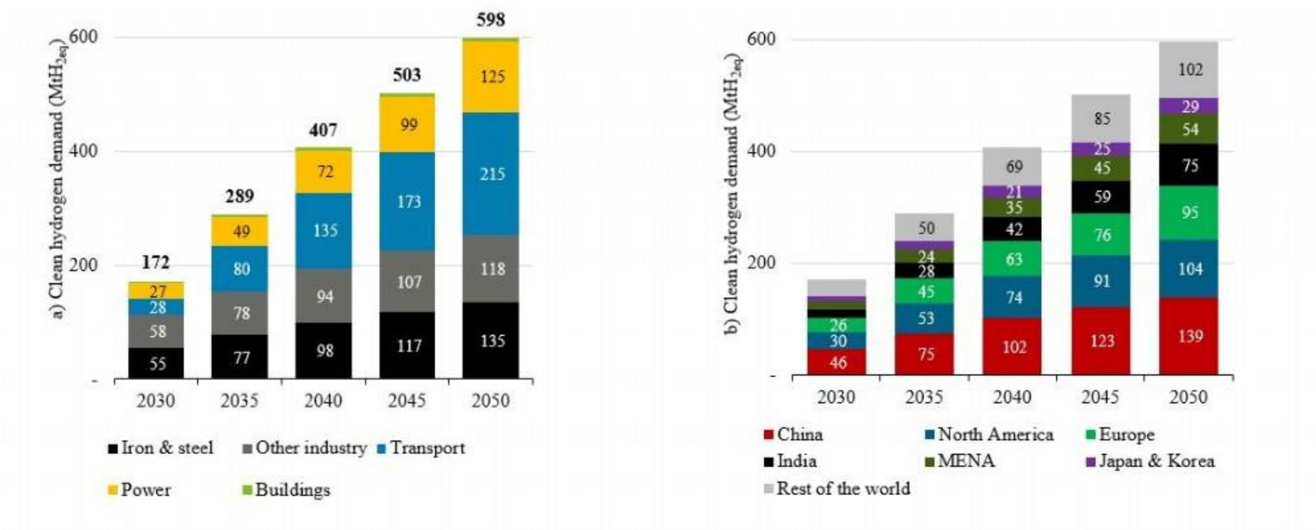
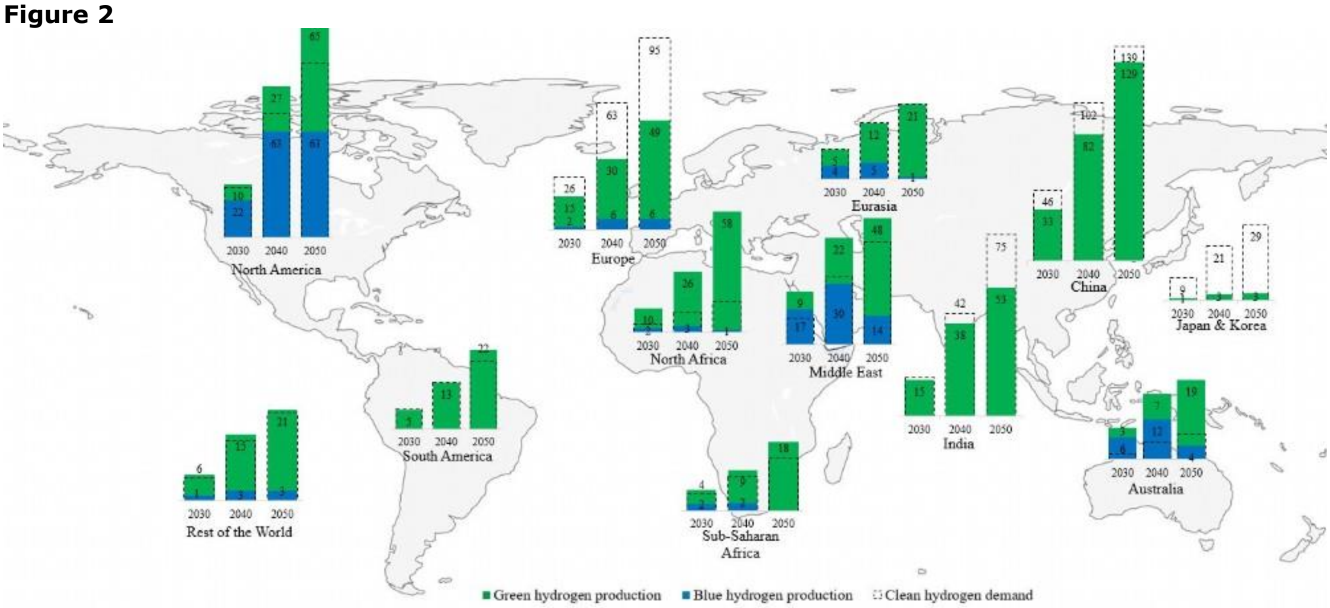
Keywords: Hydrogen, Green hydrogen, Blue hydrogen, Global trade, Energy markets, Modelling

Figure 1



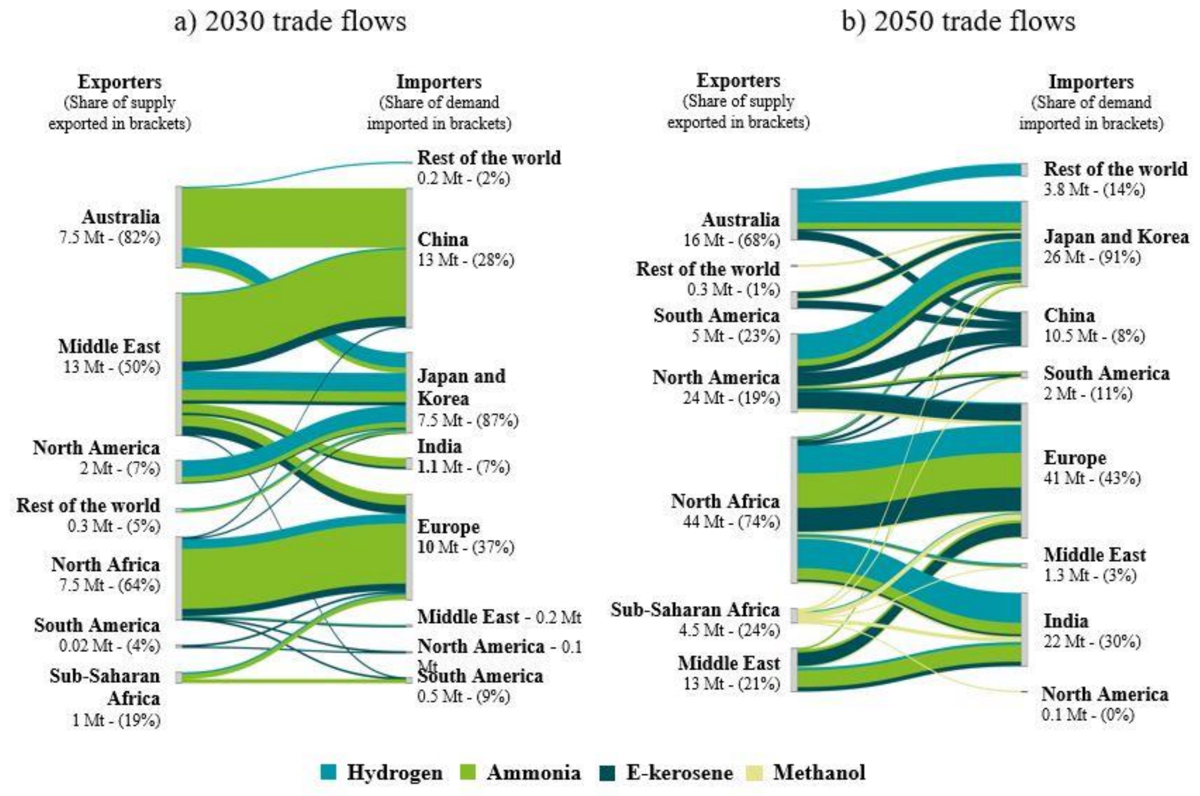
Global clean hydrogen demand evolution by (a) end-use sector and (b) region between 2030 and 2050.

Figure 2



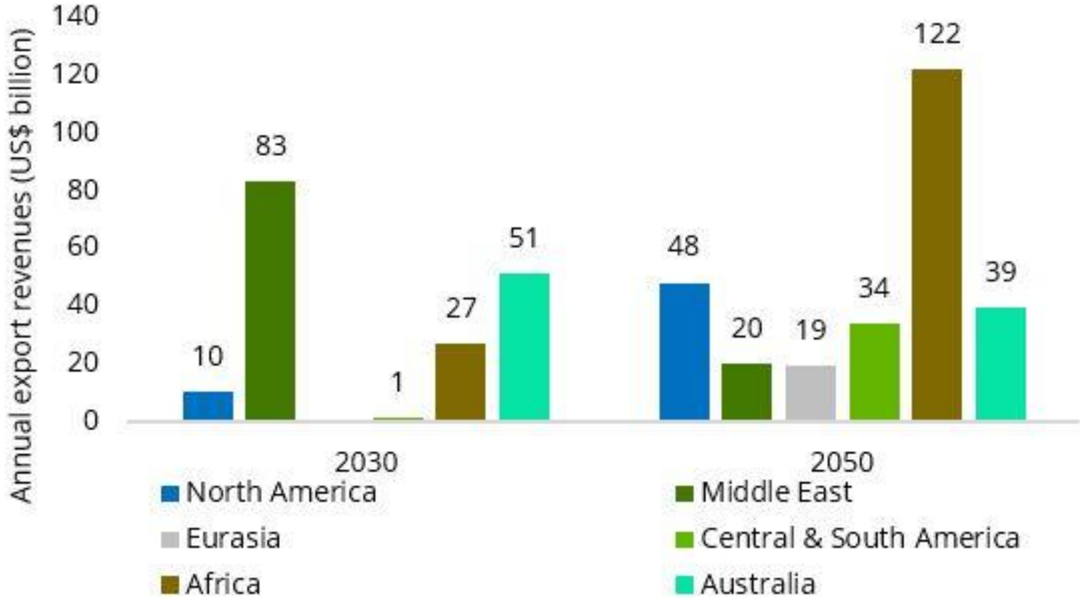
Global clean hydrogen supply and demand by aggregated region in 2030, 2040 and 2050. The green colour represents renewable hydrogen production based on electrolysis using solar and wind power, and the blue colour represents low-carbon hydrogen produced from natural gas reformation with carbon capture and storage. The dashed lines represent the clean hydrogen demand for each of the stated years, for each region. The dashed lines in some cases exceed the stacked green and blue histograms, which means hydrogen imports are required to complement the domestic demand values. Dashed lines below the green and blue histograms mean that clean hydrogen supply is higher than domestic demand and the region exports part of its clean hydrogen to other regions.

Figure 3



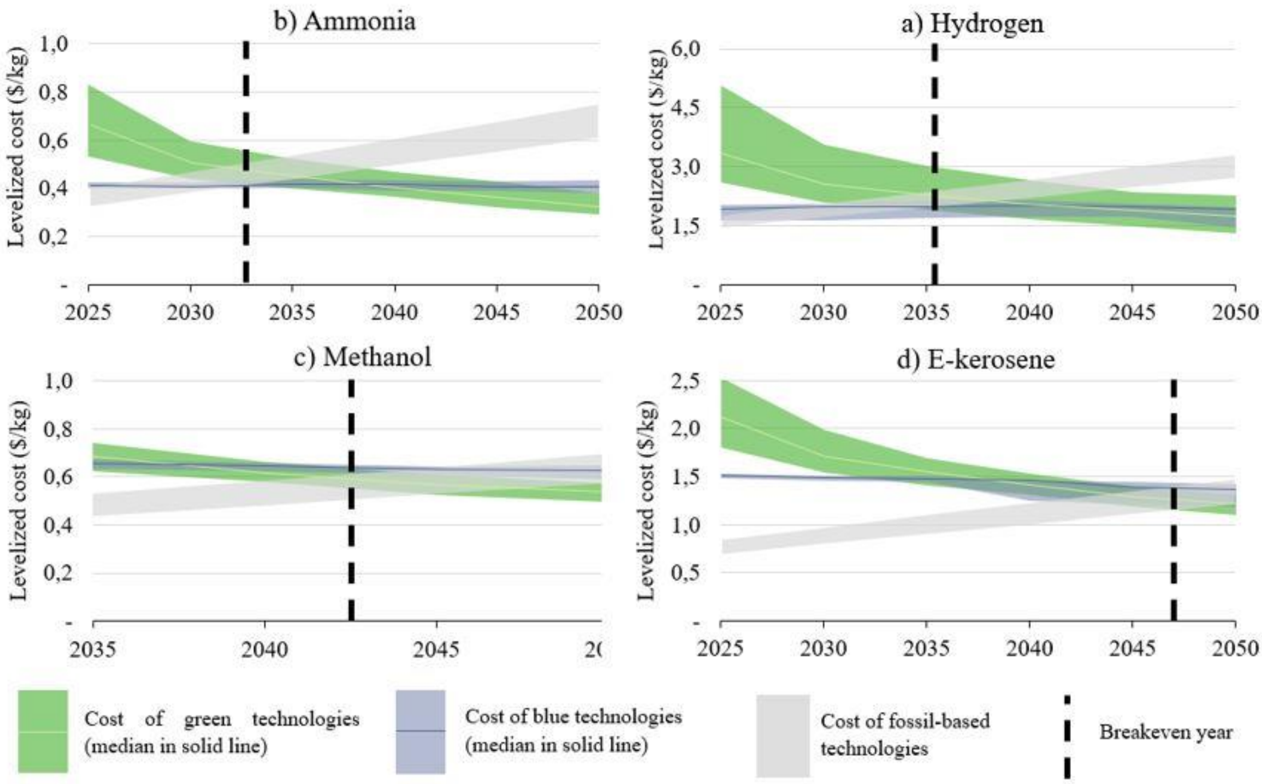
Global trade flows of clean hydrogen and derivative molecules for the years (a) 2030 and (b) 2050. The left side of each flow diagram shows the exporting region, its export quantity (in million tons of hydrogen equivalent) and the share of exports in its overall hydrogen production. The right side of each diagram shows the importing region, the imported quantity in hydrogen equivalent terms and the share of imports in meeting its overall demand. The colours of the flow show the traded molecule: turquoise for hydrogen, light green for ammonia, dark green for e-kerosene and yellow for methanol.

Figure 4



Global clean hydrogen export revenues by region in 2030 and 2050.

Figure 5



Levelised production costs of green, blue and grey (a) hydrogen, (b) ammonia, (c) methanol and (d) e-kerosene. The stacked areas show the evolution of cheapest and most expensive levelised costs considering the central 90% of the data, while the lines in each stacked area show the evolution of the median of hydrogen and its derivatives levelised production costs over the outlook period.

[Abstract:0101] OP-061 [Accepted:Oral Presentation] [Hydrogen » Markets and Prices]

How can the European Hard-to-Abate Industries navigate decarbonisation? Analysing the Conditions for the Profitable Adoption of Clean Hydrogen

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Overview:Natural gas, oil, and coal have historically dominated the energy consumption in Europe and worldwide. Climate change, however, has pushed the countries to reconsider their status quo and high reliance on fossil fuels – the culprit of most greenhouse gas emissions. Setting up the decarbonization targets, countries have committed to reduce their use of fossil energy substituting it with "clean" alternatives, such as renewable energy (RE) and RE-based energy carriers. However, while the increasing number of countries, including the members of the European Union (EU), makes plans on the clean energy production, it becomes clear that to accomplish the goals, large-scale industrial energy consumers will have to adopt and invest in new technologies to use clean fuels in their high energy-intensity production processes.
The so-called hard-to-abate sectors, including petrochemicals, metal processing, cement, and heavy industries, explore a variety of scalable and affordable solutions for substituting fossil fuels. An option that has drawn particular attention in the recent years is clean or low-emission hydrogen (H2). A growing body of technical research suggests that H2-based technologies may replace the fossil-based ones. But, while studies investigating energy efficiency are plenty, the discussion of the market conditions needed for the adoption of H2 to be profitable remains scarce.
The purpose of our work is to offer a comprehensive framework for the analysis of decarbonisation, more specifically, adoption of clean technologies strategies for hard-to-abate energy-intensive industries. We aim at developing production analysis model suitable for a consistent analysis of a wide range of factors influencing the profitability and therewith, economic sustainability of clean energy solutions. The model results and insights shall be useful for the industry, financial organizations, and policymakers trying to balance the risks and uncertainties related to the hydrogen investments. To that end, the theoretical investigations of the proposed model are complemented by numerical simulations, generating the clean energy, namely H2, adoption projections and helping develop the intuition about the key driving forces of the energy transition.
With the supply chains and market-mechanisms for H2 are still in making, we contribute to the under-researched topic of H2 demand (Oxford Institute for Energy Studies, 2023). The existing literature focuses the inter-fuel substitution and the role of emission constraints, carbon costs, and clean fuel efficiencies in the decarbonisation (Acemoglu et al., 2012; Aleti & Hochman, 2020; Damette et al., 2018; Kim, 2019; Papageorgiou et al., 2013, 2017). Yet, the studies embracing multiple drivers at once with the goal to derive the demand for clean fuels are lacking. Moreover, the energy policy studies often neglect the discussion of the future dynamics paying little attention to the likely non-trivial dynamics in the policy versus technological progress interplay. In this context, contingency plans or investment risks are rarely reviewed letting the individual industry agents developing their own which, in turn, results in a divergence of views and slows the development.
Our work brings together a comprehensive conglomerate of factors to highlight the dynamic nature of the future demand for H2, including carbon policies and fossil fuel costs, which are essential for the adoption of clean energy. In doing so, we want to shed light on the risks for the long-term (non-negative) profitability of industrial consumers dependent on the clean energy costs.
Methods:For our framework, we turn to the classical producer theory expanding the (energy) input choice model by incorporating environmental constraints and costs. Considering a profit-maximizing industrial firm, we adopt a constant elasticity of substitution with diminishing returns production function. In a stylized setup, we analyse how fossil energy with initially lower per unit costs will be

complemented by higher cost but lower-emission H2. We derive the demand for input energy, including H2, but optimizing the profit with respect to the two constraints: a non-negative profit and the emission allowance.
To examine how the demand for hydrogen may change driven by various exogenous parameters, such as fossil fuel prices, CO2 costs, etc., we create a simulation tool informed by the actual data. We use three databases: (a) the OECD Input-Output tables, (b) worldwide trade data, and (c) EU energy balances to select 3 hard-to-abate sectors: Steelmaking, Petrochemicals and Refineries. With the statistics collected on them from the major EU countries, i.e., France, Germany, Italy, Poland, Spain, and we estimate the parameters of the production function to use in our simulation model.
Results:Solving the maximisation problem analytically, we derive the reaction functions for H2 and fossil fuel demand shedding light on the interplay between the profitability and emission constraints, helping us explain further sensitivity of H2 demand to a variety of factors (Fig. 1).
In a nutshell, we learn that whilst the profitability constraint influences the substitution decision making between fossil fuels and clean hydrogen in the early development stage, the emission constraint will put increasing pressure and drive the H2 volumes up in the future. Other notable insights are:
1. Mutatis mutandis clean-price constraint drives a higher willingness to pay for clean hydrogen adoption than the emission allowance.
2. Price of carbon emissions constitute an important factor – and the model represented is sensitive to its changes. Its influence becomes bigger the more is the hydrogen adopted.
3. Pushing the higher capital cost of low-carbon hydrogen to the final clients via increasing the output price seems a viable solution under both constraints. However, it implies several countereffects (especially inflationary pushes) that can negatively affect the overall economic stability.
Conclusions:We aimed at modelling and numerically calculate the adoption drivers of clean hydrogen as well as which combination of them can harm or boost hydrogen adoption within the European hard-to-abate industries. The basic insight is that clean hydrogen adoption is a function of different factors that are not exclusively techno-economical, but also political and environmental, and each one of them is decided by different stakeholders: e.g., companies, academia, institutions. In practical terms, we formulated the idea about the size of the challenge of decarbonising hard-to-abate industries.
Amongst the main lessons learned it that a structured and ordered hydrogen adoption strategy requires a dynamic combination of the two constraints considered. In particular, it has been derived from a firm standpoint that whilst a non-negative profit perspective is essential at the beginning of the hydrogen adoption – or in any case for small-scale volumes – in the long run and towards a large-scale vision is the emission threshold which takes the lead. The non-negative profitability is in any case a fundamental factor as it is a conditio sine qua non required by the shareholders to the companies.
Hence, the environment in which the clean energy transition will happen is indeed dynamic and needs concertation between policymakers and industries. In that way, it will be possible to mitigate market volatility enabling long-term, clean-hydrogen investments.
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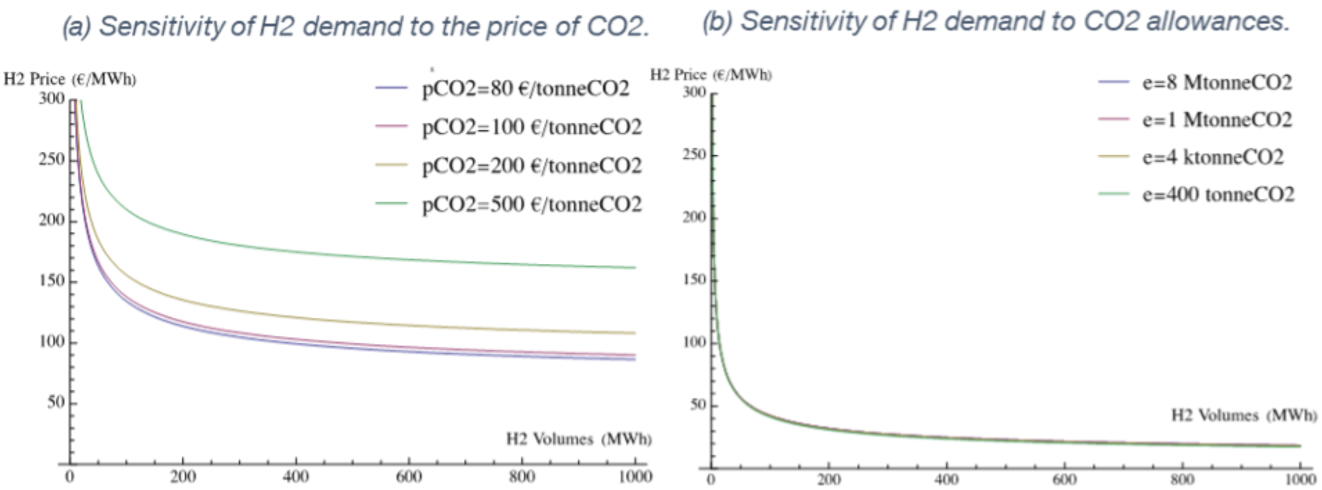
Keywords: Hydrogen, Industries, Europe, Decarbonisation

Figure 1 The Analysis of H2 demand and its sensitivity to various factors.



The image is referred to in the "Results" section. It is a first run of the model taking inspiration from Hard-to-abate European industries, in particular a stylised Steelmaker.

[Page: 62]

[Abstract:0172] OP-062 [Accepted:Oral Presentation] [Hydrogen » Markets and Prices]

Navigating hydrogen pathways: comparision of life cycle emissions and costs for hydrogen production and import pathways to Germany

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Overview:Hydrogen might play a significant role in upcoming low-carbon-emission energy systems. Nations like Germany, characterized by high energy demand and restricted hydrogen production capacities, are likely to import hydrogen from countries abundant in low-emission energy sources. This prospect could potentially trigger the development of an international hydrogen economy. Nevertheless, the precise framework and scale of this hydrogen economy remain uncertain, presenting diverse conceivable production and import pathways. Existing reseach has already explored global production and supply costs (e.g., Moritz et al., 2023) and their associated uncertainty factors (e.g., Öberg et al., 2022). Kulawik, Kockel and Praktiknjo (2023) and Kockel et al. (2024, under review) analyse the comprehensive environmental impact of these different hydrogen production and import pathways to Germany and to what extent the results are influenced by regional differences and currently uncertain parameters.
However, a critical aspect that has yet to be explored is the direct comparison between the most cost-efficient routes and those with the lowest greenhouse gas (GHG) emissions. In addition to the comparison, one way of combining the values is to include the external costs associated with greenhouse gas emissions in the production and supply costs. Therefore, our research aims to answer the question: What are the comprehensive production and supply costs of hydrogen when considering externalities from GHG emissions?
Methods:Building upon the findings of our previous research in Kulawik, Kockel, Praktiknjo (2023) and Kockel et al. (2024, under review), we expand the investigation by incorporating life cycle costs into our model for assessing diverse hydrogen production and supply pathways. This integration allows us to simultaneously evaluate both the environmental impact and the associated costs of these pathways, considering identical uncertainty parameters. Our research centers on two types of hydrogen production: (1) green hydrogen derived from renewable sources through electrolysis using renewable electricity and (2) blue hydrogen produced by implementing the carbon capture and storage (CCS) process after a more carbon-intense production phase, either directly through methane steam reforming with natural gas or indirectly through electrolysis using electricity from fossil fuels. For longer transportation distances, it can be economically feasible to liquefy hydrogen or convert it into derivatives. However, high uncertainties are attached to this cost as some of the technologies are not yet fully developed and the cost of the energy-intensive (re-)conversion processes depends on volatile energy prices (Ortiz Cebolla et al., 2022). Therefore, we assess different transportation methods for hydrogen: (1) in gaseous form via pipelines and via ships in the forms of (2) liquid hydrogen (LH2), (3) in its derivate form ammonia (NH3), or (4) with Liquid Organic Hydrogen Carriers (LOHC) as storage medium. For the different transportation methods, the conversion and reconversion steps for the different hydrogen forms, derivates or carriers are taken under consideration as well. Given the abundance of uncertainty, particularly for routes that are still in the developmental stage, our research carefully considers the diverse parameters such as different efficiencies as outlined in Figure 1 (see Appendix).
The outcomes of our model provide insights into both GHG emissions and costs associated with each production and supply pathway. To integrate these results effectively, we explore different carbon pricing mechanisms to establish a comprehensive value for hydrogen costs, encompassing the externalities of GHG emissions.
Results:The initial results of our study highlight the critical impact of employing distinct electricity mixes on greenhouse gas (GHG) emissions, particularly within ancillary processes like conversion and reconversion. It becomes clear that the emissions associated with these ancillary processes must be considered when determining the overall GHG emissions of hydrogen. To present a more realistic portrayal of costs, incorporating the externalities we connect the results of GHG emissions with costs through the application of CO2 prices. This integrated approach enables a comprehensive understanding of both environmental impact and economic considerations, contributing to a more accurate assessment of the genuine costs associated with different hydrogen production and supply pathways.
Conclusions:In conclusion, our integrated approach presents a thorough analysis that combines a life cycle assessment with the life cycle costs of hydrogen production and supply routes. With this, our research aims to provide insights for decision-makers involved in developing environmentally and economically sustainable strategies for hydrogen import pathways. In the context of the ongoing deliberations on "green hydrogen" regulations for example within the European Union, the comprehenisve GHG emissions and associated costs become particularly significant. Thus, this analysis sheds light on the effectiveness of existing regulatory frameworks in promoting environmentally sustainable hydrogen pathways from a comprehensive point of view. By evaluating possibilities to align between current carbon pricing mechanisms and the comprehensive GHG emissions over a life cycle, our research might contribute to refining regulations to better reflect and address the environmental impact of hydrogen production. These findings may add a layer of precision to the ongoing discussions surrounding the definition and regulation of "green hydrogen," fostering a more informed and effective approach to sustainable hydrogen strategies.
References:Kockel, C., Kulawik, J., Wohlleben, D., Praktiknjo, A. (2024). Which way to choose? A

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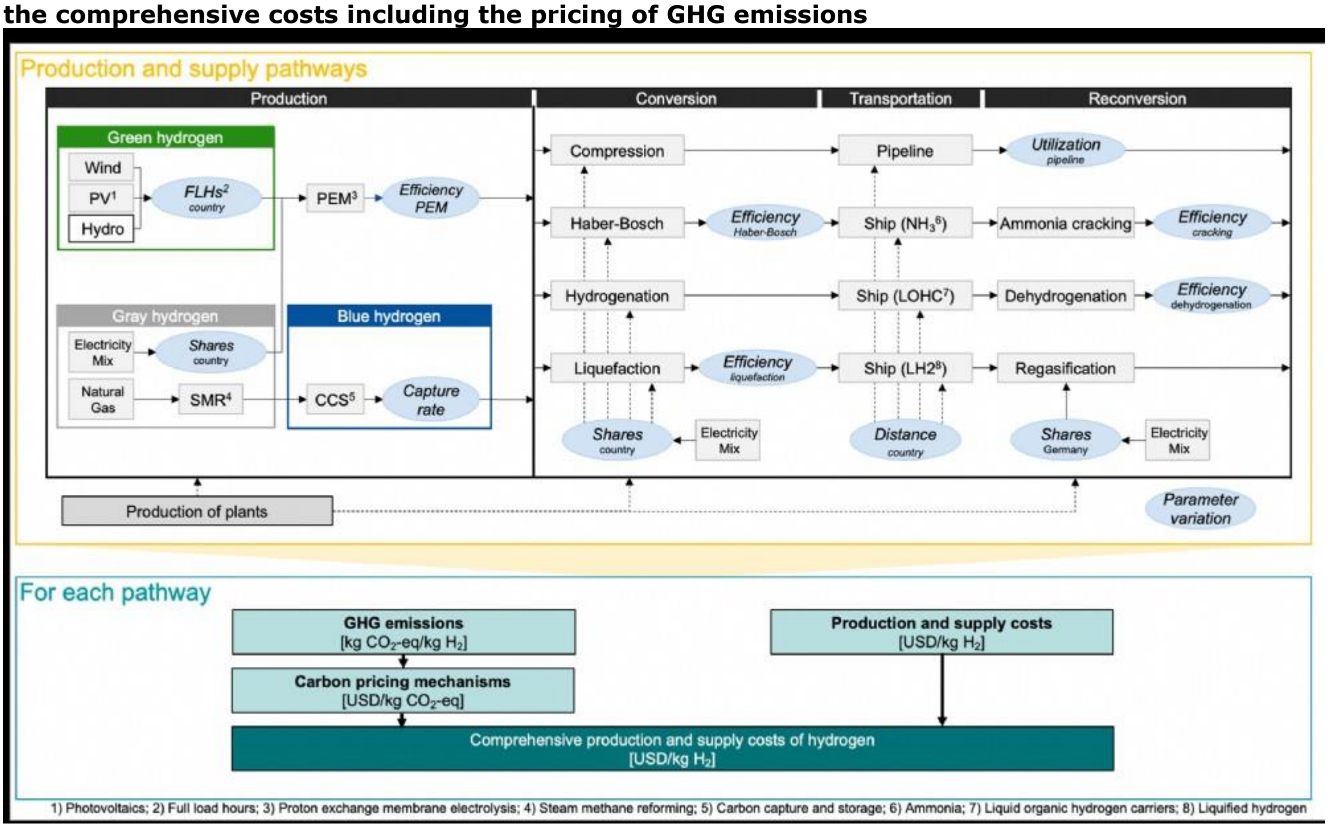
Keywords: Hydrogen Import, Life Cycle Assessment, Global Warming Potential, Life Cycle Costs, Carbon Pricing, Emissions

Figure 1: Overview of considered supply and production pathways and the calculation of the comprehensive costs including the pricing of GHG emissions



[Abstract:0210] OP-063 [Accepted:Oral Presentation] [Hydrogen » Markets and Prices]

Price scenarios and color distribution of future European hydrogen supply

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[2]Volue Insight

Overview:Hydrogen is seen as a key factor to decarbonize energy supply in Europe. Next to green hydrogen produced out of renewable electricity production, blue and turquoise hydrogen produced out of natural gas, pink hydrogen out of nuclear energy and imported green ammonia from outside the European Union will play also an important role. This diversification will be necessary, since the amounts of green hydrogen produced within the EU will not be sufficient to meet the hydrogen demand of the decarbonized demanding sectors.
Methods:Based on the technological properties and investment costs of the individual hydrogen production processes an expansion scenario until 2050 based on different literature sources was developed, which contains the installed generation capacities. Subsequently, the costs of the technologies and hydrogen sources are considered. Based on the results of the marginal costs, a scenario of the hydrogen demand coverage was developed.

A scenario based on a cost optimization model for the coverage of the hydrogen demand until the year 2050 was developed for the German market as example in order to determine the composition of the technologies and hydrogen sources involved in the coverage of the demand in the respective years.

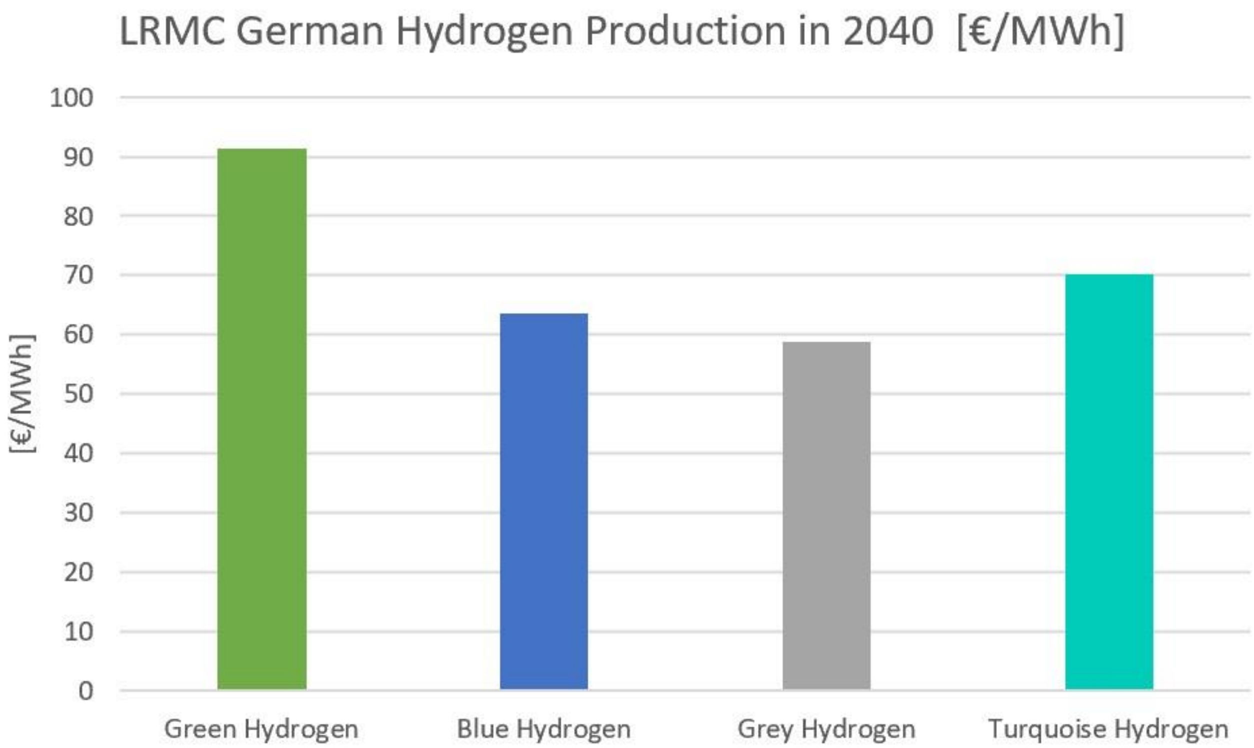
Since green hydrogen production is depending on renewable energy production which is to a large extent weather dependent, also different historic weather years have been investigated in order to study weather-dependent variations in green hydrogen production.
These calculations were conducted in yearly resolution for the years 2025 to 2050 with assumptions and different scenarios for hydrogen demand, technological progress and development especially regarding production efficiency grades as well as investment costs and their development over the years. Also different price scenarios were investigated: Price scenarios for electricity prices in order to calculate short-run marginal costs for green hydrogen, gas and EUA-prices for the calculation of production costs of grey, blue and turquoise hydrogen. Investment cost scenarios for the different technologies were used to calculate long-run marginal costs for the different technologies.
Results:The results show that, depending on the assumed weather scenario, around 20-40 % of the hydrogen demand can be covered by green hydrogen produced in Germany. The remaining demand is initially predominantly covered by blue hydrogen. From around 2040, the green and blue hydrogen will be also supplemented by small amounts of turquoise hydrogen, before starting in 2043 the blue and turquoise hydrogen are gradually replaced by imported green ammonia.
Hydrogen short-run marginal costs exemplary for 2040 show lowest price levels for green hydrogen production with around 45 €/MWh, since it mostly runs with low electricity prices, but if investment and fixed costs are included, blue and turquoise hydrogen have a cost advantage of around 20-30 €/MWh, showing levels of 60-70 €/MWh while electrolysers show levels of around 90 €/MWh. This is caused by the fact that electrolysers for green hydrogen are able to reach only 3000 to 4000 hours a year, while the production of of blue and turquoise hydrogen is independent from green power offering and could reach up to 8000 hours, so fixed costs are distributed over more production hours. Different sensitivity studies for assumptions are presented. However, green hydrogen prices are mostly dependent on electricity prices while blue and turquiose hydrogen are more dependent on natural gas prices and deposit costs.
Conclusions:The supply of green hydrogen produced within the European Union will not be sufficient to meet the demand potential including the need for decarbonising the relevant sectors industry, traffic and buildings heat demand. Significant amounts of blue and turquiose hydrogen as well as imported green ammonia will be necessary. Countries with significant nuclear capacities would also have the option to produce in addition pink hydrogen which is under EU regulation equal to green hydrogen.

Expected price levels of hydrogen supply show significant higher price levels than current natural gas prices, their levels will be dependent on future production costs and costs of ammonia imports.

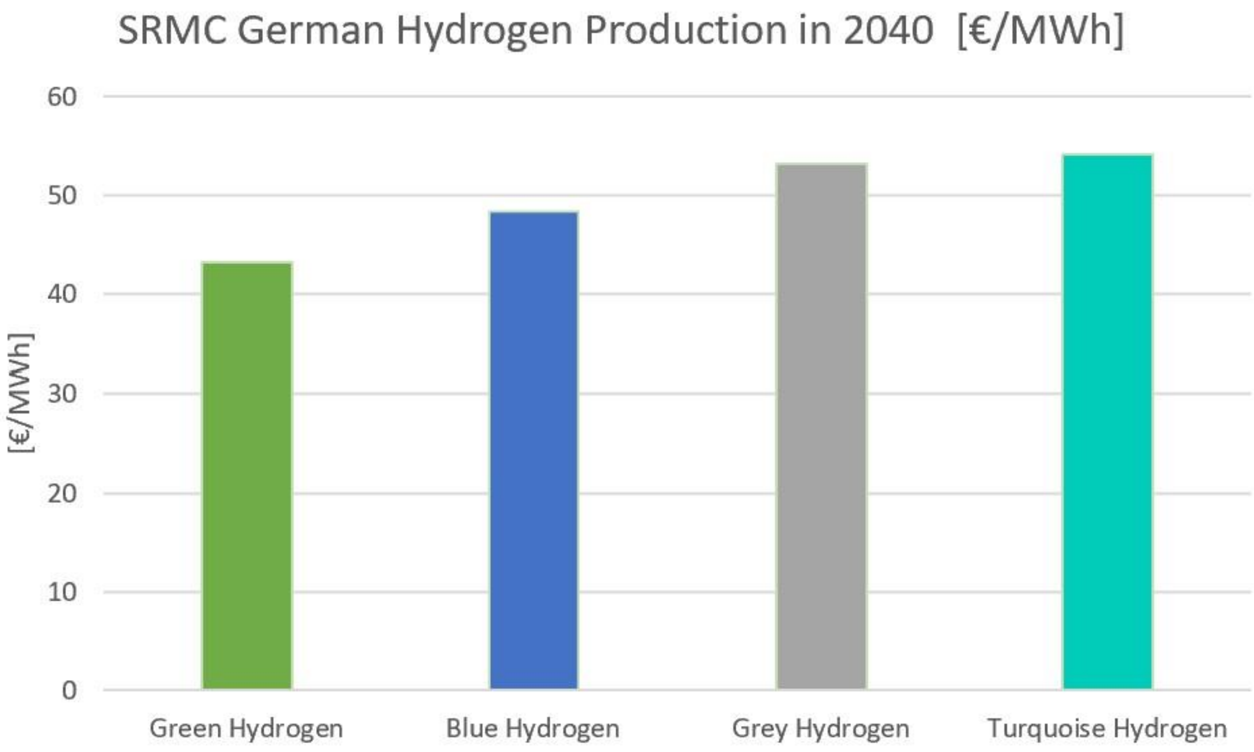
References: -Wasserstoffnachfragepotentiale bis zum Jahr 2050 in Deutschland und der Europäischen Union, Schlichtmann et al., 2022
-Entwicklung einer Angebotskurve zur Deckung der deutschen Wasserstoffnachfrage bis 2050

Keywords: green hydrogen, blue hydrogen, green ammonia, weather dependency, hydrogen prices

Calculated Long-Run Marginal costs of different hydrogen sources in Germany in 2040



Calculated Short-Run Marginal costs of different hydrogen sources in Germany in 2040



AuthorToEditor: Hi. Even if I am member of the IEAA for more than ten years, it is the first time that I send an abstract for an IAEE conference. So please apologize and indulge in case that something is not equivalent to the usual standards.The abstract reflects the current state of research, however, more research is planned to take place until the conference, so additional interesting results might be also presented. Best regards Konstantin Lenz

[Page: 64]

[Abstract:0274] OP-064 [Accepted:Oral Presentation] [Hydrogen » Markets and Prices]

Green hydrogen market development and water issues

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Overview:Following the recent trend of interest in hydrogen, there is a growing belief that green and low-carbon hydrogen will play a critical role in the transition to a zero-carbon economy. This is evidenced by the breadth and depth of hydrogen strategies and roadmaps that have emerged around the world in the last years [1–2]. The goals of a new clean hydrogen sector go far beyond decarbonisation. Clean hydrogen offers the opportunity to develop new supply chains, jobs and innovation, and to radically reshape the global economy and the geopolitics of the energy sector more generally. For countries without fossil fuel resources, hydrogen could reduce their dependence on imports or even turn them into energy exporters. For countries that are rich in fossil fuels, hydrogen may be able to be used as part of a just transition to a more sustainable future. Some researchers argue that the growth of green hydrogen within the global economy could lead to such geoeconomic and geopolitical changes, in which new scenarios and interdependencies will be shaped [3,4,5]. According to IRENA [6], green hydrogen will cover 12% of global energy consumption by

2050. This will be due to targeted investments in the sector that will increase economic competitiveness and change the current hydrocarbon-based relationships. But one issue that is at the centre of the debate concerns water resources. Researchers from various scientific fields are comparing and assessing the effect of green hydrogen on the global water resource. The key question is: will there be enough water to meet our future demand for green hydrogen? Various international bodies envisage different predictions. The issue was also discussed at COP 28, where IRENA and Bluerisk launched a document [7], which provides tailored recommendations to guide policymakers and industry towards more water-efficient practices. This includes conducting thorough water risk assessments and setting up stringent water use regulations, to ensure sustainable growth in the hydrogen industry while preserving scarce and shared water resources and minimising disruptions that could arise from climate risks or competition for water use. In addition, representatives from around the world have come together to sign a joint agreement [8] to address the pressing issue of climate change and to codify the world's common understanding of renewable hydrogen as a potential solution for a net zero future. Regarding the water issu, they state that sustainable water management practices should be implemented in cooperation with the local communities.
Methods:This study is the result of a desk research in which we analysed research articles, official documents from national and international organisations, as well as magazine and newspaper articles. This is the first step of a research activity we are undertaking to understand the spillover effects of the development and deployment of green hydrogen on natural resources, such as fresh water, and how these might affect the economic and social conditions, particularly of local communities.
Results:Some scenarios can be foreseen from the literature and reports by various international bodies. Many scholars agree on the low impact of green hydrogen production on water resources. For instance, a research conducted by Newborough & Cooley [9] stated that if all current fossil fuels used were converted to green hydrogen, the need for water for electrolysis would amount to 1.8% of the current global water consumption. However, even if the consumption of water to produce hydrogen is less than that required to produce energy from fossil fuels, concerns over the scarcity of fresh water call for a reduction in the use of water sources. Some researchers see a feasible and concrete solution in utilising salt water resources, which can further reduce the water footprint of hydrogen. Many researchers believe that salt water is a potential optimal solution because it would prevent hydrogen production from contributing to the increase in demand for fresh water leading to the depletion of sources. Some of them highlighted the technical challenges that still need to be addressed in order for this technology to be fully deployed. Khan et al. [10] noted that there are limited economic and environmental incentives in pursuing R&D on the up-coming technology of direct seawater electrolysis. For Pflugmann & De Blasio [4] the issue of water resources is particularly important for countries where fresh water is scarce. They focused on the case of Saudi Arabia, which can rely on an abundance of renewable energy but limited water resources. To produce an amount of hydrogen equivalent to about 15% of Saudi Arabia's annual oil production, 26 million tonnes of renewable hydrogen would be required per year. This amount of hydrogen would require 230 million m3 of fresh water. In order to obtain the freshwater Saudi Arabia's needs, at least five desalination plants would need to be added to its existing 31 large desalination plants. Referring to Africa, the World Energy Council [11] also pointed out that access to water suitable for electrolysers might require upstream investments to desalinate water in some parts of the continent. Terlouw et al. [12] argued that the large-scale spread of hydrogen production in combination with other factors – such as climate change, population growth, economic development and agricultural intensification – could lead to water scarcity. The World Economic Forum [13] carried out an analysis estimating what impacts on water resources could be expected from the transition to a hydrogen economy. The research was carried out by analysing data of energy demand and water withdrawal from 135 countries. According to the estimates derived from that analysis, only nine of the 135 countries studied would need to increase their current freshwater withdrawal by more than 10% to fully switch to hydrogen-based energy, while 62 countries would need to increase their freshwater withdrawal by less than 1%. The average value for all 135 countries is 3.3%. The increased demand for water resources would affect desert countries with low annual rainfall (e.g. Qatar, Israel) or small island states (e.g. Singapore, Malta) which would also experience difficulties due to limited freshwater reserves. According to analysts at the World Economic Forum, the hydrogen economy can open up interesting prospects not only for the energy system, but also for addressing the issue of water scarcity.
Conclusions:This study has shown that there are different views and perspectives in the debate on the relationship between the market development of green hydrogen and the management of water resources. Some of these are positive and considered good spill-over effects, while others raised concerns and socio-environmental risks if appropriate solutions are not taken. Analysts at the World Economic Forum [13] are among those with a positive outlook. In their view, the widespread use of hydrogen could not only increase the affordability of energy, but could also contribute to the solution of the water shortage problem. Countries with water shortages are unlikely to be able to produce

their own hydrogen and will therefore have to rely on imported hydrogen. While this may be seen as a disadvantage, it will allow these countries to use the water produced by converting hydrogen back into energy, either through combustion or fuel cell technology, and reuse this high purity water locally. The same applies to the water-hydrogen-water cycle, which, as already described by the authors [14], theoretically allows up to 100% of the water used to produce hydrogen to be recovered. Other scientists and experts believe that the issue of water scarcity should be taken into account, as it is one of the biggest problems in the world today due to climate change. For this reason, they have made and proposed recommendations or suggestions to policymakers as well as to company representatives. For them, it is crucial that policies for the development of green hydrogen in some countries include an increase in the storage capacity of water flows (dams and local rainwater storage systems). It is also necessary to develop strategies for the optimal management of available stocks, to create tools for recycling the resource to optimise its use and avoid waste, to control water pollution, to develop seawater desalination plants and to use waste water for water electrolysis.

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Keywords: Green hydrogen, Water issue, Market, Policies, Hydrogen economy.

[Abstract:0555] OP-065 [Accepted:Oral Presentation] [Hydrogen » R&D and Emerging Technologies]

What matters most for Hydrogen R&D spending? Evidence from OECD Countries

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Overview: Research and development (R&D) plays a crucial role in stimulating long-term economic growth. This role has attracted government actions in incentivizing significant monetary and non-monetary resources for the R&D sector. Public R&D spending in particular is critically important in supporting basic R&D to generate new knowledge or ideas. As an idea is generated, direct and indirect incentives can be provided by the government to encourage innovation and diffusion of the idea. This government strategy has been implemented across different sectors including the energy sector.

The energy sector requires more R&D investment in low-carbon technologies (LCTs) in order to meet Paris Agreement targets of keeping global temperatures well below 2°C. Thus, more ambitious efforts are required to decarbonize hard-to-abate sectors such as energy-intensive industries. For instance, it is hard to electrify long-distance flights and maritime transportation, as was the case for passengers' vehicles (IEA, 2020b). About 75% of these LCTs needed to achieve the decarbonization ambitions by 2050 either need to be developed beyond their early stage or require R&D investment to become commercially viable (IEA, 2020a). Therefore, long-term government support is needed for the development of such technologies (IMF, 2023).

At an early LCT development stage, the government has to play a key role in funding basic research. Along with this support, the government needs to assure innovators that there will be a market for the technology in order to create substantial opportunities for firm growth and job creation. Still, LCT firms may require government incentives such as subsidies to scale up its production and achieve further cost reductions, which would allow the technology to become competitive, as observed in the case of solar photovoltaic technology. For instance, the support of the Chinese government for the mass production of solar technology resulted in significant cost reductions which stimulated the rapid global deployment of the technology. At present, solar technology has the lowest levelized cost of electricity generation (IRENA, 2022; Nemet, 2019).

Green hydrogen is among the key LCTs that will require active intervention to make new technologies available and reduce the cost of the existing ones. The provision of adequate R&D spending is considered as one possible measure to support this approach. Thus, our study provides new insights into how policymakers can adopt appropriate strategies to support adequate R&D spending toward a rapid deployment of low-carbon hydrogen technologies.

Previous studies on R&D spending have adopted two main approaches. The first strand of the literature explores the role of government as an innovation input in stimulating innovation outputs such as patents, scientific publications, and new products. This first stream implements their empirical strategies using different methods such as parametric (stochastic frontier analysis), and non-parametric (data envelopment analysis) methodologies. By contrast, the second main strand of the literature examines the relationship between private R&D spending and public R&D spending across different sectors of the economy. This second strand mainly relies on various econometric techniques, such as fixed-effect models or Poisson regression methods, to test hypotheses related to either crowding-in or crowding-out effects. However, few studies have focused on the determinants of cross-country R&D spending.

Thus, our paper extends this sparse literature by examining the extent to which aggregate R&D spending determinants can improve our understanding of the potential drivers of hydrogen R&D spending. Using a comprehensive data we have assembled across OECD countries over the period between 2000 and 2022, we seek to answer the following three questions: (i) what is the relationship between R&D spending more broadly and economic growth? (ii) do governance, demographic structure, and resource endowment influence R&D spending (iii) do these identified factors matter for hydrogen R&D spending?

Our study is divided into five sections including the introductory section. Section 2 reviews the related studies on determinants of R&D spending, while Section 3 describes the methodology and data. Empirical analysis is conducted in Section 4, with a discussion of the results in the context of related literature. Section 5 summarises our findings, offers some policy recommendations and acknowledges the study's limitations.

Methods: Following Wagner's theory of government sector spending (Pistoresi et al., 2017) which postulates that government expenditure is determined by the expansion of the state arising from its economic and social progress, we provide a theoretical framework that links the country's R&D spending (as a form of government expenditure) to the country's GDP per capita (as a measurement of a country's wealth). We use this framework to specify the cross-country panel regression model in the context of OECD countries:

$$RD_{it}=\alpha_1+\beta_1 GDP_{it}+\varepsilon_{(it,1)} \qquad (1)$$

Where RD_{it} denotes R&D spending as a share of GDP, and GDP_{it} is GDP per capita for each OECD country i over each year t. α and β represent the model's estimated parameters, while ε_t is the error term. Then, we extend the baseline model in Eq (1) by including control variables such as government effectiveness, government size, natural resource rent, and renewable energy endowment, etc. as in eq. (2):

$$RD_{it}=\alpha_{(i,2)}+\beta_2 GDP_{it}+\sum_{k=1}^{q} \gamma_k X_{(it,k)}+\varepsilon_{(it,2)} \qquad (2)$$

Where $X_{(it,k)}$ represents a list of the above-mentioned control variables. We gather data for these variables across 38 OECD countries over the period 2000-2022, from different reliable data sources such as the World Bank's World Development Indicators, the UK Data Service, etc. Based on these gathered data, we employ system GMM (generalised method of moments) approach to address all potential sources of endogeneity (Zhao et al., 2023) after conducting pre-estimation checking related to multi-collinearity, cross-sectional dependence, Granger causality, and stationarity.
Results:We find a significant positive impact of GDP per capita on both aggregate R&D and hydrogen R&D spending as theoretically expected. However, GDP per capita actually has a negative significant influence on energy R&D spending, thus this may be due to unobserved factors. While government effectiveness stimulates R&D spending at the aggregate and subsector levels, it has an insignificant effect on hydrogen R&D spending. Government size hinders R&D spending except for renewable energy (with insignificant positive effect). However, an increase in natural resource rent encourages more R&D spending in the aggregate and hydrogen sectors. As potential wind energy resource has a significant positive relationship with R&D spending on energy and its subsectors, a significant positive influence from solar energy endowment is found in the case of total and energy R&D spending.
Conclusions:We examine the drivers of country-level R&D spending across all OECD countries using data spanning 2000 to 2022 and employing the panel system GMM technique. We implement this empirical approach in the context of aggregate, energy, renewable energy, and hydrogen R&D spending. Based on the Granger causality technique, we find that GDP per capita and government effectiveness are common causal factors that influence all the considered forms of R&D spending, while natural gas rent is commonly responsible for both renewable energy and hydrogen R&D spending. In addition, only hydrogen R&D spending depends on government size. Our further estimation results from the system GMM reveal that GDP per capita has a positive significant impact on aggregate R&D spending and its components. While government size hinders spending on hydrogen R&D, increased resource rent and potential wind energy resources encourage more hydrogen R&D spending.
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Keywords: R&D Spending, Hydrogen, OECD, System GMM

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Optimizing Germany's energy transformation: Connecting labor markets, training strategies, and migration policies with energy system modelling

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Overview:The transformation of the European and German energy systems requires a diverse workforce specializing in the installation and production of wind and photovoltaic (PV) facilities, the expansion of network infrastructures (e.g., transmission and distribution grids for electricity, heating networks, hydrogen networks), energy-efficient renovations for buildings, and the restructuring of heating systems. Concurrently, the large cohorts of births in Germany are transitioning into retirement, resulting in a decline in the working population (Demografieportal 2021). While the majority of existing literature focuses on the gains in jobs that can be made from a switch to renewable energy sources, the political debate in Germany is usually the opposite. Instead, the question arises as to how the necessary workforce for the transformation of the energy system and other sectors in Germany can be provided in the future, given that there is already a shortage of skilled labor across many sectors. It is therefore evident that the number of workers in key sectors such as energy must increase. Potential options for boosting the workforce in these sectors include retraining existing workers/unemployed individuals, training new workers, or attracting foreign labor (from Europe and beyond) (Burstedde et al. 2021).
On one hand, Germany could prioritize the energy transition over other sectors, meaning incentivizing the retraining for unemployed and current workers for the energy sector over other sectors, educating young people for related professions, and actively recruiting workers from abroad. This would represent the best-case scenario for the energy transition and meeting Germany's climate goals. On the other hand, geopolitical tensions and an increasingly right-leaning political landscape may divert resources towards defense measures, limiting the availability of personnel and funds for the energy transition. Additionally, the growing right-wing political climate in Germany may deter prospective immigrants, making it challenging to achieve the best-case scenario. Germany and Europe are shifting towards more conservative immigration policies. Immigration is intended to be more difficult, with only specific immigrants allowed into the country. The situation worsened in Germany in November 2023 when a coalition, including members of the right-wing German party AFD (with seats in the Bundestag and European Parliament), entrepreneurs, and right-wing radicals (e.g., Identitarian Movement), gathered to plan the deportation of individuals with a migration background (Correctiv 2024). There is a serious risk that Germany will not achieve the "best-case" scenario but, at best, a scenario with low immigration or, in the worst case, a scenario involving emigration or expulsion of people from the country. We conduct economic optimizations for the energy transition in Germany considering the "best-case," "low migration" (limited immigration and fewer retraining opportunities for energy-related professions), and "worst-case" (emigration and no retraining for energy-related professions) scenario, aiming to answer the following question: What impact does the development have on the labor markets, primarily determined by training measures and migration policy, for the transformation of the energy system and, consequently, the climate targets in the three described scenarios?
Methods:To address this question, we conduct a literature review in the first step to analyze the required workforce for each specific technology deployment and the current and future development of employment in Germany. We also explore potential changes in the job market achievable through training measures in Germany. In the next step, we develop scenarios regarding the development of

job numbers in various sectors in Germany. These scenarios describe the maximum number of workers who could be suitable for employment in the energy sector if the energy transition receives a prioritized position in labor market policy. The scenario development includes evaluating the right-wing plans for the expulsion of people from Germany for the worst-case scenario. Following the scenario development, we perform energy system modeling using the linear techno-economic optimization model GENeSYS-MOD based on the three cases. GENeSYS-MOD can model comprehensive energy-economic case studies at a global, European, national, or city level with up to hourly resolution (Löffler et al. 2022; 2019; Burandt et al. 2017). The model considers the electricity, transportation, heating, and industrial sectors and their coupling through sector coupling technologies. Various foresight variants can be chosen (myopic/perfect). Typically, the modeling period extends to 2050 in 5-year increments, allowing an examination of the energy system transformation in the context of the climate goals and adherence to CO2 budgets. Additionally, the model integrates a job module introduced by Hanto et al. (2021) for a South Africa case study. This module is further developed in the paper to analyze different transformation paths of the energy system based on training and migration policies in Germany.
Results:Expected RESULTS: In the best-case scenario, workforce growth in the energy sector through retraining and education in Germany is maximized. Additionally, a potential labor shortage can be covered by immigration from abroad. In the best-case scenario, the energy system can be optimized purely cost-effectively without labor force constraints. The value of immigration can indicate how many workers need to be recruited from abroad to fill the "domestic job gap".
In the two other cases ("Low-Migration" and "Worst-Case"), the lack of a skilled workforce is expected to hinder the transformation of the energy system. This illustrates the impact of migration and labor market policies on climate policy goals. Comparing the results from the "low-migration" and "worst-case" scenario will highlight the importance to attract people from abroad to help with the transformation of the energy system.
Conclusions:Based on the expected results, we assume that additional efforts will be needed in labor market policies. It might be necessary to prioritize the energy sector over other sectors to enable a timely energy transformation.
Further, the results will likely show, that nationalist migration policies can jeopardize the success of the energy transformation, leading to a worsened climate crisis. Hence, even more effort is needed to stabilize the political spectrum and enable migration of workers to Germany. The efforts should not stop by only implementing legal possibilities for migration to Germany but also create an environment that attracts people to work in the energy transformation and other sectors.
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Implications of Energy Justice for Energy System Modelling – The Impact of Acceptance on the Energy Mix

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Overview:In the dynamic landscape of energy system modeling, a focus on equity and fairness becomes increasingly imperative. Techno-economic aspects and cost-efficiency cannot be the only criteria in advancing the much-needed energy transition in politics and society. Recognizing and addressing social equity concerns and including affected actors is vital in advacing the transition to renewable energy, as resistance to implementation can stall emissions reduction action.

Energy system models are a key tool to evaluate trends and examine scenarios of potential future scenarios based on techno-economic assumptions often informing strategies and decisions regarding the energy transition. As we aim to better comprehend the complex web of technological advancements, policy formulations, and societal dynamics, understanding and properly representing aspects of energy justice in energy system modeling is important for shaping a more inclusive and ethical energy transition [1].

This study aims to improve the representation of justice aspects in energy system modelling using a two-step approach. Firstly, it employs a systematic literature review aimed at evaluating the current incorporation of justice aspects into energy modelling. Secondly, the Global Energy System Model (GENeSYS-MOD) is modified to integrate the justice indicator "Acceptance" identified in the first step. Subsequently, a case study is conducted in Germany to investigate the impact of the indicator on the energy system from 2018 to 2050. The findings are then analyzed to derive policy implications and provide insights to improve energy system modeling in accordance with a more equitable approach.

Methods:In the following, the approach for the systematic literature review and the modelling approach with GENeSYS-MOD will be introduced.

To systematically assess existing research on justice considerations in energy modeling, we conducted a structured literature review. Our approach involved a semi-structured review to establish clear definitions for key concepts in energy justice and energy modeling. Formulating a focused search string, we conducted a search on Web of Science for papers published from 2017 to 2022, yielding 1,771 relevant papers. Applying inclusion criteria based, subsequent vetting by two reviewers and adjusting scores based on actual paper relevance resulted in a final set of 85 papers for in-depth analysis. To comprehensively evaluate the role of justice in current energy modeling, we considered justice concepts, dimensions, paper scope, (vulnerable) groups, indicators used, and integration methods. The evaluated papers resulted in a large number of indicators used to translate or measure justice aspects of the energy transition in the larger context of energy models. Figure 1 gives an overview of indicators and their temporal scale in their different topic groups as found in the papers.

Based on multiple parameters such as data availability, temporal scale, and regional scale acceptance was chosen as the indicator best suited to be implemented in GENeSYS-MOD.

The Global Energy System Model (GENeSYS-MOD) is a linear open source energy system model which is tailored to analyze low- carbon energy transition pathways considering all energy sectors: electricity, buildings, industry, and transportation. First published by Löffler et al. [2], it extends the

Open Source Energy Modelling System (OSeMOSYS) framework and was expanded by numerous features and functionalities since then. Its main strength lies in the simultaneous optimization of capacity expansion, energy generation, and dispatch of all energy sectors as illustrated in Figure 2.

To integrate acceptance into our modeling framework, we first gathered data from a comprehensive Hertie School of Governance analysis, gauging local climate protection attitudes among German citizens [3]. Approval (acceptance) levels, ranging from 0-100%, are assessed for specific policies or technologies, eg. "Willingness to protest against local wind turbines.". The data is used in our study to generate acceptance values on a 0 to 100 scale for each technology in each German federal state (referred to as region), where 100 indicates full acceptance and 0 signifies complete non-acceptance (eg. Wind onshore in Bavaria has an acceptance of 71.4 while solar Photovoltaic (pv) has an acceptance value of 91.1). The data allows us to evaluate public sentiments at the federal state level, mirroring GENeSYS-MOD's regional granularity. Average acceptance per year represents the average acceptance value per installed Capacity (GW) in each year and is computed by multiplying technology- and region-specific acceptance values with corresponding installed capacities, resulting in Total Acceptance per Technology & Region & Year; this is then summed across all technologies and regions to obtain Total Acceptance per Year, which is divided by Total Installed Capacity per Year that has an associated acceptance value. To optimize for acceptance, the model first calculates the average acceptance of the energy system in 2025. We then introduce a constraint that allows the user to define by how much (in %) the average acceptance needs to increase (or decrease) each year. We apply 3 scenarios in total, a Base Scenario with no optimization, a High Acceptance Scenario where average acceptance is greatly increased and a Max Acceptance Scenario that returns a considerably higher average acceptance than the High Acceptance Scenario. These scenarios aim to provide initial insights into the impacts of different acceptance constraints on the energy system.
Results:Preliminary findings indicate a rise in average acceptance over the timeframe from 2025 to 2050 in all scenarios (see Figure 3). A significant surge in 2030 can be seen as average acceptance experiences a steep incline. This surge is attributed to the phase-out of multiple fossil fuels, driven by emission restrictions. Simultaneously, the installation of new renewable energy sources, substantially elevates the overall acceptance within the energy system across all scenarios.

Comparing the scenarios, the High Acceptance Scenario shows a significant increase in average acceptance over the full model period, peaking in 2050 at 85.7 average acceptance. The same goes for the Max Acceptance Scenario that reaches a much higher surge in 2030 and reaches a higher peak at 87.1 average acceptance in 2050. However, this surge in acceptance comes with a trade-off, as total energy system costs rise by over 4% in the High Acceptance Scenario and surpass a 20% increase in the Max Acceptance Scenario. Essentially, the energy system is trading acceptance for increased overall system costs.

Examining the regional power production distribution in Figure 4, a trend towards solar PV, with higher acceptance compared to wind, is notable in the High Acceptance Scenario. This results in increased solar production across all federal states. In the Max Acceptance Scenario, this trend intensifies as power production shifts southward to Bavaria, capitalizing on the region's high solar potential while simultaneously increasing acceptance.
Conclusions:The integration of acceptance into the GENeSYS-MOD framework enhances the model's capacity to offer comprehensive insights into the complex dynamics of energy transitions. Overall, results show an energy system based on acceptance will favour more accepted technologies (eg. Solar PV), potentially leading to increased overall energy system costs. In turn, these findings suggest that an increase in acceptance for less accepted technologies (eg. Wind onshore) might reduce overall system costs. Thus, the preliminary results of this study offer dual applications: firstly, they can inform strategic planning to shape a more widely accepted energy system. Secondly, the results can play a pivotal role in guiding political decisions and policy formulations. By pinpointing technologies and regions where an increase in public acceptance would yield the most significant reduction in overall system costs, these findings provide a valuable foundation for crafting targeted policies. This approach ensures a more efficient and cost-effective energy transition, aligning with both societal preferences and economic considerations.

Future research will focus on enhancing the representation of acceptance within our modelling framework and a more detailed analysis on federal state level. This involves refining the methodology to capture nuanced facets of public acceptance in all sectors, contributing to a more accurate and comprehensive portrayal in the energy system model. Additionally, a key objective is the development of a dedicated tool in GENeSYS-MOD to identify technologies and regions where an increase in acceptance would yield the most substantial positive impact on overall system costs. By pinpointing specific areas for intervention and improvement, this tool will serve as a valuable resource for planners and policy makers to optimize the cost-effectiveness of the energy transition while

reducing potential social disparities.
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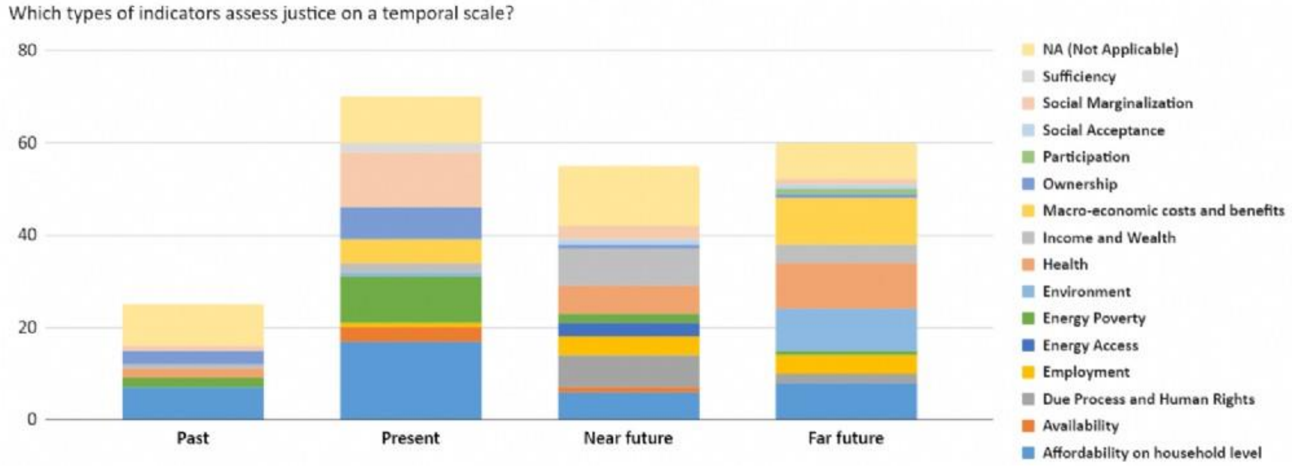
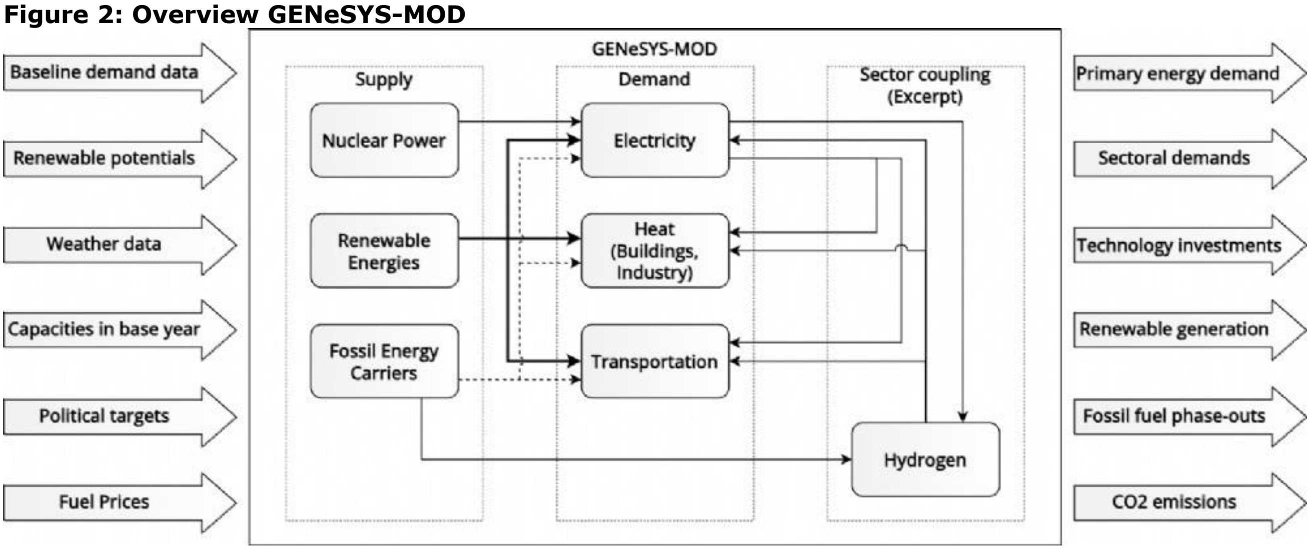
Keywords: Energy System Modeling, Decarbonization, justice, Acceptance

Figure 1: Justice indicators on a temporal scale



Justice indicators grouped by temporal scale

Figure 2: Overview GENeSYS-MOD

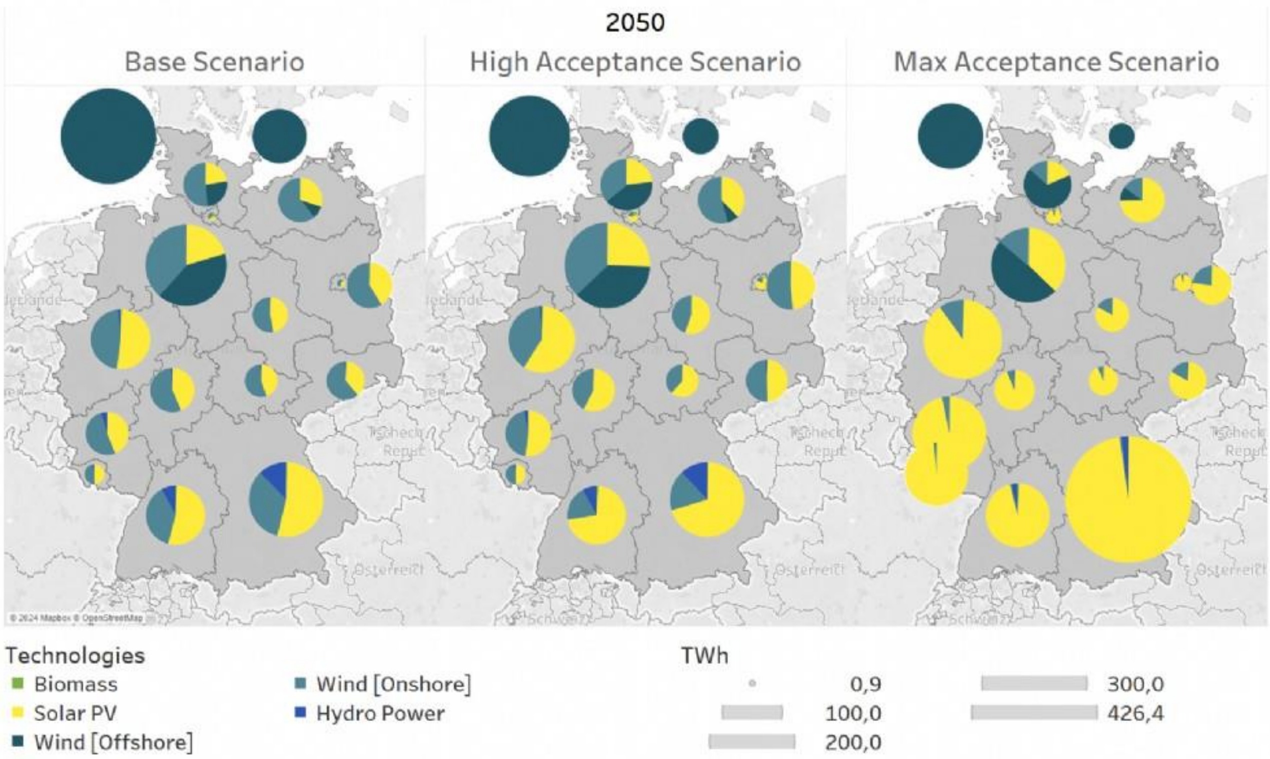


Overview GENeSYS-MOD

Figure 3: Average acceptance & Difference of System Costs

Shows the development of the average acceptance for all sccenarios and all timesteps. Additionally, the difference of system costs compared to the Base Scenario are shown for 2 Scenarios

Figure 4: Power production in all scenarios in 2050



Power production in all scenarios in 2050

[Abstract:0281] OP-068 [Accepted:Oral Presentation] [Energy Modeling » Other]

Modeling Ukraine's electricity sector decarbonization in 2035

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Overview:Progressing towards carbon neutrality through electricity sector transition is today's priority for many countries. Many recent research papers thus investigate the potential role of renewable electricity technologies, trying to form a carbon-free future configuration of this industry in different countries. Green energy transition is urgent in Ukraine too since Ukraine heavily depends on energy import, has a high energy and carbon intensity of the gross domestic product, and faces accumulating problems with electricity supply due to the ongoing Russian-Ukrainian war and destruction of domestic infrastructure. As a member of the European Energy Community and a contributor to the Paris Agreement [1], Ukraine is obliged to reach carbon neutrality by 2060 and has developed a national strategy to tackle this goal [2].
However, uncertainty about the future of the United Energy System of Ukraine (UESU) increases under the ongoing hostilities. This uncertainty questions the applicability and feasibility of existing energy system models and strategies [3,4,5] and requires updated solutions for rebuilding the UESU in the post-war period. Therefore, the research aims to offer alternative scenarios for developing the UESU in 2035 using different constraints on the applied electricity technologies available in the market and contributing to the national decarbonization targets.
Methods:In the study, we modeled the UESU with the spatially-explicit cost-optimization EXPANSE model [6,7,8] adapted to Ukraine. The previous publications on modeling Ukraine's energy sector mostly used the macro model TIMES-UKRAINE [3,4,5,9,10], building scenarios for the whole national economy and its main sectors. Unlike the TIMES-UKRAINE model, UKRAINE-EXPANSE allows regional analysis of renewable and conventional electricity generation, storage, and transmission technologies and assessment of their social, economic, and environmental impacts.
The UKRAINE-EXPANSE model covers five neighboring countries (Poland, Romania, Slovakia, Moldova, and Hungary) presented as single country nodes and 24 Ukraine's regions (except for Crimea and the territories of Luhansk and Donetsk regions occupied by Russia before February 2022) linked to 11 nodes. We model 16 electricity generation technologies (onshore and offshore wind, solar PV, biogas, wood biomass, agricultural and municipal wastes, energy crops, small hydropower, run-of-the-river (ror), geothermal, gas, coal, lignite, oil, nuclear energy), four storage options (hydro dam, pumped hydro storage (PHS), hydrogen (H2), battery), and two types of transmission lines (direct current (DC) for neighboring countries and alternating current (AC) for Ukraine's domestic lines).
We run 12 cost-optimal or near cost-optimal scenarios for the USEU and its five neighboring countries in 2035, combining constraints on nuclear power, coal, renewable sources of solar PV and wind power, hydropower and PHS technologies, as well as greenhouse gas (GHG) emissions connected to national mitigation commitments [1,2]. We calculate the total amount and the structure of Ukraine's installed capacities of electricity generation and storage technologies in 2035 for all scenarios based on the projected power demand. Then, we estimate annual electricity volumes generated with these technologies in 2035 and export and import flows. Finally, we calculate overall GHG emissions, particulate matter PM10 emissions, annualized direct electricity sector jobs, direct land use, and total system costs for each scenario.
Results:For all scenarios, our modeling shows declining total installed capacity in Ukraine due to capacity structure rationalization despite a 25% increase in electricity demand expected in 2035 as compared to today. All scenarios also follow today's pattern of the electricity generation mix, where in 2035 Ukraine still continues to bet on nuclear power and reduces coal use if considering the national decarbonization goals [1,2]. If GHG emission targets are ignored, coal remains the key source for electricity generation due to available domestic coal deposits and the lower costs of coal compared to renewable energy sources. Achieving national decarbonization goals without the wide use of cheap but environmentally unfriendly coal implies deviating from minimum cost scenario and requires more funds (up to 13.5%).
While the combination of nuclear and coal capacities prevails, solar PV, onshore wind power, hydropower, and PHS facilities play a significant role already in 2035 too, along with gas plants and offshore wind power having less weight. In many scenarios, the Donetsk region is considered the most promising for offshore wind power generation, the Odesa oblast – for solar PV generation, and Zaporizhzhia and Donetsk regions – for hydropower generation. Other notable components in the electricity generation mix are hydropower, solar PV, onshore wind power, gas, and PHS. However, the contribution of each of them remains still much lower than the coal and nuclear outputs together. Scenarios with a reduced coal share require higher costs and larger land areas to place energy installations but will also provide more direct employment in the sector and lower GHG emissions.
The increase in electricity demand in 2035 necessitates the expansion of domestic transmission grid in all scenarios, mostly in central regions of Ukraine, adding Chernivtsi, Chernihiv, and Odesa oblasts in some options. The extended nuclear power and renewable electricity generation determine the growth in export volumes in the corresponding scenarios due to the decreasing flexibility of electricity production with such technologies. To balance the UESU, electricity imports rise too, but to a lesser extent than exports. Due to this, all scenarios require increasing capacity of transborder transmission grids between Western Ukraine and five neighboring countries.

Conclusions:In this study, we considered the case of the Ukraine's electricity sector transition, which has a high electricity import dependence, high energy and carbon intensity, and an unprecedented destruction of electricity facilities due to ongoing Russian aggression. Using the newly built UKRAINE-EXPANSE model, including 24 Ukraine's oblasts and five neighboring countries, we analyze 12 cost-optimal or near-optimal scenarios for the UESU development in 2035, considering national decarbonization targets and not. We show that total installed electricity capacity could be reduced by 10-26% compared to the pre-war period due to transformations of regional electricity infrastructure and technology mix despite the increase in total future electricity demand by 25%. Nuclear and coal power still remain the primary sources, although renewable electricity technologies have a significant role to play too in 2035. Analysis of the impacts of air pollution emissions, direct employment, land use and total system costs of each scenario reveals that implementing decarbonization goals will require 2.3-13.5 % more annual costs than the minimum cost scenario, but this might be socially acceptable to make more environmentally friendly policy decisions. Overall, the developed UKRAINE-EXPANSE model presents a first-of-the-kind regional energy system analysis approach in Ukraine, focusing on the electricity industry. In the future, update of pre-war data used to build the model and the longer time horizon beyond 2035 present prospects for future research.
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Keywords: Ukraine, decarbonization, electricity sector modeling, subnational analysis, cost-optimal scenarios, near-optimal scenarios

[Abstract:0293] OP-069 [Accepted:Oral Presentation] [Energy Modeling » Other]

Does myopic foresight modeling better capture the real-world energy transition? Hindcasting in 31 European countries

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Overview:Cost-optimization energy system models, e.g., TIMES[1], MARKAL[2]and MESSAGE[3] with perfect foresight have been extensively used to analyze long-term energy transition[4,5]. However, decision makers and investors typically prioritize the near term with more information available, while postponing the long-term decisions to wait for new information that may arise[6]. In this context, a model with myopic foresight may be an alternative[5,7], where information for a long-time horizon is not available at first and thus sequential decisions are made under incomplete information. Existing studies show that, compared to perfect foresight modeling, myopic foresight modeling tends to result in delayed investment decisions[8,9] and higher carbon price[8], and increases the difficulty in meeting energy system decarbonization[10]. Limited knowledge availability inherent in a myopic foresight model can also lead to a technology lock-in, where potentially innovative technologies may not be adopted[11]. Despite of some myopic least-cost models in literature, it remains unclear whether such models can better capture real-world development as compared to perfect foresight models. Earlier research shows that retrospective evaluation of models and scenarios is particularly valuable[12–14]. In light of these knowledge gaps, this study retrospectively models national electricity systems in 31 European countries from 1990 to 2019, employing both perfect and myopic foresight models, and evaluates hindcasting accuracy of various model versions by comparing them with the real-world transition.
Methods:We develop myopic model versions with limited foresight based on D-EXPANSE (Dynamic version of EXploration of PAtterns in Near-optimal energy ScEnarios), originally designed for perfect foresight[12,13,15,16]. Model versions vary in time horizon of myopic foresight and approaches to incorporate policies. We evaluate the hindcasting accuracy[16] of both myopic and perfect foresight model versions by comparisons with real-world transitions. We focus on the electricity system transition from 1990 to 2019 across 31 European countries (European Union 27, Switzerland, the United Kingdom, Iceland, and Norway), using historical data collected by Jaxa-Rozen et al.[17].

In terms of the time horizon of myopic foresight, the model is altered by two parameters: the projection horizon of each short myopic optimization (n) and the decision horizon between two successive short optimizations (m). By this, the myopic foresight model enables a sequential decision-making setup, allowing for decisions to evolve over time with new information, but certain previously made decisions are irreversible[4]. In this study, the cumulative system costs and installed capacity of each technology are specified as irreversible and are transferred between successive short optimizations. By varying n and m from three years to 30 years in the myopic foresight model, we generate around 400 scenarios for each country. In addition, at a policy level, we incorporate three historical policies – CO_2 emission targets, share of renewable electricity generation targets[18,19] and three policy instruments [20,21] (subsidies on investment costs, tradable green certificates, and feed in tariff), one by one and as combinations into both myopic and perfect foresight model versions. In the perfect foresight model, all policies throughout the entire time horizon (1990 to 2019) are considered. In contrast, the myopic foresight model, based on different n and m, only takes into account policies announced before the initial year of each short optimization, but not those published during and after the short optimization. Finally, by comparing different model versions with the real-world transition, we calculate symmetric mean absolute percentage error[16] (sMAPE) for the key model's outputs (total system costs, installed capacity and electricity generation of each technology) to quantify errors between the modeled projections and the real-world transition, reproduced in the model, and to compare the hindcasting accuracy among various model versions.
Results:Compared to perfect foresight model, myopic foresight model generally exhibits higher hindcasting accuracy in total system costs in 18 countries, but similar accuracy in installed capacity in most countries (Fig. 1). For example, in Belgium, Hungary, Sweden, and Slovakia, the sMAPE of the total system costs in perfect foresight model is more than twice as high as in the myopic foresight model (Fig. 1a). In most countries, the hindcasting accuracy of installed capacity in myopic model runs is close to that in the perfect foresight model. By comparing the sMAPE of total system costs and installed capacity across 31 countries, we find that myopic foresight model shows wider range in terms of total system costs (sMAPE = 0.2 – 1.2), compared to installed capacity (sMAPE = 0.2 – 0.8). In addition, compared to changes in the projection horizon (n), total system costs seem to be more sensitive to changes in the decision horizon (m) in most countries. Poland, for instance, demonstrates substantial fluctuations in sMAPE as m changes. However, installed capacity is more sensitive to changes in projection horizon (n) in some countries, such as Cyprus, Malta, and Latvia.

This may be attributed to the relatively lower electricity demand and simpler electricity system structure in these countries, leading the model to switch between different technologies with comparable costs within limited foresights.

We also find that the incorporation of historical policies has the potential to alter the model's outcomes, but unnecessarily in improving accuracy. Both perfect and myopic foresight models still exhibit high and comparable deviation from real-world situations. For instance, except for a few countries (such as Malta or Iceland), across the scenarios of the seven policy combinations, countries exhibit sMAPE ranges between 0.5 and 0.8 without one policy combination demonstrating much higher accuracy (Fig. 2). Moreover, across the majority of model versions integrating diverse policy combinations, a consistent pattern emerges where 15 countries demonstrate superior performance in the myopic foresight model, while the remaining 16 countries exhibit enhanced performance in the perfect foresight model. This trend persists, with exceptions observed in model versions pertaining to CO2 emissions targets, renewable generation targets, and their combination. In these scenarios, myopic foresight models demonstrate high accuracy in over half of the countries compared to perfect foresight models. The incorporation of policies does not effectively reduce the discrepancies between model outcomes and real-world transition that much. However, at national level, varying accuracies are observed across models and policy combinations among countries. For instance, in Slovenia, the myopic model shows better hindcasting accuracy than the perfect foresight model if policies combinations include three policy instruments, while the reverse is observed for other policy combinations. Conversely, in Malta, the myopic models consistently outperform the perfect foresight models across all policy combinations, with the highest accuracy observed in the case of all the policies combined.

Conclusions:In this study, we retrospectively model national electricity systems in 31 European countries from 1990 to 2019, using both perfect and myopic foresight cost optimization models, and evaluate hindcasting accuracy of various model versions by comparing them with the real-world transition. Results show that the myopic foresight model demonstrates advantages in hindcasting accuracy in total system costs, whereas for installed capacity both perfect and myopic foresight models exhibit high and similar deviations from reality. The incorporation of historical policies does not consistently lead to improved hindcasting accuracy. Modelers hence still need to further investigate potential sources of hindcasting errors in the models from other perspectives, such as social factors or deviations from cost optimization, which may have an impact on real-world transitions. This also suggests that the real-world energy transitions may not necessarily align closely with the trajectories expected in models from simulating policies, e.g., CO2 emissions targets. Consequently, decision-makers may need to exercise greater caution in evaluating the effectiveness of policies.

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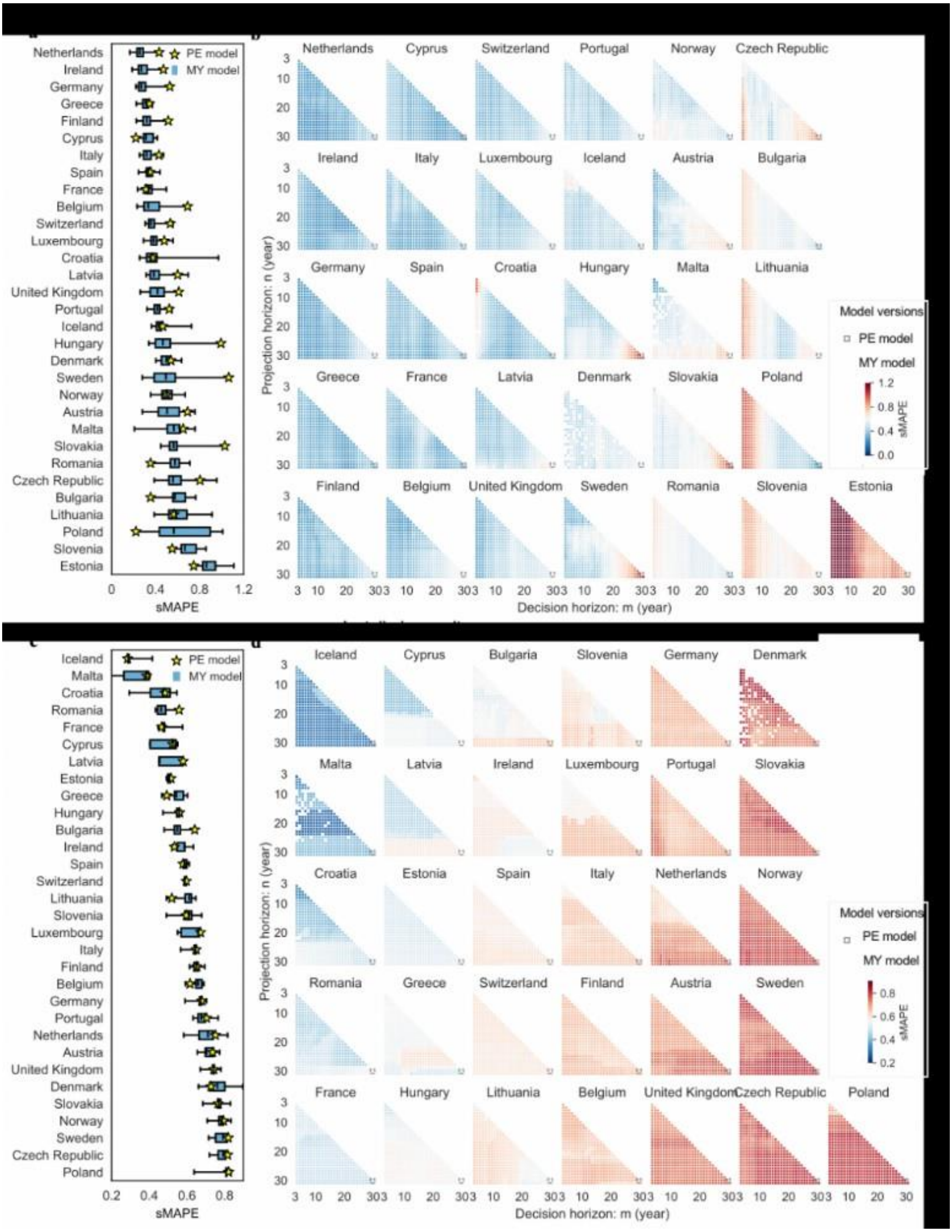
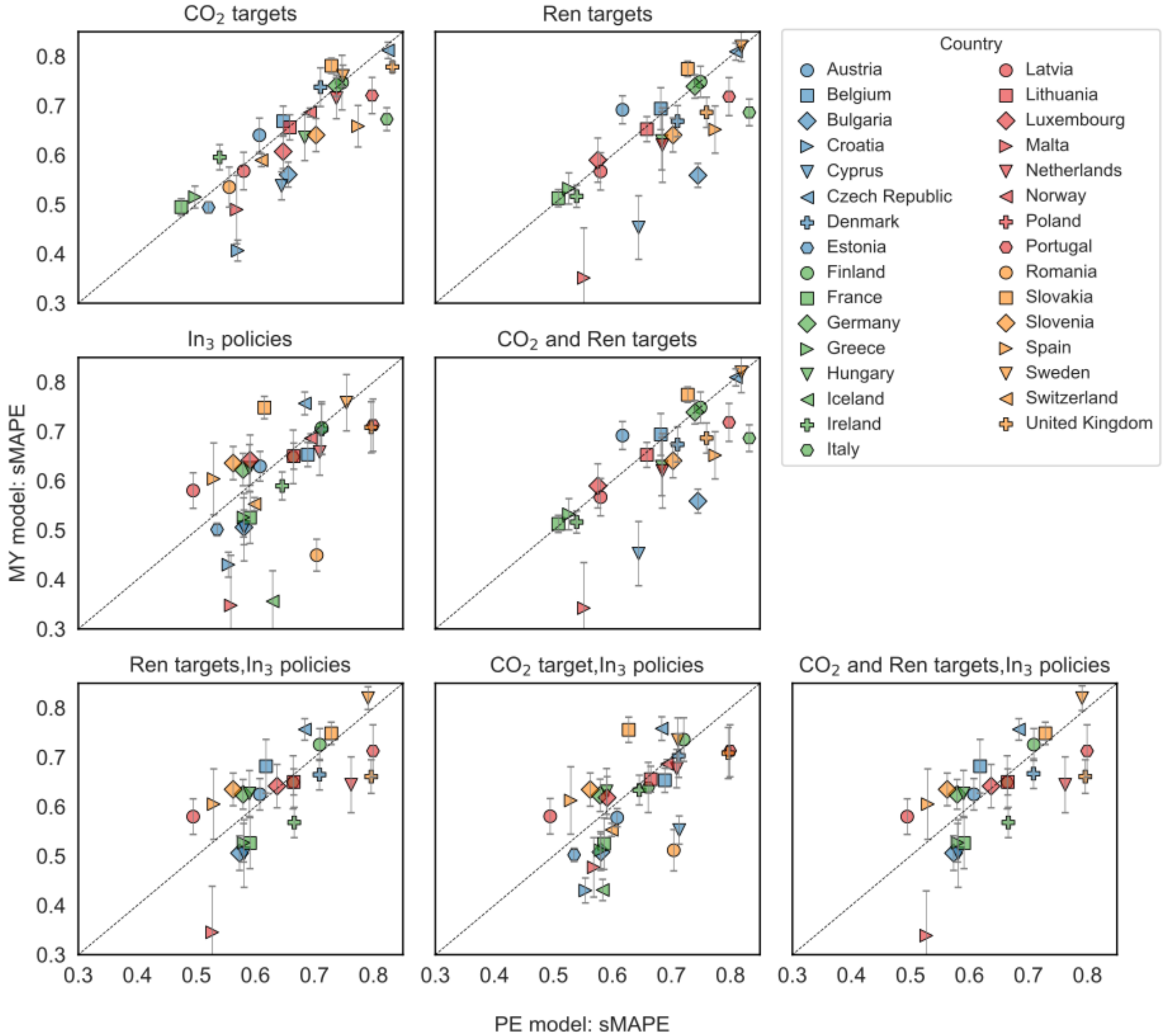
Keywords: Optimization, Energy system models, Perfect foresight models, Myopic foresight models, Accuracy assessment

Fig. 1 Symmetric mean absolute error (sMAPE) of projecting total system costs (a, b) and installed capacity (c, d) for 31 European countries from 1990 to 2019 in perfect and myopic foresight models.



(a, c) Ranges of sMAPE for total system costs and installed capacity: boxplots depicting the range of sMAPE values across 406 myopic foresight scenarios; the upper and lower limits of the boxplot represent the maximum and minimum values. (b, d) Heatmaps of 406 combinations of all projection and decision (n and m) horizons: illustrating the variations in sMAPE of total system costs and installed capacity with changes in n and m. The ranges for n and m span from three to thirty years. PE model: perfect foresight model. MY model: myopic foresight model.

Fig. 2. Comparative Analysis of Symmetric Mean Absolute Errors (sMAPE) in perfect and myopic foresight (PE and MY) models.



This figure presents a hindcasting accuracy comparison across seven policy combinations in terms of annual installed capacity for 31 European countries at policy level. CO2 targets: submitted EU CO2 emissions targets. Ren targets: share of electricity generation from renewable technologies. In3 policies: three policy instruments for renewable technologies (subsidies on investment costs, tradable green certificates, and feed in tariff).

[Abstract:0410] OP-070 [Accepted:Oral Presentation] [Energy Modeling » Other]

Energy expenditure, energy intensity and price pass-through

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Overview:Energy intensity, defined as the ratio between a volumetric measure of the energy input and a real measure of the corresponding economic output, is commonly used in analyzing the energy efficiency of an economy or an industrial sector. Meanwhile, there is a rich body of literature accounting for the macroeconomic effects of energy price changes, both on the real side of the economy and on the pass-through from energy price to overall price in the economy. We explore using the nominal expenditure share devoted to energy in an economy to unify the two aforementioned approaches in research, modeling, and policy discussions. This can also serve as a measure of energy affordability, as a lower value of energy expenditure share indicates the society can more readily afford the required energy to operate effectively.
Our compilation of energy price and volume data leads to an expanded data set of the energy expenditure share for major economies. Preliminary analysis suggests that the energy expenditure share declines as income grows. However, there are significant differences across countries and over time, reflecting varying development stage, industrial structure, energy policy, as well as other idiosyncrasies. We evaluate the energy expenditure share of GDP in the context of income growth, energy efficiency in economic output, and energy price cycles.
Methods:First, we calculate the energy expenditure based on end-user nominal prices in local currency and energy consumption, by sector and by fuel, before aggregating a country's total nominal energy expenditure. On the price side, the difficulty lies in the lack of credible data, particularly in many developing countries. There are also widespread distortions in the end-user prices, for example, due to price controls and/or subsidies. We use end-user energy price data from IEA World Energy Outlook database wherever feasible, supplement with price data from alternative sources, and develop a proxy approach for other missing price data. On the energy consumption side, we use a combination of historical energy volume data from IEA, energy demand data from alternative sources, as well as proprietary data. Particular care has been given to matching volumes of primary fuels and electricity consumed to end-user prices.
Then, we arrive at the energy expenditure as a share of the GDP using nominal measures for energy expenditure in the numerator as well as GDP in the denominator. This nominal percentage share of GDP provides a more accurate measure of cost burden on the overall economy. Take the U.S. as an example; our derived energy expenditure share of GDP closely resembles the official series published by the U.S. EIA. This gives us the confidence to apply the same methodology to other major economies as long as there is adequate data.
We currently have covered the following countries and regions with varying lengths of historical data: U.S., EU, Russia, Romania, Turkey, China, South Korea, India, Indonesia, Saudi Arabia, Morocco, Kenya, Mexico. More are being added.
Results:Preliminary analysis on our complied data reveals the following. Clearly, energy expenditure share declines as income grows. This is intuitive as lower income societies spend a higher share of income on energy and other basic necessities. Interestingly, these lower income countries also tend to experience higher volatility of the energy expenditure share, possibly due to import barriers and/or price distortions. Furthermore, there are significant differences across countries and over time, reflecting varying development stage, industrial structure, energy policy, as well as other idiosyncrasies. We are pursuing additional analysis to better understand all these aspects.
Work is also underway to evaluate the historical energy expenditure share trends for insights on how economies and consumers react to sudden changes in the affordability of energy. This has potential implications on the coming energy transition where the world faces the dual-challenge of reducing emission while supporting social-economic development.
Conclusions:The energy expenditure share of an economy provides a unified way to look at both the energy intensity and the energy price pass-through issues. It also provides a measure of energy affordability in an economy. We develop an expanded international data set of the energy expenditure share of GDP. Preliminary analysis suggests the energy expenditure share is negatively correlated with income, exhibits significant country/region variations, and carries potential implications on energy transition.
References:Interational Energy Agency (IEA) World Energy Outlook, various issues

U.S. Energy Information Administration (EIA) Monthly Energy Review, various issues

Metcalf, Gilbert E. and James H. Stock. 2020. "Measuring the Macroeconomic Impacts of Carbon Taxes." American Economic Review: Papers and Proceedings, 110(May), 101-106.

Keywords: Energy expenditure, energy demand, energy price, energy intensity, price pass-through, energy transition

[Abstract:0406] OP-071 [Accepted:Oral Presentation] [Energy Modeling » Panel Data Analysis]

Industrial Fuel Demand and Interfactor Substitution: Evidence from Emerging Economies

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Overview:Fuel demand elasticities are critically important in forecasting future energy consumption, assessing appropriate timing of energy technology development and energy tax policies, and predicting energy pricing strategies. The detailed elasticities play a considerable role in analysing a model-dependent specific policy. Therefore, numerous empirical studies attempt to estimate fuel demand elasticities to have a better understanding of the extent to which fuel consumption can be reduced in response to increasing fuel prices or costs. However, there is little consensus in the magnitude of fuel demand elasticities (price and income elasticities) either in the short run or in the long run due to heterogeneity, aggregation bias and adopted methodologies, which have not been adequately resolved in the literature. Therefore, we provide new insights on the role of energy substitution in the production using disaggregated sectoral level data. In addition, we acknowledge possible heterogeneity in the characteristics and activities of our sampled industries, thus, we control for this by the sector-specific component to account for differences in production classification between the sector types- manufacturing and service sectors. As little attention has been given to the estimation of output elasticity with respect to changes in factor inputs; in particular, to changes in energy input while using a translog model, we estimate the output elasticity with respect to energy demand as well as the index of scale economies for our sampled individual countries and their sector types.

The overall structure of the paper takes the form of six sections, including this introductory section. Section 2 presents the overview of the existing related literature, while methodology is discussed in Section 3. Following the presentation of the empirical models, Section 4 provides the details of the data used for the estimations. The main results from the estimations are then discussed in Section 5. Section 6 summarises empirical findings and concludes with policy recommendations. Methods:We implement our contributions by estimating a translog cost model for a panel data of 54 sectors for seven emerging economies- Brazil, China, India, Indonesia, Mexico, Russia and Turkey over the period 2000–2014. To complement estimating standard translog model, we account for the imperfectly price reversibility of changes in fuel prices by incorporating asymmetric prices responses in our analysis. Data for this study are obtained from World Input-Output Database (WIOD), Penn World Table (PT7.1) and High-Resolution Gridded Dataset by Climatic Research Unit and Tyndall. Results:The main results emerged from this study are summarised as follows.

Firstly, our results indicate a significant heterogeneity in the estimated elasticities from models estimated across countries and subsectors. The values of our average own-price elasticities are within the range of estimates from previous studies. However, our average fuel own-price elasticities with asymmetric responses are relatively larger.

Secondly, we find no clear evidence indicating that a particular fuel is generally more sensitive to price changes as evidenced by the mixed results across countries and sector types. This finding cautions against the use of general policies, but instead reinforces the use of more fuel-and sector-specific policies to achieve desired results.

Thirdly, our results could not support substitution possibilities among energy fuels, but evidenced

interfactors substitution. However, the magnitude of the cross substitution is small, which suggest limited substitution.

Lastly, the production technologies of the sampled countries appeared to be relatively inefficient as evidenced by the index of return to scale and the output elasticities with respect to fuel demand. Conclusions:From policy perspectives, our findings pointing in the direction of limited scope of the emerging economies to implement clean substitution strategy for sustainable growth. Thus, we recommend it is imperative for emerging economies to implement progressive energy-saving plan and incentivise installation of low-carbon energy production technologies. Further, the output elasticities and indices of returns to scale strengthen the need for technology improvements and forward-looking cleaner production plan for the emerging economies. Consequently, targets related to energy security, clean environment and sustainable industrial growth appear more feasible.
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Keywords: Industrial fuel demand, Interfactor substitution, Estimated elasticities, Emerging economies

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[Abstract:0013] OP-072 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Impact of green power trading mechanism on power generation and interregional transmission in China

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Overview:Both green power trading mechanisms and interregional power transmission are effective approaches to increasing renewable energy absorption and reaching net-zero emissions. They attract more attention than ever before in China after the issue of "dual carbon" target in 2020. Few studies have compared the effects of policies incentivizing green power trading and their comprehensive impacts on power transmission. Considering the tradable green certificate (TGC) market, green power (GP) market, and power transmission, this study formulates a high-resolution power market equilibrium model (HREM) to stimulate effects of multi-market scenarios and address the above issues. The results show that: (1) The GP market can significantly promote green power absorption and the TGC market provides a more flexible way for green power trading. (2) The phenomena of inefficient utilization of transmission lines arose in some areas while the demand for transmission capacity emerged in other areas along with the development of green power trading. (3) A combined mechanism of GP and TGC market is the best option for the current situation while an independent power market is the optimal way to boost green power development with sufficient transmission capacity. The results also call for the synergy development of market design and transmission line

construction.
Methods:This study formulates a national power market equilibrium model in China, which consists of producers, consumers, and an independent system operator (ISO) minimizing system cost. This modeling method is similar to Wang, Zhang, et al. (2021) and Kasina and Hobbs (2020). State Grid Corporation of China, and China Southern Power Grid are considered as one large state-owned enterprise, which is assumed to take charge of all the national dispatching businesses as the ISO does. 246 key transmission nodes were divided to improve model authenticity. Consumers in each node consist of the local grid as well as end-users. Their total demands are inelastic and viewed as exogenous. Anticipating the price in different markets, consumers minimize their total cost by dividing up their demand among different power type. Producers are the power firms, which own multiple power plants competing to sell power at different nodes in a locational marginal price (LMP)-based market, where prices are determined by market clearing results. Producers maximize their profits by adjusting the power generated.
Results:(1) Distributional effect of different markets. In the REF case, green power together with the other generation forms are all involved in the conventional power market due to the lack of an exclusive green power trading mechanism. It is difficult to internalize the environmental effect of green power only by way of a conventional power market. Green power generation increases under the incentive of improved market price with the introduction of the TGC and the GP market. Among these, the GP market contributes most to power mix changes. Compared with the REF scenario, the total amount of green power generation under the GPM and FMD scenarios increases by 45.3% and 44.5% respectively. (2) Green power generation and transmission. The GPM and FMD scenarios witness almost the same as well as the most green power generation with the introduction of the GP market. This phenomenon stands out most significantly in the Northwest and North China, which are most abundant in green power resources. With the involvement of the TGC market, green power generation increases in the North, East, South, and Northwest regions. Whereas the TGC market witnesses an adverse effect in the Northeast. Moreover, consumers in Central China significantly reduced their demand for green power under the FTM scenario. Therefore, local power generation decrease by 19.3% and 7.9% in Northeast and Central China respectively compared to the REF scenario. (3) Overall power generation and transmission. The demand for green power in some regions could be satisfied by conventional power with TGC purchasing, resulting in an increased national transmission volume under the FTM scenario. Meanwhile, national interregional power transmission under the TGC market is 4.45% higher than that under the REF scenario. The dual incentive of green power and the TGC market performs best among the four scenarios. Compared to REF, it achieves a green power transmission volume of 303.8TWH, or 16.1% higher, and a total power transmission of 1353.4 TWH, or 25.4% higher.
Conclusions:(1) The green power trading mechanism is an effective approach to boost green power development through exclusive market price incentives, resulting in a higher green power generation that 1067.2 TWH generation with a combined mechanism including the green power and TGC markets and 1073.4 under the GP market only. In addition, the power system operates most effectively with more interregional green power transmission due to more efficient power resource allocation and the total green power transmission reaches 303.7 TWH. (2) The “Three-North” region plays a key role in green power generation and interregional power transmission, which accounts for 49.4% of green power generation and 31.7% of exporting power transmission under the FMD scenario. The Central area has a diversified power mix and has better interregional power transmission capacity both economically and physically. Therefore, it plays a critical role as a transmission hub of interregional green power transactions. Its interregional green power transmission amounts to 48% of the total volume with the introduction of both the TGC and the GP market, and total power generation increased by 5.6% compared to the REF. (3) The South and East regions decreased their local power generation because the imported power is more economical under green power trading schemes. The green power resources are not fully utilized due to the transmission barrier between the South with other regions. The East witnessed a 54.5% increase in power imports and a decrease of 9.8% in total power generation compared to the REF scenario, which is more beneficial to the low-carbon development of the East region.
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Keywords: green power market, tradable green certificate, interregional power transmission, power market equilibrium model

Fig. 1 Model structure

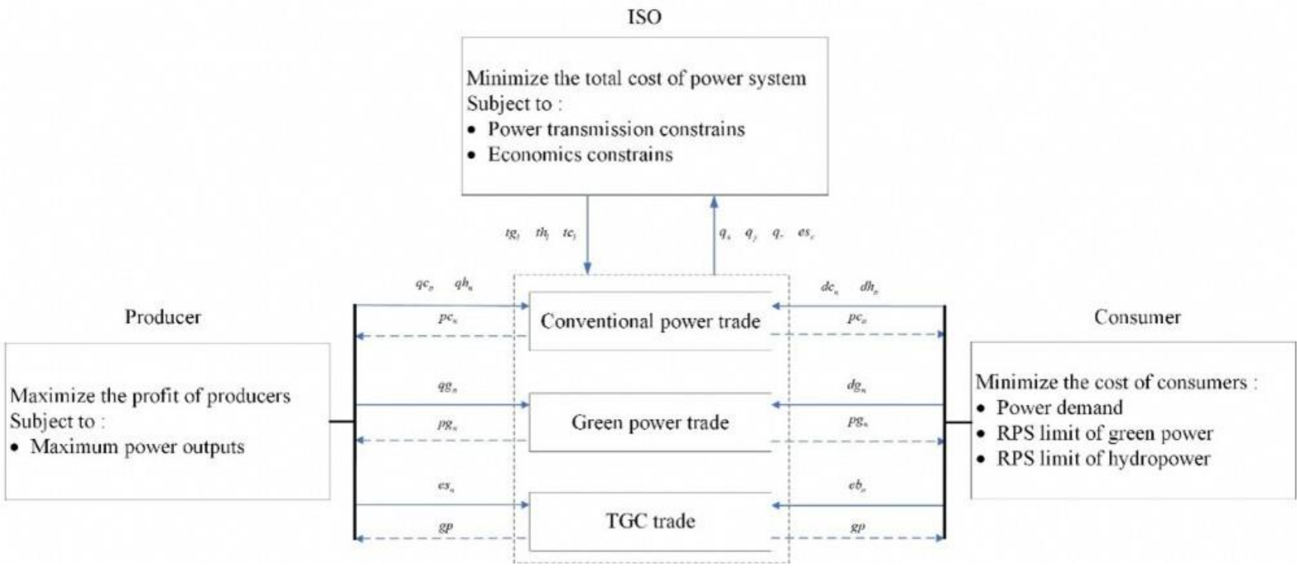


Fig. 2 The distribution of power plants in China

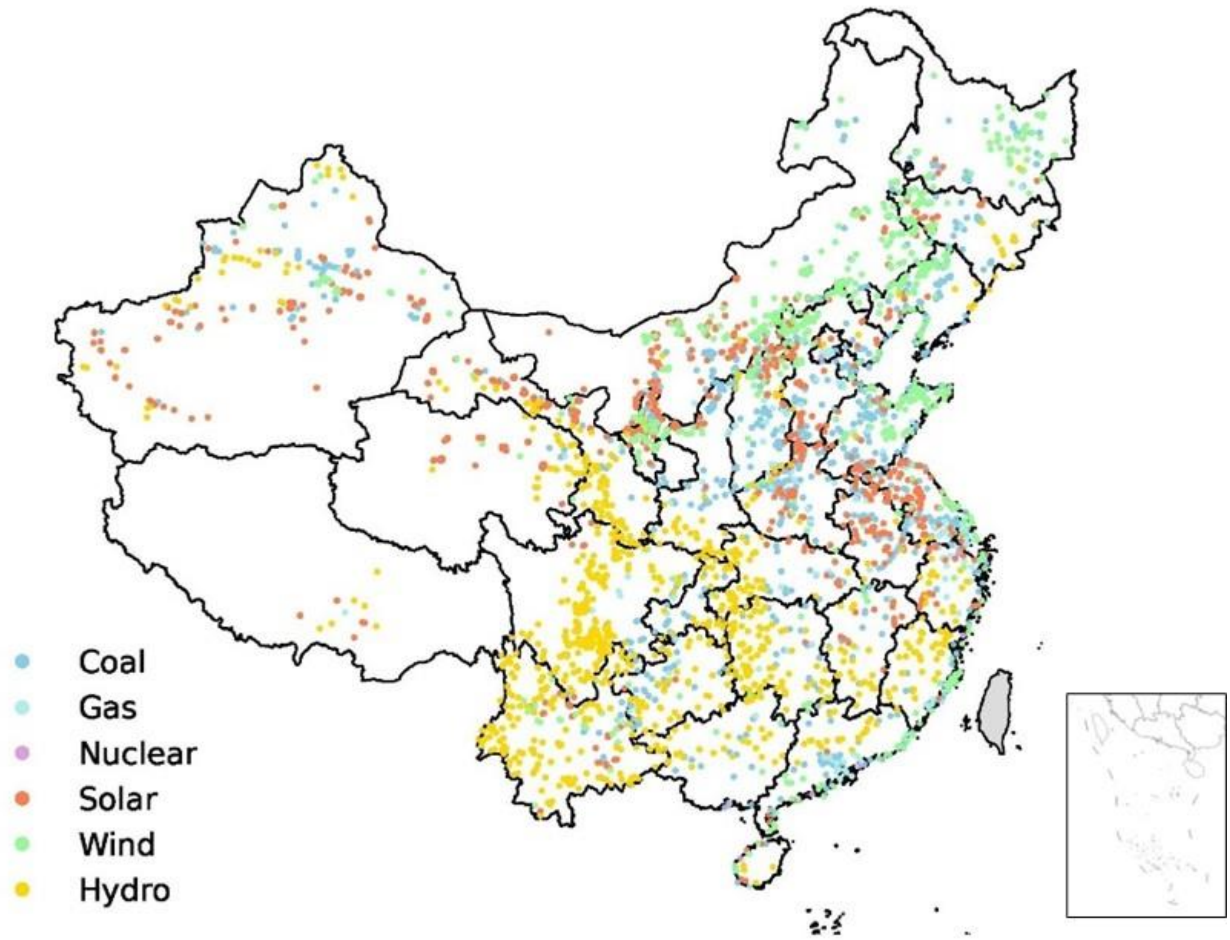


Fig. 3 Model structure of four scenarios

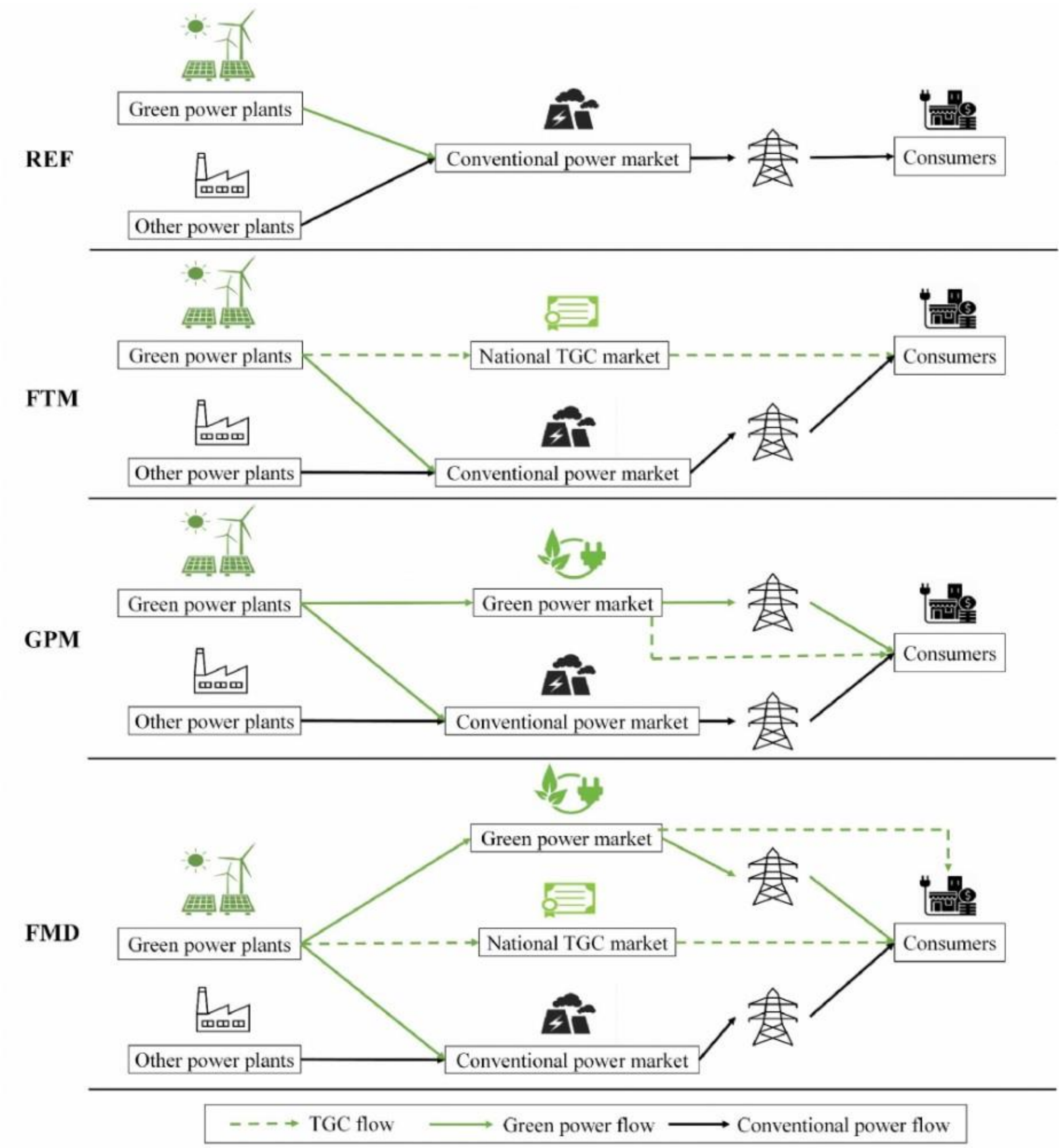


Fig. 4 Green power generation under different scenarios

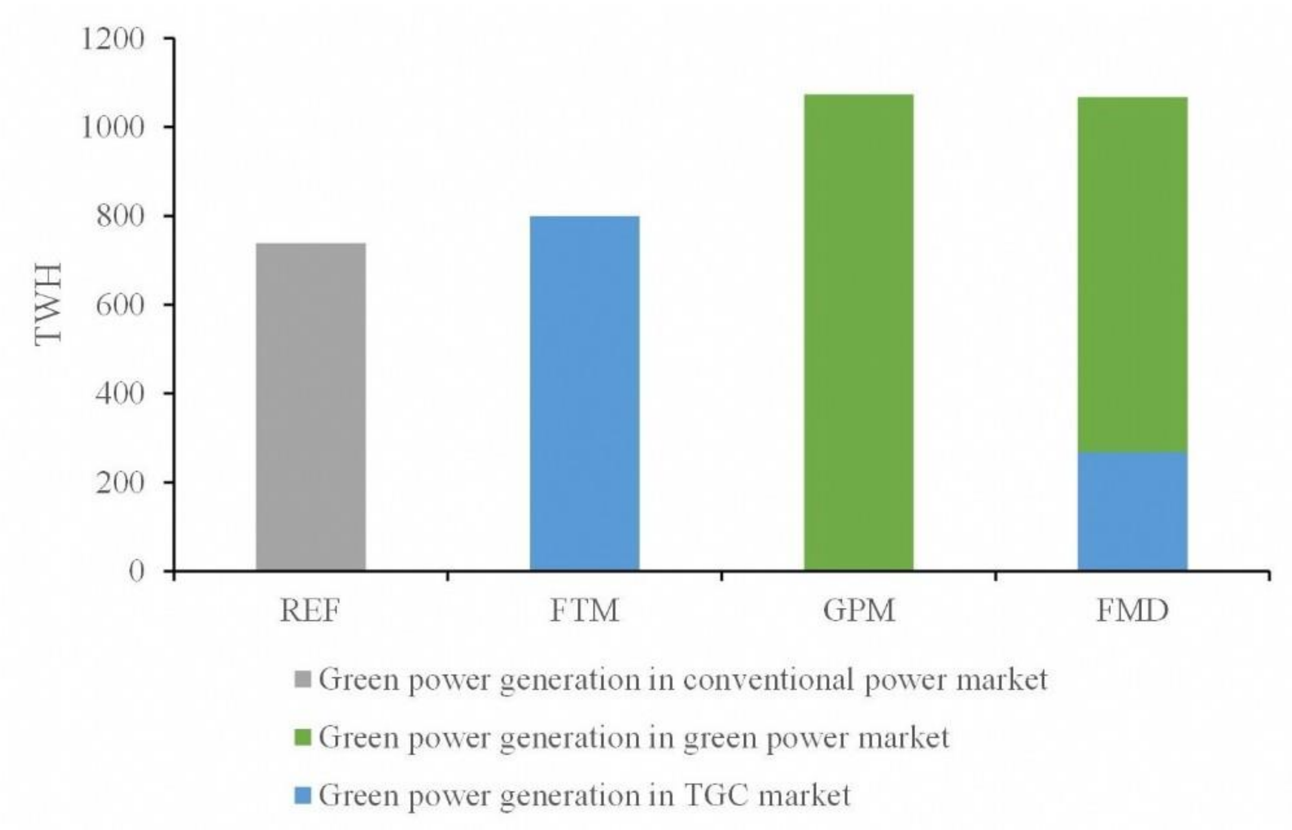


Fig. 5 The market size under different scenarios

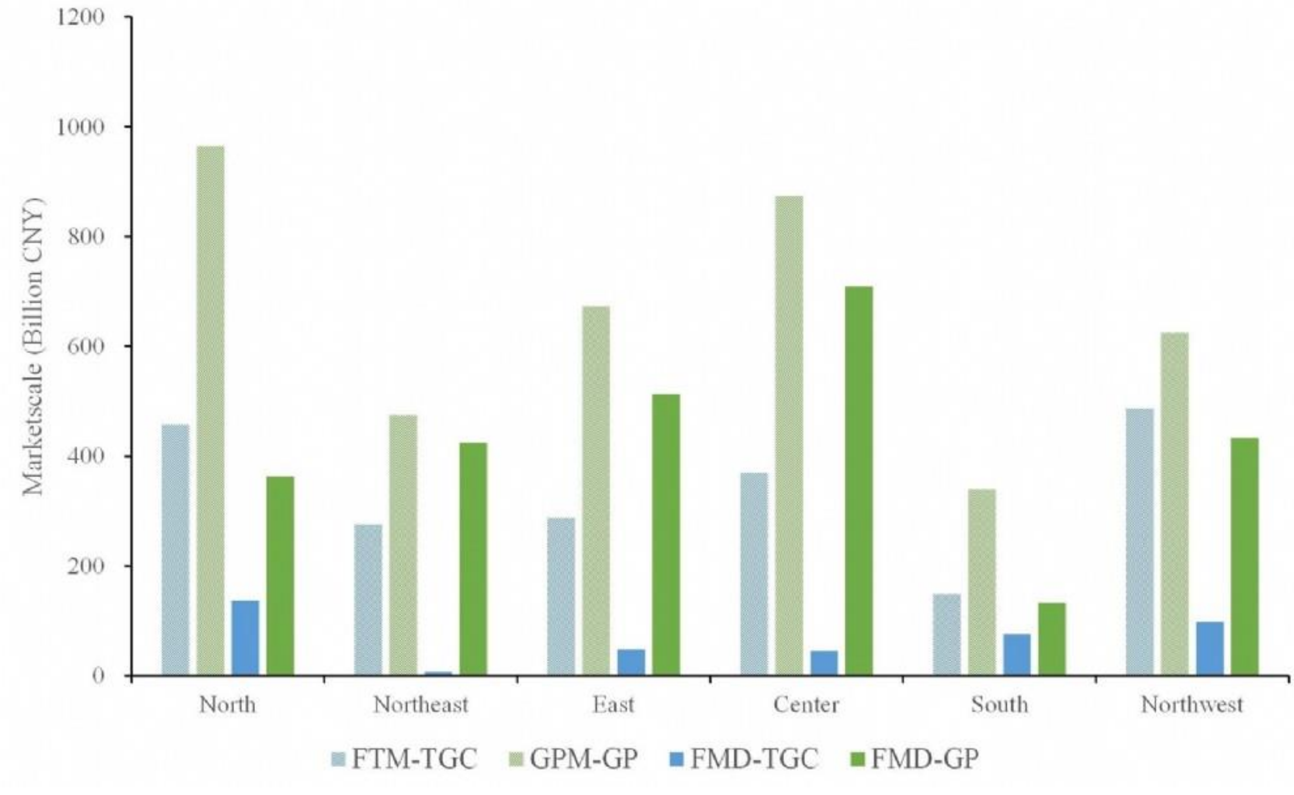


Fig. 6 External dependence on green power and TGC

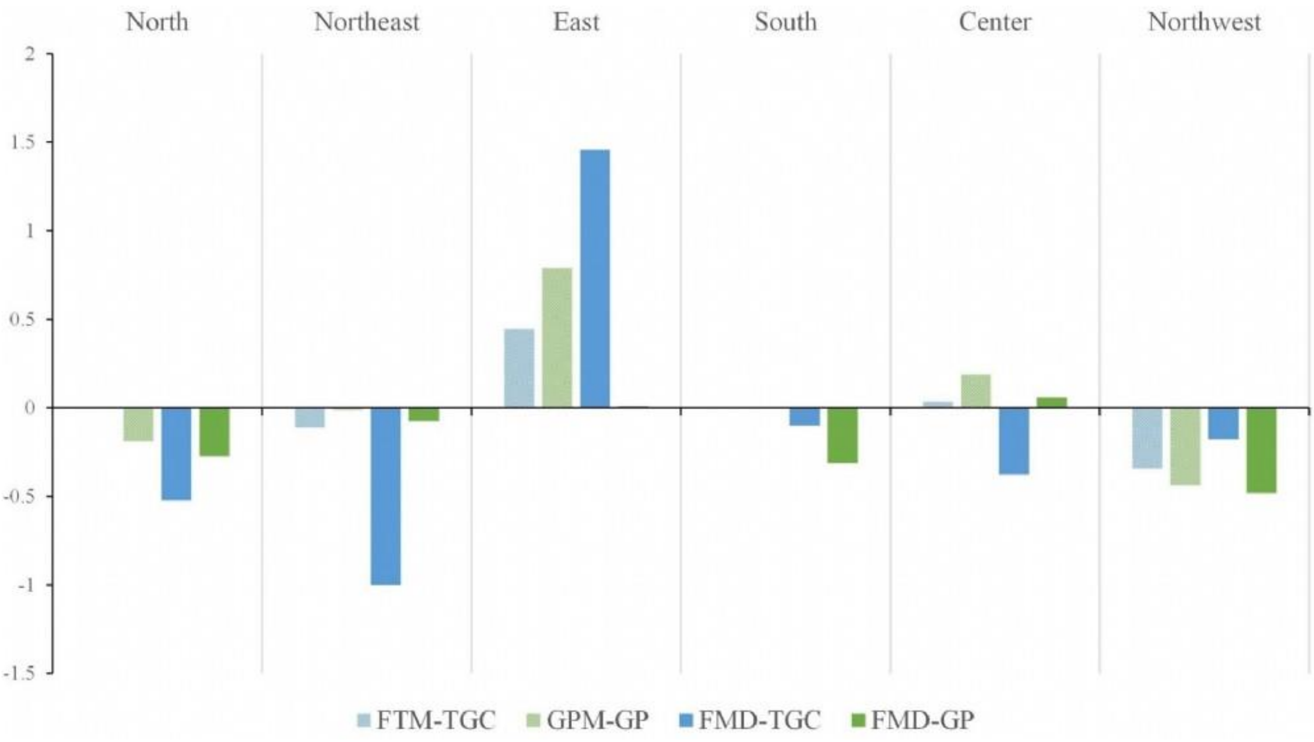


Fig. 7 Total green power generation in the six regions

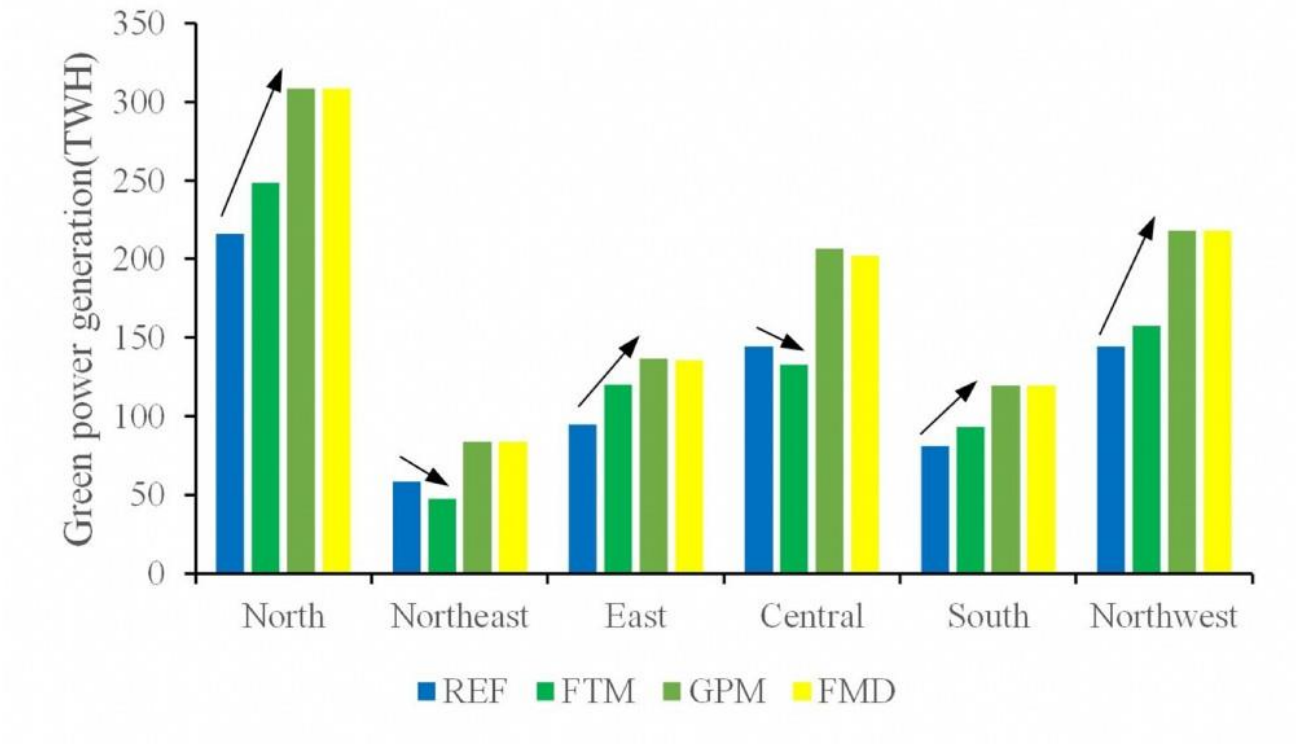


Fig. 8 Interregional green power transmission

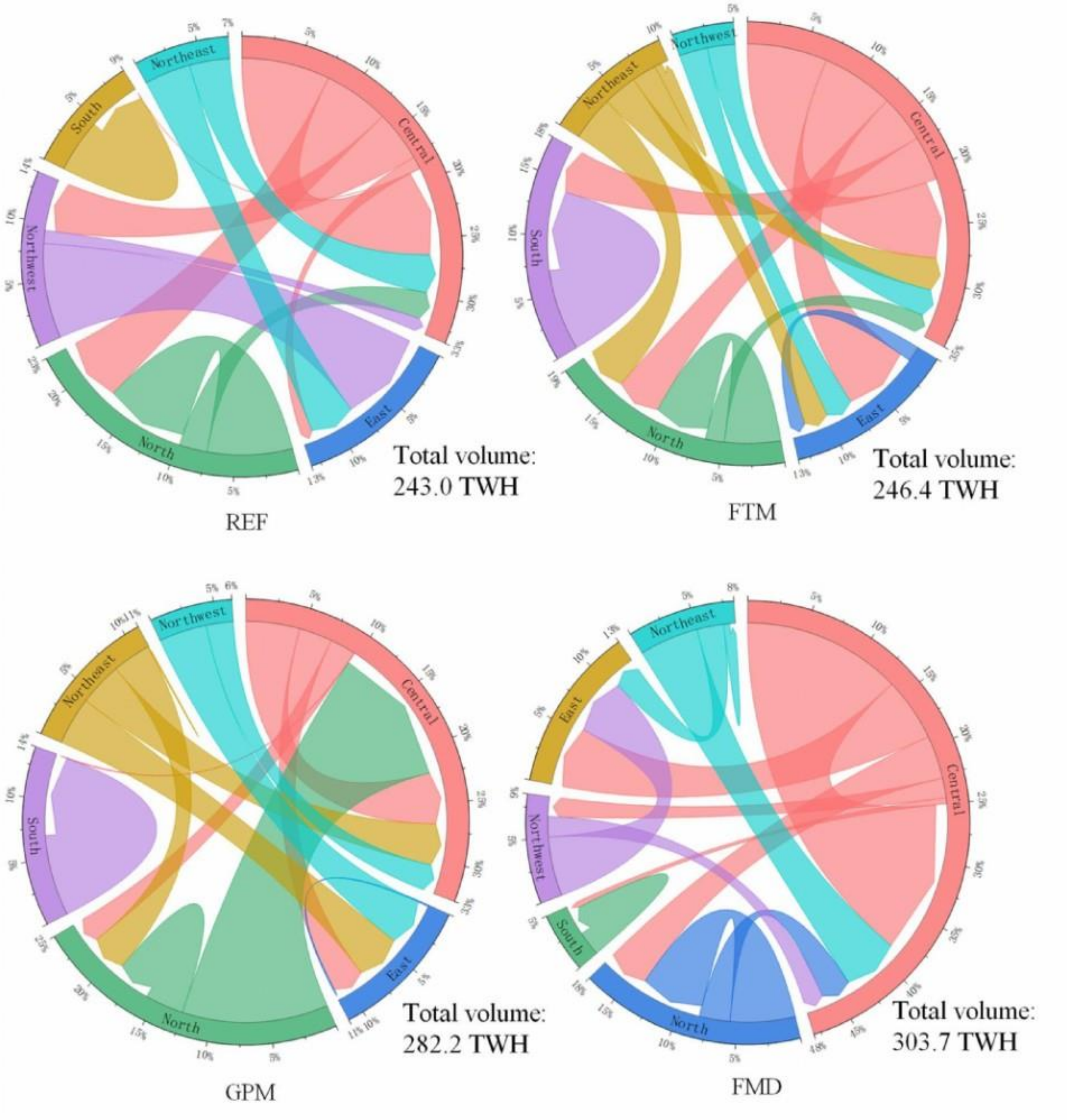


Fig. 9 Interregional power transmission

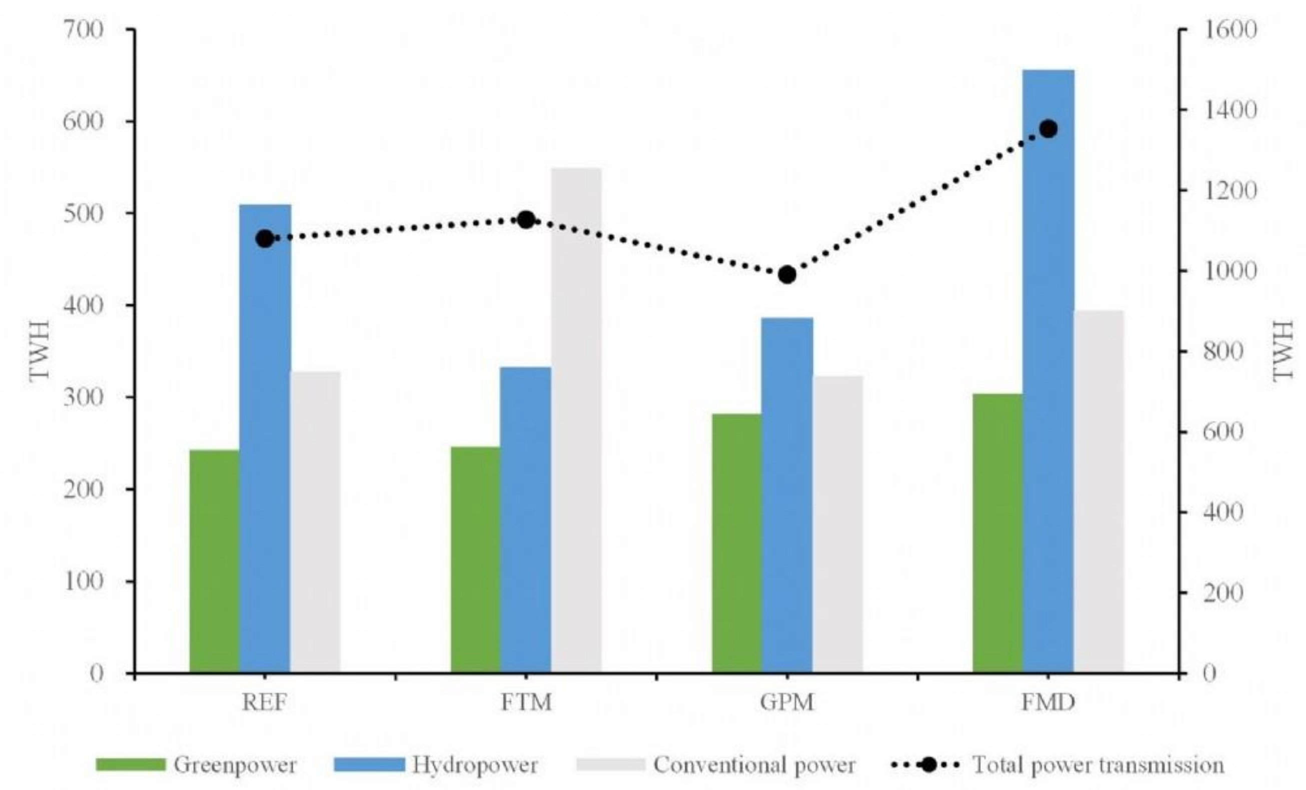
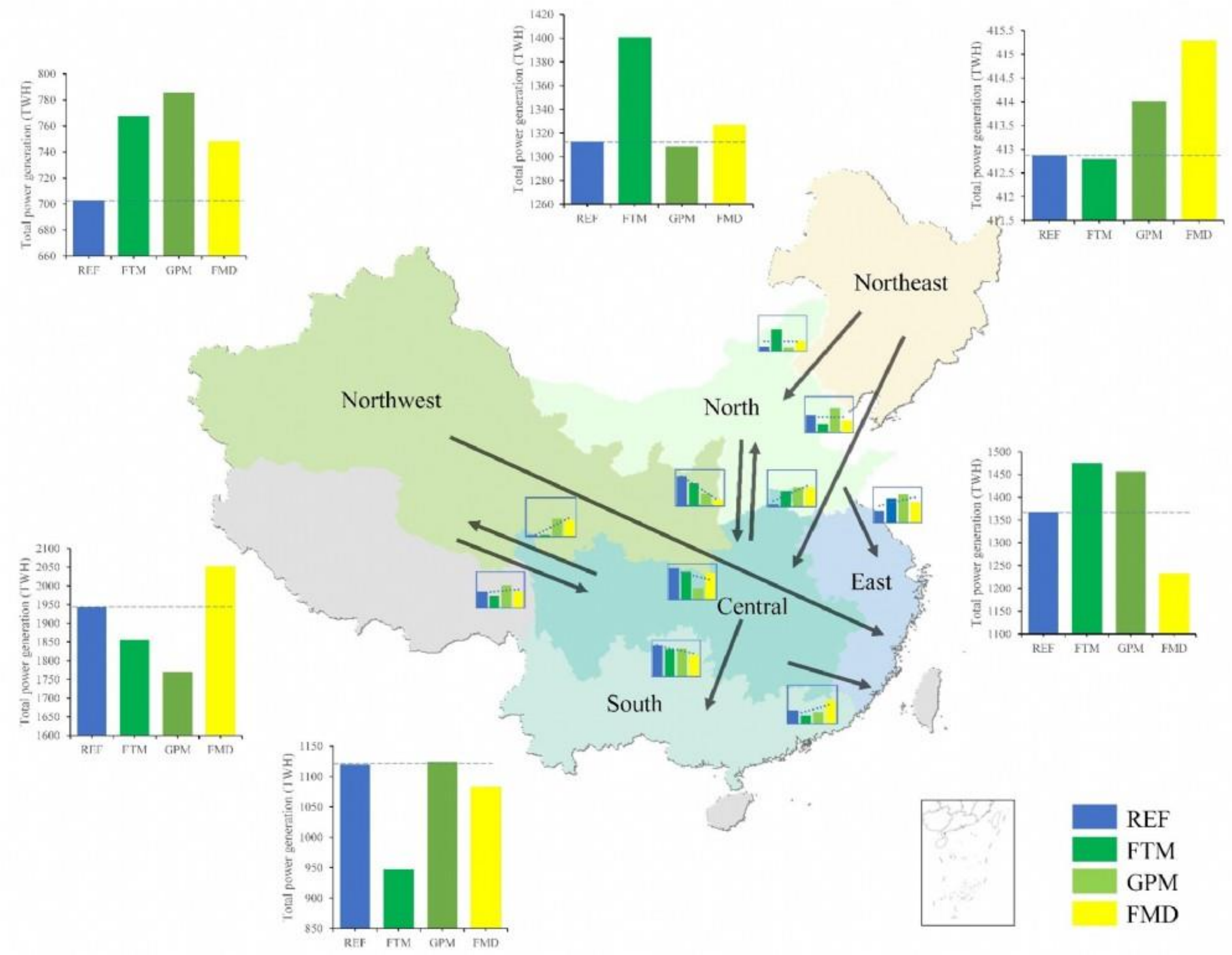


Fig. 10 Interregional power transmission and generation by regions



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[Abstract:0052] OP-073 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Redistribution mechanisms for energy community-incurred grid costs

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Overview:With legislation for Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) provided within the recast of the Renewable Energy Directive (REDII) and the Electricity Market Directive (EMD) at a European level, EU member states have been obliged to enact national legislation for energy communities (ECs). Thus, the foundation is laid for citizens to reconquer a certain extent of control of their energy supply, and make an active contribution towards a more sustainable energy future. Since EU guidelines are not precise regarding how certain aspects of ECs should be realised, member states are given a certain extent of freedom regarding the details of transposition into respective national legislations. However, it can be observed that ECs are oftentimes regulated quite strictly, which limits their potential to freely follow individual objectives. In the course of this study, an attempt is made to provide ECs with the means to follow their unique objectives and values.

For energy exchanges within the EC, certain costs arise. The two most significant parts of these are on the one hand (i) costs for energy purchased from community peers (and also revenues for selling energy to peers), and on the other hand (ii) costs for grid usage. While the price for inner-community energy exchanges is usually decided by the EC participants collectively, grid charges cannot be decided by the community, but are simply imposed by the DSOs -- being regulated monopolies, having to recover their expenses from infrastructure maintenance and grid operation. Although an EC cannot alter the height of grid charges (and/or their allocation to individual participants) directly, they still have the option to apply re-distribution mechanisms ex-post. This is one significant degree of freedom to shape cost distribution such that it fits to an ECs unique characteristics and objectives.
Methods:In the course of this work, three different EC-incurred grid cost redistribution mechanisms are developed. These follow entirely different objectives, thus benefiting different EC participants:

- Income-based redistribution: It is suggested to categorize EC participants based on their income. Thereby, three income-categories, namely low-income, medium-income and high-income households are distinguished. The redistribution algorithm is developed such that low-income households are completely relieved of their EC-incurred grid costs. This means that exactly these costs need to be redistributed between medium- and high-income households, since it needs to be ensured that all grid costs imposed by the DSO are covered. The logic behind the redistribution mechanism is that households (of the medium- and high-income category, respectively) recording higher shares of financial benefits due to community participation, also bear higher amounts of the costs needing to be redistributed.

- Contribution-based redistribution: This mechanisms benefits households with a PV system installed. The thought behind it is that without households bringing PV systems into the EC, the EC could not be realized. Thus, the EC-incurred grid costs of households equipped with a PV system are redistributed to the remaining members of the EC. The additional costs each household without a PV system has to overtake depends on the share of their load that could be covered from energy purchased from community peers, and is thus also dependent upon their individual benefits gained through community participation.

- Proximity-based redistribution: This mechanism is based on the logic to incentivize local energy consumption. For that, an EC is subdivided into different proximity areas. Energy exchanges between households within the same proximity area are exempt from paying grid charges, wherefore cross-proximity-area energy exchanges are burdened with higher grid charges, such that in total all grid charges originally imposed by the DSOs are covered.

All three redistribution mechanisms are applied to a fictitious EC consisting of twelve single-family households, out of which six are equipped with a rooftop PV system. The impact of the proposed redistribution mechanisms on the individual EC participants is evaluated, and discussed with respect to fairness.
Results:As results, I choose to provide insights into income-based redistribution in particular, since the abstract length does not allow to discuss results of all three redistribution mechanisms.

Out of the twelve households of the fictitious EC under investigation, three are considered low-income, six medium-income, and the remaining three are considered to be high-income households. Results show that the additional financial burden of medium-income households ranges between 5€ and 11.6€ per year. In contrast, the additional burden for households classified as high-income is significantly higher and ranges between 27.6€ and 39.8€ per year. When seen as pure monetary values these numbers do not make the impression of being significant for high-income households, however, it needs to be noted that the EC-incurred grid costs of high-income households are almost doubled when applying redistribution. Concluding, the number of medium- and high-income households is decisive for the relative additional financial burden of individual households, respectively. Despite medium- and high-income households face additional financial burden due to redistribution it needs to be stated that EC participation still proves to be economically viable.

One major point in favor of income-based redistribution is that it opens up a possibility to better include households with limited financial means by providing additional financial alleviations in addition to those benefits already achieved by EC participation per se. This way of redistribution also tries to tackle claims posed by the European Directives, namely to alleviate energy poverty and

include vulnerable customers. However, whether this form of redistribution would be actually applied by an EC depends significantly upon the social-mindedness of all participants, as well as on whether participants actually openly disclose their financial situation. Full disclosure of income could be a hurdle for low- as well as for high-income households. And, if participants would need to allocate themselves to one of the three income-levels (in order to avoid full disclosure), there is the danger of strategic behavior, benefiting some, while disadvantaging others.
Conclusions:The three proposed redistribution mechanisms have proven suitable for ECs to pursue individual objectives. A significant strength of the proposed redistribution mechanisms is that they are not restricted to application to EC-incurred grid costs, but can be used for any kind of cost component that needs redistribution. Moreover, the algorithms are developed such that an application to any kind of EC is possible, independent of the types (households, SMEs, etc.) or number of participants. Since such redistribution mechanisms are the first of their kind, they can also be used as inspiration for the establishment of any other redistribution mechanism that might seem fit for EC application.
References:None necessary.

Keywords: energy community, grid cost, redistribution mechanisms

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[Abstract:0118] OP-074 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

The impact of relative price on household electricity consumption

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Overview:Residential responses to price changes under nonlinear electricity pricing, like incline block tariffs (IBT) schemes, has long been discussed (Borenstein 2009; Ito 2014; Alberini, Bezhanishvili, and Ščasny` 2022). However, little evidence has been uncovered from developing contexts. We fill this gap by estimating the price responsiveness of residential electricity consumption in a developing setting - South Africa. Our analysis is underpinned by hourly metering data (for more than 600 households across the country and their locations) available both before and after a regulatory approved price rise. Timing and location allows us to match the data to weather stations, and, therefore, outdoor temperature; the location and timing also allows us to use astronomical data to separate night from day. Finally, the metered households are surveyed, and, therefore, we are able to capture many variables that correlate with electricity consumption.

The combined data provides a unique opportunity to explore the price response of a representative group of South African households at the hourly level or for other time aggregations (e.g. daily or monthly). Furthermore, since the price increase differs by 'block' – the increase is greater for households using more electricity – we are able to explore differential price responsiveness. In addition to the average and marginal block tariff effect, we can separately identify temperature and night-time effects.

To evaluate the block price effect, we employ a difference-in-difference (DD) method. In our case,

the control and treatment groups are determined by their monthly electricity consumption, where the control group consumes less electricity per month (i.e. their consumption would lead to the relatively lower price increase, because they are in the lower consumption block). Since the survey data is collected once, but the electricity and temperature data are available for (nearly) every hour from January to July of 2014, we apply both ordinary and panel fixed effect regression models.

We find that, once we control for temperature, households use less electricity after the price increase. Furthermore, our results support the expectation that households with relatively higher energy consumption are less responsive to price increases than those with lower energy consumption. This research contributes to the literature by (i) using rarely available hourly metering data, and (ii) exploring both the average and marginal price effects of block tariff increases in a developing setting.
Methods:As highlighted above, we apply a DD estimator in which the control group was defined to be in the lower monthly consumption block, while the treatment group was defined to be in the higher monthly consumption block. Since the electricity data is collected at the hourly level, we summed hourly household consumption to determine monthly consumption. We use the average consumption in the first three months of 2014 to separate our groups, see below.

One problem arising, when summing the hourly data, was missing meter readings – approximately 9% of the observations, even though millions of observations remain. Thus, we chose to impute the missing values from an initial fixed effects regression. These same variables were also included in the main DD model(s). Specifically, we control for temperature, as well as household, hour, day of week and month fixed effects. Hourly temperatures are assigned to one of 39 temperature bins having a width of 1◦C. Although the inclusion of temperature dummies may not yield a smooth temperature response pattern – something we are exploring – the advantage of this inclusion is that we do not specify any particular pattern, assuming only that the relationship is reasonably constant over each temperature bin.

With the imputed hourly usage, we are able to determine monthly electricity consumption, the crucial factor for separating the 'treated' from the 'untreated'. As previously mentioned, the control and treatment groups are determined by the average monthly electricity consumption for each household across the first 3 months in 2014, i.e. January to March, because electricity prices increased from April 1, 2014. Importantly, the block structure remained constant across that date, i.e. there are two blocks separated at the 350 kWh per month threshold. As can be seen in Table 1, the price increase for Block 1 is 5.6% and 7.6% for Block 2, i.e. the relative price increase for Block 2 is larger than Block 1.

Once the control and treatment groups are defined, we employ a DD estimator to capture the effect of relative price increases on household electricity consumption. By controlling for temperature dummies and several fixed effects separately, it allows us to distinguish the temperature impact from the price change impact. As is the case with other DD models, we include a 'post' term, a 'treatment' term and an interaction term, 'post × treatment'. We do this, because there are only 4 prices – two in each block before after the tariff hike. Thus, we do not use prices in the model. Instead, we use the block and time structure: the control group is in the bottom block, while the treatment group is in the higher block. Although both groups are 'treated' with an increased tariff, our DD application takes advantage of the differential treatment (relative difference in price increase).

With respect to interpretation, the 'post' effect captures the average change in consumption after the price increase, and it is necessary to remember that both groups face higher 'post' prices; thus, we expect a negative 'post' effect. On the other hand, the 'treatment' effect captures the average difference in consumption across the two groups, and, since the treatment group is defined as having more consumption in the first few months of the year, we expect this effect to be positive. Finally, the interaction effect captures the relative difference in the 'post' effect for the 'treated' households compared to the 'untreated'; it is the differential in price responsiveness across the two groups following the differentiated price increase.
Another concern that arises in the model is the large number of recorded zeroes in the data, missings are recorded separately. For that reason, we use the square root of hourly consumption, rather than its log. Given the square root transformation, DD parameters are not directly interpreted as the percentage change in the outcome; rather, it is the percentage change in the exponentiated outcome (which is not commonly used).
Results:For South African households, electricity is the main energy source to meet daily needs; therefore, electricity demand is expected to increase sharply during winter months (May - August). Figure 1 shows that more electricity is consumed for both the control and treatment group after April. Given that South Africa is moving into the winter months around that time, the increase is likely

driven by increased night-time, as well as reduced temperatures, requiring more electricity for lighting and heating than at other times of the year. Therefore, our analysis controls for temperature, and will also separate night-time from day-time.

As noted above, we estimate a DD model on hourly electricity consumption, having imputed missing hourly data. Initial results are shown in Table 2. The first three columns are based on a fixed effect panel model (household fixed effects are always included), and, since Block 2 households are (always) the treated households, no 'treatment' estimate is available. However, the last column is based on OLS, where we include a range of covariates that are fixed for each household (this data was only collected once); thus, this model estimates a 'treatment' effect.

Our first result, in column (1), where we include only household fixed effects, but ignore the temperature an the hour of consumption (which partially addresses day and night differences). matches those illustrated in 1: consumption is higher, on average, after April 1, and is even higher for Block 2 households. In column (2), although the model includes temperature effects, it does not include hour effects. Again, we find that electricity consumption increases after April 1 and is larger for Block 2 households. In column (3), the model includes hour effects as well. Doing so leads us to the expected result that consumption is lower, following the increase in prices, i.e., the 'post' term is negative. As before, we continue to see that the average consumption in Block 2 households, however, remains higher, suggesting that Block 2 households are relatively less responsive to the price change than households in Block 1. The results in the fourth column are similar to those in column 3, consumption decreases following the price increase (and by less in Block 2 households); however the OLS model also captures the expected 'treatment' effect (since household fixed effects are not modelled): households in Block 2 consume more electricity than those in Block 1, on average.
Conclusions:We apply DD to estimate average and marginal household price responses using combined hourly metering data and temperature data, together with household level survey and price data. We do so in a developing country, the first such study of which we are aware. We find that the ability to control for both temperature and time, as well as household features, is important. Once controlling for these features, we find relatively small reductions in electricity consumption, which is not surprising, given the small lapse in time in our analysis. We also find that households in Block 2, those that consume more electricity consumption on average, reduce their consumption less than those in Block 1: households that use more electricity are less responsive to electricity price changes, even when those price changes are relatively larger, at least for this representative group of South African households.
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Keywords: Household electricity consumption, price response, difference-in-difference

[Abstract:0189] OP-075 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Optimal and Incentive-Compatible Scheduling of Flexible Generation in Electricity Markets

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Overview:There is a growing need for electricity-system flexibility to maintain real-time balance between energy supply and demand. This talk explores the optimal and incentive-compatible scheduling of generators for this purpose. Specifically, we examine a setting wherein each generator has a different operating cost if it is committed in advance (e.g., day- or hour-ahead) as opposed to being reserved as flexible real-time supply. We model an optimal division of generators between advanced commitment and real-time flexible reserves to minimize the expected cost of serving an uncertain demand. Next, we propose an incentive-compatible remuneration scheme with two key properties. First, the remuneration scheme incentivizes generators to reveal their true costs. Second, the scheme aligns generators' incentives with the market operator's optimal division of generators between advanced commitment and real-time reserve. We use a simple example to illustrate the market operator's decision and the remuneration scheme.
Methods:The problem is analyzed in two steps. First, we study the market operator's problem of determining the optimal commitment of generators as an optimal control problem. By using calculus of variations, we are able to derive an intuitive expression that gives the optimal division of generators, depending upon their two cost characteristics. Second, we examine the related problem of how to remunerate generators to ensure that their profit-maximizing decisions are aligned with those of the welfare-maximizing market operator.
Results:We demonstrate that marginal pricing aligns the incentives of generators and market operators. If marginal pricing is not employed (e.g., due to administrative scarcity pricing or price caps), then generators must be paid information rents to align generator and market-operator incentives. We derive the optimal incentive-compatible and individually rational information rents. We demonstrate the market results with a simple example.
Conclusions:Our work shows how markets should be designed to ensure that incentives are aligned between generators and market operators to maintain needed flexibility to ensure reliable electricity supply. This can be done using "textbook" marginal pricing. If marginal pricing is not implemented, we demonstrate how information rents can be used to align generator and market-operator incentives. This work has clear implications for how electricity markets and policy should be designed to maintain reliability in the face of increasing supply and demand variability and uncertainty.
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Keywords: Electricity-market design, mechanism design, energy pricing, electricity flexibility

[Abstract:0196] OP-076 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Does Market Integration Reduce Market Power? Evidence from China

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Overview:Since the new round of electricity system reforms in 2015, China has established an electricity market system covering medium- and long-term, spot and ancillary services transactions. However, as each province has their own unique market structure and market rules, inter-provincial electricity transactions still subject to inter-governmental negotiations to determine medium- and long-term electricity purchase quantities and prices. Since 2022, the central government of China has been pushing to remove inter-provincial market barriers and has set the goal of establishing an integrated national electricity market system by 2030. Consequently, Guangdong and Yunnan provinces attempted to integrate their electricity markets.
We study the impact of electricity market integration on market power and welfare improvement. Our paper is one of the first to analyze electricity market integration and market power in a unified framework. The theory suggests that market integration reduces market power and improves total social welfare in both regions through increased trade and increased competition (trade effect and competition effect). In addition, price changes resulting from market integration may further affect residual demand, which further influences market power, social welfare, and welfare distribution. Our findings will guide designing operational models of market integration.
Methods:First, we use econometric equations to analyze how integration changes prices, generation costs, market power, and residual demand in the electricity market using hourly electricity market transaction data from 2022-2023 in Guangdong. Thus, we utilize the machine learning counterfactual estimation method to study the treatment effect of market integration on electricity prices and market power.
Next, we construct a structural model of two electricity markets to explain the underlying mechanisms for the impact of market integration. We start from using the traditional oligopolistic market equilibrium simulation method by dividing the units into fringe and residual units and combining them with aggregate demand to obtain residual demand. Then, using 8760 hours of node-level transaction data and the basic information of the generating units, we estimate the marginal cost of electricity supply, and use instrumental variables to estimate hourly supply curves of each node and sum it up to hourly aggregate bidding curve. Based on the bidding curve, we analyze the impact of market integration on prices, these impacts may come from trade and or from changes in market competition and cost markups (namely, trade effect and competition effect). Based on these, we estimate changes in market power and total social welfare for each region, as well as changes in welfare distribution between electricity suppliers and consumers.
Results:Using econometric analysis, we find that the integration of the Guangdong and Yunnan markets reduce at Guangdong side as the importer the market power by 17%, increase residual demand by about 14%, and reduce prices by 12%. In addition, the cost of generation increased by 1% due to the expansion of residual demand.
Using a structural model of the electricity markets in the two regions, we find that market power declines in both regions after integration, and that social welfare increases by $800 million per year, or about 3% of the total cost of generating from the residual units, if no change in residual demand is assumed. In the case of changes in residual demand as a result of price reductions, total social welfare increases by about 5% of the total cost of generating from the residual units, 93% of which is attributable to trade effects and 7% to competition effects. The welfare of generators in the region with high prices is impaired, but the welfare of consumers in this region is substantially increased; the welfare of generators in the region with low prices increases, and the welfare of consumers in this region increases, but the latter may become welfare-reducing under some parameter settings.
Conclusions:In recent years, the Chinese government has introduced policies to remove market barriers in order to improve the operational efficiency of the electricity market. The evidence from our study suggests that market integration reduces market power in both regions and improves total

social welfare through increased trade and increased competition (that is, trade effect and competition effect). However, there is a possibility of welfare loss for power generating firms due to the decrease in market power. Therefore, in promoting market integration, there is a need to mitigate negative impacts such as power shortages due to the exit of high-cost firms from the market as a result of lower prices, such as promoting investment in clean energy. In addition, our study covers 1-2 years of data, therefore the long-run impact is omitted -- as the price decreases, aggregate demand increases along the long-run demand curve, potentially changing the level of welfare at equilibrium. In future research, a long-term analysis could be conducted using data over a longer time period.
References:The reference is not available at the moment.

Keywords: Market integration, market power, electricity market

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[Abstract:0283] OP-077 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Simulating scenarios for preventing a coal addiction in Colombia

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Overview:Colombian government signed in 2023 the Powering Past Coal Alliance (PPCA) and the Beyond Oil & Gas Alliance (BOGA), being one of the first in Latin America and one of the largest producers of coal and gas to join the growing bloc of nations spearheading the push for a Fossil Fuel Non-Proliferation Treaty. Those agreements show Colombia's commitment to a Just Energy Transition aiming for a 100% renewable electricity mix and achieving Net zero, reducing 51% of GHG emissions by 2030. Still, there is not yet a detailed roadmap or specific actions for the coal power plants' exit; coal plants continue to appear in the generation plans because they provide reliable energy and support hydropower plants during low hydrological periods (e.g., during El Niño).
Colombia has 19 active coal-powered generation plants (1.7GW), which generate an average of 11% of the national total electricity, with an emissions factor of 0.78kCO2 per kWh. By 2037 Colombia expects to install approximately 3-7GW of solar and 5-6GW of wind, representing 45% of the total installed capacity, replacing fossil fuel generation (especially coal). Nevertheless, renewable projects are delayed due to social-environmental conflicts, successful industry lobbying (risk of gas lock-in), lack of infrastructure, delays in environmental licensing of projects, and tax exemptions, among others. Even some of the projects that have been awarded at auction have actually been withdrawn. Additionally, electricity demand in Colombia is growing at an average annual rate of 2.2-3.6% and the new renewable plants would have to satisfy the new demand in the short term and not substituting the thermal power plants. In this context, are coal plants fundamental for Colombia's future electricity generation? Could Colombia achieve a total coal phase-out? Is it urgent or strategic for Colombia to phase out coal now?
Methods:Parra et al. (2024) developed a simulation model to quantify and represent possible futures for the energy transition in Colombia by 2050. Given different economic conditions, the underlying system dynamic model (Parra et al., 2024) simulates the evolution of generation capacity and the distribution of generation technologies in Colombia. The results show that Colombia could achieve a 100% renewable generation in most scenarios, but coal installed capacity would only disappear once at least some policies are implemented. Additionally, coal capacity and generation increase under a

scenario of an economy with low fossil fuels prices and an unfavorable environment for the JET (Figure 1). So, this research uses this last scenario to test the effect of policies and actions for exiting coal plants and achieving a complete renewable generation matrix by 2050 when coal generation is needed.

Figure 1. Installed capacity for source and electricity generation mix in the scenario business as usual and Jenga (Scenario of an economy with low fossil fuel prices and an unfavorable environment for the energy transition). Adapted from Parra et al. 2024.

In this work, we test out three energy policies: 1) A phase-down policy, where no more investment in coal installed capacity is allowed, but the current coal installed capacity is preserved; 2) A phase-out policy, where additionally to the prohibition of new investments in coal, the installed capacity is progressively decommissioned; and 3) An increase in the emissions tax, a sensitive analysis with different values.
Results:Figure 2 shows the difference in the coal capacity and the other electricity sources with the implementation of the phase-down and phase-out policies. For the phase-out and phase-down policies, additional investment in renewable sources (2GW of solar and wind) replaces the potential increase in coal capacity. The main difference is the investment time; for phase-down, the investment takes place in 2040, while phase-out starts in 2030 (just when all the coal capacity is out). Since both policies replaced coal with renewables, the emissions decreased, and the average electricity prices remained low.

Figure 2. Comparison of the coal capacity in the Jenga and BAU scenario with the coal capacity with the policy implementation (Left). Coal capacity investment transference to other sources with the policies in the Jenga scenario (right).

Figure 3 compares the variation of coal and gas capacity with emission taxes, assuming a scenario unfavorable to RE, with a BAU scenario with no taxes. A carbon tax lower than 100 USD/tonCO2 does not reduce the coal installed capacity; on the contrary, it could slightly increase it. Carbon taxes near 400 USD/tonCO2 are required to gradually remove installed coal and gas capacity from the generation mix. For carbon taxes between 100 and 400 USD/tonCO2, there is a gradual substitution of coal for gas, and the reduction in the level of emissions is low. Since current thermal capacity is not decommissioned under this policy, thermal plants continue generating, and electricity prices increase as carbon taxes increase the LCOE.

Figure 3. Installed coal and gas thermal generation capacity for the reference scenario and varying carbon tax

Figure 4. Composition of the power generation matrix in the reference scenario with phase-down and phase-out policies

Figure 5. CO2 emissions and electricity prices for phase down and phase out scenarios (Jenga: Unfavorable case).
Conclusions:Is it urgent or strategic for Colombia to phase out coal now? Colombia is currently phasing out fossil fuel, coal and gas prices are high, and the environment is favorable for the TEJ. Therefore, Colombia has enough capacity to supply electricity in the short term (especially with the entry of the second unit of Hidroituango), and coal is displaced by increasingly competitive PV and Wind power generation. Therefore, the policies for coal exit do not appear essential now beyond the support and credibility of the government’s narrative.
Implementing an explicit and gradual policy for the coal plant's exit does not change the current tendency. However, the coal phase-out policy prevents the resurgence of coal if FF prices decrease and the environment becomes unfavorable for the JET. Additional research should be done to discern the urgency of the policy by evaluating the cost of implementation and its implications for the communities, which were beyond the model scope.

In a scenario with unfavorable conditions for RE, the three policies can successfully achieve a 100% renewable electricity generation mix, replacing the coal capacity with solar, wind, or gas by 2050. However, from the three policies, the increase in emission tax is the least advisable since to have a real impact, the tax should be around 400 USD/tonCO2; lower values should not be significant for reducing coal installed capacity or reducing emissions and could incentivize the gas generation instead. Additionally, implementing the policy in the short term could increase electricity prices. An alternative should be implemented after 2030 to avoid the high prices in the short term.
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Keywords: Energy Transition, Simulation, Coal Phase-out

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[Abstract:0290] OP-078 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Heading towards democratic, sustainable and competitive electricity systems

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Overview:The electricity system is virtually world-wide undergoing significant changes. In this context the following issues are important: (i) More and more customers become interested in contributing to their own electricity supply and to switch to "prosumagers" and /or join renewable energy communities (RECs). (ii) This trend is supported especially by the emergence of decentrally applicable technologies such as PV, small hydro and wind power plants and accompanying use of battery storage; (iv) energy energy communities have emerged focusing on using local electricity generation on a decentral level; (iv) These developments lead on the systems side to a need for "back-up" capacity (incl. storage) and demand-side flexibility; (v) Finally a new tariff system for end users is needed reflecting the value of energy and power feeded in and taken out of the grid at every point of time. This process is currently under way in many European countries and in California. And in these countries also a change in the principle how prices come about is already under way. A major reason for this development is that in recent years the electricity generation from variable renewable energy sources (VRES) especially from wind and photovoltaic (PV) power plants increased considerably.
The major objective of this paper is to analyze and provide insights on how to bring about a competitive, sustainable and democratic electricity system with even higher shares of VRES in an economically balanced system but without escalating political interventions. It is triggered by the current discussion on how to integrate large shares of variable RES but the fundamental intention goes beyond that. It is to show how to head towards real democracy and sustainability in electricity systems, retaining at the same competition in the system and including all dimensions such as generation, storage, but especially the customer side. This is a challenge for all countries world-wide.
Methods:Our method of approach is based on the following principles: (i) Crucial is coverage of residual load (= difference between final electricity demand and generation provided by non-flexible electricity generation); this is modeled on an hourly base over a calendar year based on assumed variable RES generation and development of the load profile; (ii) Deduction of available conventional and backup capacities including must-run (iii); consideration of flexibility on the demand-side based on consumer and RECs behavior incl. flexibility instruments such as batteries etc.; (iv) hourly electricity prices equal to short-term marginal costs and scarcity rents.

Results:The major results are:
1) Of core relevance for a complete markets and to enhance competition is a pricing system in an energy-only market where the price signals provide information about scarcity or excess capacities at every point-of-time;
2) Most important to balance variations in residual load is a portfolio of flexibility options such as: (i) Battery, pumped hydro and other storage; (ii) Technical demand-side management; (iii) Demand

response due to time-of-use pricing,
3) However, flexible power plants for capacity system adequacy will play a role in every system with and without regulated capacity payments
A very important aspect is to provide the right price signals for final customers by implementing a bidirectional tariff system for separated components for energy and power, Another major finding is that in a complete market there will be new players in the chain, prosum(ag)ers, energy communities, and the supplier as the backbone for providing residual load by means of flexible capapcities. The supplier is finally the logical market coordinator of the electricity supply chain and the organizer of competition between the different options. Finally we state that the transition towards a competitive and sustainable future electricity system will be based on the following principle of "new thinking", which is to accept a paradigm shift of the whole electricity system - including switching from an inflexible and one-way system where variable load is met with changes in generation to a more flexible and smarter system allowing two-way electricity flows – to our understanding – a greater scope for demand participation by consumers needs to be included.
Conclusions:Our major conclusions are:
• Revised Energy-only-markets have to be introduced which allow temporarily shortage prices higher than short-term marginal costs and in times of excess electricity negative prices;
• A very important element of such a market will be flexibility options. But these will only be harvested when sufficiently high price signals from the electricity markets trigger these options, when "the exploration principle in the markets work". Yet this will only be done if the market is not distorted by centralized capacity payments.
• Finally, it is important to provide the right price signals for final customers, for prosumers and especially for energy communities by implementing a bidirectional tariff system for separated components for energy and power.
• Another conclusion is, that it will be necessary to accept a paradigm shift in our understanding of the whole electricity system where no longer the generators are in the centre but coordinating entities such as balancing groups, energy communities, prosumagers respectively the supply companies.
• And finally we state that the evolution of such a creative system of integration of RES in Western Europe may also serve as a role model for electricity supply systems largely based on RES in other countries world-wide.
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Haas R., Auer H., and Gustav Resch: Heading towards democratic and sustainable electricity systems – the example of Austria, Renew. Energy Environ. Sustain. 7, 20 (2022), Published by EDP Sciences, 2022, https://doi.org/10.1051/rees/2022009

Keywords: Electricity markets, renewables, energy communities

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[Abstract:0302] OP-079 [Accepted:Oral Presentation] [Electricity » Power System Planning & Management]

Revolutionising energy: the role of flexible hydrogen production in New Zealand's renewable electricity future

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Overview:New Zealand's commitment to operating a 100% renewable electricity network against a backdrop of rapidly growing demand will require the extensive uptake of additional renewable

generation. The intermittent nature of these sources introduces significant security of supply risk to the electricity network, particularly in dry years when lake inflows are lower than normal. A balancing mechanism is needed to ensure the country's electricity system remains secure and reliable as it undergoes this decarbonisation transition.
A proposed solution to this dry year and intermittent risk is to use a green hydrogen plant as a large-scale demand response option, combined with using hydro-generation flexibility to smooth intermittent renewable generation. Green hydrogen production can ramp up and down extremely fast in response to intermittent renewable energy generation and is technically feasible at large scales.
This research takes twenty-one years of historical meteorological, generation, and demand data and uses it to model a 100% renewable 2050 electricity system. The findings reveal that the least-cost configurations of wind and solar capacity in a setting with large hydrogen production (0.5-8GW) can address New Zealand's network challenges and meet all expected electricity demand in 2050. This is the first study to model hydrogen DSR in a system with large hydro generation to achieve a 100% renewable electricity system with large amounts of wind and solar.
Methods:To start with, we simulate demand and potential renewable solar and wind generation for 2050. The model's future demand profile is created by sourcing New Zealand's historical demand profile and linearly upscaling it to a projected 2050 annual value of 70 TWh (Transpower,2020). Average daily historic wind generation capacity factors for 5375MW of operating, under construction, or consented wind farms were sourced from the renewables.ninja platform (Pfenninger and Staffell, 2016; Staffell and Pfenninger, 2016) which combines atmospheric data and reanalysis from NASA's MERRA and MERRA 2 databases to form a retrospective view of wind speeds across New Zealand. In our optimisation, we stay with the same sites but scale the total 5375 MW up or down as needed. Hourly resolution data from all sites and the daily capacity factor by location were weighted by wind farm capacity size to form a daily generation profile across the country. Daily solar capacity factors were also sourced from the renewables.ninja platform across the five best New Zealand locations close to population centres.
Hydro output, we assume initially, is the same as historic values. However, over the period from 2000 to 2021, historic geothermal output is linearly upscaled to 1,700 MW in accordance with Transpower's Accelerated Electrification scenario. New simulated wind and solar output is then added to give a projected 2050 daily renewable generation profile compared to projected demand. Our modelling concentrates on daily demand-supply imbalances as we assume any hourly imbalances over a day are smoothed by Li-Ion batteries.
The 21-year data analysis period is from January 2000 to December 2020. This time span is assumed to accurately depict various environmental scenarios and market conditions, in particular, the system's experience with "dry years" in 2001, 2003, 2008, 2012, 2017 and 2020. Dry years are when inflows into the hydro dams are low and hydro generation needs to be reduced.
Hydrogen production plants of varying capacities (0.5-8GW) were then added to the model's demand profile, and a hydro dispatch mechanism was added to fully utilise the storage potential of the system's hydro resources. Hydro re-dispatch is an important part of the model. If renewable generation is high hydro generation is reduced and vice-a-versa. After any hydro redispatch the model then calculates the system's capacity imbalance and decides if the hydrogen plant will need to reduce its load on the network. By adjusting its demand, the plant acts to "smooth" network imbalances.
The model calculates changes in the hydro storage lake levels due to the hydro redispatch and tracks total lake storage levels, with one exception to prevent the lakes from going too low during dry years. We impose a minimum redispatch level of 1000GWh. When storage levels reach this value, the model assumes that a "dry year" is occurring, and the system balancing mechanisms switch; the hydrogen plant will reduce its load to free up generation for consumption to cover any shortfalls in renewable output. If additional capacity is needed, then hydro redispatch will be used as a last-resort option. This reduces hydro generation in dry years and keeps hydro storage levels as high as possible, but still aims for there to be no unmet demand in the system. It does mean that during a dry year event, when inflows are low, the capacity factor of the hydrogen plant is significantly lower.
The total system cost is minimised by adjusting solar and wind capacities using Excel solver's GRG nonlinear tool. When the hydrogen plant has to reduce production, we assume it receives a deficit cost of $400/MWh. Overbuild of wind and solar is penalised by the long run levalised cost set at $55/MWh. Finally, if there is unmet demand, this is penalised at a price of VOLL. The number of average annual, shortage, and outage days are calculated and presented as a percentage, and the total deficit, outage, and surplus costs are calculated over the 21-year period using a fixed cost.
Results:Our preferred hydrogen production plant size is for 3GW. Projected average daily demand is around 11GW including the 3GW from the hydrogen plant. For the optimum configuration wind generation averages 5.3GW with solar at 2.9GW. In this case with hydro redispatch the system has a small number of outage hours (0.001%) when demand cannot be met even with the hydrogen plant switched. Hydrogen production is needed to back off for 6.5% of the days simulated. Even with

the hydro dams acting as a large battery there is some spill of surplus of intermittent wind and solar at 8%. Larger hydrogen plants give no outage hours but at a cost of higher spill. Since the hydro dams are acting to a large extent as a large battery the capacity factor of the hydrogen plant is very high at 97%. A summary of all results are presented in the table. The figures shows the lake levels with different hydrogen plant sizes showing that for the smallest 0.5GW plant the lake levels just stay positive. For the 3GW plant the lake levels always have sufficient storage.
Conclusions:Using a historic optimisation model, this study explores the impact of large-scale demand response in a 100% renewable electricity network. We included lake-level dynamics in the analysis to smooth the complex interaction between hydro storage and large amounts of renewable generation. In the New Zealand context hydro re-dispatch is key to achieving a 100% renewable system combined with the demand response from flexible hydrogen generation. It is the first modelling of hydrogen demand response in New Zealand. It is unique in its daily resolution, use of hydro redispatch, lack of fossil peaking plants, and scenario-based optimisation approach.
There are several important policy implications of this research. First, following the New Zealand government's commitment to ensure that electricity generation is 100% renewable by 2030, significant debate has been on the feasibility and pathway for achieving this. Our analysis suggests a strong case for using a large-scale hydrogen plant engaging in demand response to help facilitate this transition. The main benefit of doing this is to reduce the system's dependence on peaking generation. Fossil fuels currently meet this, but in the future, it is proposed to be completed by some sort of renewable battery, such as the NZD 15 billion proposed hydro lake scheme dubbed "Lake Onslow." In contrast, this modelling shows that a small battery on the same MW scale, but with significantly lower storage requirements working in tandem with hydrogen demand response and hydro redispatch, could meet all of New Zealand's 2050 demand needs with no outages.
Second, our results support the Government's pursuit of a portfolio strategy for the dry-year problem. However, we argue that more demand response could be utilised in this solution, with less reliance on over building generation. The demand response offering from the hydrogen plant is dependent upon its ability to reduce hydrogen production for sustained periods. This may have economic impacts outside the scope of this study.
Last, using demand response allows more renewable energy to be integrated into the grid. However, larger electrolysers require more renewable generation. The electrolyser places a significant load upon the electricity system, and the wind and solar capacity necessary to meet the electrolyser investigated in this research are beyond what the government has envisioned. If the government did choose to pursue hydrogen demand response as a core strategy for its 100% renewable target, it should also focus on rapid and large-scale solar and wind development. Such work is already being done through Resource Management Act Reforms and Offshore Wind Regulation development. The main benefits of demand response are improvements in system reliability, support of increasing levels of wind power integration, and a decreasing need for alternative flexibility provision.
To sum up, our key conclusions are: 1) we are the first to formally study the impact of large-scale hydrogen demand response in a 100% renewable electricity future in New Zealand, and (2) our modelling supports the case for utilising significant scale hydrogen demand response to transition New Zealand's grid to 100% renewable electricity.
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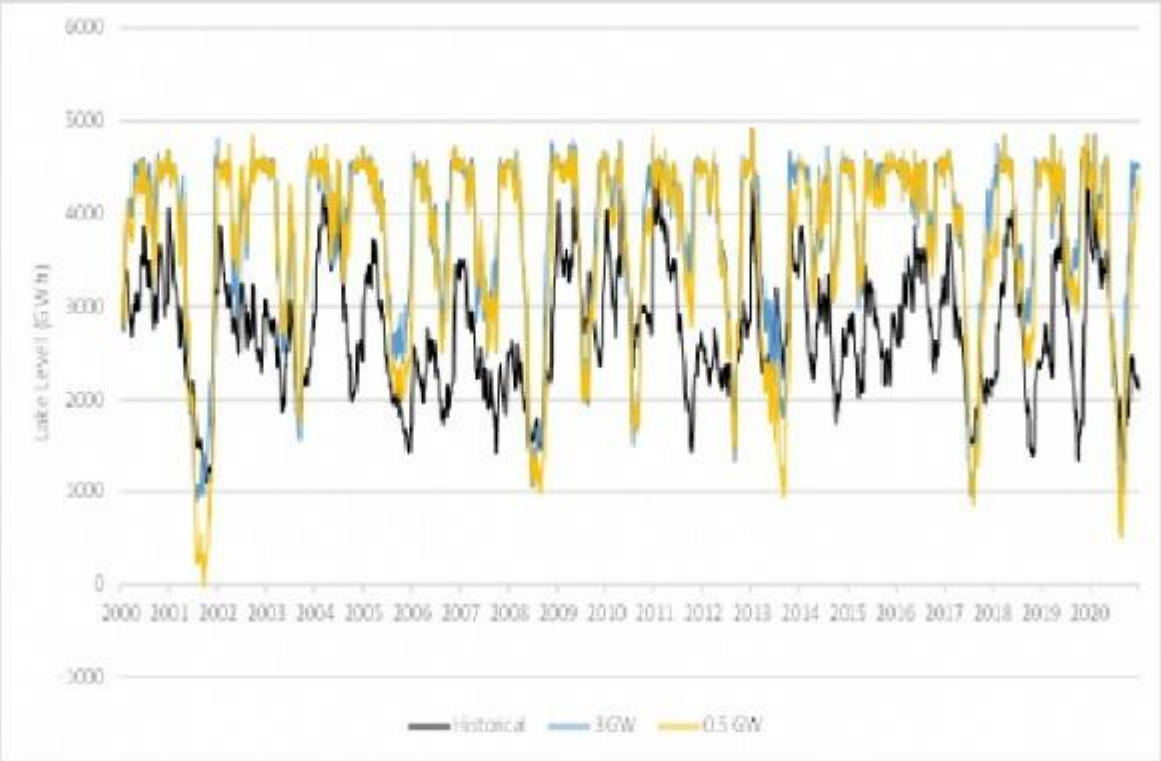
Keywords: Green hydrogen, renewable energy, demand response, system integration, electricity system, energy transition

Lake storage levels for selected hydrogen production plant capacities compared with historical levels.



Summary of results

Plant size	Solar(GW)	Wind (GW)	Shortage days (%)	Outage days (%)	Spill (%)	unserved demand (%)	Spill (%)
.5	9.5	7.3	2.8	0.23	3.5	0.3	5.5
1	11.8	7.9	3.0	0.23	4.1	0.01	5.2
3	15.5	11.8	6.5	0.07	8.1	0.001	8.1
5	23.6	14.4	8.5	0.01	13.0	0.0004	11.4
8	32.3	18.9	12.3	0	19.5	0	13.9

[Abstract:0337] OP-080 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Gaming Frontier Regulation of Electricity Network Utilities through Strategic Mergers

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Overview:Natural monopolies such as electricity network utilities are subject to different regulatory regimes. The asymmetry in information between regulator and regulated firms creates opportunities for information rent and strategic behavior. Benchmarking regulation based on yardstick competition is feasible in industries with multiple regulated firms. Regulatory mechanisms based on benchmarking have nice theoretical properties as they are incentive compatible. However, the performance of such regulatory schemes may be undermined by collusion, horizontal mergers and other forms of strategic behavior among the regulated firms.

The incentive-based regulation of the Norwegian electricity distribution sector utilizes efficiency measurements where the cost frontier is determined by the most efficient firms. The group of efficient firms has been small and stable over time. The model the regulator is using for assessing the efficiency of the firms and calculating the regulated income cap as well as all the underlying data is publicly available. This transparency in regulations allows the regulated firms (and others) to evaluate the current income cap and the relative performance of the utilities. This allows the utilities to easy assess and predict the effects of changes in operating expenditure and capital investments. Furthermore, it also allows for an early assessment of the consequences of horizontal mergers in the industry.

The current regulatory model uses a constant returns-to-scale assumption in the assessment of efficiency thus adding an incentive for mergers. Mergers among firms that are not on the cost frontier only affects the utilities involved in the merger. On the other hand, mergers involving firms on the frontier have consequences for the efficiency scores for all utilities. Thus, one possible strategy for gaming a frontier based regulatory regime is by strategic mergers.
Methods:Using the publicly available data and computer code used in the regulation of Norwegian electricity utilities in conjunction with ownership information this paper examines a specific merger among three utilities in 2017. The regulator is using the DEA method to assess the efficiency of the utilities. We implemented a customized version of the data envelopment model. Using the same data as the regulator, our model reproduces the efficiency scores obtained by the regulator. A merger of two or more utilities is modeled as removing the merging utilities from the efficiency analysis and adding one virtual utility as the sum of the components of the merging utilities. We assess mergers by comparing the efficiency scores and income caps before and after a merger has taken place.
Results:Our case study focuses on a merger of three utilities. One of these have consistently been a frontier utility thus setting the standard for the other utilities. The two other utilities are not on the efficiency frontier. After the merger the combined merged utility is not on the frontier. However, the income cap for the merged utility clearly exceeds the sum of the income caps for the merging utilities. Thus, an early evaluation of the merger indicates that it is profitable merger even without taking into account any cost synergies and savings.

The merging utilities are not the only ones benefiting from the mergers. Other firms see increased and some decreased income caps. In aggregate, the total income cap to be collected from the customers have increased.

An interesting twist in this merger can be found in the ownership of these utilities. The leading utility in the merger process is owned by another utility. The "mother" utility is large and not on the efficiency frontier. As a consequence of this merger the efficiency score of the "mother" utility has increased. The resulting increase in income cap for the "mother" company greatly exceeds the gain expected for the merging utilities.
Conclusions:Our case study shows that mergers among firms regulated with benchmarking can serve as a means to improve the benchmarked income cap. Furthermore, strategic mergers might also greatly benefit utilities not directly involved in the merger.

Competition laws govern firm behavior including mergers. This case raises the question if mergers in a regulated industry should be subject to the same assessments as other sectors.

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Keywords: yardstick competition, efficiency analysis, gaming regulations, mergers

[Abstract:0338] OP-081 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Peak-load pricing: demand response from electric vehicle charging in a field experiment

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Overview:The widespread adoption of electric vehicles (EVs) is important for achieving CO2-emission reductions. However, the home-charging of EVs can result in sharp increases in peak electricity demand, posing a challenge to grid infrastructure. Distribution grid tariffs can encourage households to shift demand away from peak hours, redirecting it to periods of surplus grid capacity, such as low-demand nighttime hours or high renewable-generation hours (Bailey et al. 2023). This paper studies the efficacy of grid tariffs as an incentivizing mechanism for demand response of households engaged in home EV-charging.
Methods:This study employs a randomized field experiment to assess the demand response of Dutch households engaged in home EV charging. To be eligible for inclusion in the field experiment, households had to meet specific criteria: (a) participants drove an EV, (b) participants used a private home-charging station, (c) participants owned a smart electricity meter.

In August, 2023, we recruited a sample consisting of more than 600 Dutch households. For all households, smart-meter readings were collected registering electricity withdrawal and injection at 15-minute intervals. The study includes a pre-treatment period from September 1, 2023, to October 25, 2023. Before the initiation of the treatment period on November, 2023, participants were randomly assigned to one of three groups:

"*"Control group"*"": Participants in this group received general information about the experiment and a financial compensation of €5,- per month. On a webpage, participants were provided with a monthly update on their total energy consumption and a graph displaying their daily 15-minute smart-meter readings.

"*"Intervention 1 - Capacity-based tariff""*: This group operated under a tariff structure with a 5 kW capacity limit. Participants were charged an exceedance fee of €0.25 per kWh only for energy consumption surpassing the 5 kW limit. Consequently, households were incentivized to maintain power usage below the 5 kW limit at all times. On a webpage, participants were provided with a monthly update on their total energy consumption and tariff costs and a graph displaying their daily 15-minute smart-meter readings.

"*"Intervention 2 - Capacity-based tariff + Time-of-Use""*: This group faced a time-of-use capacity-tariff treatment. Similar to the capacity-based tariff treatment, these households faced a 5 kW capacity limit and an exceedance charge of €0.25 per kWh for energy consumption above this limit. However, the exceedance charge only applied during the hours of 17:00 PM to 02:00 AM. During all other hours, the exceedance charge was set at €0.00 per kWh. On a webpage, participants were provided with a monthly update on their total energy consumption and tariff costs and a graph displaying their daily 15-minute smart-meter readings.

We use household energy consumption data from both pre-treatment and treatment period to estimate a difference-in-differences (DiD) regression model. The dependent variable is the 15-minute electricity load (kW) in different time intervals. We use (a) the 15-minute electricity usage (kW) during the hours between 17:00 PM and 02:00 AM, and (b) the 15-minute electricity usage (kW) during off-peak hours 02:00 AM and 17:00 PM. Indicator variables are used to indicate the start of treatment period and assignment to treatment groups. The latter capture the average effect of treatments on electricity load. We include household fixed-effects and hour-of-sample fixed-effects, and add a vector of covariates containing o.a. hourly temperatures.
Results:The results reported here are based on preliminary data analysis. These preliminary results show that participants in intervention group 1, who faced the time-invariant tariff reduced mean electricity usage (kW) between 17:00 PM and 02:00 AM by only 0.044 kW compared to the control group. This effect is not statistically significant. Participants in group 2, who faced the TOU version of the capacity tariff, showed a substantially larger shift in electricity demand. For this group, electricity load between 17:00 PM and 02:00 AM was reduced by 0.195 kW. Furthermore, for intervention group 2, we see a large increase in electricity load in the off-peak hours after 2:00 AM. Both results are statistically significant at 0.01 percent.
Conclusions:This study employs a randomized field experiment to evaluate the influence of grid tariffs on the electricity usage patterns of Dutch households engaged in home EV-charging. The preliminary result is that households exhibit a substantial capacity to shift the timing of charging to nighttime hours, when incentivized by a Time-of-Use grid tariff. Interestingly, our findings also reveal that households demonstrate limited capability to reduce individual peak demand, when subjected to a time-invariant capacity-based grid tariff. Hence, these preliminary results indicate that TOU tariffs may be more suitable to achieve demand response from households with EVs. These findings highlight the nuanced impact of grid tariffs on household EV electricity consumption.
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Keywords: peak-load pricing, electric-vehicle charging, field experiment

[Abstract:0564] OP-082 [Accepted:Oral Presentation] [Electricity » Customer/Grid Interactions]

Telescopic Tariffs & Indian Consumers: A Smart Meter Investigation of Elasticity

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Overview:The increasing adoption of smart meters in India [1] offers a unique opportunity to gain granular insights into consumer electricity consumption and its price responsiveness. Assessing consumer response to price-elastic electricity demand is crucial for effective implementation of demand response (DR) programs. Traditional models [2]-[4], assuming consumers optimize behavior based on marginal prices [5], fall short in accounting for telescopic tariffs. These tariffs maintain consistent marginal prices within slabs and feature discrete jumps at thresholds. These jumps present a unique opportunity to study how consumers respond to an increase in average marginal prices. This opens a distinctive window into understanding how consumers adapt their electricity usage in response to changes in average marginal prices in telescopic tariffs, informing future DR strategies and tariff design.
Our study aims to overcome the limitations of traditional elasticity measures by leveraging the detailed nature of smart meter data. This research utilizes high-resolution smart meter data at 30-minute intervals for one year, collected from 880 consumers subject to a telescopic tariff structure, all located within similar proximity and served by a single distribution company, to assess the elasticity of consumers concerning increases in slab prices.
Methods:We propose a novel approach that analyzes changes in consumption patterns, particularly at the end of billing months when tariff tiers switch, as a potential indicator of price responsiveness. Additionally, we employ data clustering techniques to segment consumers based on their overall consumption profiles, potentially revealing distinct elasticity characteristics among different groups. To ensure robust findings, we account for confounding factors influencing electricity consumption, including weather data. Integrating high-resolution weather data from reliable sources will allow us to isolate the true effect of price changes on consumer behavior.
Results:Key findings include the identification of distinct consumer clusters exhibiting varying degrees of elasticity in response to the telescopic tariff. Ancillary findings provide insights into temporal patterns, peak consumption periods, and other factors influencing consumer behavior. The results highlight the relevance of clustering techniques in uncovering nuanced relationships between pricing structures and consumer responsiveness.
Conclusions:This research has the potential to make significant contributions to the understanding of price elasticity in the context of smart meters and complex tariff structures. Our findings can inform policymakers in designing more effective pricing schemes and promoting efficient energy utilization by consumers. Furthermore, the detailed analysis of individual consumption patterns and their link to price sensitivity can offer valuable insights for energy providers and retailers seeking to tailor their services and optimize demand forecasting.
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Keywords: Smart meters, elasticity, demand response, telescopic tariffs, clustering, residential electricity consumption.

[Abstract:0599] OP-083 [Accepted:Oral Presentation] [Electricity » Customer/Grid Interactions]

Determinants of electricity trade in the East African Community: "A Gravity model analysis”

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Overview: Electricity trade in Africa stands at the forefront of regional development, economic growth, and energy security. The continent, endowed with diverse energy resources, seeks to leverage regional cooperation to optimize resource utilization and foster sustainable energy practices. This is evidenced by the 2021 launching of the African Single Electricity Market (AfSEM) by the African Union. According to IRENA (2023), this plan, envisaged to be operational by 2040, is aimed at developing a single electricity market in africa as AfSEM is meant to integrate all 55 African Union (AU) member states into a single electricity market that would be the largest globally.

Africa's electricity trade landscape is marked by a tapestry of challenges and opportunities. The continent's vast and varied energy resources, including hydro, solar, and geothermal, provide the foundation for regional collaboration. However, the realization of a cohesive electricity trade framework requires a nuanced understanding of the diverse economic, regulatory, and infrastructural landscapes across African nations.

This paper, that focused on the East African Community (EAC), endeavoured to unravel the determinants of electricity trade in Africa through a Gravity Model analysis. Drawing insights from the East African Power Pool (EAPP), the study aimed at contributing to a nuanced understanding of the intricate factors influencing electricity trade within the broader African context.

Amid the broader panorama of electricity trade in Africa, the EAC emerges as a key player in regional integration efforts. It is a growing community that upon reestablishment in 2000, was made up of the three Republics of Kenya, Tanzania, and Uganda, but has since grown to seven member states having been joined by Rwanda and Burundi in 2007, South Sudan whose accession to the community was in 2016, and most recently, the Democratic Republic of Congo, that accessioned to the community in 2022.

With the East African Power Pool (EAPP) serving as a beacon for collaborative energy initiatives, understanding the determinants of electricity trade within the EAC becomes pivotal. While several empirical studies have been carried out on the determinants of trade in the EAC with a few on electricity trade in particular, this paper shades insights into how the gravity model variables come into play especially considering the growing membership of the regional bloc. This paper aims to bridge the gap in the existing literature by integrating insights from the EAPP into a Gravity Model analysis, shedding light on both the unique and shared factors influencing electricity trade across the continent. The gravity model of international trade is a well-established economic model used to explain and predict the flow of goods and services between countries. It's based on the idea that trade flows are positively related to the size (Gross Domestic Product or GDP) of the trading partners and negatively related to the distance between them. In this context therefore, electricity trade would increase with the size of the markets but decrease because of the distance between them

The research was guided by the objectives of providing an overview of the broader landscape of electricity trade in Africa, with emphasis on the key challenges, opportunities, and collaborative efforts; examining the extent to which the gravity model variables influence electricity trade within the regional bloc by blending insights from the East African Power Pool into a Gravity Model analysis, offering a comprehensive understanding of the determinants of electricity trade within the EAC and, by extension, in the broader African context.
Methods: Approaching cross-border electricity flows from a trade theory perspective using the gravity model, the researchers adopted a methodology that wove together elements from the traditional Gravity Model framework. This resulted into a panel structural gravity model to include such variables as infrastructure developments, collaborative agreements, and the strategic positioning of power generation sources to quantify the effect of economic, structural, cultural, and institutional variables on electricity trade in the EAC.
The study was premised on the assumptions that i) Economic differentials affect bilateral electrical

trade flows, (ii) Institutional and physical constraints affect bilateral electrical trade flows, (iii) Larger markets have larger trade flows, (iv) Electrical trade flows increase with the installed capacity and that third countries have an incidence on bilateral electrical trade flows. Results:Preliminary results revealed that international economics theories like that of comparative advantage emerge in the trade in electricity, speaking to the Institutional and physical constraints that affect electricity trade. Results further suggest that electricity trade flows are mainly driven by importer demand probably due to institutional agreements in the context of energy integration and of course the sheer size of markets but could be hampered by differences in language as electricity trade involves navigating complex regulatory frameworks and agreements, negotiating contracts, discussing pricing mechanisms, and coordinating grid operations. Language differences may hinder smooth communication between electricity traders, utilities, and regulatory authorities, affecting the efficiency of market operations. In line with Zlatinov1 et al (2022) Distance was conceptualized the interconnection of electricity systems between countries instead of the distance between them, as is the case in the standard gravity model. Conclusions:In weaving together aspects of electricity trade in Africa, with a focal point on the East African Community and insights from the East African Power Pool, this paper aimed at contributing substantively to the discourse on electricity trade, and therefore regional and continental integration of electricity markets. It is hoped that the paper will offer valuable insights for policymakers and stakeholders navigating the complexities of electricity trade, regional collaboration, and sustainable energy development across the African continent. References:Batalla, J., Paniagua, J., & Trujillo, E. (2018). Energy Market Integration and Electricity Trade: A gravity model (No. 1901).

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Keywords: Gravity model, cross border Electricity trade, East African Community

AuthorToEditor: Analysis of results is still ongoing, what has been presented in the results section are just preliminary results

[Abstract:0615] OP-084 [Accepted:Oral Presentation] [Electricity » Customer/Grid Interactions]

What will you Accept? A Socio-Demographic Analysis of Occupants' Preferences for Direct Load Control in Residential Buildings

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Overview:This study comprehensively examines Direct Load Control (DLC) acceptance and tariff preferences in Germany, Austria, and Switzerland. The research aims to compare and contrast regional differences in DLC acceptance and preferences, with more than 10,000 participants. It provides insights into consumer attitudes towards different tariff schemes and highlights the role of socio-economic factors in shaping these attitudes. Methods:The study employs a multifaceted methodological approach, incorporating 5,000

respondents from Germany, and 2,500 each from Austria and Switzerland. It utilizes a principal component wealth indicator and a three-dimensional socioeconomic status (SES) indicator to assess DLC acceptance within different socio-economic groups. Additionally, the study explores preferences for various DLC tariffs using a Discrete Choice Experiment (DCE). The DCE considered attributes such as financial compensation, controlled appliances, frequency and duration of control, and the option for users to control these settings. This approach allows for a detailed examination of consumer preferences and their influencing factors in different cultural and economic contexts. Results:The findings from Austria and Switzerland, when juxtaposed with the German data, reveal significant regional differences in both DLC acceptance and tariff preferences. While socio-economic factors such as occupation, education, and income continue to play a central role in shaping attitudes toward DLC, as seen in the German context, the Austrian and Swiss populations exhibited different patterns. These differences are evident not only in levels of acceptance, but also in terms of specific preferences for tariff attributes, reflecting different economic, cultural, and regulatory environments. Conclusions:This comparative study not only reinforces the complexity of DLC acceptance across different European contexts but also highlights the nuanced differences in consumer preferences for DLC tariff attributes. The findings emphasize the need for a tailored approach in the design and implementation of DLC programs, one that considers the specific socio-economic backgrounds, cultural contexts, and tariff preferences of different populations. Such an approach is essential for the successful and equitable adoption of DLC strategies in Germany, Austria, and Switzerland, ensuring that they are not only economically efficient but also socially and culturally acceptable. Smart meters are highly relevant for DLC programs because they serve as a critical enabling technology for efficient and effective demand response strategies. The importance of this study is underscored by the impending widespread adoption of smart meters across Austria, Switzerland, and Germany. In Austria, a staggering 95% of households are mandated to have smart meters by 2024, a move that is poised to dramatically transform energy management and consumer interaction with DLC programs. Switzerland is also on a similar trajectory, with a target of 80% smart meter coverage by 2027, a significant leap from the current 26%. Germany, aiming at a complete coverage with a 100% target by 2032, currently has a nascent smart meter infrastructure coverage of just 0.2%. Smart meters provide real-time data on electricity consumption and enable utilities to communicate with and control appliances remotely. Findings on preferences in Austria, where the rollout is already well advanced, can therefore be indicative of future developments in Switzerland and Germany.
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Keywords: Direct Load Control, Demand Response, Socio-economic Status, Residential Energy Consumption, Choice-based Conjoint, Principal Component Analysis

[Abstract:0154] OP-085 [Accepted:Oral Presentation] [Electricity » Demand]

Impact of monetary incentives on the adoption of direct load control electricity tariffs by residential consumers

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Overview:To overcome the inherent clash between the ever-increasing push for electrification in the transportation and heating sectors, and the intermittent nature of renewable energy sources, demand response solutions such as direct load control (DLC) tariffs are receiving growing attention from researchers and policymakers. The present study aims to investigate the impact of two measures (i.e. a video intervention and an upfront subsidy) in increasing the acceptance rates of an existing Direct Load Control (DLC) tariff targeted at electric vehicle charging stations and
heat pumps in Switzerland. To achieve this, we combine two randomized-controlled trials: (1) a stated-choice contingent valuation on electric vehicle owners to confirm the validity of the upfront subsidy, and (2) a revealed-preference field experiment on an existing DLC tariff proposed to the clients of a local distribution system operator. Results suggest that both measures of video and monetary intervention increase contact and subscription rates to the proposed DLC tariff, although the monetary intervention appears to be more convincing to consumers. Further, we use these results in combination with a bottom-up electricity market model to simulate the consequences on the level of system cost of a large-scale implementation of a DLC tariff.
Methods:In the stated-choice RCT, we were primarily interested in using a contingent valuation (CV) protocol to estimate the willingness to accept (WTA) a DLC tariff under two situations. In the first, the local electricity company covers the installation cost of the remote control switch device needed to implement this tariff, whereas in the second, the customer has to pay for it. The motivation for applying a WTA protocol is based on the fact that, as mentioned in the previous sections, a DLC tariff creates discomfort for the client because it limits the possibility of consuming electricity during some predefined periods. For this reason, an electricity company that wants to introduce a DLC tariff generally proposes to the customer a discount on the electricity price or a fixed financial contribution per year as compensation for the discomfort. Consequently, we have estimated the value of the necessary compensation by analyzing answers that customers have provided to a contingent valuation protocol.

To estimate the stated WTA we implemented an online survey with a sample of owners of electric vehicles living in the Italian part of Switzerland. The survey has been organized in cooperation with the company that owns and manages the public charging stations in the region. Within the survey, we first illustrated the purpose of a DLC tariff as a measure to prevent episodes of peak electricity demand. Then, we presented the general characteristics of this type of tariff: maximum frequency of blocks, duration of each block, installation costs of the DLC remote control system, and annual electricity discount. Afterward, we gathered the yearly willingness to accept (WTA) compensation to adopt a DLC tariff via a single-bounded dichotomous choice question. More specifically, in line with standard contingent valuation (CV) protocols, we presented different levels of annual compensation to the participants of the experiment, and to some of them the treatment, i.e. the installation-cost upfront discount. We then provided them with a dichotomous question (yes/no) on whether they would accept such a tariff.

In the second part of the paper, we organized a revealed choice RCT in cooperation with a local electricity and gas
distribution company. This company serves approximately 97,000 households living in the city of Lugano and in its surrounding areas. Since 2022, the company has introduced a DLC tariff known as the ”Tariffa Flessibilit`a” for its customer base. However, since its introduction, this tariff has attracted scarce attention from clients and has achieved only minimal levels of adoption.

The main goal of this randomized controlled trial is to evaluate whether, in a revealed setting, owners of EV charging stations and heat pumps are more willing to subscribe to a DLC tariff when the electricity distribution utility takes charge of the organization and installation cost of the DLC remote control system (i.e. installation-cost treatment). As already anticipated, we also decided to verify the impact of information framing and presentation format on adopting a DLC tariff. As discussed in the literature section, several studies suggest that dynamic images (compared to static ones or texts) have more impact on increasing consumer involvement and attention to new products. For this purpose, we introduced a video treatment as part of the RCT setting.
In order to do so, the local provider agreed to contact via mail a total of 1,500 clients, who were randomly selected among eligible clients of the tariff, i.e. owners of EV charging stations and heat pumps in April 2023. Clients were randomly assigned to one of the three following groups, each composed of a total of 500 individuals:
1. A control group, who received a brochure that outlined the standard conditions for the

tariff;
2. A video treatment group, received a brochure that outlined the standard conditions for the tariff, plus an additional QR-code to access a video presenting the same information contained in the brochure (see Figure Appendix C.2). The video was linked to a dedicated and unindexed page on the energy provider website, to ensure that only owners of the brochure could access the content. In Appendix Table C.1 we present a transcript of the video.
3. An installation-cost treatment group, who received a brochure outlining the standard tariff conditions with one exception. Differently from the other groups, for this treated group the electricity distribution utility takes charge of the organization and installation cost of the DLC remote control system needed for the functioning of the DLC tariff
Results:In the empirical analysis, we considered two outcome variables, i.e. the number of contacts to the energy provider to get more information on the DLC tariff and the number of new subscriptions to this tariff. The decision to consider also the number of contacts as an outcome variable is based on the fact that the period considered after the treatment was only two months, which is likely to be a short period for customers to complete the process of subscription. Additionally, it provides a good benchmark to compute how many of the clients who appear to be interested in the tariff are eventually willing to switch to it.

Approximately 8% of the total sample reached out to the provider, with a quarter of these switching to the DLC tariff. Among the 121 clients who contacted the energy provider, approximately 53% of them belonged to the installation treatment group,17 around 28% were linked to the video treatment group and only 19% belonged to the control group. In terms of new subscribers (34 in total), roughly 61% were from the installation treatment group, around 32% from the video treatment group, and around 7% were included in the control group. In terms of the video treatment, most of the treated clients that contacted the electricity company or adopted the DLC tariff did watch the video between April 18th and June 30th.

The econometric results show a clear and statistically significant impact of the installation-cost treatment. The results are similar across the different model specifications (columns 1-4) and across the econometric model (logit and linear probability model). Being offered an installation cost treatment increases the probability of contacting the provider by around 10 percentage points compared to the control group. The results also indicate that the impact of the video treatment is only confirmed in the linear probability model and only at a level of significance of 10 percent. As expected, when adding covariates to the model the magnitude of estimates decreases for both treatments. Finally, under all model specifications, we find no evidence of the two treatment estimates being possibly statistically equivalent to each other.
Conclusions:This study provides empirical evidence on the impact of monetary and information interventions on DLC tariff adoption, combining revealed choices and stated choice methods. The empirical results suggest that to increase the number of customers that opt for a DLC tariff the local electricity distribution company could: (1) organize an information campaign on the functioning of a DLC tariff using different media approaches, including a video; (2) Take charge of the organization and installation cost of the DLC remote control system need for this type of tariff.
However, it is acknowledged that both framing and monetary interventions may not be potent enough to significantly increase DLC adoption rates and shift peak demand. A more robust approach to encourage demand shifting could involve making DLC tariffs a mandatory contract for owners of heat pumps and charging stations. Nonetheless, this might come at the expense of decreased consumer surplus, as it could affect overall comfort. As a feasible alternative, we suggest defaulting eligible clients into DLC tariffs while allowing them the option to opt-out. This approach is seen as the most economically viable and efficient solution for managing increased electrification while maintaining consumer flexibility.
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Keywords: Monetary incentives, Direct load control, RCT, Demand response

[Abstract:0140] OP-086 [Accepted:Oral Presentation] [Electricity » Power System Planning & Management]

Social Vulnerability to long-duration power outages in Brazil

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Overview: Between 2013 and 2022, natural disasters such as storms and floods affected 5,199 out of 5,570 Brazilian municipalities (93%). These disasters affected the lives of more than 4.2 million people, who had to leave their homes. More than 2.2 million homes were damaged, in 4,334 municipalities (78% of the total), of which 107,413 were destroyed. Financial losses associated represented about R$ 18.3 billion. The South Region of Brazil had the highest percentage of affected houses: 46.8%.

In 2023, two events must be highlighted: i) a general blackout that affected the entire country in August; and ii) a long-duration power outage in the State of São Paulo, in November, due to a severe storm. According to the National Electric System Operator (ONS), in August, the general blackout interrupted 27% of Brazil's energy consumption. In its report, ONS describes that the shutdown of a Chesf transmission line was responsible for an interruption of 19 gigawatts (GW), corresponding to 27% of the total system load – around 29 million consumer units, such as homes, businesses, schools, and hospitals were affected by the blackout on August 15. All states of the Brazilian federation were affected, except Roraima.

These occurrences illustrate two fundamental and connected issues: (the lack of) resilience of critical infrastructures in Brazil and its corresponding impact on people's lives, most of whom are unprepared to face extreme events.

This vulnerability is aggravated within the country, depending on social and economic factors and the infrastructure available for crisis management – we must also consider the high inequality among the different regions in the Brazilian federation. Hence, it is crucial to prioritize the ranking of locations based on their vulnerability to such events in terms of public policy, economic regulation, and decision-making by electrical utilities. By mapping the most vulnerable regions, specific public policies and proper investment decisions by utilities can be implemented to minimize the negative impacts of the lack of electricity.

This article proposes the development of an index to measure the social vulnerability to long-duration power outages in Brazil, using the state of Rio de Janeiro as a pilot region, divided into municipalities, census tracts, and weighting areas. Rio de Janeiro was selected due to its susceptibility to adverse effects caused by extreme weather events, leading to long-duration power outages. Following the methodology of [1], the global index comprises factors associated with health, preparedness, and infrastructure for evacuation during emergencies.

The rest of this paper is organized as follows: Section 2 reviews the literature specific to the Brazilian case. Section 3 presents the methodology, adapted from [1], and the data. Section 4 provides the results and discussion for Rio de Janeiro State. Section 5 discusses possible public policy measures and preventive actions from other stakeholders involved. Finally, Section 6 presents opportunities for future work and concluding remarks.

Methods: Factors of social vulnerability specific to long-duration power outages have been identified in [1], and are summarized in Figure 1.

Figure 1: Dimensions of vulnerability specific to power outages and the factors that impact them.

The proposed methodology to construct a three-dimensional metric of social vulnerability to power outages is outlined in Figure 2. Based on the factors identified in [1], data for each dimension of health, preparedness, and evacuation is sourced from publicly available datasets at the most granular level available. Each dataset is preprocessed so that values lie between 0 and 1 and higher values indicate higher vulnerability. Principal component analysis and an L1 norm model are used to develop a composite index for each dimension of vulnerability. An overall index of vulnerability is computed using Pareto ranking. Choropleth maps are then created in ArcGIS Pro to visualize how vulnerability varies across the geographic area. The methodology is applied in a case study for the state of Rio de Janeiro using data at the smallest granularity possible for the year 2010. Data sources include the Rio de Janeiro State Department of Health and the Brazilian Institute of Geography and Statistics (IBGE). Three scales of data are considered including municipality-level, census weighting area-level, and census tract-level data. In the state of Rio de Janeiro, there are 92 municipalities, 538 census weighting areas, and 27,769 census tracts.

Results:We have results for each attribute (health, preparedness, and evacuation), considering municipalities, weighting areas, and census tracts. Below we show an example regarding the overall vulnerability by census weighting areas. The three L1 vulnerability scores are aggregated into an overall vulnerability score through the Pareto ranking. Municipality-level health scores are applied to all census weighting areas and census tracts within that municipality. The Pareto ranking results are translated to scores between 0 and 1, where 1 is the most vulnerable and these scores are mapped in ArcGIS Pro and darker colors indicate higher vulnerability.

Figure 2: Overall social vulnerability to long-duration power outages for census weighting areas in the state of Rio de Janeiro.
The vulnerability indices developed in this article and applied first for the state of Rio de Janeiro can be integrated with power grid planning and operation to help reduce social vulnerabilities to long-term power outages. In this situation, results may be used by the already mentioned National System Operator (ONS) and by the Energy Research Office (EPE), an entity responsible for long-term planning in the country. Therefore, the theme of resilience/vulnerability can easily be included in these kinds of discussions in Brazil, a country that has been suffering the effects of events of this nature.
The electric utilities may also take advantage of the results – the most vulnerable areas match with the regions affected by recent power outages in the state of Rio de Janeiro. Thus, the proposed indices and methodology can be used to assign higher criticality levels to grid sections that are in more vulnerable areas, allowing to quantify the effects of outages while considering disparities in how those events affect different communities in the same census tracts, like in the south region of Rio de Janeiro City. It will be possible also to overlap the maps of social vulnerabilities with information at the feeder level, allowing better investment strategies for utilities regarding resilience, an issue that is on the agenda of the Brazilian Electricity Regulatory Commission (ANEEL) for the year 2024. The indices can also be used by utilities during electric service restoration to prioritize the energization of areas where residents are more vulnerable.
From the point of view of governments and public policy, the methodology and results allow also for better-informed investment decisions and previous actions capable of mitigating the risks for people in more vulnerable communities. Federal, state, or local entities involved in emergency management can also use such indices to distribute resources more efficiently among affected residents and aid in a more targeted way.
Conclusions:This study proposes the construction of a long long-duration power outage vulnerability index for Brazil, using as a pilot the state of Rio de Janeiro. The results will be expanded for the entire Brazilian federation and will be available to the public, through an online interactive platform. It is expected that the tool can be used by policymakers, utilities, and different stakeholders in the Brazilian power sector, in a context where the country has been suffering the effects of extreme weather events and resilience becomes an important field of research in local terms.
The results and maps can help better informed Cost-Benefit Analysis regarding resilience investments, from the point of view of all stakeholders involved – governments, regulator, utilities, and entities responsible for planning and operation of electricity in Brazil. These investments, once properly decided, will help not only in risk mitigation against the outages and disasters but also in decreasing social inequalities, that are unfortunately very high in the country.
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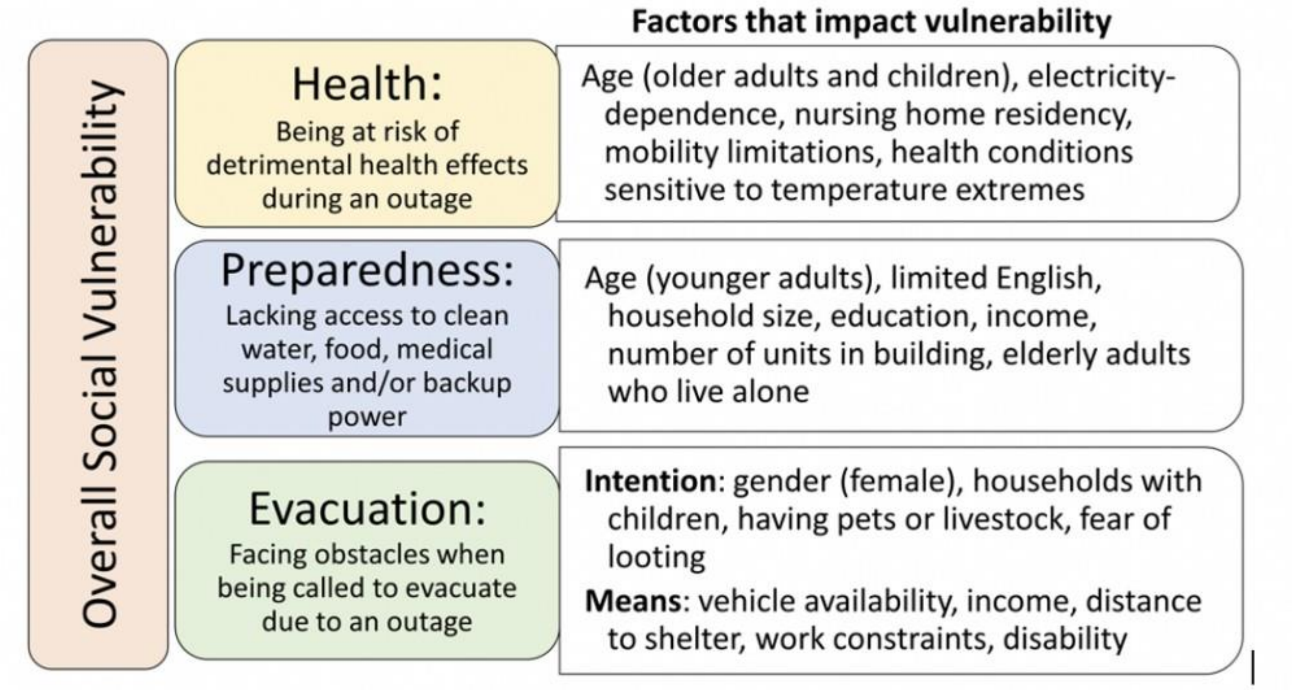
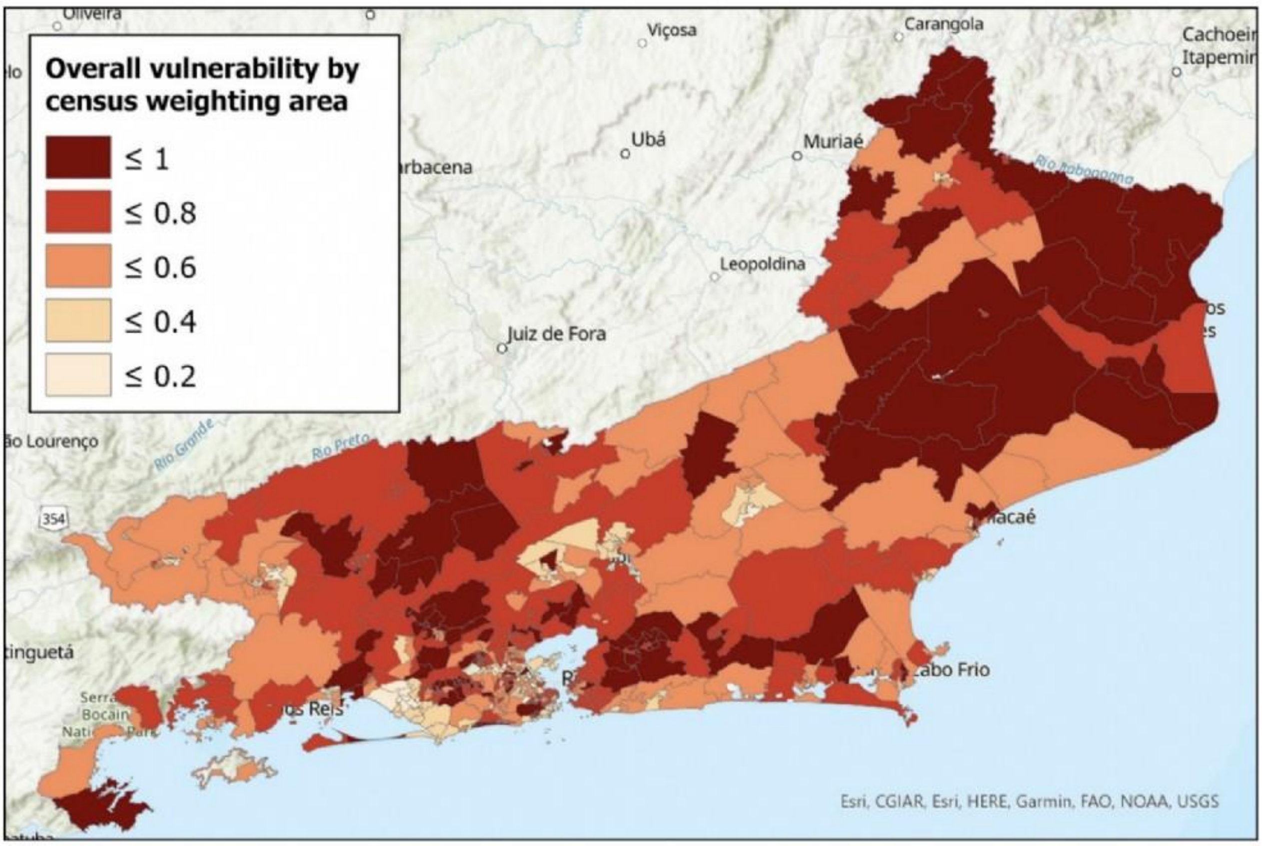
Keywords: Power Outages, Social Vulnerability, Resilience, Data Science Methods

Figure 1



There is a mention of figure 1 on the text (Methods)

Figure 2



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AuthorToEditor: We have uploaded a version in.doc with the text and figures.

[Abstract:0294] OP-087 [Accepted:Oral Presentation] [Electricity » Power System Planning & Management]

Multi-Objective Transmission Expansion: An Offshore Wind Power Integration Case Study

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Overview:We describe a multi-objective, multistage generation, storage and transmission expansion planning (GS&TEP) model for the electric power sector, emphasizing coordinated offshore and onshore grid planning. Unlike traditional capacity expansion models that focus exclusively on investment and operational costs, our model explicitly accounts for negative externalities such as the social cost of greenhouse gas emissions and local damages from reduced air quality. We put the model to the test using an 8-zone representation of the New England power system to study the sensitivity of grid expansion decisions with the primary focus on optimal capacity expansion decisions due to large-scale offshore wind power integration. Our model allows investment decisions to be made in multiple stages and accounts for short-term uncertainty during operations through scenarios. Our results indicate that considering externalities leads to greater upfront investment in cleaner generation and storage, which are largely offset by lower expected operational costs.
Methods:We use an 8 onshore-zone and 6 offshore-zone representation of the Independent System Operator New England (ISO-NE) system combining data from EIA, NREL, and Li and Tesfatsion (2017). We, furthermore, use the ``Intervention Model for Air Pollution'' (InMAP; Tessum et al., 2017) to compute marginal damages from air pollution at the existing fossil-fuel power plant level. We include the following non-transmission investment options in our model: fossil-gas combustion turbine, combined cycle with and without carbon capture and storage, solar PV, battery Storage (4-hour), and wind. In terms of transmission investment options, we account for upgrading existing interfaces between onshore zones, building new interfaces between offshore zones, as well as optimizing the interconnection points between offshore and onshore zones. The latter is particularly relevant to answer the question of how offshore wind zones should be connected with each other and to the onshore grid, and how it will affect onshore transmission needs and the optimal investments in generation and storage resources.
Our baseline model is a multistage capacity expansion model along the lines of Qiu et al. (2016) and Munoz et al. (2013). The model aims to co-minimize investment costs as well as operating costs over the exogenously defined horizon. Additionally, we include annual costs of externalities such as the economic cost of greenhouse gas emissions and the economic costs of damages from local air pollution. Investment can be spread over four epochs, with each epoch lasting five years, totaling to a 20-year time horizon. We account for demand shifting potential and we include the following non-transmission investment options in our model: fossil gas combustion turbine, combined cycle with and without carbon capture and storage, solar PV, battery storage (4-hour), onshore wind. Offshore wind capacity paths are accounted for through policy commitments. Annualized investment costs are derived from the National Renewable Energy Laboratory’s (NREL’s) 2022 Annual Technology Baseline (ATB) cost estimates (NREL, 2022).
Results:Results show that using multi-objective models to explicitly account for economic costs of greenhouse gas emissions and damage from local air pollution will decrease the need to upgrade onshore transmission in our case study. Most planned investment comes from onshore (or land-based) wind resources and far less from gas-fired generating and battery storage resources. Note that some states in the ISO-NE footprint have very ambitious RPS targets, which contribute to the onshore wind expansion decisions (and also to the exogenous offshore wind expansion plans). Accounting for all economic costs lead to no or insignificant investment in gas-fired generating resources but to more investment in battery storage.
Conclusions:We introduced a multistage capacity expansion model (encompassing generation, storage, and transmission) based on multi-objective programming, offering a comprehensive

approach to coordinated offshore and onshore grid planning. Unlike traditional planning models, our framework includes considerations for unpriced or underpriced externalities, such as greenhouse gas emissions and local air pollution. This provides a deeper understanding of both economic and non-economic costs in grid expansion decisions, thereby aiding in equitable cost allocation processes.
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Keywords: Coordinated capacity expansion, Multi-objective programming, Offshore grid planning, Transmission expansion planning

AuthorToEditor: Dear Scientific Committee, here is the link to the working paper: https://arxiv.org/abs/2311.09563. Thank you.

[Abstract:0483] OP-088 [Accepted:Oral Presentation] [Energy Access » Energy Poverty and Equity]

The Role of Digitalization in Reducing Energy Poverty

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Overview:Energy plays a central role in modern society, serving as a fundamental commodity that supports various activities such as heating, lighting, and cooking. It is one of the most exchanged assets, satisfying human needs and propelling countless services (Wang et al., 2023). The global concerns surrounding the energy system bring awareness of the need to reduce energy poverty. Energy poverty is a complex and multidimensional challenge, with different assessments depending on the context of the study. For instance, for low-income countries, energy poverty involves households lacking access to modern energy for essential activities like electricity and cooking fuels. Yet, for higher-income countries, energy poverty can be described as a situation in which citizens spend most of their income on energy debts or must lower their energy consumption to a level that negatively impacts their well-being, increasing their inability to keep homes adequately warm or cold (European Commission, 2023; McCauley et al., 2019; Zhao et al., 2022).
Many individuals are experiencing energy poverty or are at risk of losing access to essential energy services due to energy price inflation, coupled with low income and the lack of efficient energy systems. As a result, the risk of losing access to crucial energy services increases (European Commission, 2022). Recent metrics reveal that global progress toward universal access to energy

has been hindered. For instance, the number of people living without electricity had a global increase in 2022 for the first time in decades, topping the alarming value of approximately 775 million individuals (IEA, 2022). In addition, according to the International Energy Agency (IEA), more than two billion citizens are unable to access clean cooking appliances, falling under the energy poverty bracket (IEA, 2021). Furthermore, the Eurostat indicates that around 9.3% of European Union citizens could not properly warm their homes in 2022 (i.e., about 41 million people). As a result, countries' primary concern should be building a viable power sector.
The path to accelerate the clean and efficient energy transition is, to some extent, focused on the potential of digitalization. By promoting ubiquitous connectivity, digital technologies have been revolutionizing economies, with digitalization being accountable for having the capacity to enhance the energy network's security, sustainability, and accessibility (IEA, 2017). Indeed, digitalization emerges as a potential catalyst for a clean energy transition, with the need for alignment between the rapid pace of digitalization and energy decarbonization services (Wang et al., 2023). Usually called twin transitions, digitalization and decarbonization are often perceived with divergence in what concerns the intensity associated with their deployment. In other words, digital transitions tend to occur faster than energy transitions (Fouquet & Hippe, 2022). Building synergies and fostering connections is necessary to incorporate digitalization into the energy industry. Therefore, new perspectives on the link between digitalization and energy are needed. This article is a step in that direction, exploring the connection between digitalization and energy poverty.
Methods:Econometric models are applied using panel data from 27 European Union countries, for the period 2013 to 2021, to study the impact of the digitalization revolution on energy poverty. More specifically, affordability and thermal comfort issues are assessed, considering variables such as the population's share of arrears on utility bills and the incapacity to keep home warm, using data collected from Eurostat. In addition, the models are disaggregated to test the effects of digitalization on energy poverty for the overall population, but also separately for those below and above the threshold of poverty (i.e., those living below/above the poverty threshold set at 60% of the national median equivalised disposable income). In addition, other economic and energy-related relevant variables are considered, such as the unemployment rate, urbanization level, or electricity and gas prices.
A digitalization index based on digital factors, such as internet access, broadband subscriptions, ownership of digital devices, and usage of e-commerce, among others, is also developed, using Principal Components Analysis (PCA), to serve as a proxy for a country's digitalization level, offering a comprehensive view without multicollinearity concerns.
Results:The preliminary results reveal that digitalization can decrease the share of households with arrears on utility bills and the share of households suffering from an inability to warm homes properly. More specifically, a 1% increase in digitalization's level decreases households' arrears in utility bills by 0.056 percentage points and the incapacity to keep home warm by 0.028 percentage points. When examining disaggregated models, the impact varies based on whether individuals are below or above the poverty threshold. For instance, the use of e-commerce, a component of digitalization, affects the incidence of arrears on utility bills for those above the poverty threshold but does not show a similar effect for those below it. This can be attributed to the limited access low-income families have to advanced digital technologies, making it difficult for them to experience or benefit from the effects of such digitalization. Regarding the incapacity to keep home warm, preliminary results suggest that individuals below the poverty threshold are the ones more positively influenced by digital technologies.
Conclusions:Digitalization offers opportunities to revolutionize the energy system through practical solutions, such as influencing consumer behaviour and integrating digital technology into economic and energy infrastructure. The policy implications vary depending on the context and the indicators used to measure energy poverty. While these findings are based on studied digital indicators, they confirm the hypothesis that the digital world can pave the way for increased energy access and inclusivity. Nevertheless, further research is necessary to take advantage of the digital revolution and maximize its potential, providing policymakers with practical guidelines to implement it while ramping up the deployment of energy-saving and equity strategies.
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Keywords: Energy poverty, Digitalization, European Union, Econometrics

[Abstract:0573] OP-089 [Accepted:Oral Presentation] [Energy Access » Energy Poverty and Equity]

"Modern universal energy access and socio-economic development"

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Overview:1.0 Introduction/Background

Energy plays a crucial role in the development and sustainability of country's economy, as it drives all other sectors of the economy including Agriculture, Health, Education, Service Sector, Information Technology (IT) the Environment among others. Energy is critical to achieving virtually all the 17 Sustainable Development Goals (SDGs). Whether it is electricity for schools' services or clinics, energy for the delivery of health, education, water and sanitation, services, clean fuel to reduce indoor pollution, energy for heat and cooking food, boiling water, energy in all its forms will be required to achieve these ends (McCollum 2017). Current patterns of energy consumption in Developing Countries and particularly in Uganda are polluting and unsustainable, and are characterized by inequity in consumption, costing (tariffs) and limited access to few. The Uganda (2023) energy policy sets 2040, the prime year for Modern Universal Energy Access (MUEA), opted to offshoot socio-economic development of Uganda.

Uganda's experts competently have been always applying econometric for modelling such socio-economic policies. The models' projections or policy directions are considered a probable predictor of socio-economic problems affecting the economy by the citizens, but most often are not correctly integrated into the Ministerial Policy Statements (MPS) to address the challenges, thus failure in the policy' implementation. Optimal Control Theory (OCT) is proven a better approach and solution to these challenge, as its application yields both the optimal values of the key policy parameters and the time path to those values. It is therefore postulated that, application of OCT to model an appropriate holistic policy that links, MUEA to Socio-economic Development of Uganda is essential, and this journal's journey is way forward.

0.2 The purpose of the paper.

The paper intends to literally contextualize the concept of modern universal energy access at Uganda's perspective; Establish the policy drivers for modern universal energy access in Uganda; Theorize, conceptualize and from the recent literature apply appropriate model to understand modern universal energy access; and finally determine holistic policy to address the gaps What are the probable policy gaps that need to be addressed in order to realize Modern universal energy access for sustainable socio- economic development.
Methods:3.0 Materials and METHODS: In order to capture the breadth of different types of evidence that might be available, the literature review to be considered in this paper will be in both peer reviewed published journals and grey literature. The literature searches projects over 250 documents, which will be sorted according to the relevance to the review based on the titles, abstracts and key words to identify a long list of literature consisting of studies. This long list will further be analyzed using a set of classification criteria to identify at most 50 documents covering both conceptual and empirical findings across the various dimensions of drivers to Modern universal energy access and socio-economic development. The literature review is expected to manage and capture the vast majority of relevant peer reviewed publications and grey literature that are available in English. Given the length of time to complete the literature review, this review primarily focused on studies that were easily available and could be accessed such as policy documents, websites and databases.

3.1 Systematic review

Systematic investigations are to be conducted in Google Scholar and SCH-HUB, to classify all journalistic explanations, methods and challenges relating to policy drivers of Modern Universal Energy access to Socio-economic development from 2013 to 2023. The paper aims to identify all articles related to the policy on modern universal energy access and socio-economic development in their research to make a comparison of these studies together. The search method will consist of search terms for systematic review, for policy drivers of modern universal energy access, analysis methods and a policy drivers of modern universal energy access, search description filter among others. Boolean such as OR, AND, FOR, WITH words, field specifications (Title, Abstract, Conclusion, Findings, recommendation and others), duplicate or triplication checks, an assessment between articles and criteria will also be used as a technique for making progress. The complete parsing to be used in this study is Modern Universal Energy access AND Socio-economic Development. The following enclosure criteria will be used in studies of the Modern Universal Energy access to be performed at Households, Industrial and National level in Developing countries.

3.2 Material collection

It is principally paramount to guarantee that the right information and or articles will be selected for systematic literature review. To achieve this objective of the study, the process of identifying the materials and its contents for this review was funnel by: Database choice; Choice of the journals and Content/factual collection among others.
Results:The purpose of this paper was to provide a systematic review of modern universal energy access at household level with key focus on the conceptualization and policy drivers of modern universal energy access to socio-economic development. More specifically, the intention was to uncover what is in literature that constitutes households' modern universal energy access and what are the policy drivers of households' modern universal energy access to socio-economics development. The review will identify identified different descriptions of modern universal energy access and the policy drivers to socio-economics development. Appropriate model that would specify the parameters and the path toward policy implementations and addressing the gaps.
Conclusions:This review is expected to show trends in publication of household, industrial, and national modern universal energy access and socio-economics development in developing countries to be categorized and clustered by years under investigation that is 2013-2023. Furthermore, the paper will find out the different scholars' concepts about household, industrial and national modern universal energy access. However, in general concept, contextualizing modern universal energy

access to developing countries will have to be reached since, energy access is taking shift or a switch from one fuel source and associated technologies to another.

In terms of the theories and methodologies to be used, the paper will observe energy access ladder and stacking theories which most studies used to anchor household energy access studies on, and contextualize it to industries and national energy access. Furthermore, the paper will use descriptive analysis prior of the application of Optimal Control Theory (OCT). Moreover, a number of modern universal energy access backgrounds are expected to be identified and categorize as household, industrial and national characteristics, on personal preferences, structural, environmental and gender related basis.

The review will further identify gaps in literature especially those that influences modern universal energy access amongst households, industrial, and national to socio-economics development. For example, the review will foresee to show those important factors that influence energy access decisions such as housing physiognomies (nature of housing, migrations, kitchen space). Similarly, the use of energy ladder and stacking suggestion only talks about socioeconomic factors but do not satisfactorily explain other factors beyond socio-economic aspects that affect household energy access decisions yet they can affect industrial and national. Hence, this review will apply a systematic literature methodology which is identical with some form of biases, most especially the use of limiters. However, as a result, some important articles can easily be screened out and not included in this study. Finally, the paper will provide the answers to the objectives as fore set in the previous paragraph.

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Keywords: Modern, Universal, Energy, access, Socio-economic Development

AuthorToEditor: This proposed journal article is expected to form part of my PhD programme in Energy Economics and Governance work. Giving me the opportunity to present this paper in the forward coming conference would mean: (a) a push on my journey to the completion of the PhD programme; (b) an exposure and adventure avenue for me to join the global team of technical persons toward making our world better place to live in; (c) and finally, it would be an opportunity to get first hand views at global perspective towards search for solution to holistic policy deficiencies of Modern Universal Energy Access (MUEA) and Socio-economic development of developing countries, but particularly Uganda.

[Abstract:0607] OP-090 [Accepted:Oral Presentation] [Energy Access » Energy Poverty and Equity]

Unveiling the health impacts of energy poverty in germany: a comprehensive analysis of objective and subjective indicators

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Overview:Energy poverty, defined broadly as the inability to afford basic energy needs for a decent standard of living, has gained prominence as a multidimensional challenge affecting individuals worldwide (Bouzarovski and Petrova, 2015). This challenge has in recent years been exacerbated by the global economic and geopolitical landscape, including the Russia-Ukraine war. These events have contributed to a surge in energy prices, causing many individuals to spend a significant portion of their income on energy-related expenses in order to maintain a comfortable temperature at home. The implications of rising energy prices and hence energy poverty on individuals' economic and health wellbeing are profound as it poses a direct threat to the health and wellbeing of vulnerable populations.

Previous studies have showed a strong negative correlation between energy poverty and an individual's health status and subjective wellbeing (e.g., Awaworyi Churchill and Smyth, 2021; Abbas et al., 2021; Recalde et al., 2019; Kose, 2019; Liddell and Morris, 2010; Harrington et al., 2005), with the negative impact of energy poverty on subjective wellbeing being even more pronounced for the elderly and individuals with lower incomes (e.g., Welsch and Biermann, 2014; Nie et al., 2021; Welsch and Biermann, 2017; Zhang et al., 2021a). In Europe, rising energy prices have only exacerbated the issue of energy poverty and remains a significant problem for lower-income households (Oliveras et al., 2021; Davillas et al., 2022; Bouzarovski, 2013; Welsch and Biermann, 2017). With a significant portion of income allocated to meeting heightened energy costs, individuals may be forced to make difficult choices between necessities such as heating, healthcare, and adequate nutrition.

The risk of falling into energy poverty could have pronounced repercussions on an individual's physical health, mental or psychological well-being, and overall wellbeing (Liddell and Guiney, 2015; Thomson et al., 2017; Lin and Okyere, 2020; Zhang et al., 2021b), highlighting the multifaceted nexus between energy poverty and health outcomes. The adverse effects of energy poverty on physical health manifest in several dimensions. Insufficient access to heating during cold periods has been associated with increased respiratory illnesses, cardiovascular problems, and exacerbated chronic conditions (Liddell and Morris, 2010; González-Eguino, 2015). Inadequate cooking facilities, often a hallmark of energy poverty in developing countries, contribute to indoor air pollution, leading to respiratory infections and other pulmonary issues (Duflo et al., 2008; Zhang et al., 2019). Extreme temperatures has also been shown to cause illnesses such as colds and the flu, exacerbate arthritis and rheumatism, and increase the risk of cardiovascular disease due to indoor air pollution (Cabraal et al., 2005; Bonan et al., 2017).The lack of reliable energy sources further impedes access to essential medical services and compromises the preservation of medications, particularly for individuals dependent on refrigerated medicines.

It is crucial to note that the impact of energy poverty on health is uneven across demographics, with its complex interplay with socio-economic factors exacerbating inequalities. Liddell and Morris (2010) and Liddell and Guiney (2015) emphasizes the disproportionately detrimental effects of energy poverty on vulnerable populations, including children, the elderly, and caregivers, who are more susceptible to respiratory diseases and other health complications. This disparity is particularly pronounced in low-income households, where the health impact is felt disproportionately across generations. For example, children in energy poverty may face developmental challenges, while the elderly are at an increased risk of health issues due to heightened susceptibility to extreme temperatures.

As highlighted by Liddell and Morris (2010), energy poverty is influenced not only by energy costs but also by household income and energy efficiency. Regarding income, Pan et al. (2021) demonstrate that the overall standards of living play a role in how energy poverty affects public health, with countries having higher standards of living exhibiting a lower prevalence of energy-poor individuals. However, even in wealthier nations with colder climates, such as Sweden and France, lower health outcomes persist in energy-poor households (Kahouli, 2020; Thomson et al., 2017). Similar adverse health effects have been documented in other developed countries with warmer climate such as Australia (Awaworyi Churchill and Smyth, 2021).

This paper explores the nexus between energy poverty, defined as a situation in which a household cannot afford to heat or cool its home to an ambient temperature and meet its other energy needs Maryon-Davis and Ballard (2014), and self-assessed individual health outcomes in Germany. The significance of our study lies in its unique approach, differentiating itself from prior research on energy poverty in the German context. Unlike previous studies that predominantly concentrated on subjective well-being (Biermann, 2016) or delved into energy dynamics and the determinants of

energy costs (Grösche, 2010; Heindl and Schuessler, 2015; Drescher and Janzen, 2021), our analysis deviates by specifically examining the correlation between various energy poverty indicators and self-assessed health status. Utilizing the German Socio-Economic Panel (SOEP) data spanning the years 2010-2021, we contribute to the literature by investigating both subjective and objective indicators of energy poverty and their impact on individuals' self-assessed health. Importantly, our study represents the inaugural attempt to comprehensively assess the influence of energy poverty on health outcomes in the German context, filling a critical gap in existing knowledge.
Methods:This research paper delves into the topic of energy poverty in Germany, focusing on the impact it has had on vulnerable households. The study utilizes data from the German Socio-Economic Panel (SOEP-Core v38) from 1984 to 2021. To evaluate energy poverty, the study employs variousapproaches, including expenditure-based methods such as the 10% rule (TPR), 2 median (2M), and low-income high cost (LIHC). Additionally, a consensual-based approach is used to assess whether a household can adequately warm their home. The study takes into account health status by analyzing the satisfaction with health (scale 1-10: 1=Completely dissatisfied, 10=Completely satisfied) and self-assessed health status (scale 1-5: 1=Bad). The analysis also considers other factors that may impact health outcomes, including socio-economic status, demographic factors, and regional factors. We adopt the standard Fixed effect regression method applied in the majority of energy poverty studies to estimate the effect of energy poverty on health.
Results:To ascertain the extent to which energy poverty influences self-reported health, a fixed-effect panel regression analysis was conducted, employing diverse energy poverty indicators as key predictors for self-reported health scores (see Table 1). Across all models analyzed, we find a consistent and statistically significant pattern: households identified as energy poor have diminished health outcomes (refer to Table 1, Columns 1-10). Notably, the degree of energy poverty within a household correlate directly with lower self-reported health scores. While expenditure-based indicators (Columns 1-3 and 6-7) show discernible effects, the consensual-based indicator (Columns 4 and 9) exerts greater influence, which is indicative of its potency in capturing energy poverty dynamics at the household level. Moreover, we find that the composite indicator (Columns 5 and 10), which identifies households at risk energy poverty across multiple indicators, echoed similar trends of compromised health outcomes.
The findings underscore a glaring reality: the most vulnerable energy consumers in Germany are unable to adequately afford energy services. Among these households, the inability to maintain warmth during colder months drives lower self-assessed health scores. Additionally, the inequitable distribution of heat within dwellings exacerbates health risks by subjecting such households colder temperature. Such adverse living conditions invariably exerts a toll on personal health, underscoring the urgent need to address energy poverty. Our findings highlights a sobering observation: energy poverty exertsa disproportionately heavy toll on the health and overall well-being of households compared to other manifestations of poverty. The ramifications of living in energy poverty reverberate across multiple dimensions, posing a significant threats to individual health.
Conclusions:The rising cost of living is expected to affect a significant portion of the German population, leading to a pressing issue known as energy poverty. However, to fully understand the extent and severity of this problem, further research is necessary. This study focuses on the impact of energy poverty on self-reported health, specifically in households that are particularly vulnerable based on their current energy expenses and income levels. The findings indicate that those experiencing energy poverty tend to have lower levels of health. By examining both expenditure and consensus-based indicators, the research identifies households that suffer from energy poverty based on their electricity and heating expenses. As energy-poor households spend a significant portion of their income on energy, policymakers must prioritize reducing energy costs and improving living conditions to combat this issue.
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Keywords: energy poverty, health outcomes, LIHC, consensual indicator

Regression Results

Table 1: Fixed Effects estimates of the impact of energy poverty on reported Health Status among Germans

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Dependent Variable 1: Current Self Assessed Health					Dependent Variable 2: Satisfaction with Health				
TPR (10% Rule)	-0.0177***					-0.0303**				
	(0.0051)					(0.0120)				
2 M		-0.0314***					-0.0794***			
		(0.0068)					(0.0165)			
LIHC			-0.0195**					-0.0534**		
			(0.0099)					(0.0244)		
Consensual				-0.0507***					-0.1814***	
				(0.0168)					(0.0411)	
Composite					-0.0326***					-0.0695***
					(0.0067)					(0.0162)
Observations	245,171	245,171	245,171	122,047	245,171	239,133	239,133	239,133	121,110	239,133
Adjusted R^2	0.67719	0.67721	0.67717	0.74248	0.67722	0.66474	0.66478	0.66474	0.72631	0.66477
Within R^2	0.00160	0.00167	0.00155	0.00121	0.00168	0.00126	0.00139	0.00126	0.00091	0.00136
Number of Individuals	55,048	55,048	55,048	55,048	55,048	53,474	53,474	53,474	53,474	53,474
Number of Households	33,468	33,468	33,468	33,468	33,468	32,835	32,835	32,835	32,835	32,835
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Data are from various SOEP(v38). The dependent variable is satisfaction with health (scale 1-10: 1=Completely dissatisfied, 10=Completely satisfied)/ self-assessed health status (scale 1-5: 1=Bad). *Demographic Controls* include age, age squared, years of education, marital status (1 = married/living together, 0 = otherwise), employment status (1 =currently unemployed, 0 = otherwise) *Socioeconomic Controls* include log of monthly income in euros. *Household Controls* include household size, household type (1 =Single, 2 =Couple without children, 3 =Lone parent, 4 =Couple with children, 5 =Other household) and urban dummy (1 = urban, 0 = rural). *Year, Region and Individual FE* are fixed effects of the survey year, region and individuals. Clustered standard errors by individuals are shown in parentheses.
*: Significant at the 10% level. **: Significant at the 5% level. ***: Significant at the 1% level.

[Abstract:0647] OP-091 [Accepted:Oral Presentation] [Energy Access » Energy Subsidies]

Fossil Fuel Subsidies and Energy Access: Opportunities and Challenges of Subsidy Reform for Globally Just Transition

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Overview: National experiences of energy transition demonstrate that fossil fuel subsidies (FS) – measures that governments take to support the consumption and production of natural gas, coal and oil - are often detrimental to multiple aspects of human development such as poverty eradication, global health (Webb et al., 2023), gender equality (Sharma et al., 2019), sustainable consumption and production (Parry et al., 2021), education (Clulow, 2023) and access to reliable and/or sustainable energy (Li et al., 2024). Around the world, there is a growing consensus among academics, policymakers, NGOs and national publics that subsidy reform is vital for facilitating just energy transition. Yet despite the nominal commitment to subsidy phase-out, the share of world income spent on FS continues to rise; accounting for around 6.8% of global GDP (5.9 billion US$) in 2020 (International Monetary Fund, 2022).

The mechanisms behind the detrimental FS effects are complex, multifaceted and vary widely across countries. Most obviously, FS expenditure uses up resources that could be invested in more sustainable, efficient and equitable energy infrastructure and meeting human development goals that are integral to just transition. Yet the negative relationship is not just one of limited resources; governments that rely on fossil revenues face strong disincentives to invest in other - more sustainable – industries (Ross, 1999). In these countries, fossil-intensive activities often attract the highest revenues, leaving little incentive for private sector investment in other industries or energy sources (Bjorvatn et al., 2012), reducing the ability to provide incentives for new skills development (Douglas & Walker, 2017).

Undoubtedly, the consequences of FS are shaped by many factors such as natural resource endowment (Parks & Roberts, 2009), wealth (Coady et al., 2017), industrial capacity (Henisz & Zelner, 2006) and global energy prices (Trutnevyte, 2016). Yet even after these factors are accounted for, we find that the most detrimental effects are concentrated in the poorest countries. This is true both in terms of performance for key energy metrics (e.g. shares of renewable energy sources of total electricity and energy access), as well as broader socio-economic and distributional indicators of just transition. This research investigates the implications of FS for multiple aspects of just transition and explores the multiple factors that shape these effects. In this way, this study takes an important first step in identifying priority sectors and countries for subsidy reform and assessing the potential fit of different reform strategies for aiding transition in different countries.

Methods: While numerous studies explore the implications of FS for energy-based and broader socio-economic indicators of energy transition, most quantitative work focuses on cross-sectional differences between countries (Li et al., 2024; Vieites et al., 2023; Webb et al., 2023), which creates the possibility that observed correlations might be due to other (unmodelled) factors such as fossil resource endowments, modernisation and cultural preferences rather than subsidies. As a corrective, we build a two-level hierarchical model consisting of country-years nested in countries to isolate the effects of FS and other potential drivers on a comprehensive range of just transition metrics within the same country. By modelling separate FS-transition relationships for each country, we are able to estimate comparable metrics for evaluating how FS implications vary across countries and the role of conditioning factors that shape these effects, providing valuable insights into potential strategies and priority countries/ regions for subsidy reform globally.

We use country-year data spanning 172 countries over 1980 to 2020 to evaluate the implications of FS on energy and socioeconomic, distributional and environmental indicators of just transition, providing a dataset of 7,052 observations. For each just transition performance indictor, we employ three separate models: (i) a single level ordinary least squares regression, (ii), a random intercept model which differentiates between observations from different countries and (iii) a random coefficient model (RCM) that allows the effect of FS to vary between countries. We compare the country-specific subsidy effects predicted by our models to evaluate whether and, if so, how the relationship between FS and just transition varies across countries at different stages of industrialisation, energy transition, fossil rent endowment, institutional capacity, energy access, poverty, healthcare and education rates. We add nuance by exploring which types of subsidy (e.g. consumer, producer, oil, gas and coal) are more influential for different transition outcomes by setting up granular models using data from the World Bank Development Indicators, International Energy Agency World Energy Balances and International Monetary Fund Fossil Fuel Subsidies databases.

Results: Our results indicate that even when other potential drivers of energy transition are held constant, FS do indeed have significant implications for access to reliable, affordable and sustainable

energy as well as socio-economic indicators of just transition such as healthcare provision, educational attainment, poverty rates, environmental outcomes, gender equality and carbon footprints. However, we also find that subsidy effects vary widely across countries; the worst effects tend to be concentrated in the poorest countries and regions; in low-income countries, increases in FS spending (relative to GDP) are associated with large decreases in energy access and human development indicators. Yet our results show that detrimental effects tend to diminish with economic development and are even (mildly) positive in some high-income countries. Conclusions:Our comprehensive analysis of global FS and just transition datasets provides strong evidence that FS obstruct the global transition to affordable, reliable and sustainable energy, as well as other sustainable development goals such as poverty eradication, health, gender equality, sustainable consumption and production and educational, particularly in the poorest parts of the world. Our findings support growing calls for FS reform (e.g. International Institute for Sustainable Development, 2023; International Renewable Energy Agency, 2023; The World Bank, 2024) and suggest that, if well designed and implemented, subsidy phase-out could greatly assist efforts to transition to a more sustainable and just world order. Our results also demonstrate the need for detailed country-specific analysis of the impediments to (and drivers of) just transition.
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[Abstract:0684] OP-092 [Accepted:Oral Presentation] [Energy Access » Energy Poverty and Equity]

Does Environment and Health Awareness Matter for Household Fuel Choice? Empirical Evidence from Central Asia

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Overview:Household consumption of coal and other dirty fuels for heating and cooking greatly contributes to air pollution both outdoors and indoors. We contribute to the literature on the determinants of household heating choice (dirty versus modern energy source). Energy transition in countries where a large proportion of the population is energy-poor could be challenging. To investigate the energy choice of the energy-poor population we conducted a survey with 1,522 households from three countries in Central Asia: eastern Uzbekistan, the southern Kyrgyz Republic, and northern Tajikistan (also called Fergana Valley). Half of the households (50%) use coal for heating. We find that the energy-poor (who comprise 66% of the population) are more likely to use dirty fuel for heating. The determinants of heating choice (dirty fuel versus modern energy) vary for the energy-poor and energy-non-poor. For example, households that care about environmental harm are less likely to choose dirty fuel for heating, but only among those who are energy nonpoor. Awareness of health impacts has a significant effect on the heating fuel choice across all groups (energy-poor and -nonpoor). Based on the above findings, policy recommendations for promoting the transition from dirty to modern heating are provided.
Methods:The household energy survey was carried out in-person in the territory of Fergana valley, which is located in three countries of Central Asia: eastern Uzbekistan, the southern Kyrgyz Republic, and northern Tajikistan. The survey was designed jointly by the CAREC Institute and the ADB Institute. The survey was conducted during July–August 2023 following pilot tests. The questionnaire included information on energy consumption, energy access for heating, cooling, and cooking, the quality of energy infrastructure, energy efficiency, and environmental education. The survey also traced down households' heating methods and behavior and their willingness to switch to cleaner energy. Based on the above data, we use the logit model to study the determinants of heating choice.
Results:First, the energy-poor (which comprise 66% of the population) are more likely to use dirty fuel for heating, thus energy-poor households are more prone to "fuel stacking." Therefore, the energy transition from dirty to clean heating will require more incentives and support for energy-poor households.

Second, households that care about environmental harm are less likely to choose dirty fuel for heating, but only among those who are energy-nonpoor. The awareness of environmental harm is not significant for the choice of heating fuel among the energypoor, thus raising environmental awareness will have a limited impact on switching to clean heating. On the other hand, awareness of health impacts has a significant effect on the choice of heating fuel across all groups (energy-poor and -nonpoor). Thus, raising environmental awareness for promoting switching to clean heating will have a limited impact (affecting mainly the energy-nonpoor and having no impact on the energy-poor), while raising awareness of health impacts will have a greater effect across all groups (energy-poor and -nonpoor). Policies for raising awareness of the health impacts from dirty fuel are more

likely to lead to a greater effect on fuel switching than raising awareness of environmental harm.

Third, environmental awareness is the main reason for households to switch from dirty to clean heating; however, the actual use of clean heating is affected by environmental awareness only for the energy-nonpoor, indicating that the energy-poor, although they could be aware of environmental impacts, have limited ability to switch from dirty to clean heating, which could be due to other factors such as limited access to finance to change the heating system (or moving house), or the access to, or affordability of, clean heating.
Conclusions:Using the household energy survey that was carried out in-person in the territory of Fergana Valley, which is located in three countries of Central Asia, namely eastern Uzbekistan, the southern Kyrgyz Republic, and northern Tajikistan, during July and August 2023, this study provides the following key results and evidence-based policy recommendations for promoting clean heating among households.

Overall, our results suggest that raising environmental awareness is not enough for energy-poor households to adopt modern fuels. They will also need more policy support, besides raising awareness, such as improving access to finance, access to clean heating, and its affordability.
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Keywords: fossil fuel, heating, energy-poor, Central Asia, household energy consumption, energy transition

AuthorToEditor: Dear Scientific Committee, I am very sorry for missing abstract submission deadline. I hope you can still consider my submission. It was indicated PhD day, which i could not change. please consider my paper for the sessions not PhD day, i am not phd student. Best regards, Dina

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[Abstract:0037] OP-093 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

India’s Road Passenger Transport Energy Demand: An Assessment through Life Cycle Analysis

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Overview:The key driver of transport sector demand has been India's overall economic growth, which has led to increasing energy demand, purchasing power, and demand for passenger transport. The demand for passenger vehicles such as two-wheelers, 4-wheelers, and public transport has increased strongly over the past several years, with extremely robust growth in crude oil consumption. The rising prevalence of vehicle ownership in India has ushered in fresh challenges, including traffic congestion, extended travel durations, environmental concerns, and road accidents. This shift in circumstances prompted a revaluation of the Indian government's policy approach. Numerous initiatives have been introduced to tackle India's transportation issues, with the overarching objective of establishing a sustainable transportation system.
This paper aims to present the evolution of road passenger transport policies in India. The Government of India (GOI) policy interventions considered in this study are from the post-independence (after the year 1947) period and are restricted to road passenger transportation. While examining policies related to other modes of transportation sectors is equally significant, however, attempting to encompass them all within a single paper may compromise the in-depth review required. Hence, it is suggested as the future scope of this paper. The scope of the current paper is as follows:
Section 1 will present a decision-making approach based on life-cycle assessment (LCA), which considers not only the carbon emissions from a vehicle's use, but also from its manufacturing, delivery, and infrastructure needs. LCAs provide an effective means of understanding the impact of alternative policy choices on greenhouse gas (GHG) emissions.
Section 2 Highlight and identify the challenges and gaps in the existing road transport policies and infrastructure.
Section 3 finally, concludes with policy recommendations and a way forward for India's road transport.
Our analysis of India's clean road transport policies and emission standards provides an opportunity for oil-producing countries to estimate the future demand for crude oil in India. Furthermore, a decision-making approach based on life-cycle assessment (LCA), which considers not only the carbon emissions from a vehicle's use but also its manufacturing, delivery, and infrastructure needs could provide an effective means of understanding the impact of alternative policy choices on greenhouse gas (GHG) emissions.
Methods:The LCA study is attributional and comparative, following the ISO standard. The functional unit of the assessment is person x kilometre, matching the purpose of passenger vehicles to transport people from one point to another. The system boundary includes the production stage (covering material extraction and manufacturing), the operation stage (covering fuel production, use and vehicle maintenance), and the end-of-life stage (covering treatment and disposal) of the vehicles in an Indian context. In addition, road infrastructure construction and maintenance are considered during the vehicle operation phase. The foreground inventory of the different passenger vehicle technologies is modelled based on the literature. At the same time, background system data are derived from the ecoinvent v3.9 database using the SimaPro v9.5. The ecoinvent datasets utilized for vehicle manufacturing were primarily derived from average global market processes. However, modifications are made to the electricity generation processes for vehicle and component assembly to match the current all-India electricity mix. An exception was made for the Li-ion battery production, for which average Chinese conditions were used as China is globally the leading supplier of traction battery components.
Results:The life cycle results for global warming potential (GWP) of all passenger vehicles assessed, expressed as CO2-equivalents per passenger km. All the bus options showed clear benefits for reducing GWP compared to the passenger cars, with the CNG bus contributing the best GWP reduction potential considering the current Indian local context. For all the bus options, Operation stage as the most important contributing over 95% of their life cycle GWP impacts. A similar pattern is observed for the passenger cars and two-wheelers (2W), where the operation phase contributes between 63 – 82% of the total impacts, except for the motor scooter, with 91% of the impacts coming from its operation stage. These results indicate that more efforts should be placed on mass transportation (in this case, public buses) and improving current passenger vehicles' operation phase. This is especially important for supporting India's ambitious target of making EVs account for at least 30% of new vehicle sales by 2030. Considering India's current electricity generation mix with an average carbon intensity of xxx g CO2-eq/kWh, efforts to decarbonize transportation should prioritize buses over passenger cars while simultaneously promoting efforts towards decarbonizing the electricity sector.
Shifting focus toward the electrification and expansion of bus transit systems rather than passenger cars provides greater potential for GWP reductions, with the CNG bus the best option now and possibly in the short term. However, electric buses can be the best option in the long term, but only if the electricity mix is decarbonized, as suggested in the literature. Besides, mass transportation systems provide more equitable mobility benefits for densely populated urban areas in India and align with the avoid-shift-improve paradigm for sustainable urban planning and transport. Generally,

buses transport far more passengers per km travelled and use relatively less critical minerals and urban space (for road and packing), emitting a fraction of the GWP impact per passenger km than passenger cars. Moreover, municipal bus fleets are more centralized and relatively easier to upgrade (considering the infrastructural requirements for vehicle electrification) than dispersed privately owned cars, further enabling the rapid transition to electric buses and increased ridership. Urban bus networks also provide essential transportation for lower-income populations without car access, contributing to the just transition discourse. While passenger cars still warrant decarbonization efforts, prioritizing bus electrification and transit-oriented city development provides superior emissions cuts, traffic congestion relief, and equitable access for the efforts invested, creating a virtuous cycle for further sustainable mobility transition in India.
Conclusions:India's daunting task of decarbonization the passenger road transport sector, still needs a significant push from the policy makers. However, policy makers should start prioritizing the sector wide development with transitional pathways. Some of the recommendations are as follow.

- Initiate a shift to buses and prioritise their electrification.
- Encourage a shift in the car fleet towards shared electric vehicles.
- Promote ethanol blending and biofuels.
- Promote electric two -wheelers.
- Government should mainstream life-cycle assessment into public policy and investment decisions.

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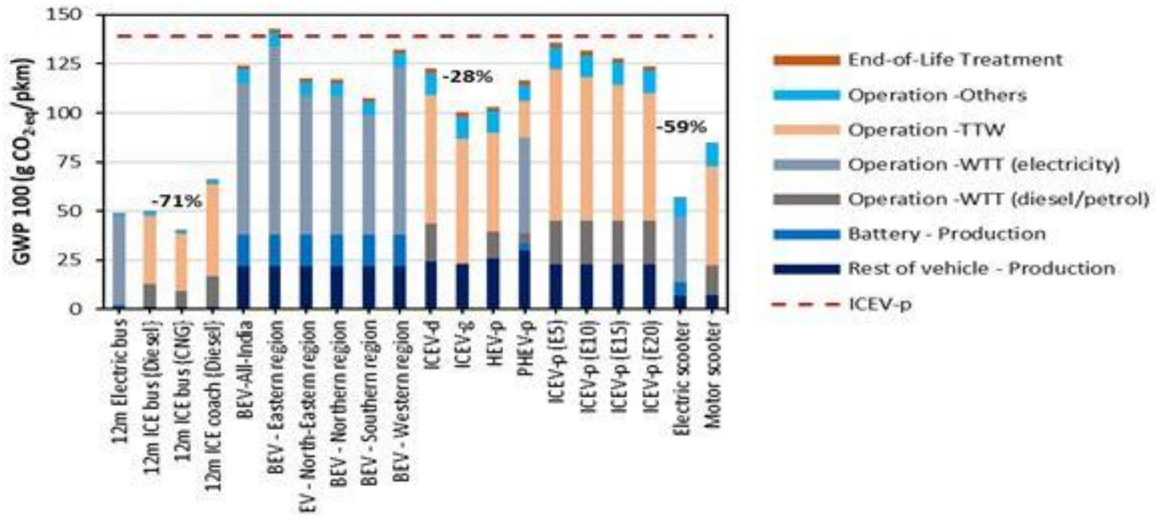
Keywords: Oil, India, Road transport, Transport Policy

Result of Life cycle analysis

Figure 1. LCA results as per the passenger vehicle type and fuel.



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[Abstract:0088] OP-094 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

The Analysis and Prospect of CNPC's EV Charging Business

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Overview:With rapid development and great potential of Chinese EV charging sector, many companies which are outside the industry step into this field in recent years. China National Petroleum Corporation (CNPC) is very active in branch establishment, company acquisition, facility construction and industrial layout in this new area. The paper analyses the current trends and prospect of CNPC's EV charging business and consists five parts. First, it introduces important events of EV charging business involving CNPC. In June 2023, CNPC and Wuliangye Group signed an agreement to jointly establish Sichuan Zhongxin Green Energy Company, whose business includes centralized fast charging stations, operation of EV charging infrastructure, energy storage technology services and PV power generation equipment manufacture and sales. In September 2023, CNPC acquired 100% shares of Potevio New Energy. Potevio New Energy is the earliest state-owned company in China to carry out EV charging business, comprising vehicle technology, power batteries, charging equipment and carbon trading. After acquisition, CNPC becomes the 15th largest charging operator domestically. Nearly at the same time, CNPC Beitou Winter Olympic Village Super Charging and Battery Swapping Station (Beitou Charging Station) opened in Beijing. It marks the official operation of CNPC's most advanced and comprehensive EV charging station in China. Beitou Charging Station integrates photovoltaic, energy storage, charging, discharge, battery swapping, battery testing and non-oil service. It currently has 111 charging spaces, which provides convenient and efficient charging services for hundreds of EV at the same time. It also adopts various cutting-edge technologies, such as high-power liquid-cooled supercharging, wireless charging and automatic charging, in order to enhance charging efficiency and convenience. In October 2023, CNPC's first "super charging plus convenience store" station was put into operation in Tianjin. The station, which has 80 charging spaces, is equipped with energy storage, slow charging, fast charging, high-power liquid-cooled charging, battery detection and intelligent platform system technologies. Besides, the station has a two-story, 400m2 convenience store, providing clients with dining, shopping and rest services. It is worth noting that the parking lot ceiling is installed with 185kW capacity PV power generation modules, generating more than 400kWh of daily power and 175 tons per year.

Second, it analyses the reasons for CNPC to enter EV charging business. To begin with, by facing with energy transformation and global low-carbon trend, oil companies, including CNPC, seek to enter and expand their new energy business. For example, BP, Shell and Total are the earliest oil companies who get involved in a wide variety of green energy business, ranging from wind power, solar energy, biofuel to energy storage. Most IOCs are transforming their business and setting the goal of becoming integrated energy companies instead of solely oil and gas players. Under energy transformation circumstance, CNPC hopes to follow this trend and seize the opportunity as well. Next, CNPC's step into EV charging sector is followed by vigorous governmental advocates for green energy and low carbon vision. As one the most important national companies in China, CNPC bears the responsibility to carry out national policies and government decisions. In order to achieve China's 2060 carbon neutrality goal, CNPC has adopted low-carbon and energy transition into its development strategy and set the target of identical importance of green energy, oil and gas business by 2035 and near zero emission by 2050. In addition, with rapid development of EV and charging industries in China, CNPC should also seize the opportunity to make more profits by engaging in this business. Energy is closely linked with transportation. As China's leading enterprise in traditional energy, CNPC has its advantages and motivations in the involvement of EV charging industry.

Third, it tries to explain the advantages of CNPC in EV charging industry. To start with, cost advantage cannot be ignored. It requires huge capital and time for independent charging pile operators to find and construct charging stations. However, as for CNPC, who owns more than 22,000 domestic gas stations, transforming existing stations by adding new charging facilities will save huge amount of money. Besides, financial advantage is essential as well. In 2022, the revenue of CNPC ranked second among China's top 500 enterprises and its profit exceeded CNY266 billion (US$37.3billion roughly). According to its fiscal report, CNPC will invest CNY7billion (US$1billion roughly) for the construction of "oil, gas, hydrogen, electric and store" integrated stations and the optimization of terminal network layout. Besides, industrial advantage is another strength. As an energy giant in China, CNPC is both involved in fossil fuels and new energy in recent years. There are many overlapping parts of CNPC's current business and its extended EV charging business. By utilizing natural gas, wind, solar and geothermal for electric generation in its mining area and surrounding area, CNPC has favourable conditions for the development of EV charging business.

Fourth, it summarizes the disadvantages of CNPC in EV charging development. Above all, the EV charging market is relatively saturated market dominated by private enterprises. The total number of public charging piles in China is 2.27 million units. After the acquisition of Potevio New Energy, CNPC will possess more than 20,000 charging piles, ranking only 15th in terms of amount. There is still a big gap between CNPC and other top ten charging operators regarding market share. Besides, CNPC is not competitive enough in expanding market in this area. The EV charging facilities in China have characteristics such as scattered in distribution and various in types. For CNPC, the EV charging business is still in the incipient stage and accounts for a small proportion of the entire company's business. Thus, to compete with the companies who are focus on this industry for years is difficult regarding market expansion.

Fifth, this paper proposes suggestions for CNPC's EV charging development. Firstly, transforming current gas stations into "oil, charging and store" integrated stations. The renovation of existing facilities will save space and capital. In current stage, most of CNPC's gas stations are equipped with convenience stores. The company should select appropriate gas stations, which have enough surrounded space for expansion, and add charging facilities on-site. In this way, the integrated stations can satisfy the demand of gasoline vehicle refuelling, EV charging and also rest and dining for drivers. In general, to construct large-scale, efficient and comprehensive stations instead of decentralized layout of a few charging facilities in small parking lots or shopping malls is future industrial trend and CNPC's development priority. Secondly, making full use of additional energy generated during oil and gas production and promoting energy storage technologies. During oil production process, huge amount of additional energy, such as gas, geothermal and solar, is produced as well. By utilizing those energy for electric power generation can reduce cost. Besides, the company should also promote energy storage applications in EV charging stations. By doing this, energy can be generated during low-price trough hours and released among high-price peak hours. Utilizing additional energies produced during oil and gas production for electricity generation in combined with energy storage promotion, the company will reduce cost and increase efficiency greatly. Thirdly, making comprehensive and specified development plans according to different charging scenarios and needs. Currently, the focus of CNPC is the construction of independent charging stations and the transformation of gas stations in metropolises. The company should layout different charging and swapping facilities by different scenarios, including communities, highways, tourist destinations and so on based on drivers' demand. Fourthly, strengthening cooperation with

leading enterprises in super charging, rapid battery swapping and automatic and intelligent charging technologies. As an industry newcomer, the best way for rapid progress is to create complementary advantages. For instance, CNPC can cooperate with Huawei in deploying its ultra-fast liquid cooled supercharging terminals. By combining technical, capital, location and human resources advantages with other industry leaders, CNPC will not only promote the development of its own EV charging business but also push ahead the whole industry growth nationwide.
Methods:The paper adopted interdisciplinary research, case study and statistical analysis methods.
Results:By renovating and construction facilities, establishing new companies and acquiring existing enterprises, CNPC has entered EV charging sector and intended to expand this business in the near future. After analysing advantages and disadvantages, the article considers that CNPC has a great potential in developing EV charging business.
Conclusions:As for CNPC, EV charging business is small in scale currently but great in potential in the future. To better develop EV charging business, the paper suggests CNPC to transform current gas stations into “oil, charging and store” integrated stations, make full use of additional energy generated during oil and gas production and promoting energy storage technologies, make comprehensive and specified development plans according to different charging scenarios and needs and strengthening cooperation with leading enterprises in super charging, rapid battery swapping and automatic and intelligent charging technologies.
References:

Keywords: CNPC, EV charging, low carbon, charging station

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Consumer Preferences For Battery Electric Vehicles Considering Energy Mix: A US Choice Experiment Study

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Overview:In the United States, transportation is responsible for approximately 29% of greenhouse gas emissions, making it the country’s largest source of greenhouse gases. The transportation sector also accounts for about 30% of the United States’ energy needs and 70% of its petroleum consumption (US EPA, 2020). As policymakers focus on mitigating factors that contribute to climate change, battery electric vehicles (BEVs) and their markets have become increasingly important to understand. According to the Alternative Fuels Data Center (US DOE, 2021), BEVs can improve fuel economy, lower fuel costs, and reduce emissions. In addition, BEVs have been considered a favorable alternative to internal combustion engine vehicles because of their potential to improve energy security and public health by decreasing both reliances on petroleum and emissions that harm air quality. However, the BEVs market has long been troubled by a lack of consumer demand driven by the low availability of infrastructure and other convenience and preference factors. Until recent years, suppliers have had little incentive to change this, and low supply and demand continue to reinforce each other. This has often been referred to as a “chicken-and-egg” problem, implying the need to solve supply-side problems to grow markets and fuel demand.
As BEV adoption rates in the U.S. grow, it is of continued importance to understand how consumers respond to these markets’ features and the changes associated with using new technology. Currently, a few key states (e.g., California) and large companies (e.g., Uber) have enacted aggressive zero-emission regulations for the transportation sector by a deadline, usually 2035. The current

administration recently signed an executive order setting a target that 50% of all new car sales nationwide by 2030 will be zero-emission vehicles, primarily BEV. Most recently, the Infrastructure Deal was also passed, dedicating billions of dollars for BEV deployment nationwide. However, eliminating the emission at the tailpipe without addressing where the electricity to fuel BEVs comes from may result in economic inefficiency and possibly a loss in social welfare. Further, electricity source is increasingly relevant to the U.S. transportation sector as growing numbers of BEVs coincide with how the U.S. produces and consumes electricity. Many studies have investigated how consumers respond to vehicle attributes and related aspects of BEV ownership. However, there currently has been no study looking into energy source as a BEV attribute or estimating consumers' willingness to pay (WTP) for clean electricity as a BEV fuel source in the U.S. This study investigates whether the source of electricity affects consumer attitudes towards BEVs and estimates willingness to pay (WTP) for clean energy as an attribute of BEVs through a choice experiment survey. This research also explores consumers' attitudes towards various policy incentives for BEVs, changes in the number of jobs, and ultimate changes in electricity costs.
Our initial evaluation considers the "average" driver's support for increasing the BEV requirement policy, then controls for observable and unobservable heterogeneity and focuses both on the driver's location (i.e., rural versus urban) and exposure to charging station infrastructure. While there is extensive literature on BEVs, consumer preferences on the source of electricity that fuels BEVs are less well understood. We find that, on average, a positive value is associated with increasing the BEV requirement policy as long as they are charged via clean energy sources such as renewables and nuclear energy. Further, we find heterogeneity regarding location, exposure to BEV charging stations, and sociodemographic variables such as respondents' age, gender, education, income, and political affiliation.
Methods:We administered an online discrete choice experiment survey, developed following the Tailored Design Method (Dillman et al., 2014) with a Bayesian efficient design, to 1900 randomly selected U.S. drivers using the Qualtrics XM platform. The data were analyzed using random parameter logit with flexible mixing distribution and hierarchical Bayes logit models (Bansal et al., 2018; Train, 2016; Train & Weeks, 2005; Train Kenneth, 2003) to assess marginal WTP (MWTP) for each attribute and various transportation plans. GIS is applied to calculate the spatial heterogeneity variables, the charging infrastructure exposure, and rural and urban areas within the U.S. This paper extends the literature by constructing MWTPs coupled with their confidence intervals at the individual level and in the WTP-space. We find considerable heterogeneity in preferences among the decision makers, which are not explained by differences in sociodemographic variables.
Results:Preliminary findings show that U.S. drivers have a positive MWTP for increasing the share of BEVs in the transportation system and are supportive of clean energy to provide power for charging BEVs. The average respondent (i.e., not controlling for heterogeneity) exhibits a MWTP of $1.24 for a 1% increase in the current BEV level. The MWTP value increases at a decreasing rate as the BEV regulation level increases. Our results also suggest that U.S. drivers prefer renewable energy sources such as solar, wind, and hydro-power more than nuclear energy as a clean energy source for an electrified transportation sector. We find that drivers are willing to pay $12 per month to replace the existing 15% nuclear power in the electric grid with renewable energy sources.
Furthermore, drivers are supportive of increasing the number of jobs associated with accelerated vehicle fleet decarbonization in the U.S., prefer tax credit incentives over free charging and free parking initiatives, and dislike the status quo transportation plan. Lastly, controlling for spatial and individual heterogeneity results in a divergence of values. Respondents who live in urban areas are more supportive of BEV and clean energy policies and less supportive of jobs. Similarly, respondents that are pro-environment (captured by the New Environmental Paradigm scale), male, and young with high income and education level, who affiliate with the democratic political party, are more supportive of BEV and clean energy policies. Thus, we find that heterogeneity impacts the outcome.
Conclusions:A large nationwide choice experiment study is developed to estimate U.S. drivers' preferences and valuation of BEVs considering the electricity mix that fuels the vehicles. Preliminary findings suggest that drivers support an electrified transportation sector and have a positive MWTP for increasing the share of renewable energy sources to fuel BEVs. However, controlling for heterogeneity results in a divergence of values. An efficient energy policy requires both technological efficiency and economic viability. In addition, public acceptance is necessary. For the U.S. regulators considering accelerated transportation sector decarbonization, this research provides improved information with which to develop efficient policy. Understanding the significance of energy sources to consumers in the U.S. can help shape policy, especially as states move forward with renewable energy and clean transportation initiatives. Overall, preliminary results suggest that efforts to increase the use of renewable energy in the electricity sector may be important in driving the adoption of BEVs in the U.S. This information is also relevant to policymakers attempting to address supply and demand issues in BEV markets as these markets and their infrastructure continue to develop, especially after the recently passed infrastructure bill. The results also suggest that regulators in other countries considering changes to their transportation sectors may find an

improved understanding of consumer heterogeneity valuable.

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Keywords: Electric Vehicles, Stated Preference, Choice Experiment Survey, Marginal Willingness to Pay

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Electric vehicles: when will they charge ahead? exploring the factors driving ev adoption

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Overview:Over the past decade, many international agreements, such as the 2015 Paris Agreement and conferences such as COP, have seen 196 countries agree on the importance of drastically reducing CO_2 emissions, causing the detrimental effects of global warming. The global transport industry is one of the largest contributors to CO_2 emissions, accounting for 20 per cent of the global emissions in 2022 (Statista, 2023). To reduce carbon emissions in this sector, governments worldwide have seen great support for implementing electric vehicles (EVs). Because an EV gets all its driving power from batteries installed within vehicle's body, they do not produce CO_2 emissions (Li et al., 2017). However, introducing EVs into global transport networks is challenging for many countries as they do not possess the necessary infrastructure to handle the demand EVs place on electricity grids and policies that encourage EV adoption. Possible solutions to these challenges include local production, implementation of successful policies that help reduce high purchase and operation costs, and investments into smart grid technology. A significant portion of the literature focuses on individual factors determining EV adoption with little emphasis on comparing and contrasting the effects of various determinants on EV sales as addressed in this study. The objective of this study is to identify key factors that highlight differences in EV sales between EV manufacturing and EV-importing countries in the European Union (EU). The significance of the results intends to provide insights into worldwide successful technology and policy implementation regarding future green investments toward achieving the United Nations Sustainability Development Goals.
Methods:The study uses a panel data regression, with country-fixed effects allowing for differing

country-specific factors to be analysed. The data is collected from a variety of energy economic sources; the International Energy Agency (IEA) was used for EV-specific sales data and the European Automobile Manufacturers' Association (ACEA) along with The World Bank database was used for economic data. All data is collected for the period 2014 to 2022 for 17 of the EU's 32 major European countries. This period was chosen because 2014 saw the start of a significant increase in the adoption of EVs due to implementing improved policy frameworks in the EU and its member states, such as The Alternative Fuels Infrastructure Directive (EU, 2014) and the signing of the Paris Agreement a year later.
The model specification in this study is based on the following equation tested by various studies (Plötz et al., 2017 & Yao et al., 2020) with the intention of this study to expand and develop the model further:

lnEVSALESit = (β_0 +μ_i)+ β_1 lnCHARGINF_it + β_2 DUM_MANU+ β_3 GOVINC + β_4 lnPETREG_it + β_5 lnCONT_it +v_it

Where subscript i represents a country in the EU, t accounts for the year, u_i accounts for country effects and v_it is the error term.

A feasible GLS estimation is used to gradually build the model one variable at a time, considering the effects one variable may have on the other, as joint effects could render individual effects insignificant. In addition, Swamy RC estimators are included to identify the effect of variable effects in each country which are not identified in the model.

The model uses a natural log on the dependent variable to even out the spread of EV sales across the EU. The model focuses on four main variables expected to have a more significant effect on sales. These include the number of available charging stations in each country ($lnCHARGINFit$). Two dummy variables are added to distinguish between EV manufacturing (DUM_MANU) and importing countries and whether or not a government incentive (GOVINC) is available to purchase an EV. A variable for new petrol vehicle sales ($lnPETREGit$) in response to EV sales in the same period is added, representing the information on the substitute products. In addition, the control variable ($lnCONTit$) includes other factors that may influence sales.
Results:The European Union has the second-largest EV market and has achieved this due to three key factors. These well-established EV manufacturing companies play the most important role in EV adoption through local production. Secondly, the EU is home to the third largest economy in the world, making up one-sixth of the world's GDP; with this wealth, the large-scale adoption of EVs is achievable (Rao, 2023). Not only can the consumers afford the high purchase prices, but governments have the funds to invest in the infrastructure needed to accommodate EV adoption. Government infrastructure investment projects closely link to the necessity of charging stations available in almost all major cities in the EU; however, studies show that the deployment of charging stations available in the EU is not keeping up with the growing demands for EVs (ACEA, 2023). The study results showed that all three of these factors were significant in explaining EV adoption alongside the introducing a carbon tax to focus purchasing decisions on green energy technologies in EVs. The study found that the relationship between EV sales and alternative technology (petrol) sales was significant and showed that if consumers were not purchasing petrol vehicles, they were purchasing EVs. The relative fuel price (electricity to oil price ratio) was tested in the study to complement the alternative technology factor; however, the results showed no significance and no relationship with EV sales. Government incentives and policies to encourage EV adoption played a significant role in explaining EV adoption within the EU, as their focus is solely on the transition to green energy transportation. The study's results show a clear path to introduce large-scale adoption of EVs, and thus, it can be applied to countries worldwide in the pursue of green energy transitions.
Conclusions:The devastating effects of global warming on everyday life are becoming more frequent. Thus, there is a need for worldwide acceptance to reduce climate change. Reducing the amount of carbon dioxide released into the atmosphere is the most important factor in achieving this goal. This calls for governments to focus their transitioning to green energy production and usage. One way to reduce CO2 emissions is by introducing EVs into transportation networks. However, adopting EVs is expensive and challenging for many countries worldwide as they lack available funds or do not have policies for EV adoption. This study examines EV-specific and socio-economic factors in the EU market to understand how a worldwide large-scale adoption of EVs is possible. Recognising
The study's results indicate that having a local EV manufacturer does play an important role in the adoption of EVs. Overall, EVs are new and complex technologies, thus making their initial purchasing and maintenance costs higher than ordinary combustion engine vehicles. This creates a gap in the market where consumers who would consider purchasing an EV cannot do so because they are not financially able to do so. The successful implementation of purchase and maintenance incentives

greatly influence EV sales and will ultimately allow EVs to be more accessible. The challenge faced by most countries outside of the EU, excluding the USA and China, is that of outdated and deteriorated infrastructure to accommodate the transition along with low economic wealth and policies to encourage EV adoption. This study is necessary as it aims to provide details on several significant determinants in EV adoption within the EU and analyses these determinants to promote EV deployment in regions worldwide, adapted to each countries own economic stance on investing in green technology.

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Keywords: Electric Vehicles, Green Energy Transportation, Energy Transitions, Climate Change

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[Abstract:0303] OP-097 [Accepted:Oral Presentation] [Energy System Transition » Policy]

User-Centred Governance for the Cross-Border Transmission Network Investments in Europe

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Overview:The cross-border transmission network is the backbone of a low cost and reliable electricity system in Europe. The 2023 Grid Action Plan, proposed by the European Commission, also recognized the pivotal role of the cross-border transmission network [1]. However, its investments in Europe present intricate complexities and challenges [2]. The current decision-making structure in Europe, fragmented by national institutions, poses significant challenges for cross-border cooperation. At the same time, cross-border network investments grapple with the asymmetry of costs and benefits. Furthermore, the perceived costs and benefits of transmission investments are not static; they evolve over time. The rapid evolution of distributed generation and storage technologies, as well as the mobility and heating electrifications, not only results in substantial forecasted growth for transmission investments but also introduces new technical and commercial characteristics in the network capacity usage. Thus, the energy technology paradigm shift brings greater uncertainties into the cost and benefit evaluations of transmission investments.

As a consequence of institutional and political barriers, injunction to maximize system-wide social welfare in European cross-border transmission network planning, such as the Ten-Year-Network

Development Plan (TYNDP), does not provide a realistic guide to action. Traditionally, harmonizing national regulations has been the solution to address the cross-border coordination challenges. However, as discussed in the literature, incremental improvements based on national preferences could eventually reach a Pareto efficiency boundary [3]. Additionally, the Meroni doctrine in European legislation indicates that while EU agencies can be delegated a limited amount o executive power, they cannot be granted discretionary power [4]. This limits the possibility of creating a centralized regulatory agency to decide on cross-border network investments and directly finance them in the near future.
Methods:The intergovernmental cooperation for cross-border network investments has led to gridlocks. To foster more effective cooperation, it is crucial to reflect on and redefine 'who can draft the rules' and 'policy decisions within the constraints of collectively made rules' within the institutional analysis and development (IAD) framework [5]. In this research, we propose that eliminating the national fragmentation of cross-border network investments should be entrusted to the direct participation of the electricity industry stakeholders and various grid users. Furthermore, integrating a diverse set of sectors that represents the new technologies into transmission planning and considering their effect on transmission utilization is crucial to ensure the cost-effectiveness of future energy system.
Results:For cross-border network planning, a multi-level governance structure is envisioned, proposing the inclusion of new governance layers in cross-border cooperation for network investments, alongside national institutions.

• Subnational governance level: Engaging cities and states in the energy infrastructure governance allows for local policy flexibility and innovation. Given that cities and states often spearhead local policies for mobility and heating decarbonization, their policies in these areas will play a critical role in the ensuing phase of the energy transition. Therefore, their input is proposed to be an integral part of the network scenario making process, with these inputs being aggregated by national planners or energy authorities to formulate National Energy and Climate Plans (NECPs).

• Supranational governance level: New regional institutions, such as an independent system operator, regional planner and regional energy committee are envisioned with functions related to cross-border electricity market and network investments. As a vital component of the collaborative governance, a regional energy committee with fair representation from various sectors from electricity sectors and grid users, is proposed to serve as a grid user cooperative and a common supervisory and dispute resolution body.

A novel mechanism, the user voting approach, is proposed to complement administrative project approval for cross-border network investment decision-making. An Argentinian experience is analyzed to design a mechanism that engages the most affected grid users in co-determining cross-border network investments [6]. This project selection approach incorporates user preferences and ensures long-term user commitment to investments deemed necessary. Furthermore, a joint regulated asset base for user-approved projects is proposed as a long-term commitment tool for investors to mitigate regulatory risks across borders. An output-based remuneration regulatory framework is envisioned to make renewable energy auctions and grid planning accountable. In essence, users are directly or indirectly involved in scenario data collection, project cost-benefit analysis, and network investment decision-making and remuneration.
Conclusions:This research advocates a transformative approach to cross-border network investment, emphasizing a collaborative governance where grid users play a crucial role. The following main policy recommendations emerge from the analysis:
• Adopting multi-level governance in cross-border network planning
• Establishing a regional energy committee
• Implementing a user voting mechanism for cross-border network project approval
• Incorporating a joint regulated asset base for approved projects
• Implementing output-based asset remuneration
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Keywords: collaborative governance, European cross-border transmission network investments, user-voting mechanism, joint regulated asset base

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Planning Long-Term GHG Mitigation Pathways in GCC Countries: The Case of Qatar

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Overview:The countries of the Gulf Cooperation Council (GCC) account for 45% of proven global oil reserves and 17% of proven natural gas reserves (Eskandar, 2023; Suwailem & Aldayel, 2020). While global oil and gas demand is expected to remain high in the short term, it is bound to substantially decline in the coming decades. To ensure their long-term prosperity, GCC countries need to, on the one hand, extract as much value as possible from their oil and gas and, on the other, reinvest their proceeds in the diversification of their economies. All GCC countries recognize this as a policy priority, including Qatar which, in its National Vision 2030 (General Secretariat for Development Planning, 2008) clearly identifies economic diversification, the creation of a knowledge-based economy and environmental protection as critical to its long-term sustainability. GCC countries are also all signatories to the Paris Agreement and, in their Nationally Determined Contributions (NDCs), they have gradually introduced quantitative GHG emission reduction targets and, more recently, pledged net zero GHG emissions. All GCC countries have quantitative targets for year 2030 and, with the exception of Qatar, net zero GHG emission targets by 2050-2060; however, they are yet to develop evidence-based net zero strategies, of the kind published by the EU, UK and US (Al-Sarihi, 2023; Commission & Action, 2019; Department for Energy Security & Net Zero, 2023; Net-Zero Knowledge Consortium, 2023; United States Department of State & United States Executive Office of the President, 2021).
GCC countries face unique challenges: they must rapidly reduce their domestic emissions, currently among the highest in the world on a per-capita basis, while moving away from an economic model that has developed around abundant and cheap fossil fuels and into a yet-to-be-defined diversified economy. This introduces substantial uncertainty into the long-term planning of a low GHG emission energy infrastructure. The goal of our research is to characterise such uncertainty and help policymakers in Qatar and the GCC define strategies that are both cost-effective and robust under uncertainty.
Methods:This study explores long-term GHG emission reduction strategies for GCC countries through a model-based case study of Qatar. In particular, we have built a TIMES energy systems model of Qatar, the first of its kind in the GCC, and we are in the process of soft-linking it with a simulation model of its economy, the Green Economy Model (GEM) (Bassi, 2015; PAGE, 2017) developed by another team, to identify cost-effective long-term GHG emission reduction pathways that are robust under different economic diversification scenarios.

TIMES (The Integrated MARKAL EFOM System) is a technology-rich, bottom-up optimization framework based on linear programming (Loulou & Labriet, 2008). TIMES models are widely used for climate change policy analysis and long-term planning; a notable example is that of the UK TIMES model, which has been used to conduct analysis supporting the country's climate change policy for almost two decades now, including the Net-Zero Strategy (Department for Energy Security & Net Zero, 2023).

We have developed a dedicated TIMES model for Qatar; its structure is illustrated in Fig 1.

Fig 1 – Simplified representation of the structure of Qatar TIMES

The model architecture reflects the structure of Qatar's energy economy, dominated as is by its industry. Qatar is one of the largest LNG producers and has a large petrochemical industry and other energy-intensive industrial productions. As a small country of only 2.68 million people, the buildings and transport sectors are comparatively small. Accordingly, we have structured Qatar TIMES around 6 sectors – Upstream, Industry, Electricity, Residential, Services, and Transport, of which the first two are modelled in more detail. In particular, Upstream, Qatar's largest sector, consists of oil and gas extraction activities, natural gas and NGL processing, oil refining and GTL. The industry sector consists of all the energy-intensive industries – iron and steel, cement, ammonia, urea, and aluminium manufacturing. The other sectors are modelled as appropriate, with lower level of detail.

The reference energy system used is that of Qatar in year 2015 and the model has also been calibrated to replicate the 2019 energy system structure. The energy flows for year 2015 are illustrated in Fig 2. Energy flows, stocks of technologies and their techno-economic performance for both year 2015 and 2019 are based on data from publicly available sources (QATALUM, 2016; Qatar Fertiliser Company (QAFCO), 2016; Qatar General Electricity & Water Corporation "KAHRAMAA," 2016; Qatar Petrochemical Company (QAPCO), 2016; Qatar Petroleum, 2016; Qatar Steel, 2023).

Fig 2 – Energy balance for Qatar for the year 2015

The techno-economic database of all technologies that can be deployed in future was built based on international databases available in the public domain and adapted as appropriate to the circumstances of Qatar (Lenox, 2019; Nijs & Ruiz, 2019). The population projection for Qatar used in the model is based on the UN median range forecast (United Nations, 2022) and the GDP growth rate is taken as 3% after 2023 until 2060. The model so built is run for the target year 2060 with 5-year milestones.

We use Qatar TIMES to study 3 GHG emission reduction scenarios: Business-As-Usual; NDC-consistent and Net-Zero. The first two scenarios are derived from Qatar's latest NDC and National Climate Change Action Plan (NCCAP) (Ministry of Municipality and Environment, 2021a, 2021b). As for the third, we have set a net zero target for year 2060, in line with those of other GCC countries, and are exploring pathways to meeting it taking into account the latest strategies of the government and national oil and gas company, QatarEnergy (Planning and Statistics Authority, 2024; QatarEnergy, 2023). The robustness of the net zero pathways will also be tested under different economic diversification options.

To better inform our scenarios and ensure relevance of our insights, we are engaging with all relevant national stakeholders (government ministries, the national utility company, industry and research community).

Results:So far we have run the 3 scenarios in the case of no economic diversification, i.e.: assuming that the oil and gas sector does not grow after year 2030 and the other sectors grown proportionally to GDP. Here we present selected results from the BAU and Net Zero scenarios.

The BAU scenario shows the continued deployment of conventional technologies in all sectors. The increase in emissions observed (see Fig 3) is driven by capacity growth in oil and gas operations (extraction, refining and processing), industrial production, and increase in population and GDP per capita. The unabated oil and gas upstream operations were responsible for nearly 42% of total emissions in 2015 and 46% in 2060, and industry accounted for 32% emissions in 2015 and 30% in 2060. The operation of unabated Combined-Cycle Gas Turbines (CCGT) and Combined Heat and Power (CHP) plants to supply electricity and heat for water desalination continues through to 2060. Similarly, conventional vehicles continue to operate in road transport and aviation. Total GHG emissions reach 209 MT by 2060 with the upstream sector as the largest contributor.

Fig 3 Emission profile for the business-as-usual scenario

In the net zero scenario, most emission reductions come from the upstream sector by 2060. We assume that oil and gas extraction and refining continue till 2060, driven by international demand, therefore large scale deployment of CCS is needed in oil and gas extraction, oil refining and natural gas processing and liquefaction. The industry sector is the second largest contributor of emission reductions, with fuel substitution in manufacturing and CCS deployment. After 2035, all ammonia produced is blue. Heat in cement manufacturing is electrified and CCS is deployed to capture process emissions. Blue hydrogen is used for high-grade heat in the iron and steel industry. Remaining emissions from upstream and industry are abated through direct air capture. In road transport, conventional cars are replaced by electric cars, diesel trucks by hydrogen trucks, and diesel buses by hydrogen buses. Achieving net zero also requires adoption of energy-efficient technologies in residential cooling, heating, electrical appliances and lighting. See Fig 4. Fig 5 and 6 show technology adoption in net zero scenario in transport and industry sub sectors.

Fig 4 – Emission profile for the net zero scenario.
Fig 5 – Activity breakdown for trucks in the net zero scenario.
Fig 6 – Activity breakdown for cement industry in the net zero scenario.
Conclusions:Assuming no diversification of the economy of Qatar through to 2060, it is apparent that, although energy efficient technology in the residential and services sector may be the cheapest to deploy in the short term, deep GHG emission reductions can only be achieved with extensive deployment of CCUS and hydrogen in upstream and industry, the viability of which will require, inter alia, the development of carbon markets. Moreover, the technical feasibility of developing CCUS on the very large scale required would have to be duly assessed. The availability of blue hydrogen will also allow its use in heavy-duty road transport. The use of renewable energy is partly constrained by land availability, and partly to the extent to which electricity can be used to decarbonize upstream and industry.
As next steps, we will be testing the 3 scenarios above under different economic diversification trajectories, to identify GHG emission reduction pathways that are robust under uncertainty.
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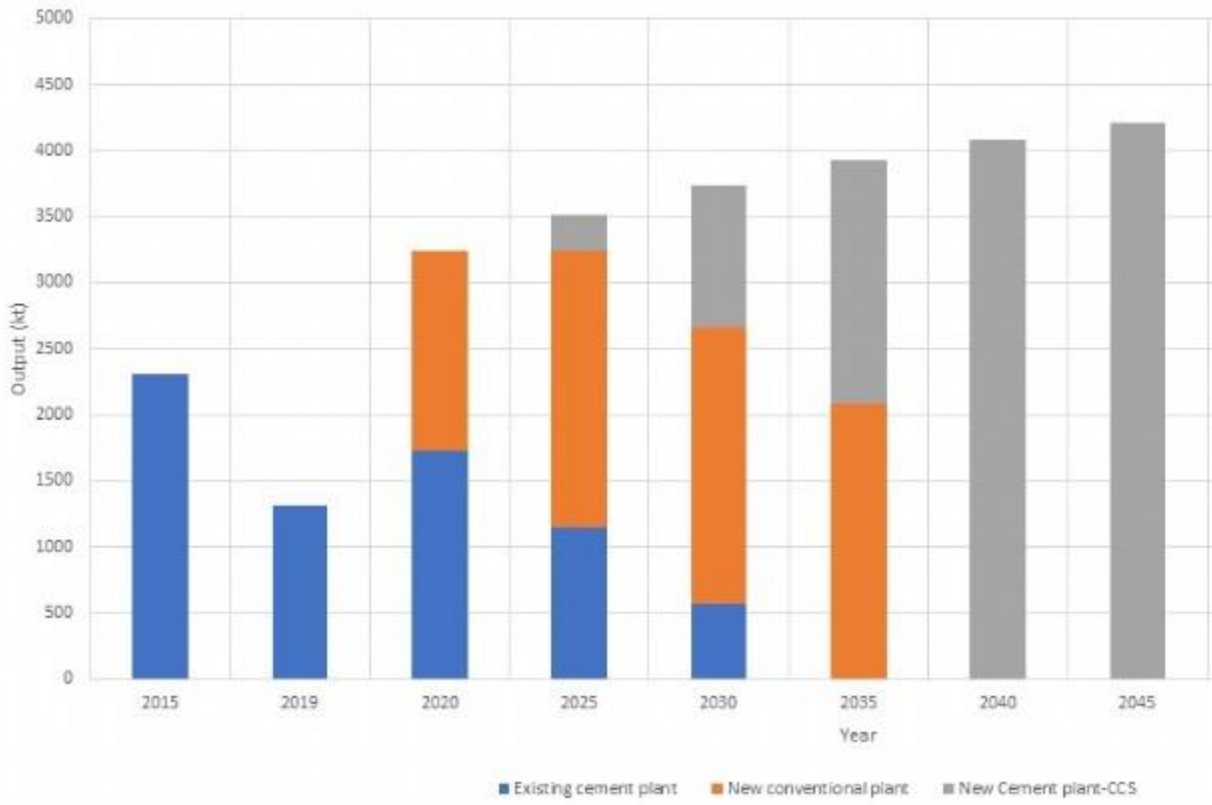
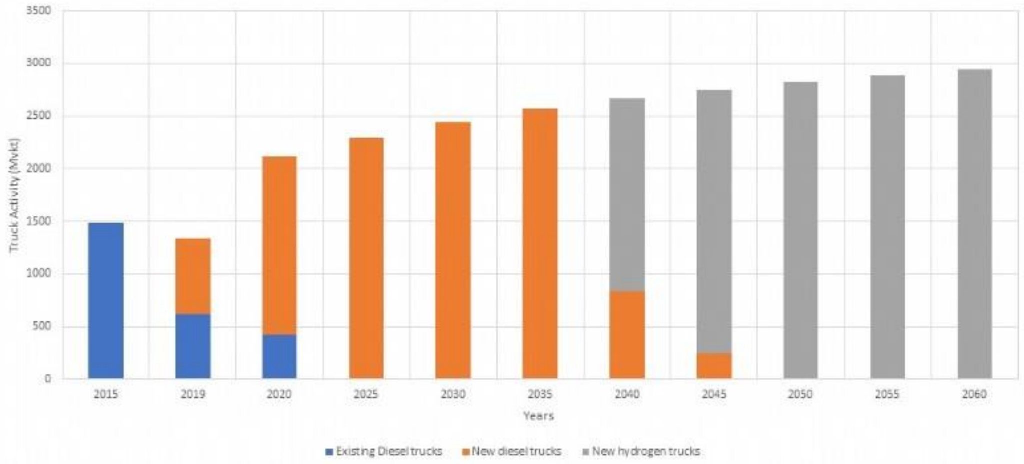
Keywords: Energy Systems Modelling, Qatar, Energy Transition

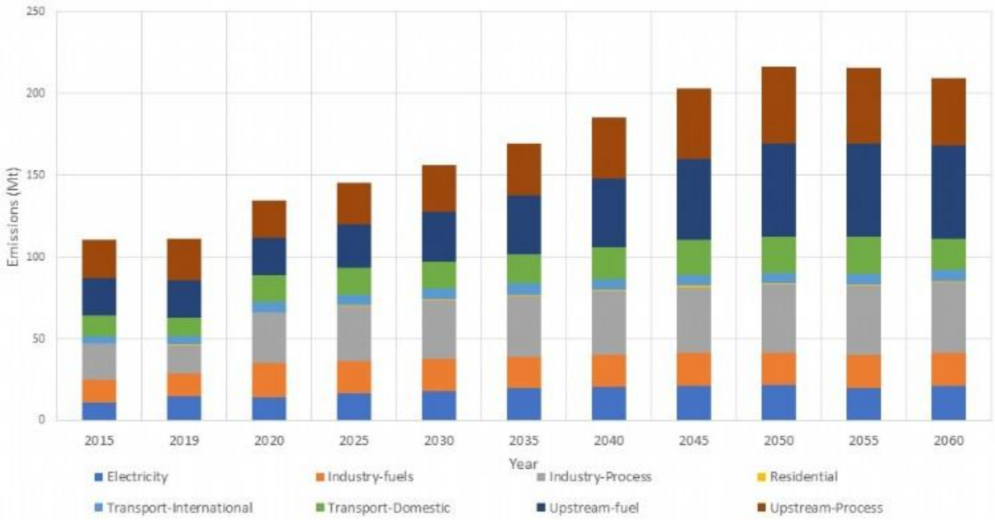
Activity breakdown for cement industry in the net zero scenario.



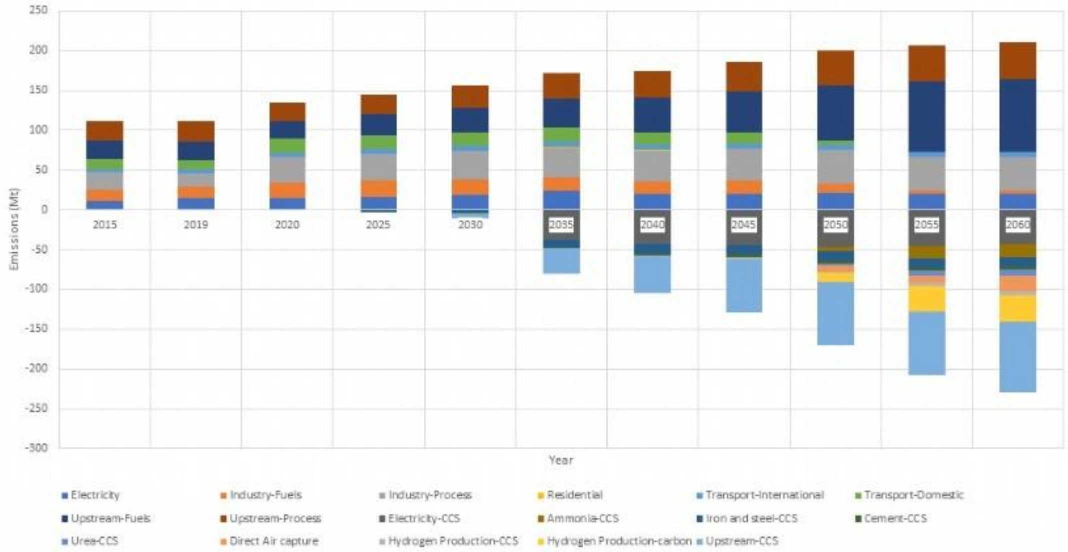
Activity breakdown for trucks in the net zero scenario.



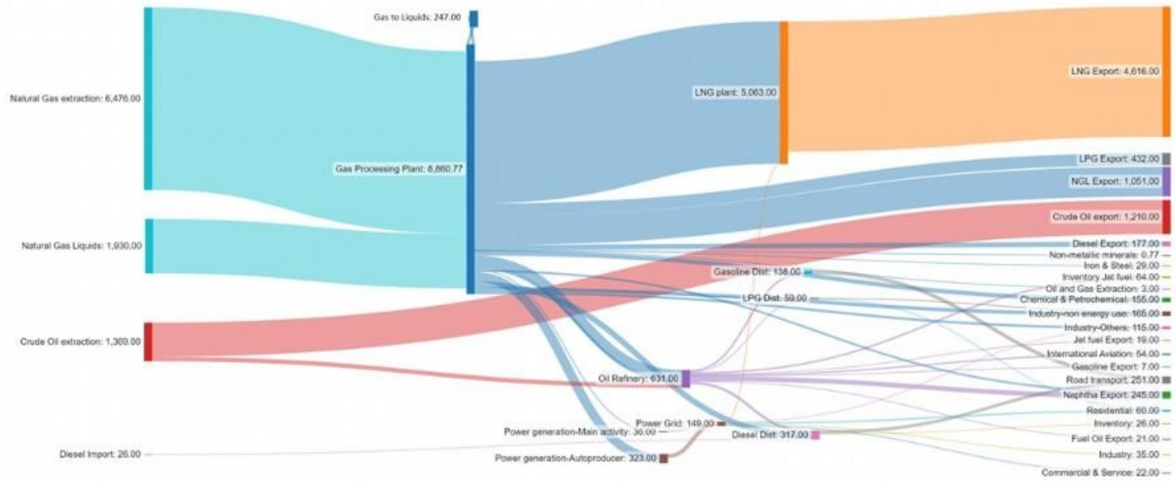
Emission profile for the business-as-usual scenario



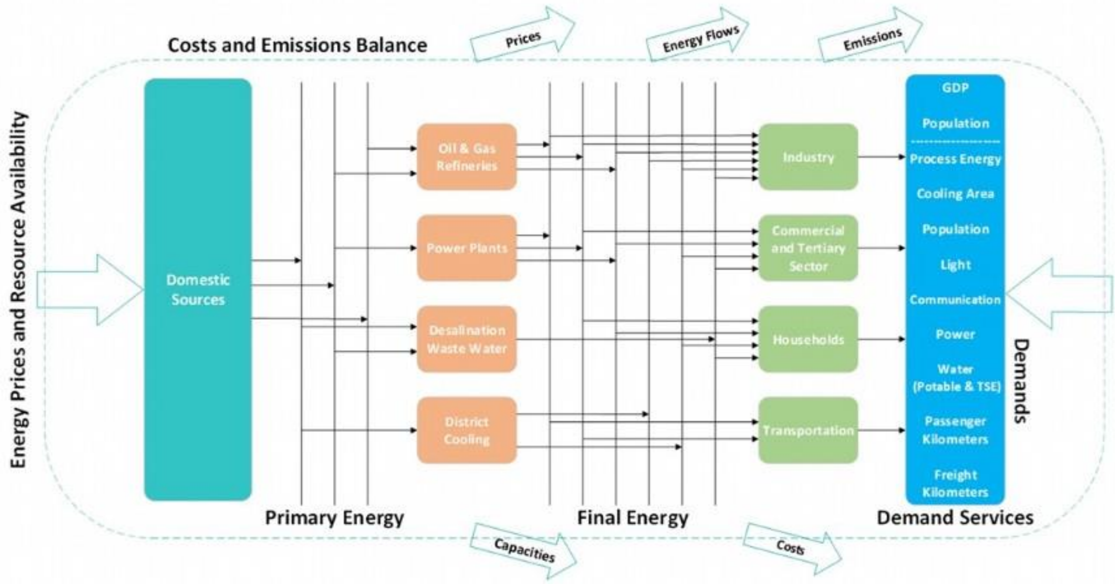
Emission profile for the net zero scenario.



Energy balance for Qatar for the year 2015



Simplified representation of the structure of Qatar TIMES



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[Abstract:0465] OP-099 [Accepted:Oral Presentation] [Energy System Transition » Policy]

The energy transition towards carbon neutrality: Evidence from China's low-carbon city pilot policy

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Overview:Since the beginning of the 21st century, the unprecedented adverse effects of global climate change have become one of the most significant challenges to human development. To cope with the increasing global warming, countries worldwide have made a common consensus on low-carbon and sustainable development. China, the largest developing country, has also taken measures to shed light on its commitment to green development. Aiming at emission reduction and energy development, China has implemented the low-carbon city pilot policy in three batches since 2010, covering ten province-level regions with more than 80 cities. During the critical period of combating climate change for now and future, a good understanding of whether it can promote renewable energy development is of great importance.

Many issues need to be resolved before moving toward a low-carbon economy, among which sustainable energy management will be the most emerging and urgent. With the substantial increase

in global energy demand, new strategies for high-quality energy supervision have become necessary and requirable. As an essential measure to promote energy transformation and sustainable development, the low-carbon city pilot policy focuses more on improving energy efficiency and accelerating low-carbon technologies, thus gradually establishing a green development system. In practice, this pilot policy can fulfill energy management and emission reduction goals by regulating, managing, supervising, and handling the relevant activities of energy-related industries and companies. Therefore, this study pays attention to renewable energy companies by identifying the policy effect on their total factor productivity (TFP).

Methods:First, based on the CES utility function and the Melitz heterogeneous theory, this study constructs a theoretical framework to analyze how low-carbon city pilot policy can affect corporate TFP among renewable energy companies.

Second, Since China's low-carbon city pilot policy has three different batches, this study employs the staggered DID model with multiple fixed effects to observe whether corporate TFP will change among renewable energy companies.

Results:First, the low-carbon city pilot policy can increase corporate TFP by 2.83% among renewable energy companies, equivalent to an almost 18.11% improvement calculated by its average standard deviation. Due to the appropriately-designed environmental regulation, this pilot policy reflects exactly the innovation compensation effect of the Porter theory, which shows the strong potential for the feasibility of the carbon neutral economy.

Second, the overall policy effect on corporate TFP differs with some industrial and corporate characteristics. Basically, companies in low-monopoly-level, low-leverage-level, and non-"two high and one surplus" industries will enjoy more positive effects of the low-carbon city pilot policy. Furthermore, companies with sufficient total assets, high institutional shareholdings, and better financial backgrounds can get more evident policy effects, implying that more customized fine-tuning is necessary for the regulatory policies.

Third, this positive policy stimulation effect can be effectively transferred to corporate TFP by three major mechanisms: enhancing policy attention, increasing economic support, and promoting technological innovation. In policy attention, more detailed research on the low-carbon city pilot policy can largely promote its effect on corporate TFP. In economic support,

Fourth, the low-carbon city pilot policy will improve the regional energy infrastructure. It implies that harmonizing development between environmental regulation and economic incentives is necessary for the carbon neutrality transformation. Specifically, the pilot policy can increase the number of public electric vehicle charging piles by 41.09%. Besides, as the main participants, renewable energy companies can also get better business performance and diversified development.

Conclusions:First, China's low-carbon city pilot policy can promote corporate total factor productivity by an overall effect of 2.83%, equivalent to an 18.11% improvement calculated by its average standard deviation, implying that carbon neutrality is feasible but difficult. Second, the policy effect will be more substantial when companies participate in better industrial positions and financial backgrounds, indicating that public-private partnerships are necessary for carbon neutrality. Third, this low-carbon transition can be effectively achieved by enhancing policy attention, increasing economic support, and promoting technological innovation. Last, as a consequence, the pilot policy can increase corporate diversification growth and regional energy infrastructure development.

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Keywords: Low-carbon city, Renewable energy companies, Total factor productivity, Energy infrastructure, Carbon neutrality

[Abstract:0541] OP-100 [Accepted:Oral Presentation] [Energy System Transition » Policy]

Designing socially acceptable Swiss electricity supply scenarios for 2035 by linking population survey data and electricity supply modeling

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Overview:Model-based scenarios are important tools to support policymaking and investment decisions, especially in the context of the ongoing energy transition and climate change mitigation. While existing energy system models heavily rely on techno-economic optimization, they often neglect the essential influence of many social phenomena, which drive the transition [1–5]. Studies have shown that the model-based scenarios rarely reflect the social acceptance of energy technologies, especially high support for renewable technologies [6–8]. Having said that, methods to integrate social factors in techno-economic models are still at a nascent stage. The aim of this study is to model Swiss electricity supply scenarios for 2035 that consider the social acceptance of electricity technologies. This study mainly investigates three methods to integrate social acceptance data [9] from a population survey (N=6’203) into the electricity system model EXPANSE with a spatial resolution of 2’136 municipalities. The three methods are based on modifying the potential constraints, technology costs, and objective function based on survey data. We also test different methods for generating scenarios regarding spatial aggregation of the survey data, ways to quantify the impact of acceptance, and ways of translating survey data into model parameters. The findings highlight high sensitivity of modeled scenarios on social acceptance of a couple of key technologies (such as solar PV, onshore wind, nuclear power, and interconnection in Switzerland) and on the chosen social acceptance integration method.
Methods:To design socially acceptable Swiss electricity supply scenarios for 2035, we integrate the survey data on social acceptance into a spatially-explicit cost-optimization modeling framework EXPANSE [10–14]. EXPANSE (EXploration of PAtterns in Near-optimal energy ScEnarios) is a single-year model for the Swiss electricity sector with a spatial resolution of 2’136 Swiss municipalities and with a temporal resolution from 1 to 6 hours. The social acceptance data used in this study comes from the results of a national-scale online survey in 2022 about the future of the Swiss energy supply as part of the SWEET EDGE project [9]. The survey received 6’203 responses throughout the country and the available spatial resolution is at the municipality level. To integrate the social acceptance survey data in the EXPANSE model, we compare three different integration METHODS:
• Modification of potential constraints: The maximum potential of each technology is additionally constrained by its social acceptance ratio. A lower acceptance ratio means a lower technology potential compared to the maximum possible potential.
• Modification of technology costs: To modify technology costs based on acceptance data, it is considered that lower acceptance poses an investment risk and hence technology costs are recalculated based on the technology-specific weighted average cost of capital (WACC). WACC values can range from the upper bound and lower bound estimates from previous empirical study [15], depending on the social acceptance ratio of each technology. A higher social acceptance ratio means a lower WACC value and thus lower investment costs.
• Modification of objective function: Either social acceptance or resistance (lack of acceptance) are set as the objective function instead of the cost-optimization objective. The technology-specific costs are replaced by technology- specific acceptance scores to be maximized, or technology-specific resistance scores to be minimized.

Meanwhile, in parallel to these integration methods, different method variations are considered regarding:

• Spatial aggregation choice: The survey data at the municipality level can undergo aggregation using various methods to mitigate the effects of survey randomness resulting from the limited number of respondents. We consider national level, cantonal level, regional level by nine EDGE region categories, non-spatial municipality clustering and spatial municipality clustering. We create the nine EDGE region categories based on the four mountain regions [16] and typology of municipalities in nine categories [17] of Switzerland. Here we use K-means clustering as the non-spatial clustering method to assign municipalities to categories [18], then use the cluster acceptance ratio as the acceptance score of municipalities in the cluster. For spatial clustering, we used Spatial C(K)luster Analysis by Tree Edge Removal method to form clusters considering the spatial interactions [19].
• Ways to quantify the impact of acceptance: The acceptance score is quantified by two methods: based on acceptance or based on resistance by assigning neutral opinion ("neither nor" answers) of the population differently.
• Ways of translating survey data into model parameters: The survey data is translated into acceptance scores by linear function, linear function with a threshold, and using only a threshold. Linear function assumes that the acceptance score is proportional to the acceptance ratio, and the technology potential or the costs with investment risk vary within the intervals accordingly. The threshold is set by applying a step function, suggesting that if the acceptance ratio is lower than a certain value, then the acceptance rate is set 0 [20].
Results:To investigate the impact of including social acceptance in spatially-explicit electricity system modeling, we generated and compared 122 scenarios using the Swiss EXPANSE model for 2035, where each scenario is based on a different combination of aforementioned methods. We compared three survey integration methods under different choices of spatial aggregation, ways of quantifying acceptance, and ways of translating survey data into model parameters. The results show that the installed capacity and annual generation from hydropower, biomass and waste plants are relatively constant, but these technologies also have a relatively limited expansion potential in Switzerland. The most changes are observed for the installed capacity and annual generation of solar PV, onshore wind, nuclear power, and interconnection for electricity trade with neighboring countries (Figure 1). For example, the installed capacity and the generation of solar and wind power are essential under the methods in which the acceptance scores are maximized or minimized in the objective function, but also in some scenarios with modified technology costs according to WACC. This is due to the high acceptance score of solar PV and their low investment risks. The variation in nuclear power generation is highly dependent on the chosen method. Under maximum acceptance method, the nuclear generation is less than 1 TWh in some scenarios (e.g. 0.32 TWh in the method with non-spatial clustering, resistance-based and linear function with threshold method), while in other scenarios the nuclear generation is more than 10 TWh (e.g. 13.65 TWh when the survey data translation method is changed to threshold without linear function). On the other hand, the nuclear generation stays constant in the minimum resistance method.

By observing these scenarios, we find that the installed capacity and annual generation of each technology have different sensitivity under different survey data integration methods (Figure 2). The annual generation of solar PV, onshore wind, nuclear power and net import are the most sensitive technologies to the integration method used. The generation of solar PV and wind power reach the highest values under the method in which the acceptance scores are maximized in the objective function. While the nuclear power tends to be low under the method that modify objective function and higher under the method of modifying potential constraints. The highest export value is observed under maximizing acceptance method, and the most import – under minimizing resistance method. Compared to the reference scenario without social acceptance included, solar PV generation tends to be higher under the methods of modifying technology costs to account for investment risk and of maximizing acceptance method. Under the method of constrained potential, the values are normally distributed around the value in the reference scenario. Nuclear power generation is lower in most of the scenarios, except for the minimizing resistance method. The net import is higher in scenarios under the method with potential constraints. For other scenarios, the net import generation is case-dependent. The scenarios are least sensitive to the choice of spatial aggregation when working with survey data. Under four different levels of spatial aggregation, the distribution of generation values of four technologies are similar. As for the ways of quantifying acceptance and ways of translating survey data into model parameters, the four technologies vary within similar ranges, while the distribution of the generation values depends on the methods.
Conclusions:In this study, we investigate the methodology options to quantify socially-acceptable Swiss electricity supply scenarios for 2035 by linking population survey data and an electricity system model EXPANSE. We demonstrate what the impacts are on generated scenarios if the survey data is included to reflect the social acceptance of each electricity technology, and how robust the generated scenarios are under 122 different survey data integration methods. For now, we find that the electricity supply scenarios are very sensitive to methodological choice, especially for key determining technologies, and thus we call for further testing of various methods. One pathway to

such testing could be through hindcasting exercises to see which integration method brings the results closer to the actual historical transitions (see e.g. Wen et al. 2023 [21]).
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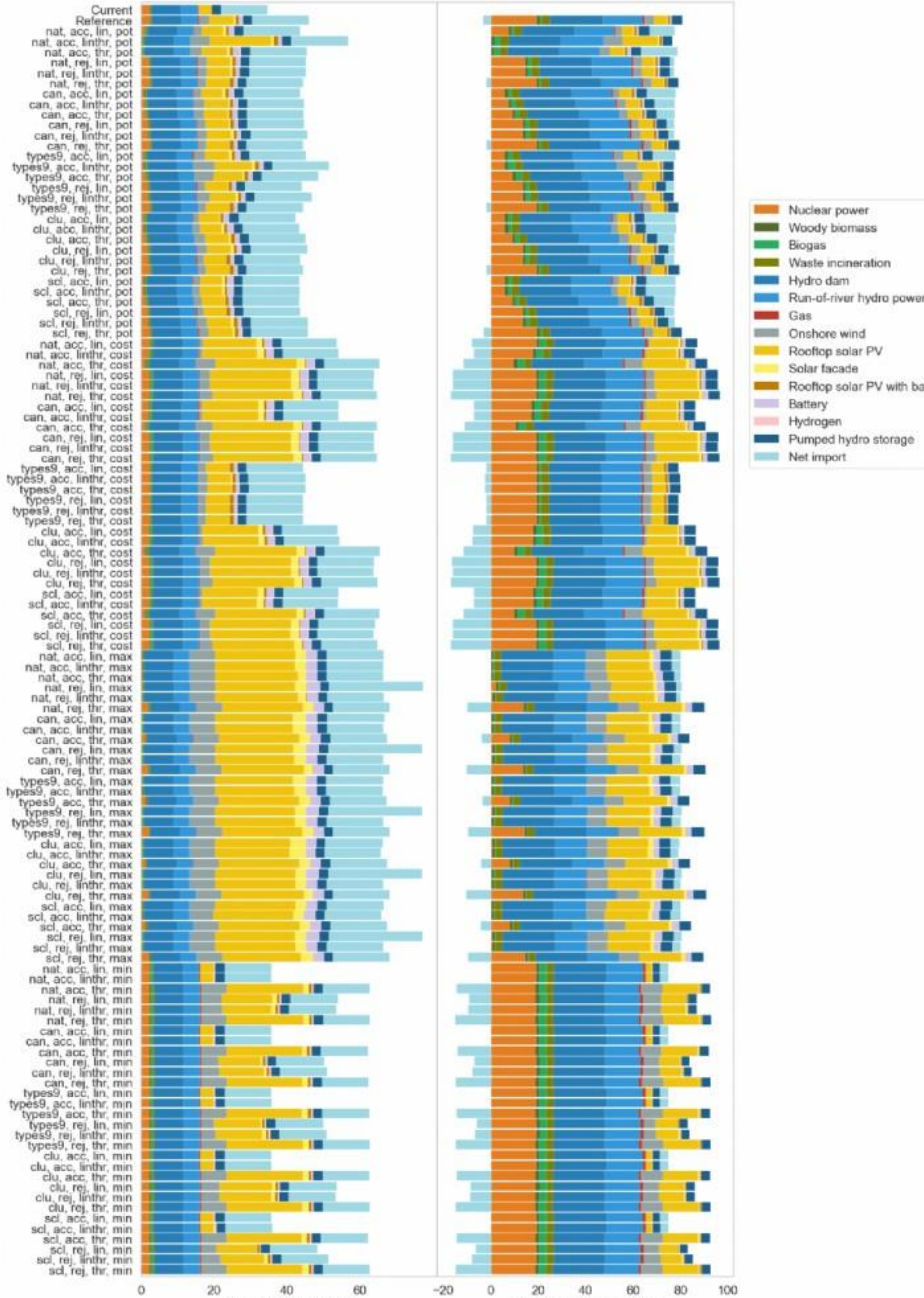
Keywords: Electricity system modeling, social acceptance, Swiss electricity supply scenarios

Figure 1. Installed capacities and annual electricity supply mix of Swiss electricity system in 2035 under 122 scenarios.



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Annual supply, TWh/year
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Woody biomass
Biogas
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Solar facade
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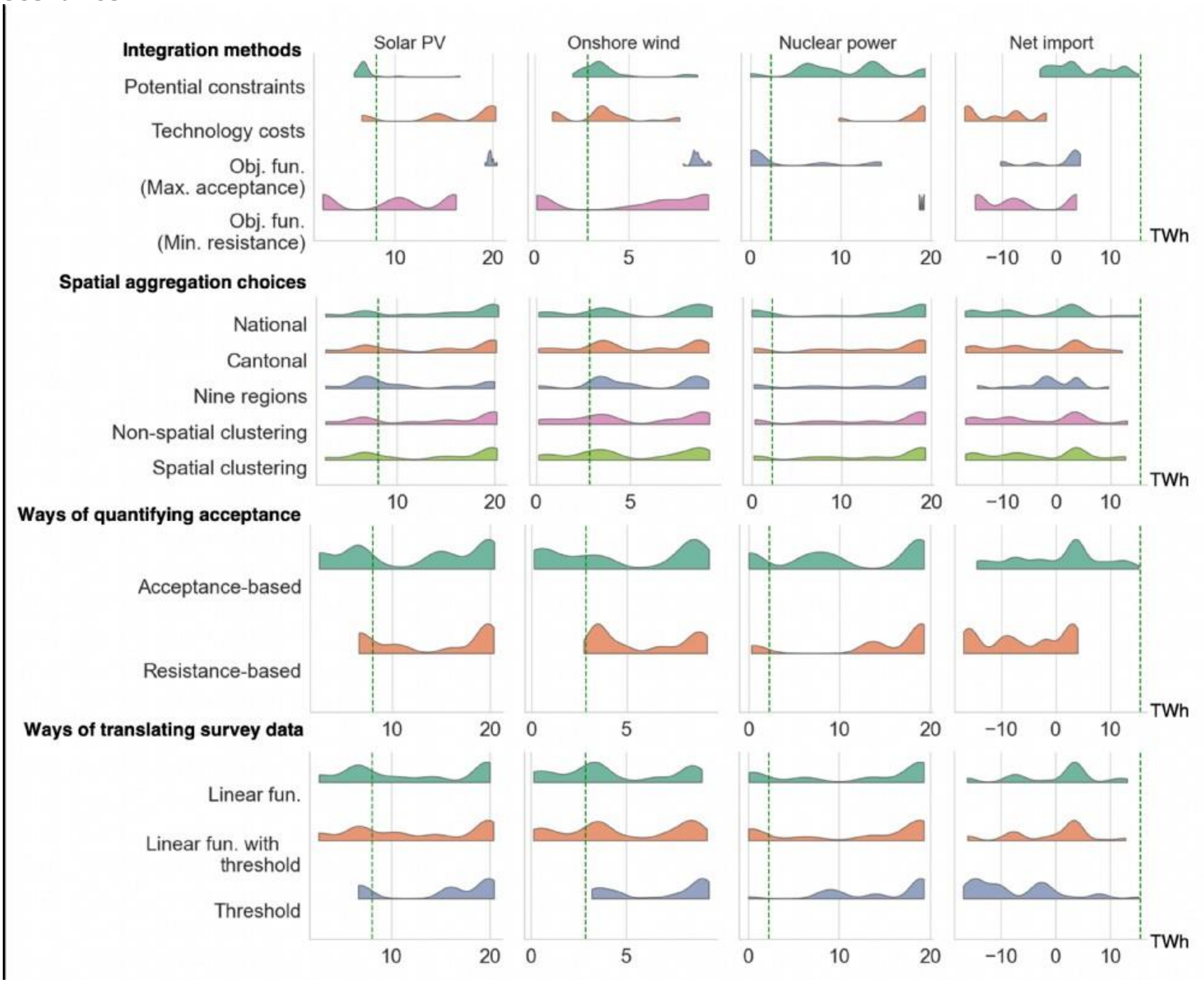
Battery
Hydrogen
Pumped hydro storage
Net import

Installed capacities and annual electricity supply mix of Swiss electricity system in 2035 under 122 scenarios from different survey integration methods and different choices of spatial aggregation, ways of quantifying acceptance, and ways of translating survey data into model parameters. The survey integration methods include modification of potential constraints (pot), technology costs (cost), and objective function (maximize the acceptance score (max) or minimize the resistance score (min)); Spatial aggregation choices are national level (nat), cantonal level (can), nine EDGE region categories (types9), non-spatial municipality clustering (clu), and spatial municipality clustering (scl); Ways of quantifying acceptance methods are acceptance ratio based (acc) and resistance ratio based (rej); Ways of translating survey data into model parameters are linear function (lin), linear function with threshold (linthr), and threshold method (thr).

Figure 2. The distribution of electricity generation of each technology under different scenarios.



The distribution of electricity generation of each technology in scenarios under four integration methods, four spatial aggregation choices (national, cantonal, non-spatial and spatial municipality clustering), two ways of quantifying acceptance (acceptance-based or resistance-based), and three ways of translating survey data into model parameters (linear function, linear function with threshold and threshold function). The green dotted lines are generation values from the reference scenario

[Abstract:0114] OP-101 [Accepted:Oral Presentation] [Energy System Transition » Policy]

Energy regulators and the energy transition

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Overview:The greenhouse gas emission reduction targets of national and sub-national governments imply a transformation of energy systems such that the unabated burning of fossil fuel-derived energy must decline significantly over the next decades. This energy transition presents cost and reliability challenges for industry and consumers, which in turn implies challenges for energy regulators, be they situated within government energy ministries or within arms-length energy regulatory agencies.

Critical uncertainties are exemplified by the following questions. Can electrification of energy end-uses accelerate? Can sufficient electricity supply investments be incentivized? Can energy reliability be sustained and (in some jurisdictions) enhanced? Can energy rates for low-income groups be kept to affordable levels? Can stranded assets be avoided or well-managed? Can the regulated and competitive components of the energy system coordinate effectively in terms of investments and operation? Can political acceptance and public trust be sustained?

This paper, by the Chair and CEO of a Canadian provincial energy regulatory agency, integrates the output of several applied research collaborations in which Canadian energy experts explored legal and regulatory strategies for implementing, and indeed accelerating, the energy transition in Canada. By providing a framework for addressing the challenges and risks of the energy transition it has relevance for energy regulators in other jurisdictions.
Methods:The author has engaged in several processes over the past few years focused on the energy transition, especially its regulatory dimension. These include (1) a full literature assessment as a 2019-2022 Intergovernmental Panel on Climate Change lead author on energy transition policies, (2) expert contribution to the energy transition advisory research of the Canadian Climate Institute and the British Columbia Climate Solutions Council, and (3) advisory input to energy regulators and policy-makers across Canada as federal and provincial governments focused on the development and implementation of laws and regulatory practices to accelerate the energy transition. These experiences provide the input evidence for the development of a decision-making framework for energy regulators and energy policy-makers in the energy transition.
Results:The developing framework has several components of which only a few are presented in this abstract.
* Policy-makers should amend (as necessary) the legislative mandate of energy regulators to ensure that their processes and decisions are consistent with government greenhouse gas commitments.
* Independent energy-economy modellers should be directed by government (and/or independent advisory institutions and/or energy regulatory agencies) to explore and probabilistically assess (by technology mix, cost, resilience, likelihood) alternative technology-energy pathways consistent with greenhouse gas commitments.
*Governments at national and sub-national levels should develop mechanisms to ensure that other levels of government (municipal, regional) can only slow energy transition developments for reasons of high social value (rights of Indigenous peoples, key non-climate environmental values, concentrated impacts on vulnerable social groups).
* Energy regulators should revise their processes as necessary to ensure timely decision-making that does not unduly hinder critical energy transition developments.
* Energy regulators should ensure that investments and operational practices of energy sector participants during the energy transition do not compromise the reliability of energy systems.
* Energy regulators should support the development of portfolio approaches to generation and transmission expansion in contrast with one-at-a-time assessments of costs and benefits.
* Energy regulators and governments should collaborate in the development of social support programs and rate designs to ensure that the energy transition is not a cause of impoverishment (e.g., low-income subsidies for zero-GHG equipment and structures and/or income-based rate designs).
* Energy regulators should develop forward thinking strategies to reduce the risk of major stranded assets resulting from the energy transition.
Conclusions:Innovation in energy system regulation will play a critical role in ensuring a well-managed energy transition. Lessons from leading jurisdictions can have a global significance if carefully researched and well communicated. This paper offers a modest contribution to this important effort.
References:The Big Switch, Canadian Climate Institute, 2022.

Keywords: energy regulation, energy transition, energy policy

AuthorToEditor: I entered my academic affiliation, since that is how I am known in the energy economics community, including my role on the editorial board of The Energy Journal. However, I have a second affiliation since I am currently on leave of absence from the university to serve as Chair and CEO of the British Columbia Utilities Commission. I would be happy if my submission is for presentation at a concurrent session. However, with this note I alert the Scientific Committee that I am a senior academic and policy maker and have served as plenary panel member at several past IAEE annual and North American conferences. If you find it convenient and appropriate to have me speak on a panel, I would be very interested in doing so. Sincerely, Mark Jaccard

[Page: 102]

[Abstract:0115] OP-102 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Do economic trade-offs matter in climate policy support? Survey evidence from the United Kingdom and Australia

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Overview:Effective climate policy is often described to have substantial economic costs (Vona, 2018). As such, it is critical to understand whether the public perceives climate policy as beneficial or detrimental to the economy and whether this perception is associated with support for climate policy. One of the most desirable relationships between climate policy and the economy is known as decoupling which is the disentanglement of greenhouse gas emissions from economic growth (Gugushvili, 2021).

Existing research on the relationship between decoupling perceptions and climate policy support is almost non-existent and has gaps. Most studies focus on the relationship between the economy and the environment as a whole omitting a specific relationship between climate action and the economy (Gugushvili, 2021; Tomaselli, 2019; Drews et. al., 2019; Drews et. al., 2018; and Drews et. al., 2017). Current studies also tend to focus on support for a single policy, usually the carbon tax, or a few generic policy tools combined into an index (Maestre-Andres, 2021; Carattini, 2018; Fairbrother, 2022) limiting the ability to understand which policies are already seen as complementary to the economic growth and which ones require more framing work to overcome opposition. Methods:Our paper addresses these gaps by collecting and analyzing survey data on public perceptions of climate-economy trade-offs in two countries with different decoupling rates, the United Kingdom (UK, n=1,009) and Australia (n=1,029). Our objectives are to assess (1) levels of public support for different types of climate policies, (2) levels of public support for different growth paradigms governments should pursue, and (3) associations between growth paradigm beliefs and support for different climate policies using Stern's (2000) Attitude-Behaviour-Context theory. We employ descriptive (distributions, factor analysis) and inferential statistics (multiple linear regressions) in R to address our research questions. Results:Preliminary results show that carbon pricing policies receive the lowest support (44% in the UK and 47% in Australia), while voluntary policies such as government investment, information, and subsidies enjoy the highest support at 63-78% in the UK and 70-79% in Australia. Regulatory policies, such as electric vehicle mandates and electricity regulations, receive moderate support between 45-70% in the UK and 48-75% in Australia. Citizens of both countries prefer the 'decoupling' growth paradigm where emissions are disentangled from the economic growth (47-48%), followed by the 'agrowth' paradigm (19-21%) where citizens believe emissions should be reduced regardless of the economic impact. The highest support for all climate policies is from 'agrowth' citizens.

Support for different policy types has unique characteristics. Carbon pricing and regulations are supported by those who are more optimistic about future economic growth whereas support for voluntary policies is associated with being optimistic about future emissions decreases. Further, environmentally active citizens are more likely to support carbon pricing and regulations, while environmentally passive citizens prefer voluntary policies. Finally, individuals who are optimistic about future economic growth and/or future emission reduction show higher support for climate policies in both countries.
Conclusions:Overall, our study suggests that individuals support climate policies less if they believe the economy will be negatively affected. Policy-makers should therefore communicate climate policies' economic and social benefits, in addition to emissions reductions, to increase support for more compulsory pricing and regulatory policies.
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Keywords: climate policy, economic growth, decoupling, public opinion, climate-economy trade-off

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[Abstract:0331] OP-103 [Accepted:Oral Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

Portfolio analysis of negative emissions technologies deployment under the 1.5°C pathway

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Overview: Due to the constrained global carbon budget [1,2], negative emissions technologies (NETs) have emerged as a vital component in achieving climate objectives in the Paris Agreement [3]. NETs differ in their removal processes, efficiency, timeliness, storage time, technological maturity, mitigation potential, costs, synergies, and side impacts [3,4]. A diverse set of NETs could maximize the benefit and minimize the negative impact on energy-water-land system. Therefore, a quantitative analysis of individual NETs in these aspects can assist decision-makers in formulating optimal deployment pathways for achieving climate goals. The Sixth Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR6) [3] and prior studies [5-7] thoroughly reviewed and summarized various indicators for evaluating NETs. However, many key indicators, such as economic feasibility and storage time, were still lack of quantitative assessments. Rueda et al. [6] utilized multi-criteria decision analysis (MCDA) to evaluate the feasibility, effectiveness, and side impacts of different NETs and develop the optimal combination of NETs to achieve the 1.5°C target. Nevertheless, they lacked quantitative assessments in economic feasibility and storage time, along with certain key indicators such as non-competitiveness or complementarity. Economic feasibility is the key constraint limiting the extensive deployment of NETs, and storage time presents a substantial challenge to deployment. Conducting quantitative assessments of both can optimize the deployment efficiency of NETs and achieve climate goals more robustly. The scale of the technical potential of one NET may be limited by rivalling NETs. The ability of a NET to coexist with others emerges as a crucial value indicator [7]. Hence, there is a need for additional consideration of non-competitiveness or complementarity indicator. To address the aforementioned research gaps, we quantitatively evaluated the benefits of five typical NETs – afforestation and reforestation (AR), biochar (BC), bioenergy with carbon capture and storage (BECCS), direct air carbon capture and storage (DACCS), and enhanced weathering (EW). Furthermore, we assessed the economic feasibility by benefit-cost ratio. We also provided optimal estimates for storage time, introduced non-competitiveness or complementarity, and incorporated these updates into a MCDA framework to identify a deployment portfolio for NETs within the 1.5°C trajectory.

Methods: We utilized the simplified FAIR climate model and the DICE damage model to evaluate the benefits of NETs. Leveraging models from prior researches [4,8], we fine-tuned critical parameters to derive storage time for each NET. The MCDA framework comprises ten indicators covering four aspects: feasibility, effectiveness, side impacts, and non-competitiveness or complementarity, as elaborated in Tab. 1. The quantification of non-competitiveness or complementarity is based on the conclusions of extensive research studies [7,9-12] on negative emissions. We also constructed seven distinct preferences to explore deployment discrepancies, outlined in Tab. 2. Based on these scenarios, we determined rankings for the five NETs, subsequently generating a deployment portfolio that takes into account priority sequences and potential curves. We considered three negative emissions need levels in line with shared socio-economic pathways (SSPs): SSP1, SSP2 and SSP5.

Results: Fig. 1 and Tab. 3 depict the performance scores of the five NETs across 10 indicators. Overall, the average score rankings are as follows: DACCS, AR, EW, BECCS, BC. DACCS demonstrates superior performance in terms of timeliness and storage time, contributing to its overall excellence with minimal coefficient of variation (CV) (0.33). Conversely, BECCS exhibits the highest overall performance variability, with a CV of 0.56, attributed to its exceptional storage time and the least favorable environmental side impacts. BC consistently falls below the average line in terms of effectiveness, thereby diminishing its overall performance. Notably, there is significant variability in the performance of the five NETs across each indicator, with CV ranging from 0.17 (for economic side impacts) to 0.79 (for timeliness), highlighting that distinctions among NETs are particularly pronounced in terms of timeliness.

Fig. 2, Fig. 3, and Fig. 4 portray the deployment portfolios for NETs under SSP1, SSP2, and SSP5. Taking SSP2 as an example, under equal weights, the deployed NETs and their priority sequence are DACCS - AR - EW. The outcomes prioritizing side impacts and side impacts with low risk are the same as under equal weights. When emphasizing economic feasibility, the deployment sequence becomes AR - EW - BECCS. Introducing low risk shifts the deployment sequence to AR - DACCS - EW. Focusing on storage time and considering risk result in the deployment sequence of DACCS - EW - BECCS.

Conclusions: We have integrated quantitative assessments of economic feasibility, storage time, and non-competitiveness or complementarity into the existing framework of MCDA to identify a more precise and robust deployment portfolio for NETs within the context of the 1.5℃ pathway. As the demand for negative emissions grows, the numbers of NETs also increases. Distinct preferences for economic feasibility, storage time, and side impacts result in different sequences of portfolios. When implementing NETs, regions must take into account their specific circumstances and decision preferences. This underscores the importance of the three indicators—economic feasibility, storage time, and non-competitiveness or complementarity—in the decision-making process for NETs. Within our framework, DACCS and AR emerge as the top two priority choices. While DACCS has consistently attracted attention, its development has been hampered by high costs. If decision-makers do not strongly prioritize economic feasibility, DACCS would be the top priority. When economic feasibility are given higher priority, AR emerges as the most cost-effective option. However, it is advisable to simultaneously deploy DACCS with AR to help mitigate risks. EW stands out as the optimal choice beyond DACCS and AR due to its combined advantages in both economic feasibility and storage time. Due to negative environmental impacts such as climate effects from the biomass supply chain, fertilizer and water resource use, land competition, water pollution, and seismic risks, BECCS has been the subject of controversy. BC performs poorly in terms of both economic feasibility and effectiveness but exhibits better performance in terms of side impacts. Therefore, except for the preference for side impacts, BC is the last to be deployed under other preferences.

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Keywords: negative emissions technologies (NETs), 1.5°C pathway, deployment portfolio

Fig. 1 Scores of the five NETs across 10 indicators

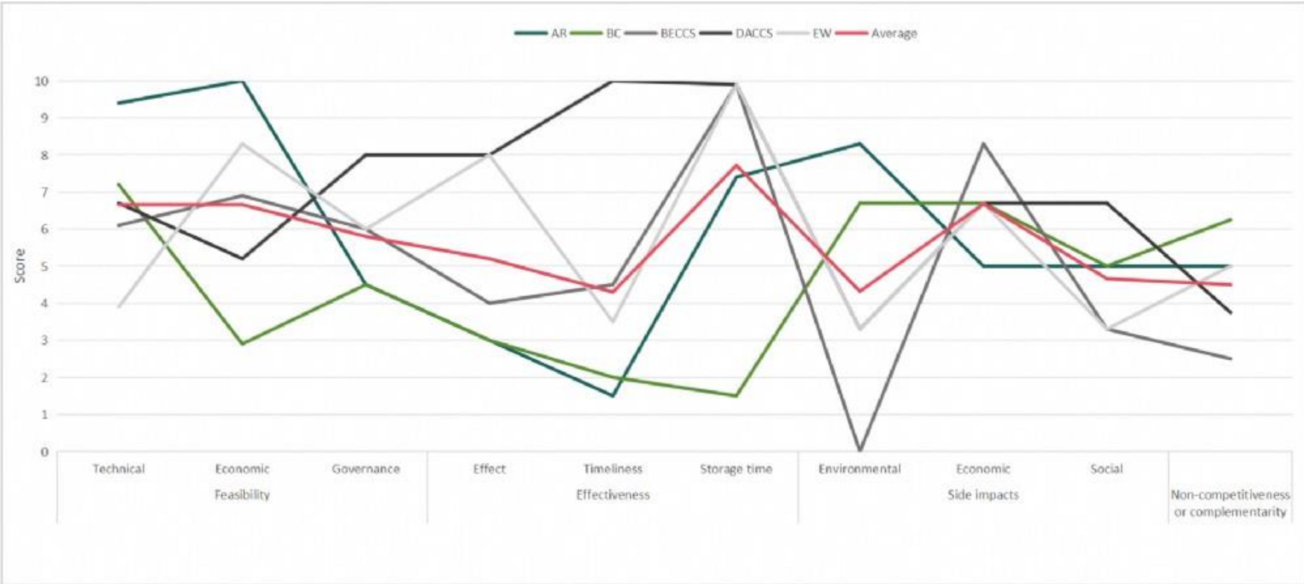


Fig. 2 The deployment portfolios for NETs under SSP1

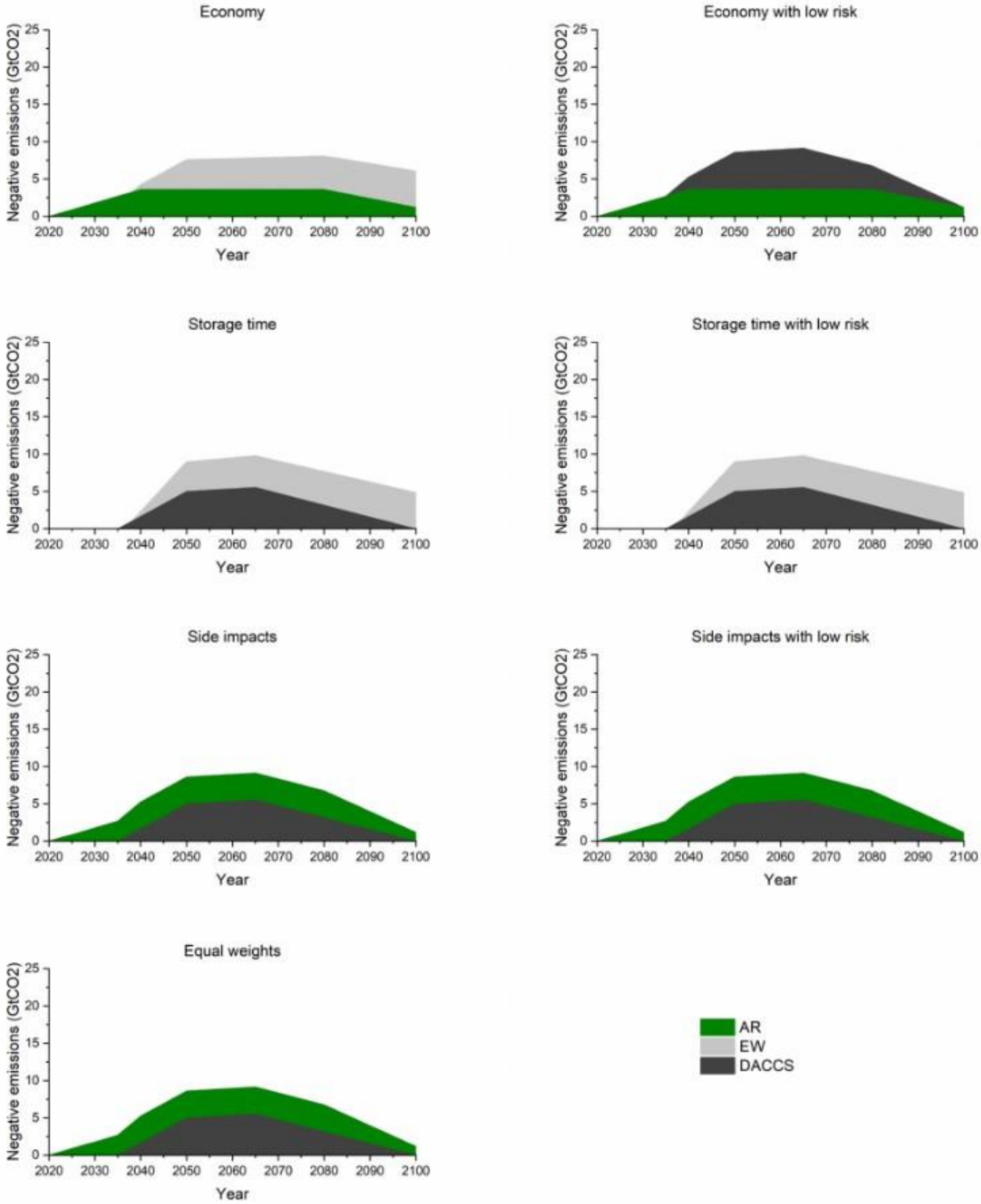


Fig. 3 The deployment portfolios for NETs under SSP2

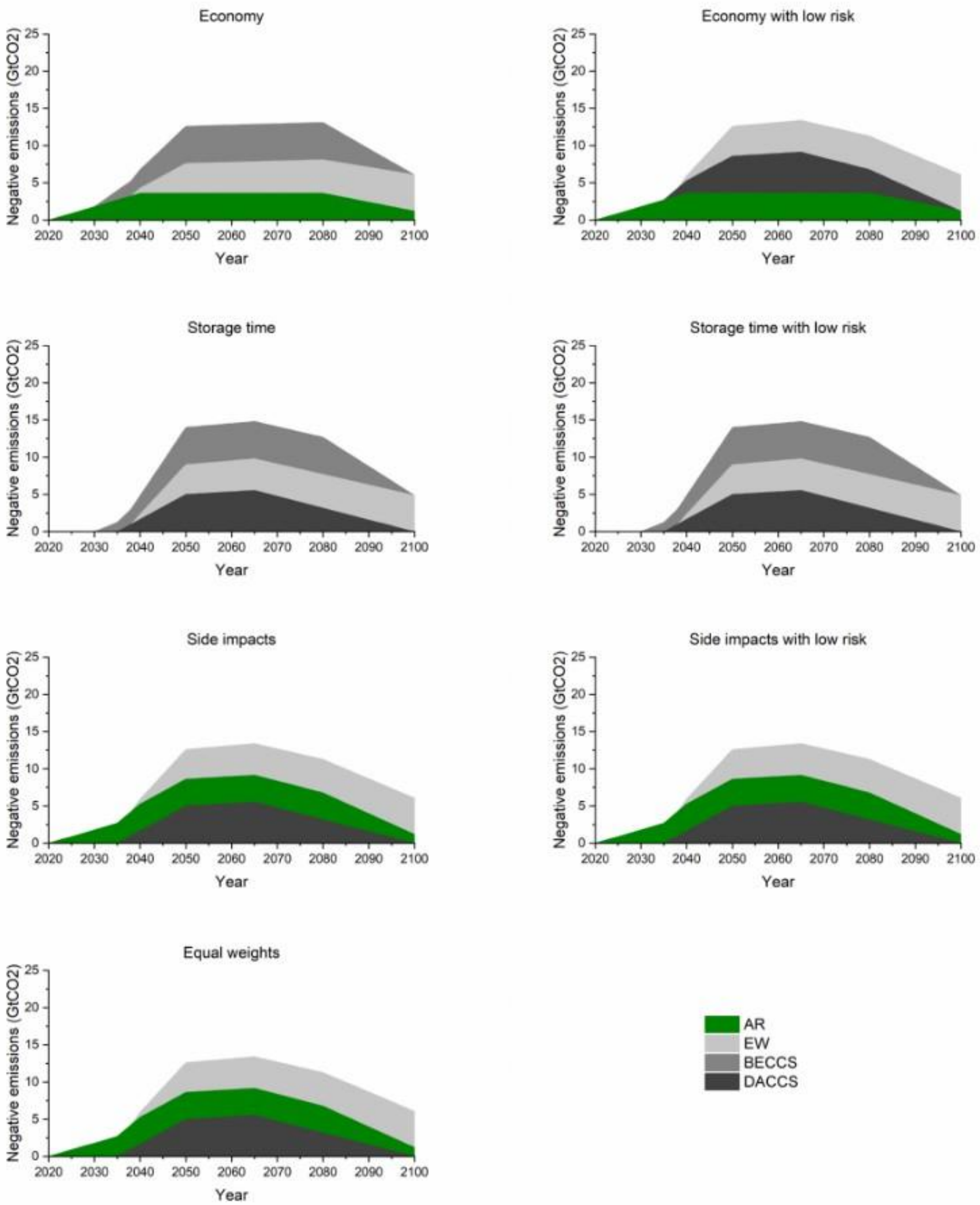
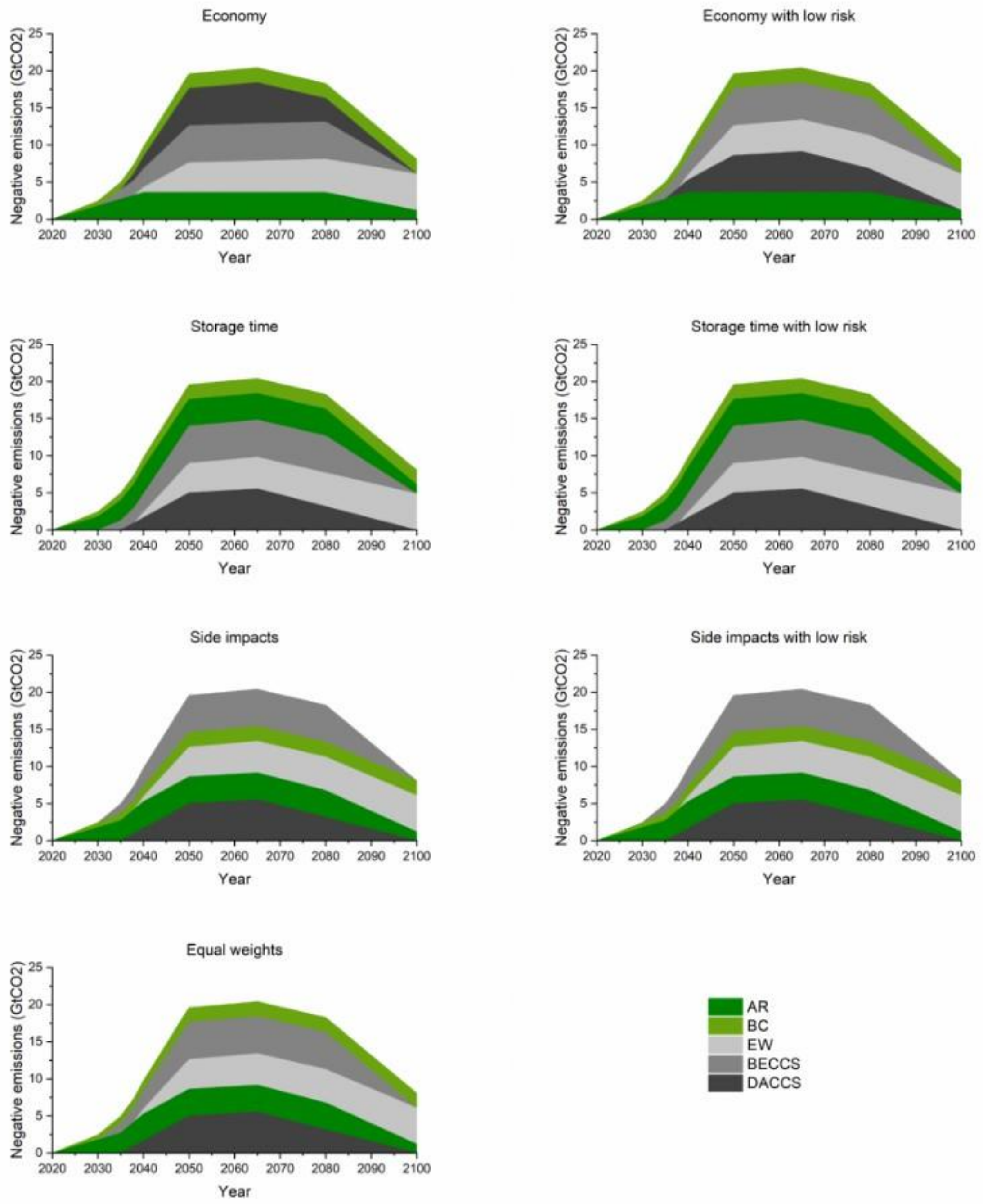


Fig. 4 The deployment portfolios for NETs under SSP5



Tab. 1 Indicators

Category	Aspect	Source
Feasibility	Technical	[3]
Feasibility	Economic	[2], our study
Feasibility	Governance	[6]
Effectiveness	Effect	[6]
Effectiveness	Timeliness	[6]

Effectiveness	Storage time	Our study
Side impacts	Environmental	[6]
Side impacts	Economic	[6]
Side impacts	Social	[6]
Non-competitiveness or complementarity	Non-competitiveness or complementarity	[7, 9-12]

Tab. 2 Weights for preferences

Preferences	Feasibility	Feasibility	Feasibility	Effectiveness	Effectiveness	Effectiveness	Side impacts	Side impacts	Side impacts	Non-competitiveness or complementarity
Preferences	Technical	Economic	Governance	Effect	Timeliness	Storage time	Environmental	Social	Economic	Non-competitiveness or complementarity
Equal weights	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Economy	0.011	0.900	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Economy with low risk	0.225	0.450	0.225	0.143	0.143	0.143	0.143	0.143	0.143	0.143
Storage time	0.011	0.011	0.011	0.011	0.011	0.900	0.011	0.011	0.011	0.011
Storage time with low risk	0.143	0.143	0.143	0.225	0.225	0.450	0.143	0.143	0.143	0.143
Side impacts	0.143	0.143	0.143	0.143	0.143	0.143	0.300	0.300	0.300	0.143
Side impacts with low risk	0.064	0.064	0.064	0.064	0.064	0.064	0.150	0.150	0.150	0.064

Tab. 3 Scores and CV of the five NETs across 10 indicators

	Feasibility	Feasibility	Feasibility	Effectiveness	Effectiveness	Effectiveness	Side impacts	Side impacts	Side impacts	Non-competitiveness or complementarity	Average	CV
	Technical	Economic	Governance	Effect	Timeliness	Storage time	Environmental	Social	Economic	Non-competitiveness or complementarity	Average	CV
AR	9.4	10.0	4.5	3.0	1.5	7.4	8.3	5.0	5.0	5.0	5.9	0.47

BC	7.2	2.9	4.5	3.0	2.0	1.5	6.7	6.7	5.0	6.3	4.6	0.46
BECCS	6.1	6.9	6.0	4.0	4.5	9.9	0.0	8.3	3.3	2.5	5.2	0.56
DACCS	6.7	5.2	8.0	8.0	10.0	9.9	3.3	6.7	6.7	3.8	6.8	0.33
EW	3.9	8.3	6.0	8.0	3.5	9.9	3.3	6.7	3.3	5.0	5.8	0.41
Average	6.7	6.7	5.8	5.2	4.3	7.7	4.3	6.7	4.7	4.5		
CV	0.30	0.41	0.25	0.50	0.79	0.47	0.75	0.17	0.31	0.32		

[Abstract:0441] OP-104 [Accepted:Oral Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

Life Cycle Greenhouse Gas (GHG) emissions Assessment of jet fuel production and consumption in the Kingdom of Saudi Arabia

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Overview:In 2018, the aviation sector’s combustion-related CO2 emissions amounted to approximately 1.04 billion tons, equivalent to 2.5% of global CO2 emissions, a figure similar to Japan’s domestic CO2 emissions in 2019 [1]. Despite a reduction in aviation activity and emissions during the COVID-19 pandemic, certain estimates suggest that aviation’s CO2 emissions are expected to double by 2050. This increase would account for approximately 14% of the total CO2 emissions from the combustion-related transport sector by that year [2]. Aligned with global efforts to decarbonize the aviation sector, the Kingdom of Saudi Arabia (KSA) has launched the Saudi Green Initiative (SGI) with the goal of reducing the country’s carbon emissions and reaching net zero by 2060 [3]. To do so, it is required to estimate the Life Cycle Greenhouse Gas (GHG) emissions of jet fuel production and consumption in the country in order to find appropriate decarbonization measurements. This paper aims to estimate these emissions, identify the hot spot of the emissions, and provide perspectives concerning enhancement opportunities along the jet fuel supply chain. Methods:The estimation of the Life Cycle GHG emissions was done through the Life Cycle Assessment (LCA) methodology and following the steps recommended by the ISO 14044:2016: (1) goal and scope definition, (2) life cycle inventory analysis, (3) life cycle impact assessment, and (4) interpretation [4]. The LCA aims to estimate the Life Cycle GHG emissions of the jet fuel production in the KSA, considering one transported passenger as the functional unit considering the current situation and conditions of Saudi Arabia’s aviation sector. Moreover, results were also expressed per energy unit (1 MJ) for comparison purposes against other studies or default values. It is expected that the technology and infrastructure involved in conventional jet fuel production will not vary at the time of the study. The system boundaries included Well-To-Pump (WTP) activities and Pump-To-Wake (PTW) activities. The sum of WTP and PTW emissions equals the total Well-to-Wake (WTW) emissions of jet fuel production and consumption. Data to build the life cycle inventory was collected from the environmental database ecoinvent v3.9.1 and properly adapted to local conditions. Fuel

consumption during aircraft operation was estimated using the ICAO carbon emission calculation methodology considering the traits of the airplanes present in the KSA's fleet, as well as different short- and long-trip distances [5].

The GHG emissions were estimated using the characterization factors developed by the impact method EN 15804 + A2 using the software Simapro Ph.D. v9.5 coupled to Microsoft Excel spreadsheets. Hot spots were identified to highlight the stages, activities, and/or inputs/emissions that contribute the most to total GHG emissions. The uncertainty of the results was studied by means of a 1,000-iteration Monte Carlo simulation and significant differences were identified considering the indicator developed by Huijbregts et al [6]. Moreover, results were compared against the default core WTW GHG value for conventional jet fuels of 89 g CO2eq/MJ estimated by the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [7]. Some alternatives to decarbonize the WTP activities involved in jet fuel production, such as the addition of renewable power sources along the supply chain, better management of the co-extracted gas during the oil extraction stage, or the addition of Carbon Capture Systems (CCS) in oil refineries, were also assessed. Results:Figure 1 summarizes the WTW GHG emissions of jet fuel production and consumption considering different aircraft types of the Saudi Arabian fleet, the number of people transported, the distance traveled, and the maximum Passenger Load Factor (PLF). Under the current situation (71% PLF), the B787 aircraft is suitable for transporting more than 200 people over distances greater than 1,000 km, resulting in emissions of 67 – 104 g CO2eq/pkm. In contrast, the ATR42 aircraft is suitable for transporting fewer than 400 people over short distances (less than 1,000 km) with emissions reaching 109 – 134 g CO2eq/pkm. The B737 aircraft is suitable for transporting 100 or 300 people over distances exceeding >3,000 km with emissions of 95 – 105 g CO2eq /pkm, while the ERJ140 is suitable for transporting 150 people over distances ranging from 2,000 and 10,000 km with emissions rising to 112 – 118 g CO2eq/pkm. The advantages of the A319 and ATR42 emerge when increasing the PLF to 80% and transporting 100 and 150 people, respectively, being outperformed by the F27 and F50 aircraft under higher PLFs of 90% and 100%, respectively. [Insert Figure 1 here]

On an energy basis (see Figure 2), results indicate that WTW GHG emissions of jet fuel in a 95% confidence interval range between 72.38 and 97.97 g CO2eq/MJ with a mean of 84.74 g CO2eq/MJ. In addition, in 74% and 25% of the iterations of the Montecarlo simulation, the estimated GHG emissions were respectively lower than the default worldwide value for conventional jet fuel and Lower Carbon Aviation Fuels (LCAF) (80.1 g CO2eq /MJ) established by CORSIA [7].

The utilization of photovoltaic-based power for oil extraction results in a 12% reduction in the average WTP GHG emissions, which, given the uncertainty of the results, is considered not significant. When the co-extracted natural gas from oil extraction is fully utilized for power generation, there is a substantial 45% reduction in WTP GHG emissions, yielding a WTW GHG emission factor of 79.38 g CO2eq/MJ. This figure is slightly lower (<1%) than the threshold for LCAFs. The integration of Carbon Capture and Storage (CCS) in oil refineries can contribute to a 26% reduction in WTP GHG emissions when using photovoltaic-based power. This reduction potential can be increased up to 35% with heat integration between CCSs and oil refineries. However, due to high investments, along with technical difficulties, opportunities for heat integration are considered unfeasible in a practical approach [8].

(Insert Figure 2 here) Conclusions:• This research has emphasized the variation in Life Cycle GHG emissions among different aircraft types within the Saudi Arabian fleet, considering factors such as the Passenger Load Factor (PLF), and travel distance. Specifically, the B787 aircraft emerges as a suitable option for transporting over 200 people on longer journeys (>1,000 km), within emissions ranging from 67 to 104 g CO2eq/pkm.

• As expected, the Passenger Load Factor (PLF) has a significant impact on the performance of certain aircraft, with the A319 and ATR42 demonstrating advantages at higher PLFs (80%), while being outperformed by the F27 and F50 at even higher PLFs (90% and 100%). It shows that even if the aviation system's environmental performance seems to improve as the number of people transported or PLF increases, some aircraft could not improve their environmental performance.

• On an energy basis, the mean GHG emissions of jet fuel production and consumption in the KSA were estimated at 84.74 g CO2eq/MJ, which is 4.79% lower than the worldwide baseline Life Cycle emissions value of 89 g CO2eq/MJ, but it is also a 5.79% higher than the world default value for LCAFs.

• This research emphasizes that mitigation strategies can be implemented in jet fuel production for the aviation sector, improving the environmental GHG performance. Implementing photovoltaic-based power for oil extraction, fully utilizing co-extracted natural gas during oil extraction for power generation, and incorporating Carbon Capture and Storage (CCS) in oil refineries can contribute to Well-To-Pump (WTP) GHG emissions. It could result in a WTW GHG emission factor slightly below the LCAFs threshold of 80.1 g CO2eq/MJ. Additionally, CCS could increase its performance through heat integration. However, practical feasibility is limited due to high investments and technical challenges.

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Keywords: greenhouse gas emissions (GHG), Life-Cycle Assessment, Aviation, Saudi Arabia,

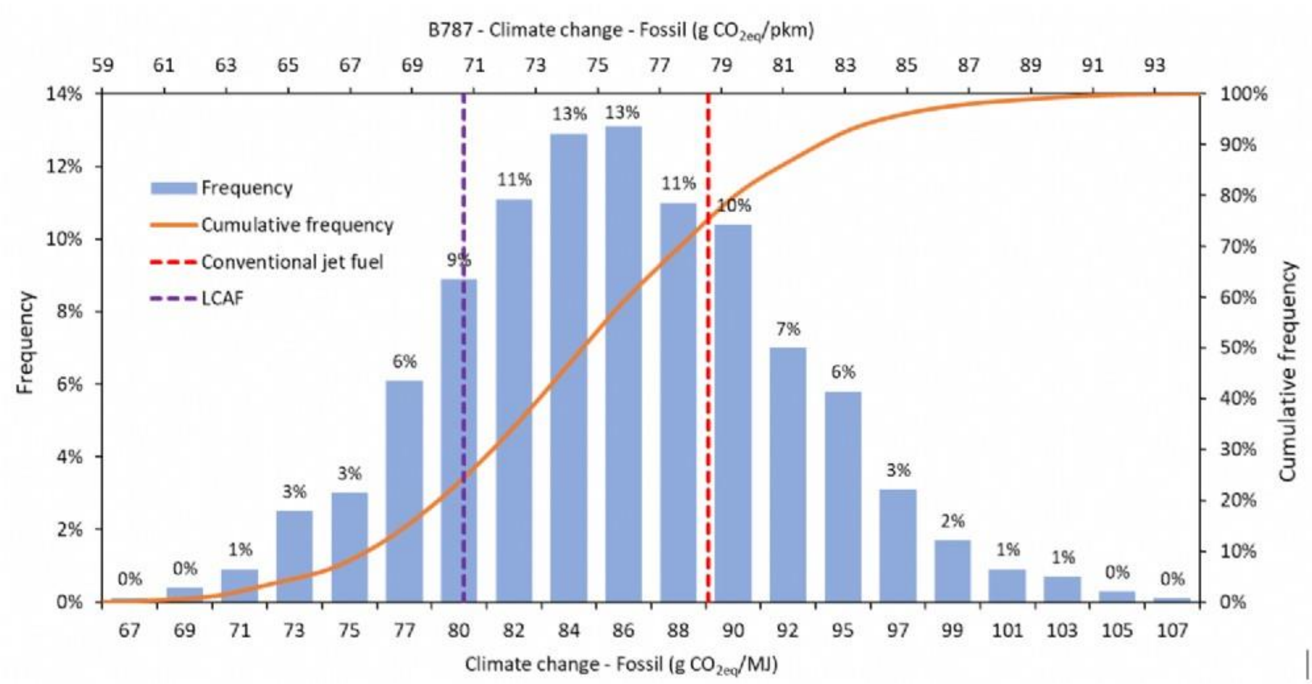
Figure 1. Aircraft types in the Saudi Arabian fleet that decrease the WTW GHG emissions of jet fuel, taking into account the number of transported people, distance traveled, and maximum PLF. Data is presented in g CO2eq/pkm.

Distance (km) \ People	100	150	200	250	300	350	400	450	500
Max PLF: 71% (base scenario)									
500	120.44	134.05	120.54	111.79	120.92	126.25	120.83	124.51	111.98
1,000	109.49	121.95	109.34	91.24	109.48	114.36	109.83	101.84	91.64
5,000	96.77	113.47	92.60	74.36	95.88	101.80	92.42	82.49	74.34
9,000	97.65	112.97	87.53	69.87	97.42	99.89	86.99	77.44	69.67
15,000	96.27	113.38	84.81	68.40	96.64	97.08	85.50	75.63	68.51
Max PLF: 100%									
500	106.39	105.97	100.01	96.19	93.01	80.49	90.08	88.79	87.83
1,000	89.38	88.93	89.20	88.29	77.07	65.81	80.68	80.72	80.14
5,000	72.46	63.84	73.08	73.42	61.79	52.96	63.83	64.00	73.00
9,000	73.44	65.91	73.58	69.31	58.19	49.51	59.98	64.76	69.45
15,000	73.65	64.43	72.46	68.45	56.87	48.92	58.52	64.37	68.44

ATR42 | F27 | B737 | F50 | ERJ140 | B787 | B777 v1 | A321 | A319

Aircraft types in the Saudi Arabian fleet that decrease the WTW GHG emissions of jet fuel, taking into account the number of transported people, distance traveled, and maximum PLF. Data is presented in g CO2eq/pkm.

Figure 2. Histogram of WTW GHG emissions of jet fuel production and consumption in the KSA. Results expressed per pkm consider the transportation of 250 people over 5000 km in a B787 airplane.



Histogram of WTW GHG emissions of jet fuel production and consumption in the KSA. Results expressed per pkm consider the transportation of 250 people over 5000 km in a B787 airplane.

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[Abstract:0468] OP-105 [Accepted:Oral Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

Ecological impact of DC grid and charging infrastructure: comparison of DC- and AC-based typologies using life cycle assessment

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Overview:In view of the need to mitigate greenhouse gas emissions and the corresponding European climate targets to be achieved by 2050, the German government set the goal of reducing 48% of greenhouse gas emissions from the transport sector by 2030 compared to 1990. In this regard the “Ampel” coalition agreement of the current German government states the aim of bringing at least 15 million of battery electrical vehicles (BEVs) on German roads and one million public charging points by 2030 [1]. Nevertheless, the electrification of the transportation sector and the broad-base integration of charging infrastructure, that accompanies it, comes with its own set of environmental issues. This is due to the emissions associated with the production of necessary materials and the operation of charging infrastructure.
As the charging infrastructure gains more importance as a key pillar to enable increased market penetration of EVs, the roll-out of DC charging stations is becoming more relevant. Using off-board charging (DC-charging) can decrease conversion losses during the charging if the operation of the distribution grids is based on DC instead of AC grids. This is due to the fact that the batteries of BEVs are charged with DC, while the distribution grid in Germany is mainly operating with AC resulting in high conversion losses during the charging process. Therefore, the implementation of underlying

local DC grids can offer multiple advantages in the broad-based integration of charging infrastructure, ranging from technical to economic and ecological benefits. While various studies focus on the environmental impact of the BEV in comparison to internal combustion engine vehicles, a research gap covering the environmental impact of the grid and charging infrastructure was identified. Hence, in this study, we examine the environmental impact of a DC-based grid and charging infrastructure in comparison to a DC charging infrastructure based on an AC grid infrastructure. In this regard we address the following key research questions:

• How does the environmental impact of installing DC-charging stations, utilizing a DC grid and charging infrastructure system differ in comparison to an AC-based grid and charging infrastructure system for BEVs?

• What are the key determinants contributing to emissions from the respective grid and charging infrastructure?

• How does the environmental impact scale with an expanded DC based grid and charging infrastructure?

Methods:To access the environmental impact of a DC-based grid and charging infrastructure in comparison to an AC-based grid with DC charging infrastructure, a comparative Life Cycle Assessment (LCA) approach in accordance with DIN EN 14040 is employed [2]. In this regard, the four phases of an LCA are carried out: firstly, the system framework and objective are defined, secondly the life cycle inventory is obtained, thirdly the impact is accessed and lastly the results are evaluated. The life cycle inventory however is confined to the production and usage phase; hence the transportation, recycling and end-of-life phases are not part of the scope of this analysis. To make the analysis more tangible, especially that of the usage phase of the life cycle inventory, a use case of parking garage in Germany has been chosen. Additionally, different scenarios regarding the expansion of the charging stations have been investigated and a sensitivity analysis has been carried out.

The system framework to be examined is outlined by the medium-voltage grid infrastructure based on either the AC or the DC technology as well as the DC charging stations within the parking garage. With this in view, the upper boundary of the system boundaries of our comparative LCA is depicted by the medium-voltage terminals of the medium-voltage-low-voltage transformer, while the lower boundary is represented by the charging cable that displays the connection to the BEV. Furthermore, the analysis within the usage phase incorporates the load profiles of the BEV charging processes along with the hourly electricity mix of Germany.

As for the life cycle inventory phase, all components for both typologies, AC-based grid and DC-based grid infrastructure with DC charging stations, are modelled within the scope of the production phase. The components for the grid infrastructure differ significantly depending on whether the DC-based or the AC-based technology is implemented. This results in a differentiated material deployment depending on the typology of the gird- and charging infrastructure, thereby affecting the overall environmental impact of the investigated typology. In order to assess the environmental impact during the usage phase of the charging infrastructure, the electricity demand required for supplying power to the charging stations and charging the BEV has to be considered. Therefore, accounting for the electricity mix used next to the charging profiles of the stations and the efficiency rate of the components within the system boundaries becomes imperative. Since the usage phase is affected by the share of renewable energies in the electricity mix, an adequate temporally resolved representation of the charging profiles throughout a year in a parking garage is modeled.

In regard to the evaluation of the environmental impact of both AC- and DC-based typologies, a tool has been developed to enable the investigation of different scenarios regarding the scale of charging stations expansion and the consideration of various sensitivity analysis.

Results:The preliminary results show that the global warming potential in the scenario with a medium extension of the charging stations, with the use case of parking garage, that the DC-based typology could save around 18% emissions in the production phase as can be seen in the figure below. In comparison to the medium extension scenario, the installed charging capacity in the maximum expansion scenario is 7.3 times higher. Nevertheless, the overall result regarding the global warming potential of the production phase is 8.8 times as high in the AC-based typology or 8.4 times as high in the DC-based typology. Furthermore, the reduction of the global warming potential through the implementation of the DC-based topology is around 3% higher in the scenario with maximum expansion compared to the scenario with medium expansion. This yields to the finding, that the implementation of DC-based typologies is more beneficial from an environmental impact point of view when accounting for larger scale implementations. Moreover, the evaluation of the environmental impact of the usage phase shows that the charging time of the BEVs makes a huge difference.

Conclusions:Through the described approach, an evaluation of the environmental impact of DC-based typologies in comparison to AC-based typologies can be conducted. In this respect, the scenarios, in which a DC-based grid- and charging infrastructure is, from an ecological point of view, beneficial can be derived. The investigation of the ecological impact of the required grid- and charging infrastructure associated with the market ramp-up of BEV, is imperative for the goals aimed at decarbonizing the transport and mobility sector specifically and the aspired energy transition. Additionally, the key components responsible for the highest share of CO2 footprint, as well as the critical materials, can be identified.

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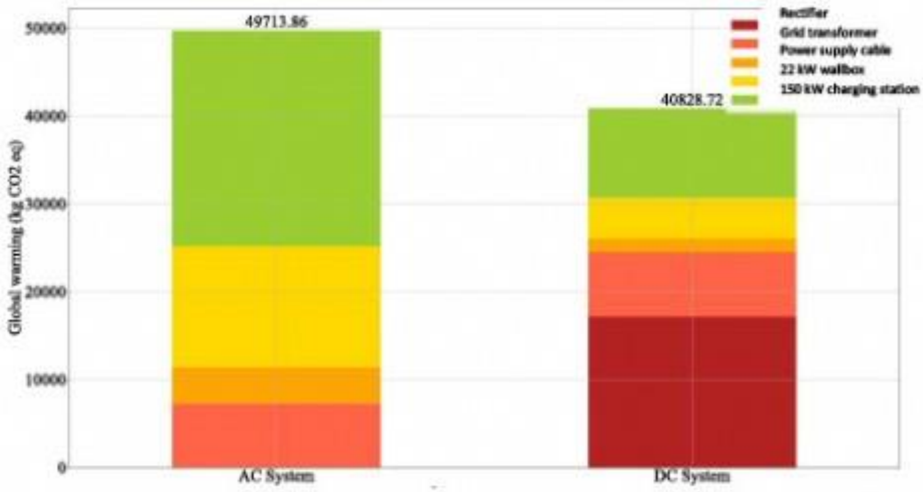
[2] S DIN, 2006. ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework. International Organization for Standardization.

Keywords: Life cycle assessment (LCA), charging infrastructure, AC and DC

Global warming potential: AC vs. DC typology



49713.86
40828.72
Rectifier
Grid transformer
Power supply cable
22 kW wallbox
150 kW charging station
Global warming (kg CO2 eq)
50000
40000
30000
20000
10000
0
AC System
DC System

[Abstract:0602] OP-106 [Accepted:Oral Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

Transition risks and sovereign debt costs

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Overview:The 6th assessment report of the IPCC published in March 2023 highlights the climate emergency and recommends a drastic reduction in GHG emissions to achieve low CO2 emission targets compatible with human life. To achieve this, the effectiveness of economic instruments such as emission standards, carbon taxes or emission trading schemes has been proven, however, their global effect remain limited in the absence of a binding international agreement involving most of the international community members. It is then worthy to ask whether financial markets may play a role in the coordination of climate action.
Since the Paris Agreement, the links between financial markets and climate change have been formally identified and conceptualized through the definition of new risks such as climate risks and low-carbon transition risks. Indeed, this agreement states that it is urgent "making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development". Climate risks are identified as damage to physical assets, natural capital, and human lives resulting in losses of production capacity and gross domestic product (GDP) due to climate-induced weather events. The low-carbon transition risk arises from policies aiming at achieving carbon neutrality by transforming the economy, with the possible consequence that assets in certain sectors may lose value. It is measured by losses resulting from asset revaluation following a poorly anticipated change in policy and/or regulation by economic actors in the affected sectors. This risk arises due to increased use of carbon pricing, stricter environmental standards, stranded assets, or market risks associated with reduced demand for carbon-intensive products.
Our work looks at the impact of fossil fuels on the cost of public debt. This question is important for a number of reasons. First, there is a direct impact of fossil fuels on the cost of public debt, which is channelled through the consequences of tackling climate change. To the extent that carbon neutrality targets require energy to be decarbonised and fossil fuels to be phased out, there is a risk that countries dependent on these resources will be left with a large amount of stranded assets (transition risk). Second, and more indirectly, the use of fossil fuels that emit greenhouse gases contributes to climate change and increases the risk of physical damage (climate risk). In both cases, exposed countries will be weakened, facing periods of major crisis and the risk of either defaulting (in the case of macroeconomic income losses) or having to borrow massively to repair the damage or adapt to the changes. These effects will be all the greater if the countries are initially vulnerable (highly indebted countries, developing countries, etc.). On the financial markets, lenders will be more demanding with regard to exposed countries, the supply of loans to these countries will decrease accordingly and investors will demand a higher risk premium on these loans (of 10 years or more).
Our article looks at the role that financial markets could play in the energy transition. Do financial markets help or hinder climate policy? Do they favour the fossil fuel sectors, for example by seeking to maximise profits from all investments in these sectors (a short-term objective)? On the contrary, are financial markets anticipating the long-term decline of these sectors and penalising countries lagging behind in the energy transition by increasing the cost of public borrowing?
Methods:In order to examine the effect of low-carbon transition risks on the country's costs of debt, we estimate a model where the countries' cost of borrowing is the dependent variable and the standard explanatory variables from the macroeconomic and financial literature dealing with the decomposition of sovereign risk premiums as follows: $Y_{it}=\alpha+\beta Risk_{it}+\gamma Z_{it}+\delta_i+\lambda_t+\varepsilon_{it}$
where Y_{it} refers to the borrowing cost of country i in year t. This variable is proxied in the

macroeconomic literature as the sovereign bond yield. In this article, we proxy the cost of borrowing by two competing variables which represent long-term and short-term costs of borrowing. $Risk_{it}$ represent the low-carbon transition risk faced by country i in year t. Z_{it} is a matrix of control variables that include debt to GDP ratio, inflation rate, GDP growth to control for the macroeconomic environment, the budget balance, exchange rates, resource rent to GDP ratio, and the institutional quality. γ represents a vector of parameters associated with control variables. δ_i denotes a full set of country fixed-effects, which will capture the impact of any time-invariant country characteristics, λ_t year fixed effects and ε_{it} is the error term.
We use unbalanced panel data for more than 80 countries from all over the world for the period 1995-2019. The data includes two different measures of government's cost of debt: i) the treasury bill rate represents the rate at which short-term government debt securities are issued or traded in the market. The maturity of these securities varies across countries and are ranging from 3 to 12 months; and ii) the government bond yield which refers to one or more series representing yields to maturity of government bonds or other bonds that would indicate longer term rates (10 years).
Our dataset also includes two groups of variables measuring low-carbon transition risks. The first group of variables measures natural resource abundance. These variables refer to countries' subsoil wealth and distinguish fossil resources, oil, gas, coal and mineral resources from all subsoil resource wealth. The second group of low-carbon transition risk proxies includes renewable energy consumption as a share of total final energy consumption and CO_2 intensity of GDP (in kg per 2010 US$ of GDP).
We also use a set of standard macroeconomic control variables among exchange rate, inflation, public debt to GDP ratio, budget balance and total natural resources rents as a share of GDP, GDP rates of growth, Institutional quality …;
Results:Our main results show that fossil rich countries borrow at more favorable interest rates. In contrast, countries with higher CO_2 emissions pay higher interest rates on their sovereign debt. In addition, while a significant share of renewable energy in a country's total energy consumption reduces its debt cost, countries with carbon-intensive GDPs pay higher interest on their sovereign debt. Financial markets reward fossil resource abundance while penalizing their use. In other words, financial markets support the energy transition while continuing to value fossil fuels.
Conclusions:Our results show that fossil fuels should be saved. An abundance of resources means we can borrow at a better rate, but burning fossil fuels increases the fossil risk premium. Fossil fuel reserves should be managed like gold. In general, the larger the central bank's stock of gold reserves, the more financially secure the country is and the cheaper it can borrow. According to our results, the same would be true for fossil fuels. So we need to continue to explore for fossil fuels (the role of exports remains to be seen), but not extract them (or just burn them?).
From a policy perspective, three recommendations are worthy to be mentioned. First, Be abundant, not dependent! Explore, not exploit: we provide arguments showing that fossil resources are important for debt sustainability. Save them, don't use them: this will prevent you from increasing the cost of public debt. (But if we look at the role of fossil fuel exports, do they play the same role as combustion and greenhouse gas emissions?). Second, the study helps understand to what extent financial markets can represent a buffer or a last resort to mitigate the natural risks that different countries are currently facing. Indeed, it is important to see how macroeconomic policies and the financial market can help mitigate the risks associated to climate change. An additional cost of public borrowing, and therefore an increase in the cost of public debt, should encourage countries to take the necessary measures to protect themselves against these risks and thus reassure the financial markets. In the shorter term, these risk premiums would further weaken the public finance of countries already exposed to major risks, which would exacerbate the difficulties of financing investments necessary to protect against environmental degradation. Finally, in the case of sovereign bonds, government should better assess and disclose their climatic and transition risks. Only Ghana did it fully when borrowing to face the COVID-19 crisis. Yet, countries face many disincentives to do so as they would face higher costs of borrowing. As countries keep investing in polluting assets and deepen their maladjustment to future needs, they become even more vulnerable to increased bond yields in the event of a change in investor's behavior towards climate risks. Consequently, central banks and financial supervisors have pushed forward the need for standardized metrics to include climate risks in financial contracts.
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Keywords: Low-carbon transition risks, Borrowing costs, Sovereign debt, Risk Premium

[Abstract:0080] OP-107 [Accepted:Oral Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

Assessing the CO2 Emissions and Energy Source Consumption Nexus in Japan

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Overview:To find out how the major energy sources contribute to CO2 emissions in Japan, this study investigates how the six major non-renewable and renewable energy sources are impacting the CO2 emissions in Japan by utilizing the Environmental Kuznets Curve (EKC) model. The study will have great significance in the context of sustainable development and environmental concerns regarding the nexus between CO2 emissions, and economic growth in Japan. This study stands out as the pioneering work delving into the existence of the EKC concept and the impact of both renewable and non-renewable energy consumption on CO2 emissions in the context of Japan. Moreover, it scrutinizes the connections between CO2 emissions and renewable and non-renewable energy consumption (highlighting the top three contributors from each category) using monthly datasets. Finally, this approach offers a more comprehensive understanding of the intricate relationships between specific types of energy consumption and their corresponding effects on CO2 emissions. Generally, in Japan, the energy demand is met through a diverse range of sources, comprising renewable options such as photovoltaic, hydroelectric power, and wind power, as well as non-renewable sources like coal, oil, and LNG. Some scholars have examined the interconnections between the consumption of specific energy resources, carbon emissions, and economic growth to inform policy decisions (Bulut, 2019). However, to conduct a comprehensive analysis, it is essential to consider all major energy sources, including renewable and non-renewable. The aim of this study is to close the existing research gap through an investigation into the relationships between each major energy source, its associated carbon emissions, and the Nikkei stock index as a proxy of economic growth.
The findings offer valuable insights to policymakers in selecting the most suitable energy sources and devising a strategy for achieving an optimal balance between CO2 emissions, and energy consumption (renewable & non-renewable) in Japan. Furthermore, gaining a sophisticated comprehension of the interaction between energy consumption and economic growth can aid in effectively allocating resources, optimizing energy efficiency, and fostering innovation within Japan's energy sector. As a result, the empirical findings from this study hold considerable potential as a valuable tool for policymakers in crafting well-informed and sustainable energy policies that combat

climate change and bolster the nation's long-term economic prosperity.
Methods:The research investigates how energy usage, economic growth, and both renewable and non-renewable energy resources impact CO2 emissions, along with considering the presence of the EKC using the autoregressive distributed lag (ARDL) model. For this purpose, we analyzed the relationship between CO2 emissions, energy consumption (renewable and non-renewable), and economic output using monthly data from January 2019 to March 2023. The daily CO2 emissions per capita are measured in metric tons (MT) and are obtained from the Carbon Monitor website. Monthly data for energy consumption (renewable and non-renewable consumption sources) are measured in thousands of kWh units per capita and obtained from the Agency for Natural Resources and Energy website. As a proxy of an economic indicator, this study considered the Nikkei stock index, and monthly Nikkei 225 datasets were obtained from the Nikkei indexes website.
Before employing the econometric approaches, we conducted the Phillips-Perron (PP) Augmented Dickey-Fuller (ADF), the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) and Zivot–Andrews (ZA) tests to check the stationarity. After checking the data, this research utilizes the ARDL model to explore the relationship between CO2 emission and economic growth.
Results:The ARDL estimation indicated that the Nikkei index, considered a proxy variable of GDP growth, positively and significantly impacts CO2 emissions in the long- run. This suggests that an increase in GDP growth will further contribute to higher concentrations of CO2 emissions. Conversely, the squared term of Nikkei, utilized as a proxy for economic growth in Japan, negatively impacts CO2 emissions in the long-run. This result supports the EKC hypothesis. As the economy grows, environmental degradation initially increases but eventually declines as societies invest more in sustainable practices and adopt environmentally friendly technologies. However, the squared term of the Nikkei represents that a 1% increase in economic growth leads to a 1.61% decrease in CO2 emissions and vice-versa. This finding aligns with the fact that in conjunction with GDP growth, government policies concerning pollution regulation have been progressively increasing and improving (Ali et al., 2017; Salari et al., 2021).
Coal, oil, and LNG significantly and positively influenced CO2 emissions, at the 1% significance level. Among non-renewable energy sources, coal emitted more CO2 than oil and LNG sources, as examined by the World Nuclear Association (2022). Non-renewable energy consumption leading to an increase in CO2 emissions is likely related to the fact that non-renewable energy consumption sources are a primary contributor to environmental pollution, and still, the country's economic growth heavily relies on non-renewable energy. Conversely, renewable energy sources such as photovoltaic have negative and significant effects on CO2 emissions in Japan. We can infer from this result that renewable energy consumption can significantly contributes to reducing CO2 emissions.
Conclusions:The Japanese government has been promoting the development of renewable energy plants through the implementation of a Feed-in Tariff (FIT) system since 2012 and a Feed-in Premium (FIP) system since 2022, with the aim of achieving a carbon-neutral society (ICLG, 2022). The new FIT program requires power companies to purchase electricity from certified renewable sources such as solar, wind, hydro, geothermal, and biomass at fixed government-set prices for a specific duration. This mechanism ensures stable revenue, thereby encouraging investments in renewable power generation (Climate Scorecard, 2021). As a result of the FIT policy, solar PV installations in Japan experienced rapid growth, establishing the country as one of the global leaders in solar energy capacity. While solar power gained more momentum than wind power in the initial stages, it is essential to acknowledge that Japan has also been making efforts to promote wind energy as part of its renewable energy portfolio (Climate Scorecard, 2021). The study's findings support the notion that wind power has yet to be entirely overlooked despite its slower development compared to solar PV. Our findings endorse the benefits of government FIT measures that promote the uptake of renewable energy by creating renewable energy markets and implementing renewable energy portfolio standards. These policies aim not only to enhance environmental conditions but also to yield positive outcomes from a macroeconomic perspective.
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Keywords: CO2 emissions, Renewable energy, Non-renewable energy, Nikkei index, EKC, ARDL model

[Abstract:0330] OP-108 [Accepted:Oral Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

The role of biochar in pursuit of China's carbon neutrality goal: A computable general equilibrium analysis

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Overview:Mitigation pathways aligned with carbon neutrality goals generally rely on negative emission technologies (NETs) that can remove carbon dioxide (CO2) from the atmosphere1. In China, NETs are expected to provide negative emissions of 0.01 to 2.91 Gt CO2eq/a in 2050 or 20602–5. Besides afforestation, such high NET demands mainly count on bioenergy with carbon capture and storage (BECCS) or direct air carbon capture and storage (DACCS)6. However, CCS still face technical barriers and social concerns7,8, posing risks of delayed deployment. Biochar, as a NET that can simultaneously provide negative emissions and renewable energy while contributing to agricultural productivity, is gradually gaining attention. According to IPCC AR6, there is medium confidence indicating that biochar has negative emission potential, estimated at 2.6 (0.2-6.6) Gt CO2-eq/a, with 1.1 (0.3-1.8) Gt CO2-eq/a at a cost below 100$/t CO2-eq9. Biochar has been applied in China for a long time, and current research on Chinese biochar is mainly focused on crop residues, revealing a negative emission potential ranging from 0.05 Gt CO2-eq/a to 0.7 Gt CO2-eq/a10–12. Although biochar can provide moderate to substantial mitigation potential, there is limited research incorporating it into IAMs13. The economic impact of biochar deployment on China’s carbon-neutral transition pathway remains unclear, hindering the comparison and integration of biochar with other NETs.
Methods:Here, we employ a computable general equilibrium (CGE) model named China in Global Energy Model (C-GEM) to investigate the role of biochar in climate mitigation pathways to meet China’s carbon neutrality goal (Fig.1). C-GEM was developed by a cooperative project between the Tsinghua University Institute of Energy, Environment, and Economy and the Massachusetts Institute of Technology (MIT) Joint Program on the Science and Policy of Global Change, currently updated to C-GEM4.02. We parameterize the biochar technology in C-GEM4.0 and configures scenarios considering biochar as the sole NET to achieve carbon neutrality goals. The aim of this study is to address key questions such as when biochar could be deployed at the earliest and whether carbon neutrality goal could be met without CCS but solely through the use of biochar technology. Similar to BECCS, the representation of biochar technology in C-GEM4.0 is nested within CES production functions, which involves a specific nested structure and elasticity values to reflect the characteristics of biochar. In comparison to BECCS, biochar technology is only constrained by biomass resources, without carbon storage limitations. Biochar can be buried in soil, improving soil physicochemical properties and enhancing crop yields. Approximately 0.52 tons of CO2, per ton of biomass pyrolyzed into biochar, can be stably sequestered in the biochar structure for over 100 years. Biochar technology is considered as a backup option, being autonomously chosen by the model only when costs decrease or carbon constraints tighten.

We defined the following scenarios in our study: 1) Reference Scenario (Ref), wherein the emission trajectory aligns with NDC goals, assuming the absence of any NETs; 2) Carbon Neutrality Target without NETs Scenario (CN60-noNET). To ensure the model has feasible solutions in the absence of additional negative emission technologies (NETs), it is assumed that by 2060, external forest carbon sinks can provide an additional 100 million tons of carbon budget. 3) Carbon Neutrality Target with Biochar only (CN60-BC). Within CN60-BC, sub-scenarios include CN60-BC-BioALL, CN60-BC-BioResi, and CN60-BC-BioSRP, reflecting considerations of all available types of biomass resources, only crop residues available, and only dedicated energy forests available, respectively. 4) Carbon Neutrality Target with BECCS only (CN60-BECCS).

Results:The results indicate that even if BECCS technology is unavailable, achieving carbon neutrality goals is possible solely through biochar technology (Fig.2). Biochar technology can provide negative emissions of up to 280-670 Mt CO_2/a by 2060. However, due to the fact that the carbon removal capacity of biochar per unit biomass is one-third that of BECCS technology, more biomass resources are required to remove the same amount of CO_2 through biochar technology compared to BECCS technology.

Therefore, when the demand for negative emissions is high, the cost of biochar increases significantly due to the rising cost of biomass resources. Additionally, as CCS costs decrease by 70% by the mid-century due to technological advancements, the cost of biochar exceeds that of BECCS by 2060. Consequently, the biochar deployment scenario leads to higher carbon prices (Table 1). Specifically, in 2060, with all categories of biomass resources available, biochar provides only 670 Mt CO_2/a, less than half of BECCS. This is because, at this point, biochar technology would require the consumption of approximately 1.3 billion tons of dry biomass per year, equivalent to 19 EJ/a in energy units. According to the supply curve of biomass feedstocks, the biomass supply price exceeds 35 $/GJ. Therefore, by 2060, in the CN60-BC-BioAll scenario, the carbon price reaches 788 $/t of CO_2. Compared to scenarios without negative emission technologies achieving carbon neutrality goals, this results in a reduction in avoided GDP losses by 5.7 percentage points. If only agricultural and forestry residues are available or only dedicated energy forests are available, the avoided GDP losses will further decrease to 4.7 and 2.1 percentage points, respectively, with carbon prices exceeding $1000, reaching $1278 and $3414 per ton of CO_2.

However, when the demand for negative emissions is low, biochar has lower per-unit carbon costs than BECCS, as it does not necessitate expensive carbon capture, transport, and storage costs. Biochar technology, benefiting from its early low costs, may enter the market earlier as a mature NET, potentially achieving negative emissions by 2025, providing 40-170 Mt CO_2/a in the early stages.

It is worth noting that although the carbon removal cost of biochar technology is higher than that of BECCS in 2060, the scenario with the exclusive deployment of biochar results in slightly higher GDP avoidance compared to the scenario with the exclusive deployment of BECCS. This is attributed to the increase in crop yields and the subsequent rise in agricultural output associated with biochar deployment.

Conclusions:In this study, we characterized biochar technology within a general equilibrium model and extensively investigated its impact on China's carbon-neutral transition pathway. As a mature negative emission technology, biochar holds the potential to achieve negative emissions as early as 2025. Even in the absence of CCS technology, relying solely on biochar technology can still achieve carbon neutrality goals, providing a maximum of 670 million tons of negative emissions by 2060. It is noteworthy that the deployment of biochar technology not only contributes to climate mitigation but also generates positive benefits for agricultural yields. These benefits may play a pivotal role in promoting the widespread adoption of biochar technology. Nevertheless, the cost of biochar may be constrained by the increasing cost of biomass resources. In conclusion, this study provides new insights into the role of negative emission technology in China's carbon-neutral transition. The introduction of biochar technology offers an alternative pathway for achieving China's carbon neutrality goals, especially when considering its positive effects on agriculture. However, it should be noted that the economic feasibility of biochar technology varies under different resource contexts, providing valuable guidance for policy making and technological development.

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Keywords: Biochar, Negative emissions, CGE, Carbon neutrality, China

Figure 1 The structure of China in Global Energy Model (C-GEM).

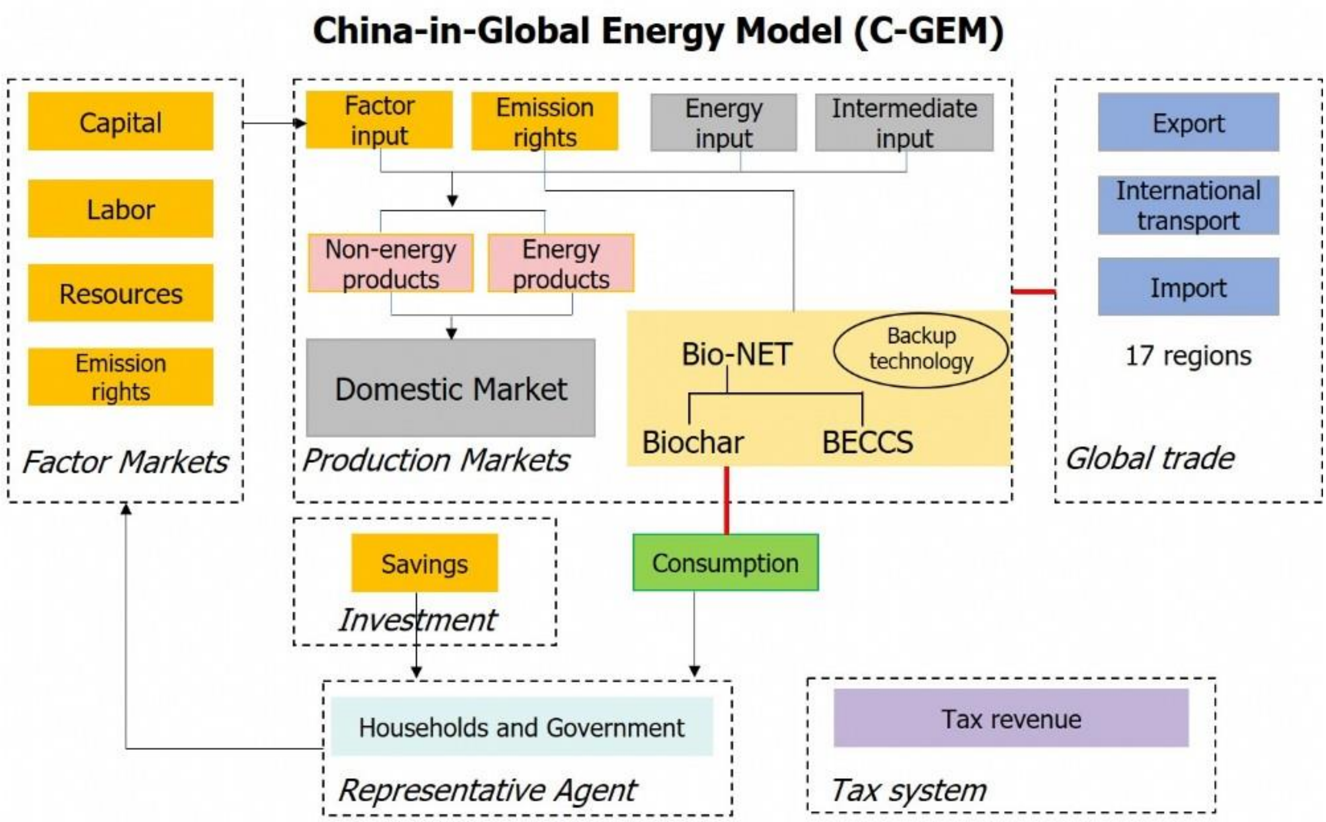

Figure 2 The negative emissions provided by biochar under different biomass resource constraints (a), along with the impact of biochar deployment on GDP (b) and carbon price (c).

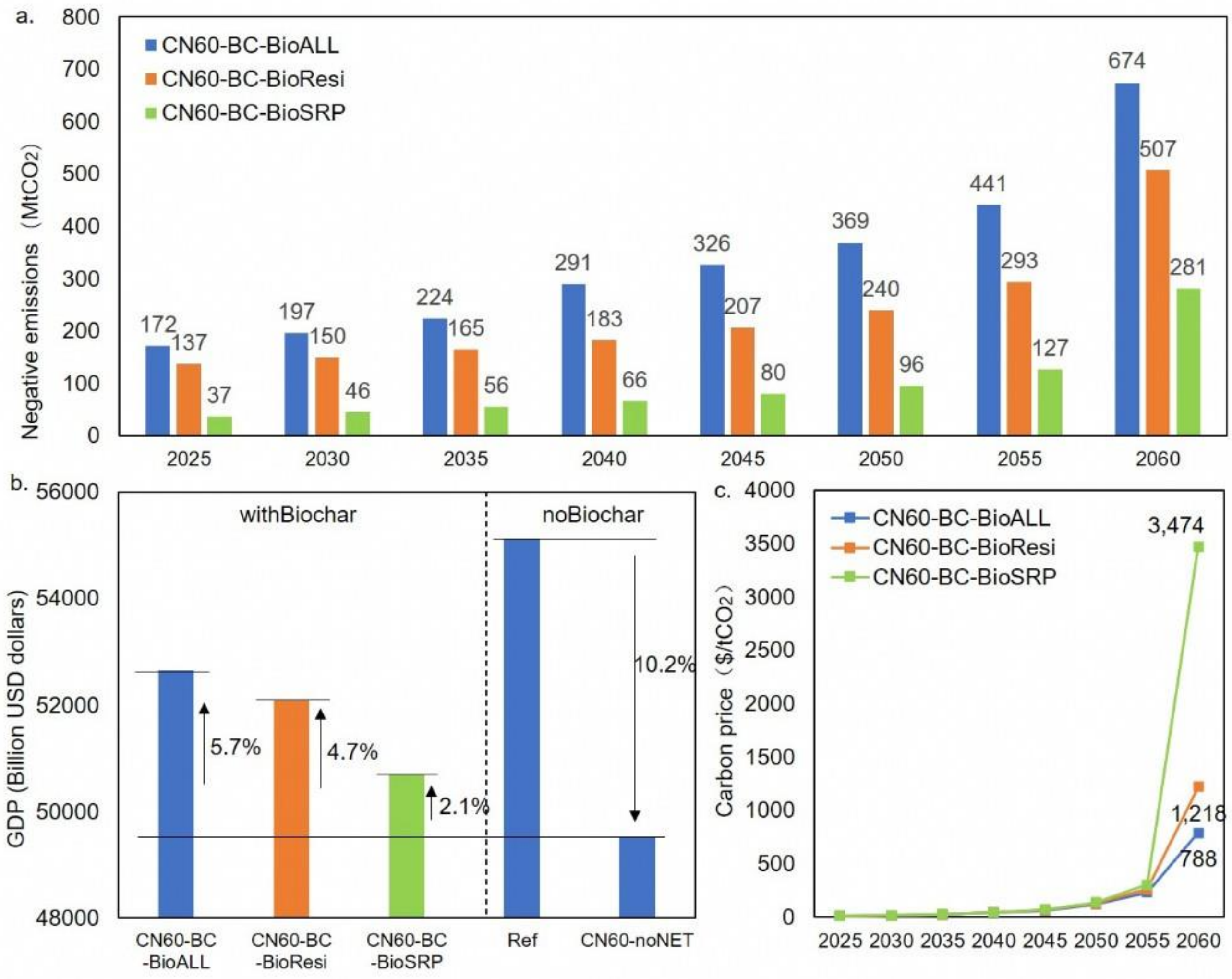

Table 1 Comparison of key results between biochar and BECCS deployment in the scenarios where all types of biomass resources are available.

	Near-term negative emissions	2060 negative emissions	2060 GDP loss avoidance	2060 carbon price
BECCS	18Mt（2030）	1359 Mt	5.7%	289$/t
Biochar	172Mt（2025）	674Mt	5.7%	788$/t

[Abstract:0654] OP-109 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Economic Growth and Energy Demand]

Impacts of Global Warming on Regional Energy and Economy: Uneven consequences arising from global warming-induced heating and cooling demand of households

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Overview:The increasing temperature caused by climate change has far-reaching consequences for global residents. These impacts can differ across geological regions and socioeconomic groups and significantly alter residents' way of living, including energy consumption patterns. This heterogeneous impact on residential energy usage and its subsequent effect on energy expenditure and income are among the issues faced by policymakers whose concern is to improve social equity and justice, especially with regard to the United Nation's 7th, 10th, and 13th Sustainable Development Goals (UN, 2023).
Methods:In this paper, we study the distributional implications of global warming impacts on household energy use for heating and cooling and the induced economic responses under different scenarios. As argued in Section 2, we contribute to the literature mainly in two ways. First, we estimate the direct impact of global warming on the household energy demand for heating and cooling in 140 global regions while considering various temperature changes across regions based on the latest climate and socioeconomic scenarios. This is an application of the approach used by Roson and Sartori (2016), which illustrated the regional impact by assuming a given temperature increase for each region. Second, we further assess the macroeconomic implications of the impacts across these 140 regions at the global level. The Gini index (Dixon et al., 1988; Damgaard and Weiner, 2000) is used to indicate the distributional implications across regions in household energy use, regional gross domestic products (GDP), regional primary energy use, and regional CO_2 emissions.
Global warming in the coming decades will vary depending on different socioeconomic pathways (SSPs). To capture potential global warming, climate models have been used to predict the temperature and other climatic variables based on greenhouse gas (GHG) emissions derived from specific SSPs. In each scenario with a particular global warming level, the temperature change and other climatic variables vary across regions, implying a different impact on the residential demand for cooling and heating services. Consequently, the impact affects the entire economy through a changed demand for the energy used for household cooling and heating.
Results:Our findings show that changes in household energy consumption for cooling and heating directly triggered by global warming vary across countries and energy sources. They reveal a considerable level of inequitable distribution in the affected residential energy consumption for cooling and heating. These direct impacts on household energy consumption shift the equilibrium of the economic system and engender a broad dispersion of impacts across countries, depending on the country-specific economic status and geographical characteristics. Higher-income countries, especially those located in cold regions, experience more significant reductions in household energy expenditures compared to other countries. Moreover, the structure of the economy plays a vital role. Low-income countries, characterized mainly by industries that are heavily reliant on fossil fuels, witness a more considerable rise in primary energy expenditure and a decline in the GDP. In contrast, high-income countries, characterized by the predominance of service-related sectors, experience GDP growth along with a decrease in primary energy consumption. Finally, the increase in the usage of fossil fuels is noticeable in low-income countries located in hot regions. This causes more intensive CO_2 emissions in these areas, whereas rich regions exhibit dramatic decreases. Such development further intensifies the global disparity in emissions, which has the potential to exaggerate the uneven impacts of global climate change.
Conclusions:In this paper, we have studied the distributional implications of global warming impacts across countries and regions with regard to the global economy. Through the application of the CGE model, we find strong inequality in the impact of climate change, with the specific structure of the economy playing an important role.
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Keywords: Household energy demand, climate change impact, inequality, socioeconomic impact,

macroeconomic model, climate simulation

AuthorToEditor: I apologize for the late submission. I really hope our abstract could be considered for the IAEE conference. Thank you very much!

[Abstract:0041] OP-110 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Economic Growth and Energy Demand]

Long-run Causality and Short-term Adjustments: The Role of Financial Development and Renewable Energy in Reducing GHG Emissions in Africa

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Overview:The African region combines emerging and low-income economies, each with distinct economic growth and development paths. A significant characteristic of these economies is their dependence on Foreign Direct Investment (FDI) because the natural resources in the region attract investment This makes the region dependent on advanced and rich countries for investment. Production in the region predominantly relies on inefficient and non-renewable energy sources, obstructing the achievement of SDG 7's clean energy goals. This energy inefficiency not only diminishes industrial competitiveness but also curtails job creation. Inconsistent energy infrastructure and a lack of sustainable practices deter FDI, as investors often prioritise stable energy prices and sustainable operations. Despite the emphasis on SDG 12's sustainable consumption and production, the region's industries are slow in adopting these practices, affecting global competitiveness and investor appeal. Seeing the climate change threats, the region's continued use of carbon-intensive energy for industrial operations presses the need for SDG 13—Climate Action. A unified policy focusing on energy efficiency, sustainable industrial growth, and a structured framework for FDI can align the region's development with global sustainability objectives.

In light of the above, we aim to provide a comprehensive empirical analysis of the long-term and short-term causality between key market-induced factors and GHG emissions, thereby informing more effective policymaking in sustainable development for African economies. Unlike previous studies that have been too broad or confined to single factors, we integrated multiple variables, such as financial development, renewable energy, share of hydropower, fossil fuel consumption, employment, industrial performance, gross domestic product, and growth, and FDI, to present a holistic picture. Thus, the research fills a crucial gap by understanding how market-induced factors influence GHG emissions in African economies.
Methods:We employ a Panel (vector error correction model) VECM to assess long-term stability and short-term shifts in GHG emissions, with financial development and renewable energy consumption as the cointegrating vectors. Our sampled economies, twenty-five, were classified into four categories—high, moderate, emerging and lower—based on their industrial output. The share of energy usage from hydropower and their national income in the classification provided further insight into how market-induced factors impact industrial growth in the region. Using the comprehensive methodological approach of VECM, we analysed the cyclic adjustments between financial development, renewable energy, and greenhouse gas emissions in these economies. In applied work, VECM is conducted by the following steps: (1) Stationarity test: all the series must be stationary at I(1). (2) Determine the optimal lag length for the model. (3) Cointegration test showing the endogenous variables are cointegrated. (4) Estimate VECM (Athanasopoulos et al., 2010).
Results:We found evidence of long-run causality between financial development, renewable energy, and GHG emissions, indicating that improvements in these sectors could be instrumental for

emissions reduction in the long term. Overall, the study reveals a robust long-run relationship, with financial development and renewable energy acting as stabilising forces in GHG emissions. Conversely, our findings show a need for more short-run causality from these factors, suggesting that policy interventions may not yield immediate results but are essential for long-term sustainability. A distinct contribution was identifying sectoral factors, such as employment and industrial performance, significantly influencing emissions levels. The result of our study brings a new perspective to the understanding of the relationship between market-induced factors and GHG emissions in African economies.
Conclusions:The research also offers policy insights tailored to countries with varying degrees of industrial output, filling an existing gap in the literature concerning the African context. The policies address each economy's challenges with the potential of balancing their growth strategies with environmental consequences in view. Countries with high industrial output would benefit from advanced policy instruments such as carbon pricing and green finance, while those with moderate output could make strides through tax incentives for renewable energy and stricter emissions monitoring. Emerging economies require a foundational regulatory structure and skill development in green technologies, whereas lower-output countries could benefit from grassroots initiatives and accessible credit facilities for green projects. These findings are instrumental for national and regional policymakers, helping them align development objectives more closely with environmental sustainability, like expanding and utilising hydropower.
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Keywords: Energy, GHG, Africa, Panel-VECM, Market-induced factors, SDGs

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[Abstract:0045] OP-111 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Economic Growth and Energy Demand]

The Contribution of Energy to Economic Growth and Convergence

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Overview:The issue of cross-country income convergence has been studied extensively in the 1990s. The empirical evidence at that time supported the lack of income convergence, as there was no tendency for developing countries to grow relatively faster than developed economies. Income convergence was only observed for a sub-sample of OECD countries (Mankiw et al., 1992) or the analysis of income among the US states (Barro & Sala-i-Martin, 1992). Instead, the world was characterized by conditional convergence in the sense that it was observed empirically only after controlling for the key variables affecting the long-run steady-state level of income. However, recent studies show that the trend has reversed since the beginning of the twenty-first century where we observe the emergence of unconditional income convergence (Kremer et al., 2022; Patel et al., 2021).

This paper aims to investigate the role of energy in cross-country growth and convergence. We extend the production frontier approach of Kumar and Russell (2002) to growth accounting to include energy as an additional factor of production. Our decomposition of economic growth consists of technical efficiency change (movement toward or away from the frontier), technological change (shifts in the world production frontier) and change in production factors per unit of labor (movement along the production frontier). The latter component is further decomposed into components attributable to capital accumulation and energy use change. The main contribution of this paper is the analysis of global income convergence and divergence trends from 1980 to 2019 incorporating energy as an additional production factor. To the best of our knowledge, such an analysis is new to the literature.

Methods: Let Y_{it} be the aggregate economic output produced by three factors of production: labor (L_{it}), physical capital stock (K_{it}), and energy (E_{it}) for a country i at time t. The reference constant return to scale (CRS) technology for the world production in period t is defined by:

$$T_t=\{(Y,K,L,E)\in R_+^4 \mid Y\le\sum_{\tau\le t}\sum_i z_{i\tau} Y_{i\tau},\ K\ge\sum_{\tau\le t}\sum_i z_{i\tau} K_{i\tau},\ L\ge\sum_{\tau\le t}\sum_i z_{i\tau} L_{i\tau},\ z_{it}\ge 0,\ E\ge\sum_{\tau\le t}\sum_i z_{i\tau} E_{i\tau},\ z_{it}\ \forall\ i\} \quad (1)$$

where z_{it} are the intensity variables that help to form the frontier such that it envelops the data with the smallest convex-free disposal cone. The technical efficiency index for country i at time t is defined by:

$$TE_{it}=\min\{\lambda \mid (Y_{it}/\lambda, K_{it}, L_{it}, E_{i\tau})\in T_t\} \quad (2)$$

The CRS technology enables us to draw the production frontier in the $\langle y,k,e\rangle$ space, where $y=Y/L$, $k=K/L$ and $e=E/L$. Therefore, the maximum or potential output per capita can be written as a function of per-capita capital stock and energy per-capita terms $\bar{y}(k,e)$. Once we estimated the world production frontier and the associated technical efficiency indexes, we can decompose output per worker into the following:

$$y_c/y_b = EFF\cdot TECH\cdot FACH \quad (3)$$

Eq. (3) decomposes the relative change in output per capita in the two periods into:

Efficiency change $EFF=(TE_c)/(TE_b)$ (4)
Technological change $TECH=(\bar{y}_c(k_c,e_c))/(\bar{y}_b(k_c,e_c))$ (5)
Changes in factor inputs per unit of labor $FACH=(\bar{y}_b(k_c,e_c))/(\bar{y}_b(k_b,e_b))$ (6)

The change in factor inputs index FACH captures the combined effects of capital accumulation and change in energy use. One can further decompose FACH into two components to separate the effect of capital accumulation from the effect of energy use as follows:

$$FACH=KACC\cdot EC \quad (7)$$

Where:

$KACC=\left(\frac{\bar{y}_b(k_c,e_c)}{\bar{y}_b(k_b,e_c)}\cdot\frac{\bar{y}_b(k_c,e_b)}{\bar{y}_b(k_b,e_b)}\right)^{1/2}$, is the effect attributable to capital accumulation.

$EC=\left(\frac{\bar{y}_b(k_c,e_c)}{\bar{y}_b(k_c,e_b)}\cdot\frac{\bar{y}_b(k_b,e_c)}{\bar{y}_b(k_b,e_b)}\right)^{1/2}$, is the effect attributable to changes in energy use.

To test for unconditional income convergence, we perform the following regression:

$$\hat{y}_{(i,t,t+\Delta t)}=\alpha+\beta\log(y_{(i,t)})+\varepsilon_{(i,t)} \quad (8)$$

Where $\hat{y}_{(i,t,t+\Delta t)}$ is economic growth during the period of interest $(t, t+\Delta t)$. Unconditional income convergence is observed if $\beta<0$.

To test for the contribution of growth component to income convergence, we perform the following regression:

$$\widehat{(GC)}_{(i,t,t+\Delta t)}=\gamma+\delta\log(y_{(i,t)})+\varepsilon_{(i,t)} \quad (9)$$

Where $\widehat{(GC)}_{(i,t,t+\Delta t)}$ is the growth component (EFF, TECH, FACH, KACC, and EC) over the period of interest $(t, t+\Delta t)$. We say the growth component is contributing to convergence (divergence) if $\delta<0$ $(\delta>0)$.

Results: We derive the decomposition components of economic growth for two periods of interest: the two decades characterized by the lack of income convergence (1980-2000) and the subsequent period (2000-2019), which exhibits unconditional income convergence as shown in recent studies (Kremer et al., 2022; Patel et al., 2021). Then, we analyze the contribution of economic growth components to the observed convergence or divergence for the two periods of interest mentioned. The results shown in Table 1 indicate that energy is the main driver of the observed convergence. The slope in column (6) for the 2000-2019 period is negative and statistically significant at the 1% level, unlike the earlier period.

Table 1: Regressions of GDP per capita growth and its decomposition indexes on the initial level of GDP per capita for the periods of 1980–2000 and 2000–2019
Conclusions:The beginning of the twenty-first century marks a new trend of income convergence as the new empirical evidence suggests. Results indicate that energy is the most critical contributor to the observed income convergence. Our analysis reveals the importance of energy for developing countries to catch up with the developed world. Acceleration of growth of developing countries entails a massive increase in their energy consumption per capita. Our journey to a decarbonized world should be more resilient to supply shocks that could negatively impact energy security and affordability. A sustainable and stable energy transition would require massive investments in diversified energy sources to fulfill energy demand affordably while overcoming climate change challenges. Global decarbonization efforts should consider the diverse income levels of economies and allow countries to develop their own path toward reducing emissions without compromising economic development, particularly for developing countries.
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Keywords: Economic Growth, Income Convergence, Energy Transition

AuthorToEditor: Please consider the word file for the review as it contains all equations and tables with the correct formatting.

[Abstract:0430] OP-112 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Economic Growth and Energy Demand]

Macroeconomic Determinants of Renewable Energy Consumption in Tanzania

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Overview:Energy is pivotal for global economic and human development, necessitating a shift towards sustainable alternatives due to the impacts of traditional energies. Recognizing the widespread availability, environmental friendliness, and affordability of renewable resources is crucial for achieving a resilient energy future. Sustainable Development Goal 7 underscores the significance of Renewable Energy Consumption for ensuring access to affordable, reliable, and modern energy. Global efforts target increasing the share of renewable energies in total energy consumption by 2030. In alignment with these global efforts, Tanzania has expressed its commitment to enhancing renewable energy usage through various government policies, regulations, and strategies. However, the current share of renewable energy consumption in the country is below 40%. While efforts to transition to clean energy have been ongoing, the critical research question pertains to the macroeconomic factors the country should focus on to achieve this goal. Existing studies provide valuable insights into Africa's renewable energy landscape but lack more in-depth, country-specific analyses.

This study aims to contribute to the existing body of knowledge by conducting a detailed analysis using Tanzania as a case study. Building on the literature, the research evaluates the short and long-term influence of economic growth, interest rates, trade openness, and foreign investment on renewable energy consumption.

Methods:Employing time-series data analysis techniques, the study uses the Augmented Dickey-Fuller and Zivot Andrews tests for unit root analysis, the Autoregressive Distributed Lag (ARDL) bounds test for short- and long-run relationships, and the Granger Causality test to unravel the direction of causality.

Results:In line with the Environmental Kuznet Curve (EKC), economic growth significantly influences renewable energy consumption negatively in the short run and positively in the long run. The effect of interest rates is positive in the short run and negative in the long run, following Keynesian theory. Trade openness fosters increased renewable energy consumption in the long run. Surprisingly, carbon dioxide emissions are found to decrease renewable energy consumption, emphasizing the need for further research on public awareness and preferences.

The study confirms the bi-directional causality between renewable energy consumption and economic growth, suggesting a feedback hypothesis.

Conclusions:The findings offer pertinent policy implications to boost renewable energy consumption and enhance energy security in Tanzania. The study advocates for sustained efforts to expand economic growth through increased trade and investments, fostering the availability, accessibility, acceptability, and affordability of renewable energy technologies. Additionally, addressing public unresponsiveness to environmental concerns calls for micro-level research on awareness and the design of targeted interventions to influence behavior positively.

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Keywords: renewable energy consumption, sustainable economic growth, environmental Kuznets curve, feedback hypothesis, autoregressive distributed lagged,error correction model

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[Abstract:0480] OP-113 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Resource Endowments and Economic Performance]

Definition and Analysis of Macroecomic Key Indicators for Technology Assessment in the Context of the Energy Transition

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Overview:In the current stage of the energy transition, socio-political resistances are becoming increasingly apparent, which have often not been foreseen by life cycle (costing) analyses, energy system optimization models or similar studies. The comprehensive transformation process can, for example, create new import dependencies or shift jobs towards new sectors, moving away from the fossil sectors, which has so far only been analysed on a system level (e.g. Lehr et al., 2012; O'Sullivan et al., 2018; Sievers et al., 2019). These and other macroeconomic effects, which can generate socio-political resistances, are intended to be identified and quantified on the technology level within the scope of this work. A set of four macroeconomic indicators for technology assessment are defined through a stakeholder process and subsequently quantified using state-of-the-art methods in an example case study. The indicators chosen for the macroeconomic technology assessment include employment, required qualifications, competitiveness, and criticality (import supply risk). Methodologically, the approaches rely on extended input-output calculations, the revealed comparative advantage method, and a weighted Herfindahl-Hirschmann approach. The case study for which the indicators are applied in this extended abstract is the comparison between individual electric vehicle (EV) ownership and car sharing with EV and the functional unit is kilometers driven.
Methods:The methodological section is divided into three subsections. Firstly, the identification of relevant indicators, secondly the definition of the scope of a case study and thirdly the methodological approaches to quantifying the indicators.
Identification: Through a collaborative process within the reseach project SoiTec (EnArgus, 2024) involving stakeholders from consumer protection organizations, industry associations, energy management consulting, politics and science, four key macroeconomic indicators for evaluating energy technology systems (case studies) were identified. The stakeholders emphasized a range of economic and non-economic factors during two workshops. These factors include for example material prosperity, economic efficiency and transparency. Stakeholders also highlighted the importance of ensuring the security and stability of the energy supply, addressing price stability, fostering economic growth and employment, and promoting industrial value addition. Additionally, considerations related to job creation, qualifications for employment, competitiveness, affordability, and combating energy poverty were deemed integral. The macroeconomic indicators, defined in consensus with the participants on the basis of the factors described and an extended literature research, include employment, required qualifications, competitiveness, and criticality (import supply risk).

Scope: To examine the effects of different technology options within the energy transition we define a technological system to be examined as the sum of its components that are essential for fulfilling its task, as predetermined by the functional unit. Through collaboration with stakeholders, three case studies were defined, each analyzing and comparing two technological systems based on the same functional unit. Once a technological system is identified, it undergoes decomposition into its individual components to the greatest extent possible. Utilizing a literature review, the techno-economic cost structure for each technology system relative to the functional unit is quantified. For this extended abstract, the chosen technology systems for comparison are "Individual Electric Vehicles (EV)" and "EV Car Sharing" and the corresponding functional unit is distance driven [km].

Quantifying the indicators: For every indicator, we conducted a thorough literature research to identify and expand state-of-the-art assessment methods which are described in the following subsection:

Employment:
Employing an input-output approach, we proceeded to calculate the sector-specific full time equivalents (FTE) for both case studies. As the case studies reference country is Germany the basis for this calculation is the german IO-table (Destatis, 2024). The different cost components of the case study are matched to their respective economic sectors (e.g. Li-Ion battery: electrical equipment, car-sharing-service: rental service) to create an industry output vector for each case study. The subsequent calculation uses the Leontief inverse to analyze the direct and indirect employment effects as outlined in the classic demand-style modelling literature (Breitschopf et al., 2012; Leontief, 1970; O'Sullivan et al., 2018).

Required Qualification:
For the Required Qualification indicator we rely on an IO-table extension approached as described in Ludwig and Brautzsch (2014) and Antoni et al. (2015). In this approach, each of the employment factors of each sector is divided into different skill levels or job descriptions depending on the data available. The composition of the required qualification is provided as a dimensionless result. The evaluation and the direction of a scale will take place at a future stakeholder workshop (May 2024). Unfortunately, the data available on German qualification matrices is scarce. For the calculation in this paper, we use the data from Ludwig and Brautzsch (2014), which was made available only at a highly aggregated level (low, medium and highly qualified workers).

Competitivness:
The theortical foundations for our assessment of competitive positions in international trade accross the different technological components are based on the work on determinants of competitiveness by Porter (1990). The determinants include input factor conditions, domestic demand conditions, related and supporting industries as well as corporate strategy, structure and competition. However, when it comes to technology and factor-specific measurements, the challenge becomes apparent as there is no data available. To address this challenge, we advocate for the application of an outcome-based indicator. A standard indicator to capture the outcome of the competitiveness factors and measure the revealed competitiveness directly is the Revealed Comparative Advantage (RCA) (Balassa, 1963; Beise, 2004; Hidalgo, 2021). The RCA is calculated independently for each component within the technology system, and aggregation is conducted with a weighting based on the cost shares of these components.

Criticality:
To determine the indicator for criticality (import supply risk) of the tradable technology components, we base our calculation on the European Commission's established method for assessing "Supply Disruption Probability" (European Commission, 2017). The criticality of a technology component is therefore determined using the Herfindahl-Hirschman Index (HHI), which assesses the market concentration of imports. In addition, each HHI value is weighted with the World Governance Index of the respective country of origin. The component-specific values are then aggregated using the cost-weighted approach analogous to the RCA method.
Results:The results presented here refer to the first case study. In some cases, the indicators show little to no difference, which is why further case study results are added for the conference presentation and in the full version of the paper to better understand the indicators (e.g. individual heat pumps vs. cold local heating networks or ground-mounted PV vs. wind power).
Figure 1 illustrates the Full-Time Equivalents (FTEs) required for driving 100,000 kilometers. Car sharing shows higher employment impacts due to its service model (Rental Services). This additionally creates also more impact within the indirect effects, which are not differentiated from the direct effects in this figure for clearity reason (see Figure 4 and 5 for the differences). Since the functional unit is defined as distance driven and the lifespan of a car is also primarily defined by its mileage, an anticipated reduction in vehicles is not reflected in this analysis, as the total number of cars produced remains constant in both cases.

Figure 2 shows the evaluation for the Required Qualifications indicator. The biggest differences are in the area of medium-skilled workers, which is due to the higher proportion in the rental service sector in the "car sharing" technology system. The differences in low and high skilled can be explained by the overall higher demand for FTEs for the "car sharing" technology system.

Figure 3 shows the RCA timeseries for all tradeable components for both case studies. As the tradable components and their cost structure are the same in both case studies for this indicator, the figure shows no differences. For the alternative case studies the differences will be clearly visible at this point. In the figure it becomes clear that Germany has an RCA above 1 in most categories, indicating above-average competitiveness in the respective technology components. The trend for the weighted average for the whole technology system is positive between 2019 and 2021.

For reasons of character limitation, we have refrained from presenting and describing the criticality indicator in this extended results section. The indicators are explained in detail in the conference presentation and in the full paper based on the various case studies.
Conclusions:This work defines and quantifies four macroeconmic key indicators which can be added to the instrumentarium of the multi-criteria technology assessment, which so far only takes into account costs from the microeconomic (LCC) perspective and indicators for measuring the impact on climate and environment (LCA). The main differences in the case study examined (Individual EV vs. Car-Sharing EV) lie in the provision of the car sharing service of the former case study, which has substantially higher direct and indirect employment effects.
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Keywords: renewable energy technologies, industrial policy, supply risk, competitiveness, technology assessment, macroeconomic

Figure 1: Full Time Equivalents (FTE) per Case Study

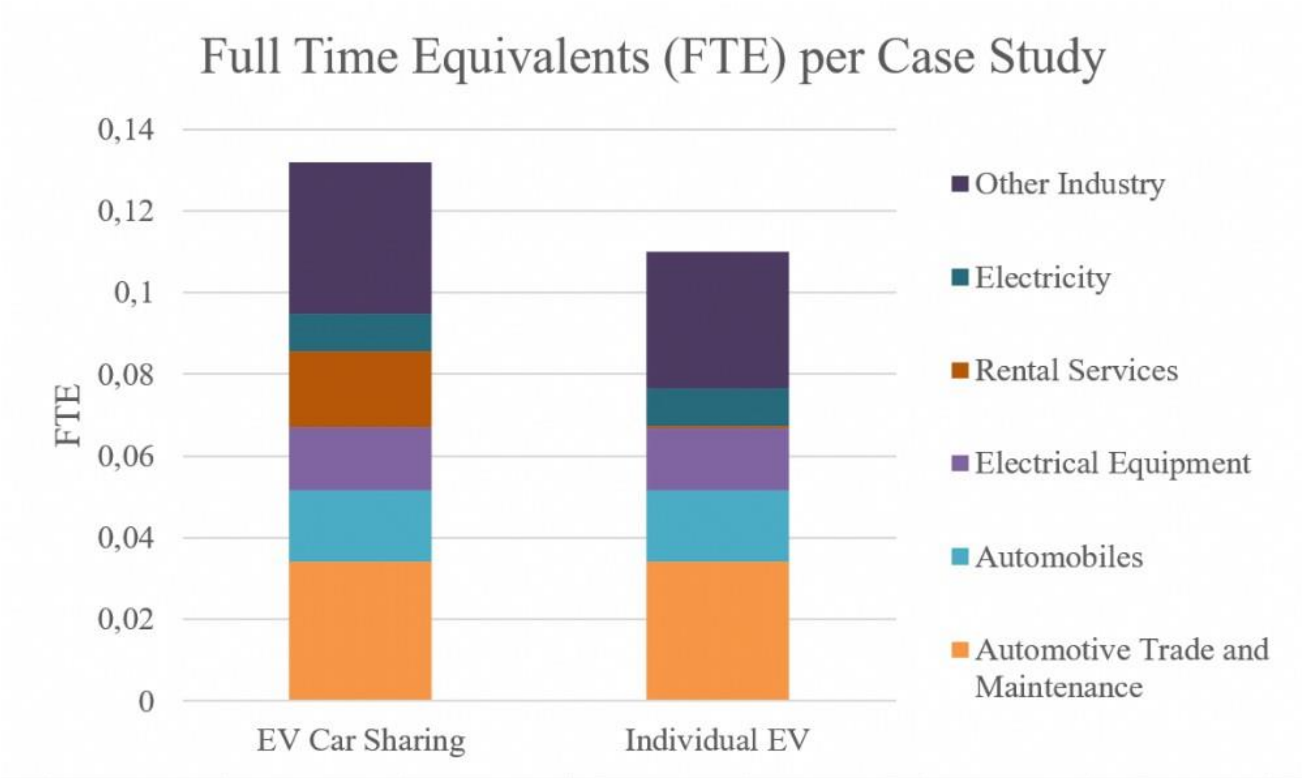

Figure 1 illustrates the Full-Time Equivalents (FTEs) required for driving 100,000 kilometers. Car sharing shows higher employment impacts due to its service model (Rental Services). This additionally creates also more impact within the indirect effects, which are not differentiated from the direct effects in this figure for clearity reason (see Figure 4 and 5 for the differences). Since the functional unit is defined as distance driven and the lifespan of a car is also primarily defined by its mileage, an anticipated reduction in vehicles is not reflected in this analysis, as the total number of cars produced remains constant in both cases.

Figure 2: Required Qualification in FTE per Case Study

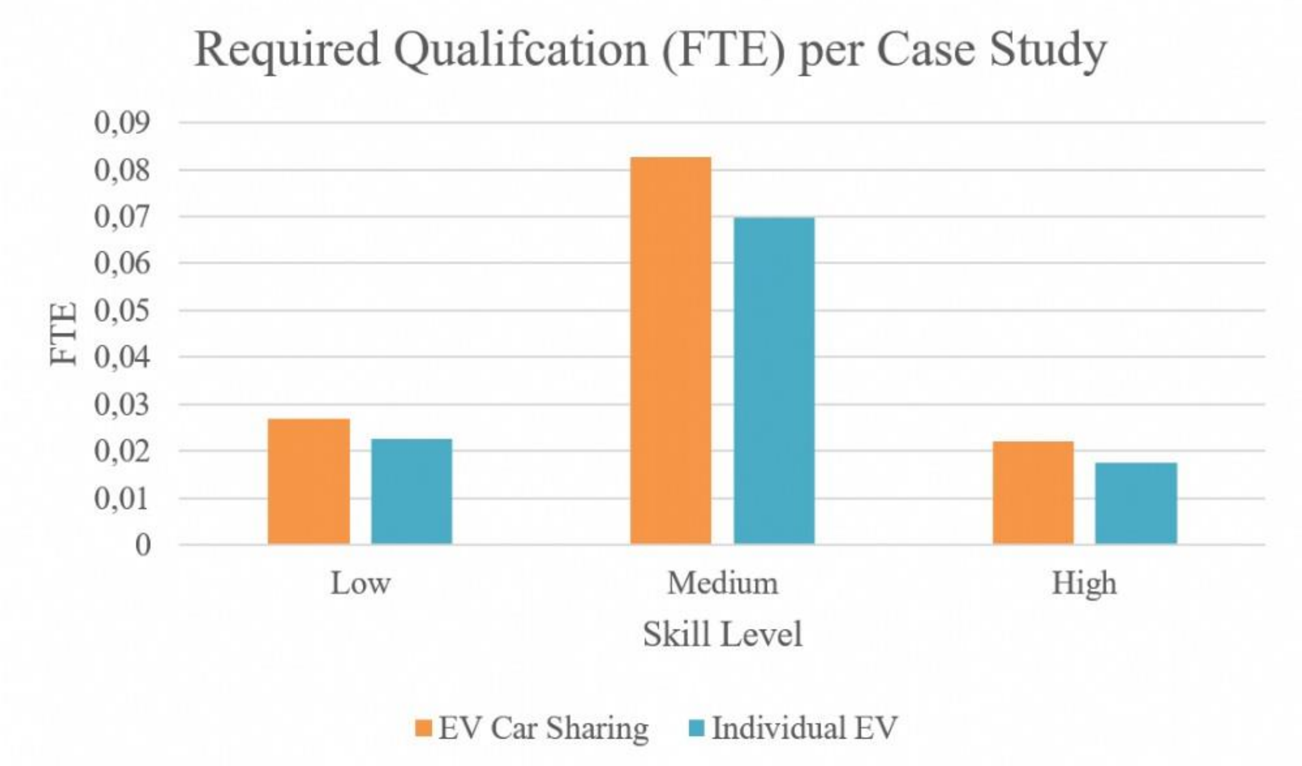

Figure 2 shows the evaluation for the Required Qualifications indicator. The biggest differences are in the area of medium-skilled workers, which is due to the higher proportion in the rental service sector in the "car sharing" technology system. The *differences in low and high skilled can be explained by the overall higher demand for FTEs for the "car sharing" technology system.*

Figure 3: Revealed Comparative Advantage for the technology system for Germany

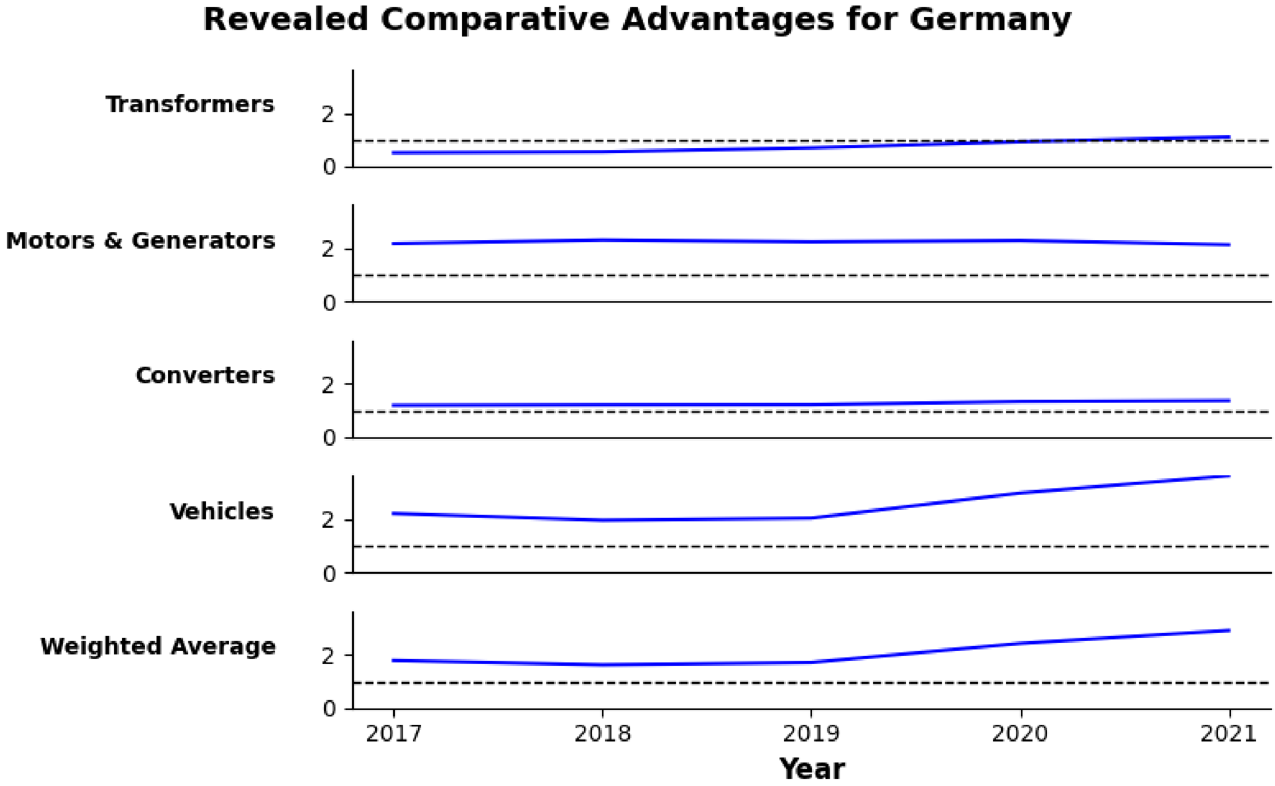

Figure 3 shows the RCA timeseries for all tradeable components for both case studies. As the tradable components and their cost structure are the same in both case studies for this indicator, the figure shows no differences. For the alternative case studies the differences will be clearly visible at this point. In the figure it becomes clear that Germany has an RCA above 1 in most categories, indicating above-average competitiveness in the respective technology components. The trend for the weighted average for the whole technology system is positive between 2019 and 2021.

Figure 4: Car Sharing Direct and Indirect Employment Effects

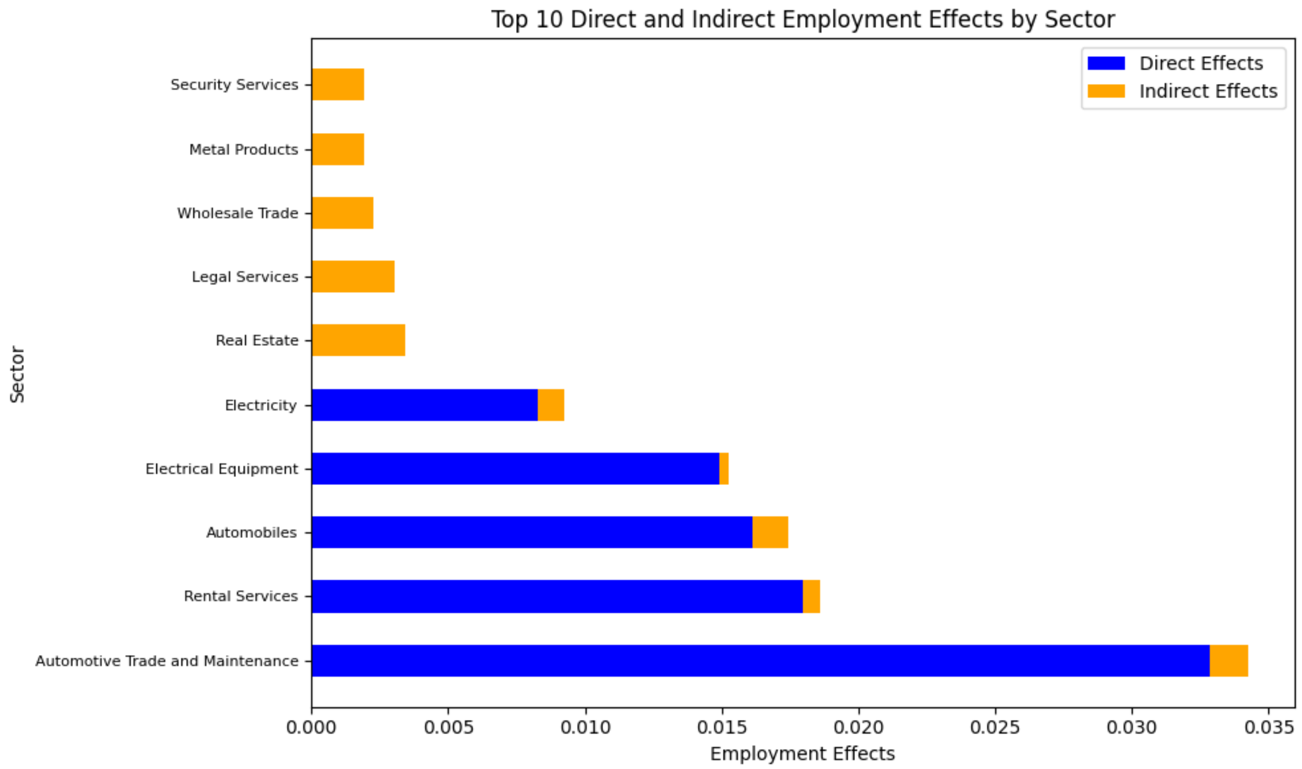

Figure 4 shows the employment effects in FTE differentiated after direct and indirect effects for the car sharing case study

Figure 5: Individual EV Direct and Indirect Employment Effects

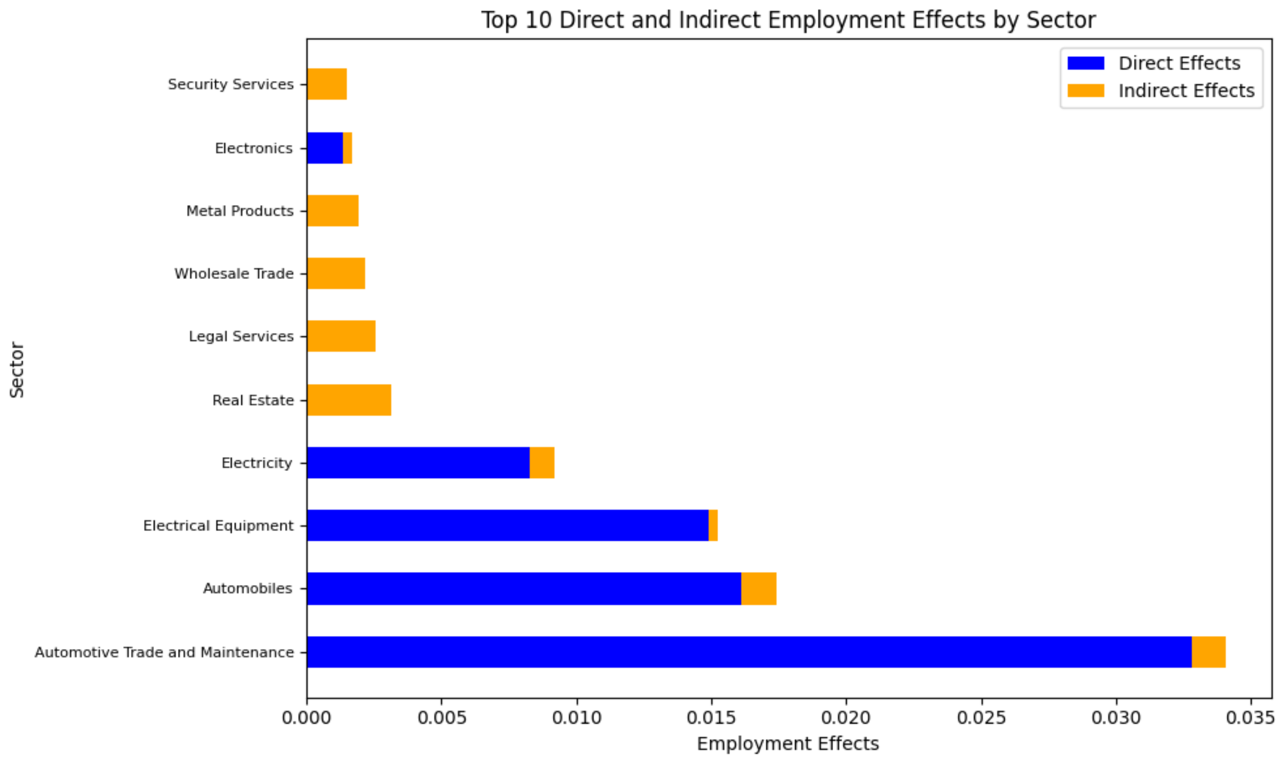

Figure 5 shows the employment effects in FTE differentiated after direct and indirect effects for the "Individual EV" case study.

[Abstract:0122] OP-114 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Other]

Jobs impacts of carbon tax - revenue recycling for jobs and growth

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Overview:The United Nations Climate Change Conference (COP28) closed with a statement signaling the “beginning of the end” of the fossil fuel era, a just and equitable transition, deep emissions cuts and scaled-up finance. Decarbonization and green transition more broadly are recognized as essential to green recovery and will inevitably be implemented, but governments struggle with the “how” and “when” and “how to pay for” policy questions. Often, the green transition is seen more as a challenge than an opportunity for development. Many issues of the transition seem unresolved, such as why developing countries should not be allowed to make the same mistakes as developed countries, why developing countries should switch to clean energy while developed countries have based their wealth on fossil fuels and how to manage jobs losses in sectors which will be losing relevance and business over the transition. One policy instrument to move to a low-carbon pathway is a carbon tax, which would disincentivize carbon-intensive activities, and the revenues generated could be recycled to finance climate actions. When climate actions – such as renewable energy investments and energy efficiency programs – are designed in a way that stimulates job creation, a double dividend can be achieved: lower emissions and more jobs. This contribution will assess a range of different policy designs around a carbon tax regime, and simulate the direct and indirect implications for jobs using a price endogenous MRIO hosted by the World Bank.
Methods:The Model of Innovation in Dynamic Low-Carbon Structural Economic and Employment Transformations, MINDSET, as a demand-driven global macroeconomic model with price-endogenous technology is employed for the simulations combines the strengths of Input Output (IO) analysis with responses to exogenous price changes. The IO approach yields short to midterm economic responses to exogenous demand changes, and accounts for all multiplier effects from intermediate demands along the value chains in a consistent framework. Connecting countries globally by bilateral trade extends the framework to capture trade effects from (intermediate and final) demand changes in one country on its trading partners, and their trading partners. Combining it with the Leontief price model allows for changes in the intermediate and final demands as a reaction to exogenous price changes. A global carbon price is administered and different uses for the use and recycling of tax revenues are simulated. Tax revenues can be added to the general budget, allocated to green or social purposes and can be used to lower other distortionary taxes and levies, for instance to lower payroll taxes.
Employment demand enters the picture via two channels. Investment yields additional demands and as a labor friendly angle to the 1.5C policy, payroll tax cuts make labor cheaper compared to other inputs and hence might yield a so-called double dividend of an evironmental tax reform, with the environmental (in this case climate change mitigating) dividend from reducing harmful externalities and the second dividend from positive labor effects
The model uses data MRIO data from the Global Resource Input-Output Assessment (GLORIA) database, a multi-regional input-output database that was built by the University of Sydney using the IELab infrastructure for the UN International Resource Panel (UN IRP).GLORIA has 164 regions, 120 sectors each, supply-use transactions T, final demand y, value added v in 5 valuations (basic prices, trade margins, transport margins, taxes on products, subsidies on products) and a continuous time series for 1990-2027. (Lenzen et al. 2017, Lenzen et al. 2022).
Results:If all countries applied a carbon tax of 80 USD/tCO2 and used the revenues to lower payroll taxes as discussed in the double dividend literature, employment globally would exceed the baseline

by a very marginal percent-age (lower than 1%) in 2030. This difference is the result of several different impacts, or drivers, exerting posi-tive and negative pressures on employment. Carbon prices make energy products more expensive and hence put downward pressure on energy demands. Households and industry, services and government try to substi-tute away from the higher priced goods, by changing production technologies, investing in efficiency, or switch-ing to less fuel consuming behavior, like bicycling or walking shorter distances. The global results mask the fact that there will be winners and losers, hence the results will be reported on a more granular level. The shift away from carbon intensive industries and processes leads to the largest negative impact on output and labor demand, followed by less investment in carbon intensive production technologies and households' demand changes. The collected revenue will be used to lower payroll taxes, also to incentivize to shift from carbon in-tensive to more labor-intensive production technologies, for instance to the use of waste materials instead of raw materials which need to be collected, cleaned etc. The results will be presented by different country groups, such as income groups, fossil fuel importers versus exporters, position relative to the demographic dividend and others.
Conclusions:The simulation results help countries to build expectations regarding job outcomes under different climate policy scenarios. First results show that the transition to a low carbon economy can be supported by tax incentives and benefit more and better jobs. Potential additional labor demand only translates into more and better jobs if the right skills are at the right place and the right time. Any caveats on spatial or skills mismatch also persist under a cli-mate friendly scenario. Moreover, depending on the revenue recycling scheme, the green transition will benefit female labor, but if not supported with additional measures, only in traditional jobs.
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Keywords: Global carbon tax, MRIO model, payroll tax reduction, jobs

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[Abstract:0157] OP-115 [Accepted:Oral Presentation] [Energy Finance and Trading » Market Instruments]

Clean Energy Market and Safe-haven Commodities: New Empirical Insights

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Overview:Considering advances in clean energy/sustainable investment and green equity holdings, we propose a sequence of methods for selection of appropriate safe-haven assets to mitigate the

risks of investment in clean energy and to enhance returns, especially in times of turbulence. Clean energy equity markets have emerged as viable alternative and sustainable investments to attract the attention of many investors (retail and institutional) and portfolio managers. However, this group of investments is not immune to downturn risks and extreme volatility or even contagion/spillover during time of crisis. Our aim is to propose a classification process for safe-haven assets. We use a methodology based on two nonlinear approaches to identify safe-haven commodity asset(s) for clean energy equity markets while investigating properties and ability of those candidate assets to protect the investor in clean energy markets against vulnerability, notably during crisis periods or when these markets experience a downturn that could harm their overall performance.

On the methodological front, related studies limit their focus only on the dependence structure between potential safe-haven candidates and clean energy equity indices, considering the homogeneous risk source for the latter (e.g., Bouri et al. (2019); Gustafsson et al. (2022)). This would mask any potential heterogeneity in the impact of the potential safe-haven assets on clean energy stocks. Unlike past studies, we propose a new maiden process to single out potential safe-haven asset(s) that allows a finer disaggregation of the risk sources to common and idiosyncratic factors affecting the clean energy market volatility. Therefore, we contribute to the empirical literature on clean energy equities' safe-haven assets in several aspects. Our work is related to a few studies (Bouri et al. (2019); Gustafsson et al. (2022)) that focused on the perspective of investors in clean energy equity markets who seek to identify potential safe-haven assets to protect their portfolios.

Methods:Our methodology proposes in a first step the analysis of the structure dependence between clean energy equity returns and potential safe haven candidates using the quantile-on-quantile regression (QQR) nonparametric approach. To identify the safe haven asset(s) among candidates in the second step, we apply tests based on a regime-switching framework, which allows the separation between common and idiosyncratic factors behind the increase of the clean energy stock volatility. We suggest that this in-depth analysis of nature of risk source is crucial, as it would help uncover potential heterogeneity in safe haven properties of energy and metals assets against the clean energy market turmoil. This is equally crucial for the hedging strategies of an equity investor who could be exposed to both common and idiosyncratic shocks when she takes a long position in a safe-haven asset. Furthermore, in contrast to previous works, we employ our empirical results based on the separation of idiosyncratic risk from common risk to explore the hedging effectiveness of safe-haven asset candidates for clean energy stock portfolios. To the best of our knowledge, this latter modeling framework allowing the desegregation of sources of shocks has never been employed to compute the hedging-effectiveness indices.

Results:In principle, the satisfactorily staged methods will suffice to ascertain whether all selected possible alternative assets or individual commodity assets are a better safe haven, notably during crisis periods. On the one hand, the QQR results show a nonlinear connection between our selected safe-haven candidates and the clean energy stock returns during their lowest quantiles, indicating the potential safe-haven properties.

Results show that mean returns in low-volatility regimes are positive and statistically significant in all cases, and that mean returns in high-volatility regimes decrease or tend to be negative for all pairs, except for the ETHANOL returns. In addition, they are statistically significant, except for GOLD regardless of the used measure.

Furthermore, we compare the above results of hedging effectiveness of our candidates in bear regime of clean energy asset to their hedging effectiveness results following a dynamic hedging strategy. In this subsection, we calculate the hedging effectiveness for each candidate but this time we are using a time-varying hedge ratio (Baillie & Myers (1991)). Then for comparison, we calculate hedging effectiveness measure by estimating the out-of-sample hedging ratios using rolling window analysis. The whole sample is subdivided into the in-sample sub-period starting from November 24, 2003 and ending at October 31, 2017. Whereas, the out-of-sample sub-period is set from November 1, 2017 to August 20, 2020.

Generally, comparing in-sample and both out-of-sample, results show identical performance of safe haven candidates. On the one hand, the results reveal that commodity indexes and PLATINUM provide the highest diversification benefits for the clean energy equity notably using out-of-sample data that corresponds to COVID-19 period. Yet, they can further reduce the variance in hedged portfolio returns by almost 75% and 35%, respectively. In contrast to COMMODITY INDEX, result of PLATINUM is confirmed according to our earlier finding about specific hedging effectiveness during only turmoil regime of clean energy market.

Our results are robust in the face of various clean energy proxies as well as use of different roll methods for selected commodity futures. In addition to providing new empirical insights, we show the hedging property of gold as a safe-haven asset. Platinum also shows to be an effective hedge for clean energy equity market turbulence, but against common risk and not idiosyncratic shocks. On the other hand, for robustness, we used various clean energy proxies as well as the most recent crisis caused by the COVID-19 pandemic. Some of our results are qualitatively similar, and the major

observations were maintained with a few exceptions such as the substitution effect, which suggests including silver instead of gold.
Conclusions:Movements of commodities such as crude oil, gold, and the major equity market are widely presented in daily news. Based on the behavior of those various assets, to support hedging strategies the need for safe-haven assets was widely acknowledged recently, as investors have been advised to identify and consider potential effects and relations of those assets with existing positions in clean energy funds and many sustainable portfolios.
The QQR results show a nonlinear but no absolute negative connection between our candidates and clean energy stocks. Our in-depth analyze using Markov switching tests and portfolio hedging effectiveness, reveals the safe haven properties of metal assets. The GOLD emerges to be the best safe haven asset against the idiosyncratic clean energy equity shock, while PLATINUM could be the best safe haven asset against the common shock.
This study has some practical and policy implications as portfolio managers and institutional investors attempt to build their own sustainable and clean energy mutual fund or exchange-traded fund (ETF) tailored to the needs of different clienteles. The study documents the need for an effective methodology and process to properly classify and capture the properties of safe-haven assets to enhance returns and shield the overall performance, especially in times of turbulence. It would be beneficial for future research to address the role of commodity assets in hedging the clean energy equity risks during crisis episodes by including the role and effect of market participants such as speculators, which could hinder and potentially limit the hedging possibilities for clean energy investors.
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Keywords: Clean energy equity market, Commodity futures, Safe haven, Sustainable investment, Pandemic crisis, COVID-19 market conditions

AuthorToEditor: Dear Prof. and chair of the scientific committee The order of the authors of the paper: W. Khallouli and K. Smimou, Yes, K. Smimou (the second author--contact author) will be the presenter. The submission system does not allow me to be the second author (contact author) and the presenter... I will really appreciate if you can change the order of the authors as indicated above here. I will still be the contact person and presenter. Best regards, K. Smimou, Ph.D.

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[Abstract:0239] OP-116 [Accepted:Oral Presentation] [Energy Finance and Trading » Market Instruments]

Thriving on uncertainty: strategic interaction and long-term supplier contracts in oligopolistic settings

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Overview:Power Purchase Agreements, often abbreviated as PPAs, are long-term contracts established between an electricity generator and a buyer. Utilities have been the traditional signatories of these contracts, but they are now increasingly popular among electricity-intensive industries and corporations. The primary purpose of a PPA is to lock in a negotiated price for electricity, providing stability and predictability in a volatile energy market.

Currently, some companies within specific industries opt to sign a PPA with a supplier, while many others have not yet done so. The decision to enter into a long-term agreement with an electricity supplier is a strategic process involving a range of complex factors. Companies evaluate the costs associated with procuring energy through a PPA compared to acquiring it from the spot market, where both renewable and non-renewable sources are available. Financial considerations play a crucial role. Firms must assess the long-term financial advantages, including stable energy prices and risk mitigation against market fluctuations. Simultaneously, environmental responsibility may significantly influence their decision, as adopting PPAs can enhance a company's reputation and foster positive stakeholder relationships, especially in sectors where sustainability is a key differentiating element.

In addition to financial considerations and environmental responsibility, in industries characterized by oligopolies, where electricity expenses make up a substantial portion of their variable operating or production costs, whether to enter a PPA becomes strategic. These companies regularly encounter challenges associated with energy price volatility, which injects uncertainty into their operations and profit margins. Yet, the impact of committing to a long-term contract with their electricity supplier is more nuanced. When electricity prices rise, having a PPA can provide a competitive advantage over competitors with no long-term contract secured. This advantage arises from the stability of energy costs, enabling these companies to operate with more predictable and steady profit margins, thus bolstering their competitiveness. However, during periods of low electricity prices, companies with PPAs may experience higher energy costs than competitors without long-term contracts. This situation presents challenges as their competitors can capitalize on lower production costs, potentially affecting their market position.

The market for PPAs is evolving, and academic research has delved into the economic and political implications of the PPAs. In particular, several authors have explored the role of long-term contracts in scenarios where competing companies grapple with significant variable costs (Allaz and Vila 1993; Cohen and Agrawal 1999; van Eijkel and Moraga-González 2010; Sun and Xiang 2011; Ledvina and Sircar 2012; Teixeira 2014). More recently, Fabra (2023) analyzed the role of PPAs in the European Commission's proposal to reform electricity markets.

We contribute with a game-theoretic analysis of the strategic interaction among firms that belong to an electricity-intensive oligopoly regarding the decision of whether to sign a long-term contract with electricity suppliers at a fair price. In this context, we analyze the equilibrium outcomes for different numbers of competing firms.

Our results show that, under certain assumptions, in an oligopoly composed of n risk-neutral or moderately risk-averse firms, no more than half of the competing firms sign a PPA in equilibrium. This outcome may seem paradoxical, as a risk-neutral agent is, in principle, indifferent between buying insurance at a fair price or not. However, the strategic interaction between rival firms makes most of them thrive in an uncertain cost environment. This result points to a possible strategic reason why some companies in electricity-intensive sectors have not signed a PPA to hedge their operational costs. Given the regulator's current willingness to implement these agreements (European Commission 2023), our results may have relevant policy implications.

Methods:We examine how strategic interaction modulates the positive convexity effect of electricity price uncertainty. Even though we consider firms that are symmetric ex-ante, we present the Cournot solution with asymmetric costs, which allows us to consider the case where one of the firms has a long-term contract with a given cost, whereas the other, is subject to the uncertain spot market prices for electricity (X). We model this spot price as a stochastic process. In each period t, the random variable X is described by a cumulative distribution function F(x). Production costs are assumed to be linear.

Firms can sign a contract with a supplier that guarantees a fixed unit cost c for T periods. We assume this contract is priced at the expected electricity price in the spot market. Therefore, the fixed value c is such that the net present value (NPV) at t=0 of the stream of expected costs in the spot market over a horizon of T periods is equal to the NPV of a constant stream of cost c.

To focus on cost uncertainty, market demand p(q) is assumed to be deterministic and constant over time, and we present the case of a linear demand p(q)=a-bq, with a>0 and b>0. We assume that the support of the distribution of X is a subset of [0, a) and that the firms are risk-neutral.

Assume that in a market with n symmetric firms, a subset of ns firms (0 ≤ ns ≤ n) is committed to a long-term contract with suppliers, while the remaining n-ns firms must decide whether to purchase the electricity in the spot market or to sign a long-term agreement with the supplier. We compute the solutions for each firm's optimization problem and solve all subgames depending on whether firms have signed a long-term contract.

Results:In this section, we briefly outline the main results of our study for different numbers of competing firms.

Monopoly (n=1): A risk-neutral, or moderately risk-averse, monopolist strictly prefers not to sign a long-term contract. Usually, a risk-neutral agent would be indifferent between buying insurance at a fair price or not buying. However, in the case of a risk-neutral monopolist, the objective function is

convex in the cost parameter, and therefore, the monopolist benefits from cost variability. *Duopoly (n=2)*: If the rival firm signs a long-term contract, not signing a contract is the best response. If the rival firm does not sign a contract, then, depending on the distribution of X, there either are one or three Nash equilibria; if cost uncertainty cannot drive any of the firms out of the market, there are three equilibria: only one firm signs a long-term contract, or none does. In contrast, when cost uncertainty may drive any of the firms out of the market, not signing a contract is a dominant strategy for any of the firms.
Oligopoly (n>2): There is an equilibrium in which ns firms (where $0 \leq ns \leq n/2$) sign and n-ns firms do not sign the long-term agreement. Under conditions for the distribution F, there are multiple equilibria with fewer signatories than ns. Multiple equilibria appear when the ns firms are indifferent between signing the agreement or not.
Conclusions:We present a game-theoretic analysis of the strategic interactions among firms in an electricity-intensive oligopoly when deciding whether to enter into long-term contracts with electricity suppliers (i.e., PPAs). Within this framework, we examine the equilibrium outcomes for varying numbers of competing firms and establish equilibrium conditions for each scenario. Our findings reveal that subject to specific assumptions, in an oligopoly consisting of either risk-neutral or moderately risk-averse firms, the equilibrium outcome involves no more than half of the competing firms opting to sign a long-term electricity contract. This outcome might appear paradoxical, as risk-neutral entities should, in theory, be indifferent between buying insurance at a fair price or not. However, the strategic rivalry among firms causes them to thrive in an environment characterized by uncertain costs for most of the firms. This observation may mirror the existing situation in certain industries, where some companies have refrained from adopting PPAs to hedge their operational expenses. Given the regulator's current push for the implementation of these agreements, our results could have significant policy implications.
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Keywords: PPA, Cost uncertainty, Oligopoly, Strategic interaction, Power Purchase Agreement

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Sustainability disclosure: An opportunity or a challenge for corporate market and financial performance?

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Overview:Continued effort to address climate change increases the demand for businesses to disclose their environmental, social, and governance practices. It is not well-understood if, and under what conditions, such disclosure will meaningfully enable or constrain corporate performance. To help address this issue, we apply fixed effects models to a large sample of 4,943 Chinese firms over the 2011-2021 period. We find that sustainability disclosure improves corporate market value and lower financial performance at the same time, especially when accounting for the growth opportunity and capital structure of firms. We also provide evidence that the negative impact observed on financial performance could be reversed depending on how stakeholder value, innovation compensation, and diminishing returns to assets are differentiated. We show that differences in these aspects lead to disproportionate and adverse effects of disclosure in some industries, which undermines its relevance and contribution as a factor that enhances value. Our findings shed light on the complex relationship between sustainability disclosure and corporate performance, and underscore the importance of rules for disclosure that can promote active engagement in innovation activities, incentivize growth opportunities for small firms, and support the unbundling of large corporations.
Methods:We test our research hypotheses using a dataset comprising information on A-share companies in the world's largest developing country, China, from the period 2011 to 2021. We use two main data sources for the construction of our dataset. First, to avoid selection bias, we initially selected all A-share firms in the Wind Economic Database (Wind EDB) for which firm-level information is largely available on financial performance, sustainability disclosure, and other control variables used in our econometric specification. Wind EDB has become the benchmark for economic analysis on China. Second, for each firm selected from Wind EDB, we obtain market indicator from China Stock Market & Accounting Research (CSMAR) database, a comprehensive financial and economic research-oriented database. When we process these data and remove firms that have been given special treatment due to losses suffered for two consecutive years as well as firms warned of risk of being delisted after three consecutive years of operating losses, we are left with an unbalanced sample of 54373 observations from 4943 firms, which we use for our econometric estimation. We provide details on the measurement of key variables below.
Results:Our results follow through four stages. First, we test the impact of sustainability disclosure as a single indicator in corporate market and financial performance. We show these results in Table 6, where the first three columns represent impacts on financial performance while the last three columns demonstrate impacts on market performance. Columns 1 and 4 present results without control variables included; columns 2 and 5 show results with only the main control variables included, such as growth prospects, financial leverage, firm size, and industry type; and columns 3 and 6 are results with all control variables, including cash flow, equity concentration, interest coverage, and the main control variables. It can be seen from Table 6 that after controlling for all considered variables that may significantly affect corporate performance, including industry type, there is no statistically significant relationship between disclosure and corporate market performance. However, a negative and statistically significant relationship can be seen between disclosure and corporate financial performance. The benefits of controlling for the industry type and other variables can be seen from the significance of the associated coefficients as well as the improvement in the R-squared value. We attribute the insignificant market impacts to the fact that more disclosure reduces a firm's information asymmetries with stakeholders and increases its risks perception at the same time, which neutralizes the benefits of disclosure. On the other hand, the decline in financial performance relates to inherent compliance cost associated with enterprise attempt to develop new resources that can facilitate disclosure. This empirical evidence confirms our first hypothesis and has basis in the neoclassical economics theory on environmental protection, otherwise known as the theory of compliance cost.
Conclusions:The results of our study confirm that the impact of sustainability disclosure on corporate performance has at least three components; a direct insignificant component, an indirect positive component, and a direct and indirect negative component. As one of the main theoretical contributions of our paper, our findings suggest that sustainability disclosure should improve corporate market value and lower financial performance at the same time, especially when accounting for the growth opportunity and capital structure of firms. We also provide evidence that the negative impact observed on financial performance could be reversed depending on how stakeholder value, innovation compensation, and diminishing returns to assets are differentiated. We show that differences in these aspects lead to disproportionate and adverse effects of disclosure in some industries, which undermines its relevance and contribution as a factor that enhances value.
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Keywords: sustainability disclosure,market performance, financial performance,growth prospects,capital structure

Table 1.ESG rating in the Wind Economic Database (Wind EDB)

Table 1: ESG rating in the Wind Economic Database (Wind EDB)

Wind EDB rating	Author assignment
AAA	9
AA	8
A	7
BBB	6
BB	5
B	4
CCC	3
CC	2
C	1

Table 2: Industry classification of sample firms

Table 2: Industry classification of sample firms

Industry type	Author assignment	Model representation
Mining	1	ind_Min
Electricity, heat, gas and water production and supply industry	2	ind_EHGS
Real estate industry	3	ind_Rei
Construction	4	ind_Con
Transportation, storage and postal services	5	ind_TSP
Education	6	ind_Edu
Finance	7	ind_Fin
Scientific research and technical services	8	ind_ST
Agriculture, forestry, animal husbandry and fishery	9	ind_AF
Wholesale and retail trade	10	ind_WR
Water, environment and public facilities management	11	ind_WEP
Health and social work	12	ind_HS
Culture, Sports and Entertainment	13	ind_CSE
Information transmission, software and information technology services	14	ind_IS
Manufacturing	15	ind_Man
Accommodation and Catering	16	ind_AC
Integrated activities [a]	17	ind_com
Leasing and business services	18	ind_LB
Residential services, repair and other services	19	ind_RR

[a] Comprises listed firms that are neither financial nor nonfinancial, which usually operate a variety of businesses including but not limited to manufacturing, trading, and services.

Table 3: Description statistics of included variables

Table 3: Description statistics of included variables

Variable	Mean	SD	Min	Median	Max
ROA	6.572	20.635	-2164.591	5.627	2078.764
TobinQ	2.199	7.012	0.641	1.586	729.629
ESGscore	4.133	1.138	1.000	4.000	8.000
Pricetobook	3.009	581.399	-1.01e+05	2.858	21788.023
Lev	44.138	88.026	-19.470	41.919	17834.547
lnSize	21.639	1.750	13.239	21.488	31.191
ind	10.000	5.619	1.000	10.000	19.000
lnFlow	19.536	1.857	9.705	19.512	28.312
Top1	37.077	17.556	0.290	34.240	100.000
Ebitdatoint	101.967	2216.732	-1.64e+04	7.504	1.91e+05

Table 4: Correlation matrix for equation (1)

Table 4: Correlation matrix for equation (1)

	ESGscore	Pricetobook	Lev	lnSize	lnind	lnFlow	Top1	Ebitdatoint
ESGscore	1							
Pricetobook	-0.019*	1						
Lev	-0.037*	0.006	1					
lnSize	0.279*	-0.025*	0.008	1				
ind	-0.069*	0.005	-0.026*	-0.336*	1			
lnFlow	0.312*	-0.029*	-0.016*	0.856*	-0.267*	1		
Top1	0.110*	-0.009	0.013*	0.244*	-0.197*	0.219*	1	
Ebitdatoint	0.035*	-0.001	-0.008	-0.003	0.011*	0.014*	0.018*	1

Table 5: VIF for equations (1) and (2)

Table 5: VIF for equations (1) and (2)

	(1)	(1)	(2)	(2)
	ROA	ROA	TobinQ	TobinQ
Variable	VIF	1/VIF	VIF	1/VIF
ESGscore	1.110	0.898	1.120	0.889
Pricetobook	1	0.999	1	0.999
Lev	1	0.996	1	0.996
lnSize	3.960	0.253	4.070	0.246
ind	1.150	0.870	1.150	0.867
lnFlow	3.840	0.260	3.940	0.254
Top1	1.080	0.923	1.100	0.909
Ebitdatoint	1	0.997	1	0.998
Mean	**VIF**	**1.770**	**VIF**	**1.800**

Table 6: Sustainability disclosure and corporate performance

Table 6: Sustainability disclosure and corporate performance

VARIABLES	(1) ROA	(2) ROA	(3) ROA	(4) TobinQ	(5) TobinQ	(6) TobinQ
ESGscore	-0.160	-0.786***	-0.777***	-0.313***	-0.009	-0.008
	(-0.397)	(-2.554)	(-2.631)	(-5.714)	(-0.166)	(-0.169)
Pricetobook		-0.001***	-0.001***		0.001***	0.001***
		(-2.633)	(-2.653)		(14.715)	(14.885)
Lev		-0.061***	-0.054***		0.007***	0.006***
		(-101.110)	(-104.280)		(71.414)	(71.512)
lnSize		-0.774***	-0.771***		-1.104***	-1.107***
		(-3.644)	(-3.614)		(-31.47)	(-31.247)
ind		-0.031*	-0.030*		0.021**	0.019**
		(-0.556)	(-0.546)		(2.142)	(2.130)
lnFlow			2.279***			0.055***
			(18.224)			(2.615)
Top1			0.075***			-0.007***
			(6.293)			(-3.456)
Ebitdatoint			0.000***			-0.000
			(4.614)			(-0.820)
R-squared	0.190	0.482	0.552	0.471	0.601	0.654
Adjusted R-squared	0.036	0.316	0.467	0.377	0.417	0.592
Time Fixed effects	YES	YES	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES	YES	YES

Note: Values in parentheses represent t-statistics, *** p<0.01, ** p<0.05, * p<0.1

Table 7: Interaction of disclosure, growth opportunities, and financial leverage

Table 7: Interaction of disclosure, growth opportunities, and financial leverage

VARIABLES	(1) ROA	(2) TobinQ	(3) ROA	(4) TobinQ
ESGscore*Pricetobook	-0.0003*	0.0003***		
	(-1.787)	(9.636)		
ESGscore*Lev			-0.0565***	0.0059***
			(-99.567)	(63.700)
Control variables	YES	YES	YES	YES
R-squared	0.5558	0.6525	0.5439	0.649
Adjusted R-squared	0.4714	0.5906	0.4573	0.587
Time Fixed effects	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES

Note: Values in parentheses represent t-statistics, *** p<0.01, ** p<0.05, * p<0.1

Table 8: Enterprise heterogeneity and corporate performance

Table 8: Enterprise heterogeneity and corporate performance

VARIABLES	(1) ROA	(2) ROA	(3) TobinQ	(4) TobinQ	(5) ROA	(6) ROA	(7) ROA	(8) TobinQ	(9) TobinQ	(10) TobinQ
ESGscore*Man	0.8625***		0.0311							
	(2.707)		(0.584)							
ESGscore*NonMan		-2.2852***		-0.0567						
		(-5.294)		(-0.7894)						
ESGscore*large					-0.1155			0.0188		
					(-0.410)			(0.3945)		
ESGscore*medium						0.4990*			0.0017	
						(1.8133)			(0.0359)	
ESGscore*small							0.2418			-0.0021
							(1.4172)			(-0.0709)
R-squared	0.5558	0.5460	0.6535	0.6531	0.5555	0.5505	0.5520	0.6535	0.6537	0.6536
Adjusted R-squared	0.4713	0.4597	0.5919	0.5913	0.4710	0.4651	0.4668	0.5918	0.5921	0.5920
Control	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time Fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Values in parentheses represent t-statistics, *** p<0.01, ** p<0.05, * p<0.1

Table 9: Heterogeneous industries and sustainability disclosure

Table 9: Heterogeneous industries and sustainability disclosure

Industry	Disclosure-Industry interaction	Coefficient	control	Time Fixed effects	Individual Fixed effects	Adjusted R-squared
Mining	ESGscoreind_Min	-1.577** (-2.47)	YES	YES	YES	0.471
Electricity, heat, gas and water production and supply industry	ESGscoreind_EHGS	0.499 (0.89)	YES	YES	YES	0.472
Real estate industry	ESGscoreind_Rei	-0.330 (-0.81)	YES	YES	YES	0.471
Construction	ESGscoreind_Con	0.084 (0.14)	YES	YES	YES	0.471
Transportation, storage and postal services	ESGscoreind_TSP	0.125 (0.13)	YES	YES	YES	0.471
Education	ESGscoreind_Edu	-6.192** (-2.36)	YES	YES	YES	0.471
Finance	ESGscoreind_Fin	-1.084** (-2.07)	YES	YES	YES	0.471
Scientific research and technical services	ESGscoreind_ST	0.104 (0.08)	YES	YES	YES	0.471
Agriculture, forestry, animal husbandry and fishery	ESGscoreind_AF	-1.124 (-1.05)	YES	YES	YES	0.471
Wholesale and retail trade	ESGscoreind_WR	-0.026 (-0.06)	YES	YES	YES	0.471
Water, environment and public facilities management	ESGscoreind_WEP	-0.730** (-1.29)	YES	YES	YES	0.471
Health and social work	ESGscoreind_HS	-2.533 (-1.36)	YES	YES	YES	0.471
Culture, Sports and Entertainment	ESGscoreind_CSE	-2.663** (-2.51)	YES	YES	YES	0.471
Information transmission, software and information technology services	ESGscoreind_IS	-1.090** (-2.18)	YES	YES	YES	0.471
Manufacturing	ESGscoreind_Man	0.251 (0.94)	YES	YES	YES	0.472
Accommodation and Catering	ESGscoreind_AC	-0.689 (-0.41)	YES	YES	YES	0.471
Integrated activities [a]	ESGscoreind_com	-0.963 (-1.12)	YES	YES	YES	0.471
Leasing and business services	ESGscoreind_LB	-4.092*** (-5.17)	YES	YES	YES	0.471
Residential services, repair and other services	ESGscoreind_RR	-	YES	YES	YES	0.471

[a] Comprises listed firms that are neither financial nor nonfinancial, which usually operate a variety of businesses; Note: Values in parentheses represent t-statistics, *** p<0.01, ** p<0.05, * p<0.1

Table A1: Hausman specification test

Appendix

Table A1: Hausman specification test

	(1) ROA	(2) TobinQ
Variable	FE	FE
ESGscore	0.735***	-0.064***
	(0.059)	(0.014)
Pricetobook	-0.001**	0.001***
	(0.000)	(0.000)
Lev	-0.054***	0.006***
	(0.000)	(0.000)
lnSize	-1.450***	-0.671***
	(0.097)	(0.023)
ind	0.303***	-0.005
	(0.108)	(0.033)
lnFlow	1.874***	0.072***
	(0.085)	(0.019)
Top1	0.054***	-0.009***
	(0.005)	(0.001)
Ebitdatoint	0.001***	0.000
	(0.000)	(0.000)
Constant	-4.940***	15.803***
	(1.323)	(0.363)
Chi-square	136.8	241.2
p-value	0	0

Note: Values in parentheses represent t-statistics, *** p<0.01, ** p<0.05, * p<0.1

[Abstract:0129] OP-118 [Accepted:Oral Presentation] [Energy Finance and Trading » Corporate Strategy and Investor Oversight]

Energy transition and non-energy firms' financial performance: Do markets value capability-based energy transition strategies?

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Overview:Energy transition has become a major challenge that will shape the global agenda in the coming decades. In addition to governments and major energy firms, non-energy firms also play a significant role in the energy transition with their growing share in renewable energy supply and other pro-environmental investments. Using the Resource-based View and Dynamic Capabilities perspectives, we discuss non-energy firms' capability-based energy transition strategies and explore the channels through which these strategies affect their financial performance. We test our

hypotheses using S&P 500 firms' data and show that capability-based energy transition strategies have a positive moderating effect on the relationship between renewable energy sector performance and non-energy firms' financial performance in the short term. Furthermore, these strategies have a positive moderating effect on the relationship between fossil fuel prices and non-energy firms' financial performance in the long term. Our findings indicate that capability-based energy transition strategies created a virtuous investment-return opportunity for non-energy firms between 2009 and 2021.
Methods:Our empirical analysis starts with machine-learning methods to understand the associations between the variables of interest and firms' financial performance. These methods are preferred to understand temporal dynamics, reveal hidden associations, and provide an outline of the empirical setting before engaging in any detailed analysis. We use unsupervised clustering methods to calculate the similarity/dissimilarity between cumulative idiosyncratic excess returns and categorize the series based on their dissimilarity. In the second stage, we analyze the temporal dynamics between the variables of interest and explore whether there are major points of structural change using time-varying Granger causality analysis. Finally, we use panel data methods to analyze statistical associations at the firm level.
Results:Our results indicate that energy transition capabilities positively impact non-energy firms' financial performance through renewable industry and stock valuation channels. Moreover, we demonstrate that energy transition capabilities created a virtuous investment cycle between financial performance and energy transition capabilities from 2009 to 2021. Firms with higher energy transition capabilities had higher returns than those with lower energy transition capabilities when the moderating effects are taken into account. In this regard, our findings support the expanding literature on sustainability and decarbonization strategies that suggest that pro-environmental investments can enhance firms' performance.
Conclusions:The first contribution of this paper is categorizing energy transition strategies into market-based energy transition strategies and capability-based energy transition strategies, and evaluating the channels through which capability-based strategies can affect financial performance. While the literature uses energy transition with clean/green energy use interchangeably, it overlooks the heterogeneity in firm strategies that can lead to the same outcome in terms of green energy use or decarbonization. Firms can use markets, in-house capabilities, or hybrid strategies to reduce their greenhouse gas emissions or increase renewable energy use; however, the implications of different strategies on firms' financial performance should differ because of the different investment requirements of each strategy. The Resource-based View and Dynamic Capabilities perspective argue that firms' investment in resources and capabilities will create a competitive advantage over their peers. Based on this premise, we rank firms with respect to their energy transition capabilities, which helps us shed light on the relationship between energy transition and firms' financial performance.

The second contribution is showing the moderating effects of energy transition capabilities on the relationship between fossil fuel returns, renewable energy sector returns, and non-energy firms' financial performance. Earlier studies argue that high oil prices make renewable energy technologies riskier; therefore, firms with higher green innovation would face higher risk premiums. However, our findings indicate that fossil fuel returns have had a positive effect on firms' financial performance with higher energy transition capabilities. This discrepancy can be explained by differences in the metrics used in the analysis. Many studies use only green innovation or fixed investments as indicators of pro-environmental investment; however, these are only a part of energy transition capabilities. As highlighted earlier, energy transition capabilities should be taken as a broader measure rather than a single specific measure because using one measure will not cover the other aspects of energy transition (innovation, physical investments, human capital, or managerial practices) properly.

The third contribution is showing the different temporal effects of energy transition capabilities with respect to the transmission channels. We observe a positive moderating effect of energy transition capabilities on the relationship between the renewable energy industry and firms' financial performance when we use daily returns. However, this effect is replaced by a positive moderating effect between fossil fuel returns and firms' financial performance when we use annual returns. These differences are consistent when the characteristics of transmission channels are taken into account. Due to long-term contracts and hedging mechanisms, the complete effect of fossil fuel prices on financial performance may be longer than that of other mechanisms. Therefore, this lag can be observed using data at different frequencies. On the other hand, stock markets are efficient in most cases, and any new information that affects cash flows is reflected in stock returns in a shorter period.

Additionally, we show that firm-level characteristics play an important role in explaining the relationship between firms' financial performance, fossil fuel returns, and renewable energy returns.

While the role of institutional and competitive pressures on firms' strategies has been highlighted in many studies, firms within the same sector or industry have varying degrees of investment in energy transition capabilities, and market responses to these investments also differ as shown in clustering and further empirical analysis. Thus, despite the importance of institutional and competitive pressures on firms to develop energy transition strategies, firm characteristics still play an important role and further research is needed to understand the effect of these characteristics on firms' energy transition strategies.

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[Abstract:0547] OP-119 [Accepted:Oral Presentation] [Renewables » Other]

Financial participation and adoption of renewable technologies - a proper design is needed!

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Overview:The overarching goal of the EU Energy Union is to achieve a carbon-neutral economy in the EU by 2050 in order to combat climate change. However, this transformation of the energy sector is not a purely technocratic process, but is also shaped by cultural and societal forces. To better understand the interplay between technological options and societal and cultural aspects, we examine the factors that influence citizens' decisions to adopt or invest in particular technologies. Following a recent study on the perception of renewable heating technologies (Breitschopf and Billerbeck 2023), we postulate that non-financial costs are crucial for the adoption of energy transition technologies by citizens. Furthermore, based on another study on financial participation (Breitschopf and Burghard 2023), we hypothesize that citizen participation in the energy transition is low in terms of investment because the design elements of financial participation are poorly matched to citizen preferences.
Methods:First, we conduct a literature review on non-financial barriers and drivers of renewable energy technology adoption, as well as the preferred characteristics of citizen investments in renewable energy projects. After identifying key drivers of adoption (Barbier 2011; Ebrahimigharehbaghi 2022; Sovacool et al. 2020; van Rijnsoever and Farla 2014) and investment decision (Fanghella et al. 2023; Guetlein and Schleich 2023; Iskandarova et al. 2021), we organize a workshop to complement and validate our findings from the literature review. Based on the results of the workshop and the literature review, we derive a typology for the different types of non-financial costs and financial participation.

With regard to financial participation, we first distinguish between different types of financial participation. We use three criteria: investment, ownership, operation and maintenance. Type 1 encompasses investment, ownership and operation of the technology, such as a personal electric car, a rooftop photovoltaic system or a heat pump in the home. Type 2 refers to investment and ownership of the technology, but not operation. Examples include shares in corporations or membership in cooperatives or communities. Type 3 includes only investment, but not ownership or operation of the technology. This is the case with loans, where investors provide capital but do not have ownership rights. Instead, they have a high guarantee that the loan will be repaid. Examples include corporate or government bonds to finance renewable energy projects. With respect to the design elements of financial participation, we compile a long list of characteristics. They comprise: Low risks, high returns, financial returns such as cost savings or profits, low com-plexity of design, administrative procedures for acquisition, minimum investment threshold, transferability of financial participation, decision rights when holding shares, number of different actors, involvement of the community, autonomy and security of energy supply, social network, status, community building, use of profits, duration or payback period of the investment, legal forms and involvement of private or public actors with implications on liability and risks, self-realization and self-contribution, contribution to climate and environment (Fanghella et al. 2023; Guetlein and Schleich 2023; Brummer 2018; Bau-wens 2019; Lowitzsch et al. 2023; Pons-Seres de Brauwer 2022). Finally, we include self-centered and altruistic values (Sovacool et al. 2020) and norms (Chadwick et al. 2022) to account for their potential influence on technology adoption.

With respect to non-financial costs, we mainly refer to type 1 of financial participation, and to a limited extent to type 2. We divide non-financial costs into physical, behavioral, cognitive, and psychological efforts, which may decrease in the long run due to learning effects (Sagar and van der Zwaan 2006). Physical effort is cleaning or construction work associated with the adoption of renewable energy technologies. Cognitive effort occurs when the technology is less known and complex, requiring cognitive skills to operate or use the technology. Psychological effort can have its origin in cognitive and organizational requirements, i.e. it is due to the required actions. Finally, behavioral effort results from required changes in routines, rules, and habits. The efforts are counterbalanced by non-financial benefits such as self-determination or realization (Brummer 2018; van Zyl-Bulitta et al. 2019), comfort and healthy atmosphere (Sovacool et al. 2020), environmental and climate benefits, and energy security aspects (VZ RLP 2022). These non-financial efforts and benefits are also partly captured in technology acceptance or adoption models, e.g. in Fleiß et al. (2024), Hübner et al. (2023), Kyere et al. (2024), Chadwick et al. (2022).

Based on these findings, we develop a questionnaire to identify which non-financial costs and design elements are critical for improved technology adoption and financial participation. We conduct an online survey among 2000 citizens in Germany in January 2024. The questionnaire consists of several parts: a) socio-economic and demographic aspects such as age, property, ge-ographic location; b) statements related to the energy transition to understand the attitudes of the respondents; they have to indicate their degree of agreement with the statements on a five-point Likert scale; c) their actual and intended adoption of technologies and financial participation, d) a ranking of perceived characteristics of selected technologies and main efforts related to the adoption of these technologies. To identify preferred design elements of financial participation, we add e) a list of investment characteristics and ask respondents to rank them according to their preferences. Finally, f) we ask respondents to indicate which benefit or contribution of the technology is most important to them.

The study covers three sectors - mobility, heating, and electricity - with one technology pair in each sector. For mobility, we selected personal electric cars and member in car sharing organization; for heating, an individual heat pump or a share in low-temperature heating network; and for electricity, a share in a solar or wind power plant.
Results:The analysis shows the results by technology. A descriptive analysis shows how respondents assess and support the energy transition and whether there are any associations with financial participation or socio-economic or demographic characteristics. The analysis also shows whether respondents have already invested in energy transition projects, measures or technologies, and how this relates to socio-economic and demographic factors. It also shows which type or form of financial participation they prefer. The efforts are ranked according to the frequency with which they are selected. For type 1 of financial participation, we obtain results for each sector - mobility, electricity and heating - in terms of effort or cost; for type 2, we focus on wind power generation. Furthermore, we find out which type of participation is preferred: either energy cooperatives or communities, investments in private or partly communal wind and solar parks or heating networks. Regarding the specific characteristics of financial participation, we learn how important risks, interest, environment, organizational issues or social aspects are. We compare these expressed preferences with the revealed egoistic or altruistic values.
To identify which factors and design elements are most important, we use an adoption model, which is a derivative of the technology acceptance model discussed in Chadwick et al. (2022). Our model explains actual financial participation and indicated willingness to adopt technology or financial participation of type 1 or 2. Explanatory variables are attitudes, values, effort, and design elements. Control variables include socio-economic and demographic items.
Conclusions:The results show which efforts are most "costly" when adopting a technology and which financial participation schemes are best suited for specific social groups. A comparison of the preferred design elements of financial participation with the actual character-istics of the currently available financial participation options reveals how badly they match. These insights into these preferences and non-financial costs provide a good basis for designing appropriate instruments to enable a large and socially broad share of the population to engage and invest in energy system transformation technologies and thus contribute to accelerating the energy system trans-formation.
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Keywords: energy transition, financial participation, preferred design elements, non-financial efforts, adoption of technology, [Abstract:0630] OP-120 [Accepted:Oral Presentation] [Hydrogen » Derived Compounds]

The Dual Role of Low-Carbon Ammonia in Climate-Smart Farming and Energy Transition

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Overview:In an era where the imperative of sustainability intersects with the critical need for energy innovation, this study offers a nuanced analysis of Low-Carbon Intensity Ammonia (LCIA) as a linchpin for both climate-smart agriculture and energy transition. The dual utility of LCIA not only paves the way for reduced greenhouse gas emissions in fertilizer application but also serves as a robust energy vector for a variety of applications, highlighting its pivotal role in a low-carbon future.
Methods:This research employs a mixed-method approach combining quantitative analysis and locational case studies. Utilizing NREL's H2FAST model, we undertake a comparative techno-economic analysis and life-cycle assessment of LCIA production pathways, evaluating their economic viability and environmental impacts (Lee et al., 2022). By integrating these insights with regional data, the research maps out the interplay between energy resources and agricultural value chains, particularly focusing on the Permian Basin and Southern High Plains (Lin et al., 2024).
Results:Our results underscore the transformative potential of LCIA in the agricultural sector as a sustainable alternative to traditional fertilizers. The simulation of hydrogen and ammonia costs within the case study regions reveals that LCIA could serve as a catalyst for regional economic development, driven by the synergistic relationship between energy production and agricultural demand. The study's locational analysis, underpinned by recent data from the U.S. Energy Information Administration (EIA, 2023), provides a concrete illustration of how LCIA could underpin the energy transition, supporting both economic growth and sustainability goals.
Conclusions:The paper advocates for a strategic framework – Sustainable Ammonia for Resilient Agriculture (SARA) – that leverages LCIA as a dual-role strategy. By drawing from successful policy precedents like the Renewable Fuel Standard (RFS), the research argues for tailored policy support that can stimulate the LCIA market (IRENA and AEA, 2022). This paper not only presents a comprehensive review of the LCIA value proposition but also calls for action from decision-makers in the agricultural and energy sectors to harness the full potential of LCIA for a sustainable future.
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Keywords: low carbon intensity hydrogen, ammonia, energy transition, agriculture, sector coupling, value chain analysis

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[Abstract:0487] OP-121 [Accepted:Oral Presentation] [Hydrogen » Policy and Regulation]

No grid is an island – The delegated act on renewable fuels of non-biological origin in an integrated european energy system model

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Overview:The European Green Deal is the most comprehensive legislative climate policy package to date. As a central aspect, the switch to renewable energy sources is enforced by the regulations. Since not all industrial processes and their respective demands, that are currently supplied by fossil energy sources, can be electrified, "green" molecules need to be included and defined. So-called renewable fuels of non-biological origin (RFNBO) cover all renewably produced energy carriers that are not grown. This also includes hydrogen from water electrolysis. To produce "green" hydrogen according to the delegated act (DA) to the renewable energy directive II (REDII) [1] there are different options how RFNBOs may be produced according to the regulation that each require different conditions to be met.
Some of these conditions have already been investigated by previous studies. In the discussion before the adoption of the DA, Schlund and Theile [2] investigate the behaviour of island grids considering especially the effect of simultaneity. They conclude that the trade-off between economic viability, full load hours and indirect emissions to produce electricity-based hydrogen must be considered. Additionally, Ruhnau and Schiele [3] conclude that the hourly simultaneity requirement increases the cost of the produced hydrogen due to an increased need for storage. Accordingly, the costs decrease with increasing flexibility. Both studies focus on operation of individual plants or projects and do not investigate the deployment of RFNBO production all over Europe. Since those studies were conducted prior to the adoption, the specific regulations could not be applied. After the adoption, Langenmayr and Ruppert [4] compare RFNBO production in Germany for 2025 and 2030 with and without the REDII regime. They conclude that applying these regulations requires more electrolysis capacity and shifts the production capacities towards renewable energy production rather than to the CO2-sources compared to not applying the regulations. Although this study already investigates the application of the specific regulations, the limited geographical scope limits the full assessment of the DA. Transport between different bidding zones and import from non-EU-countries is not investigated yet. Therefore, a comprehensive model-based analysis of the regulations on an integrated European energy system model is still missing. This study focusses on the effects of the regulation on the level of the European bidding zones also considering the hydrogen transport inside the EU and import from neighbouring regions. Therefore, the study has a lower resolution, but a wider scope than the studies mentioned before and therefore enables a more macroscopic investigation.
Methods:To investigate the effect of the different options to produce RFNBOs, specifically green hydrogen, as described in the regulation a sector integrated energy system model of Europe and neighbouring regions is set up. The model determines a cost-minimal integrated energy system under the consideration of the requirements of the DA. The goal of the analysis is the distribution of hydrogen production throughout Europe under certain production constraints. The four options as laid out by Schmidt-Achert and Mohr [5] are thereby benchmarked against an unregulated hydrogen production in different scenarios. The geographic resolution represents the bidding zones as referred to in the DA. The year under review is 2030 since by then the temporal correlation applicable will be the same-hour period. The first option to produce RFNBOs is production of the green hydrogen in an

island grid. This can either be achieved by a physically disconnected electricity grid to produce the green hydrogen, or by a nearby feed in into the grid, given that the input and output flows are the same. Those island grids are modelled separately from the electricity transmission grid and only connected to the hydrogen grid to supply the hydrogen demands. The second option is the production of RFNBOs in sufficiently decarbonized grids. Grids that are either supplied with more than 90% by renewable energy sources or that reach CO2-emissions of 64,8 gCO2eq/kWh or less are considered to qualify as renewable. This requirement is modelled by pre-optimizing the system without applying the regulations and disabling the constraint for the electricity zones that meet the requirements in a subsequent optimization. Nevertheless, the production of RFNBOs shall not be at the expense of directly defossilizing the electricity grid which is why the electricity production must be provided though newly built renewable power plants or ensured through power purchase agreements. The additionality constraint is modelled through a distinct renewable electricity commodity from correspondingly newly invested renewable electricity power plants. Potential excess electricity may be fed into the main electricity system but not vice versa. The 90 % requirement as well as the CO2-emission requirement is modelled through additional constraints. For this third option additionally a temporal and geographical correlation must be given. The temporal correlation is met by coupling the availability of the electrolyser to the time series of the renewable energy sources. Lastly, the geographical correlation shall be met in either the same bidding zone, neighbouring bidding zones with comparatively higher day-ahead prices or neighbouring offshore bidding zones. This correlation is achieved by limiting the maximum transmission capacity to the maximum production in one bidding zone, thereby making it impossible to pass through additional electricity from neighbouring zones The fourth option is the production of RFNBOs from electricity that would otherwise be downward regulated due to redispatch measures. Since the model resolution is limited and capacity reserves and redispatch are not included, this requirement is not investigated in detail. These different options are then compared to the optimized model without restrictions to identify the effect of said regulations.
To summarize, the model is optimized for all different model variants. These variants are, the model without any regulation, the individual options and the model with the whole set of options in combination.
Results:The results of this analysis are possible displacement effects on a European scale. This includes the production capacities of renewable electricity used in the electrolysis plants as well as the electrolysis plants themselves in geographical and temporal terms. Furthermore, transport capacities and volumes are determined.
Conclusions:Conclusions are drawn regarding the effects of the RFNBO regulation on the European energy system. From these results, implications towards further development of RFNBO regulating policies can be drawn. Following this study, the energy system model can be refined in terms of temporal and geographical resolution to enable further investigation also of operational effects including redispatch measures.
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Keywords: hydrogen, energy, system, policy, regulation, distribution

[Abstract:0642] OP-122 [Accepted:Oral Presentation] [Hydrogen » Policy and Regulation]

Heterogeneity in Willingness-to-Accept Compensation Measures for Hydrogen Infrastructure in Germany

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Overview:German government has the infrastructure plan to construct substantial hydrogen pipelines by 2032. While such infrastructure plans facilitate energy transition, citizens' knowledge and perception about the technology and its infrastructure might vary substantially. These in turn might affect willingness-to-accept (WTA) an infrastructure measure near one's own residence and/or property. Compensation mechanisms might be effective in increasing WTA of private households or communities towards an infrastructure plan. Previous research shows that compensation at the individual and municipal level shows systematic differences in public acceptance (see van Wijk et al., 2021). Similarly, the studies state that individuals have different preferences towards different forms of compensation (i.e. financial and non-financial) (Vuichard et al., 2022). Hence, a differentiated understanding of compensation mechanisms (i.e., monetary or non-monetary) at the community as well as household level in terms of its effectiveness might help to optimally design and plan infrastructure measures.
To bring these perspectives together, a survey-based experiment is designed and implemented. This allows to quantify (a) preferences and informedness towards hydrogen technology and (b) effectiveness of different compensation mechanisms. The preliminary results indicate significant heterogeneity in WTA compensation measures that is partly explained by differences in individuals' perception on hydrogen technology.
Methods:By means of a uniquely designed survey-based experiment, a dataset on private households that are representative for the population in Germany is collected. While all survey participants respond to the survey questionnaire, the experimental treatments (i.e., hypothetical choice scenarios on compensation) are randomly allocated to different participants. Within-subjects design allows for random allocation of different scenarios across individuals. Using a binary choice experimental setup conducted as a within-subject design, similar to Simora et al. (2018), the experimental part of the survey describes hypothetical choice situations for individuals. In the experimental part, respondents are asked to decide in favor of or against (hypothetical) hydrogen pipeline infrastructure planning near their place of residence under the influence of various forms of compensation. In addition to the specific attributes related to the compensation itself, it is assumed that citizens' perceptions (e.g. in terms of safety and trust in the technology) and knowledge about hydrogen technology and its potential use cases can be very heterogeneous.
Results:Preliminary findings suggest that private households that perceive hydrogen technology as not very safe and have little information about the technical and content aspects of the technology are more likely to decide against an infrastructure measure and their WTA compensation measures are, on average, lower. On the other hand, private households that perceive the pipeline and the applications of the technology as safe and have confidence in the technology are more likely to accept an infrastructure measure and demand lower financial compensation or are willing to accept the infrastructure measures also without financial incentives.
Conclusions:This study aims to compare individual perceptions and knowledge of hydrogen technology with the degree and form of compensation. The preliminary results indicate that there is significant heterogeneity in willingness to accept compensation for infrastructure planning, which is partly explained by individual preferences and knowledge about hydrogen technology. The preliminary findings might inform policy measures for more effective planning of hydrogen pipeline infrastructure and for optimal targeting of compensation mechanisms in Germany.
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Keywords: Compensation Mechanisms, Experiments, WTA

[Abstract:0513] OP-123 [Accepted:Oral Presentation] [Hydrogen » Other]

Towards a feasible and climate goal aligned Hydrogen Pipeline Infrastructure: A scenario-based analysis for Germany

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Overview:Emission-free hydrogen (H2) is needed to decarbonize energy supply and combat the climate crisis. To unlock the potential of H2, pipelines infrastructures and related investments are required. However, it is uncertain what future H2 infrastructure will be needed.
The aim ofthe paper is to guide these decisions by contrasting two infrastructure options, namely (1) the construction of new H2 pipelines and (2) repurposing of natural gas pipelines for future H2 admixture. These pipeline infrastructure option are assessed in terms of their (feasibility (Criterion 1) and Climate goal alignment (criterion 2) to advise decision makers on effective climate mitigation.
Methods:I combine socio-technical scenario analysis with multi-criteria and consistency analysis. Six socio-technical scenarios from are used as an evaluation framework to test the feasibility and climate goal alignment of two infrastructure options. Research findings and expert evaluation from four disciplines - law, engineering, economics and sociology - are included to assess implementation requirements.The H2 infrastructure’s impact on the environment and on energy transitions is discussed refering the emission from natural gas vs hydrogen and with respect to energy transition risk such as asset stranding and carbon lock-ins. This innovative method enables a more realistic infrastrucutes assessment.
Results:The results show that building new H2 pipelines for renewable H2 is feasible as well as in line with climate goals. Gas pipeline investments for future retrofitting are not recommended due to energy transition risks such as fossil-lock in andasset stranding, that might hinder energy transitions.
Conclusions:In conclusion, a step-by-step construction of new H2 pipelines for renewable H2 near industry cluster is advisable. In the light of the chick-and-egg problem of establishing a H2-economy, recommendations on H2 supply and demand are drawn, which are also relevant for an international context.
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Keywords: hydrogen infrastructure, decarbonisation, energy supply, scenario analysis

[Abstract:0710] OP-124 [Accepted:Oral Presentation] [Hydrogen » Policy and Regulation]

Reducing energy poverty and carbon dioxide emissions: The potential role of hydrogen - Energy Modelling Study

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Overview:The global energy landscape is facing multidimensional challenges including energy affordability, energy security concerns and energy poverty. Nowadays while energy demand is at its historic high, there are 2.3 billion people who lack access to clean cooking fuels and 760 million people lack access to electricity, with the majority of this energy poverty concentrated in Africa and Asia Pacific regions. At the same time, while energy demand is growing, greenhouse gas emissions continue to rise exacerbating global warming threats. Consequently, the Paris Agreement in 2015 calls for reducing energy related GHG emissions to limit global warming to below 2 degrees by the end the current century, with hydrogen emerging as a possible decarbonization energy carrier to reduce energy related emissions potentially from the transport and industrial sectors.
Methods:Although the majority of hydrogen produced currently is produced from unabated fossil fuels, government policies and incentives are directed towards low-carbon hydrogen. The study focuses on assessing the role of low-carbon hydrogen in the future of the future of global energy systems by 2050 through energy system modeling using the GECF Global Gas Model. The model relies on linear programing to model global and country level energy demand, supply and energy-related emissions under varies energy scenarios that take into account wide range of energy policy and technology assumptions.

The paper presents future projections of global hydrogen demand until 2050 under two energy scenarios: a reference case scenario (RCS) in which energy demand is driven by population and economic growth without major policy or technology shifts, and an energy sustainability scenario (ESS) where low-income countries attain middle-income status, developing economies phase-down coal utilizing their energy resources, scaling up of carbon removal technologies, and hydrogen demand growth in the industrial sector of developed economies.
Results:The results demonstrate that the ESS scenario could reduce global energy-related carbon dioxide emissions by 43% compared to 2019 levels. Furthermore, hydrogen demand is projected to reach 350 MtH_2 in 2050 under this scenario, compared to 270 MtH_2 in the RCS. This study highlights the potential role of gases, including hydrogen, and carbon removal technologies in reversing the global GHG emissions trend, contributing to limiting global temperature rise to below 2°C.
Conclusions:As energy demand growth is concerted in developing countries in Africa and Asia Pacific, the use of a portfolio of energy technologies is necessary to reduce energy related GHG emissions on a global scale. The use of hydrogen, low-carbon fuels, and carbon removal technologies as presented in the paper present an opportunity to reduce energy poverty as well as reduce GHG emissions.
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Keywords: Hydrogen, Energy Transition, Emissions, Climate Mitigation, Scenario Analysis, Decarbonization

[Page: 125]

[Abstract:0512] OP-125 [Accepted:Oral Presentation] [Hydrogen » Other]

Ramp-Up of Low-Carbon Hydrogen Imports to Europe: Case Studies and Transformation Pathways for Green and Blue Hydrogen

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Overview:For the energy transition hydrogen and hydrogen carriers will become an important building block to defossilize many sectors such as energy, heating, industry and mobility. In light of the urgent global need to reduce greenhouse gas emissions and combat climate change, hydrogen emerges as a potent alternative to fossil fuels. According to the European Union the production target for low-carbon hydrogen in 2030 is 10 million tons and additionally 10 million tons of hydrogen imports, of which Norway is predicted to be a significant part of [1,2]. This study presents a comprehensive analysis of the transition from natural gas to hydrogen (blue and green) as a pivotal move towards decarbonizing Europe's energy supply, with a specific case study focus on Norway's role as a primary energy exporter and as a suitable representative of further energy exporting countries. This research spans a significant timeframe, from 2024 to 2050, marking critical decades in the energy transition when the majority of Europe pledged to be carbon neutral. We assess the attractiveness of exporting blue and green hydrogen in competition to natural gas from Norway to Europe through various possible transportation modes (by retrofitted natural gas pipelines, new purpose-built pipelines or ammonia as a hydrogen carrier) in this transition period. We analyze this temporal transition from natural gas exports to hydrogen exports under different scenarios in a mixed-integer linear optimization model. Our results show, that this transition from an energy exporter perspective will take place under very different timeframes from natural gas to blue or/and green hydrogen and that the switching times are heavily dependent on factors such as CO2 pricing, capital cost developments and natural gas prices.
Methods:For the analysis in this research, we created a mixed-integer linear optimization model in

the General Algebraic Modeling System (GAMS) environment. The objective function in this model is to maximize profits for the modeled country's energy exports which includes the export of natural gas, blue hydrogen and green hydrogen over the whole timeframe from 2024 to 2050. The optimization model incorporates a variety of constraints, for example transport capacities and the inherent limitations in retrofitting existing natural gas pipelines for hydrogen transport. We also integrated a detailed sensitivity analysis to analyze the impact of pivotal parameters, including but not limited to, natural gas prices, CO2 pricing, hydrogen prices (which are influenced by CO2 pricing and natural gas prices), and various capital costs. Generally, we presume a constant annual export of energy that can be composed of natural gas, blue hydrogen and green hydrogen. The composition of energy exports is calculated endogenously as well as all required capacities along the supply chain. For blue hydrogen the required carbon infrastructure is also taken into account. For green hydrogen we have considered the use of PEM electrolysis and possible hybrid renewable electricity supply from PV, onshore wind as well as offshore wind. The model is also applicable to further countries and hydrogen derivatives.
Results:The findings underscore the nuanced interplay of economic and infrastructural factors in the transition to hydrogen. Key results highlight the feasibility and economic viability of transitioning from natural gas to hydrogen, with a specific emphasis on the role of Norway in a case study. The analysis reveals that while the transition is robust under a range of scenarios, it is particularly sensitive to fluctuations in natural gas and hydrogen prices, CO2 pricing, and the associated capital costs of electrolyzers and renewable electricity supply. Moreover, the study delves into the concept of stranded investments and lock-in effects, particularly for blue hydrogen production, providing insights into risks by investing into potentially short-lived blue hydrogen plants. The results also underscore possible pathways to fully transition into green hydrogen exports with blue hydrogen as a transitional means of hydrogen supply and the different temporal onset of ramping up blue or green hydrogen production depending on our scenario analysis. In some cases, we can show, that natural gas exports would continue until a total depletion of Norwegian natural gas reserves before hydrogen exports are considered under a loss of profits. The results thus show, that depending on the scenario, different political measures such as CO2 pricing may have to be more ambitious than usually projected for the transition to initiate earlier and reach a natural gas phase out by 2050.
Conclusions:The transition from fossil fuels such as natural gas to low-carbon hydrogen, presents a viable pathway for Europe to decarbonize various sectors, with Norway poised to play a pivotal role as a key exporter. In our study, we outline viable pathways for natural gas exporters like Norway to transition their export focus from natural gas to hydrogen. However, it is clear that for this shift to occur, there must be compelling incentives in place. The transition to exporting blue or green hydrogen hinges significantly on economic factors. Primarily, this involves the establishment of higher CO2 prices and an increase in hydrogen prices, ensuring that the profits arising from hydrogen exports surpass those from natural gas. This shift is crucial in making hydrogen a more attractive export option. Nonetheless, it is important to recognize that such a transition is also capital-intensive. Substantial investments are necessary to develop and establish a hydrogen export supply chain. This includes the infrastructure for production, storage, and transportation of hydrogen. The study underscores the need for a well-structured financial and policy framework to accelerate this ramp-up of hydrogen exports.
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Keywords: Hydrogen, blue hydrogen, green hydrogen, optimization, energy transition, hydrogen import

[Abstract:0097] OP-126 [Accepted:Oral Presentation] [Energy Modeling » Energy Supply]

Pathways to 100% Clean Electricity for a New City: Supply-demand Model and Policy Analysis for Nusantara, Indonesia

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Overview:Indonesia's Law 3/2022 and Presidential Decree 63/2022 require the Government to relocate the capital city from Jakarta to a new site named Nusantara on Kalimantan Island. This choice was made taking into account the fact that Jakarta has been undergoing environmental degradation due to the increase in sea levels, ground subsidence, and high population density, which has affected its ability to sustainably support its population. These policies also require Nusantara to attain 100% renewable electricity by 2045 as a component of its plan to establish a sustainable and modern city. The reliance on fossil fuels to power Kalimantan Island raises a fundamental challenge regarding the feasibility and methods of achieving an alternative energy objective.

The stakeholders of Nusantara need an electricity model to foresee the city's electricity demand and supply, and simultaneously, pursue the 100% renewable energy target. This study provides an electricity demand-supply model that can support the stakeholders in identifying which aspects of the electricity system need to be considered. Furthermore, the grand design of this study can be a basis for policy analysis that the stakeholders need to develop a strategy and policy framework not only for Nusantara but also for newly planned cities.
Methods:Demand Model

The system dynamics framework is a modeling approach to represent complex systems. It is capable of capturing correlations and feedback between variables, as well as handling non-linear relationships (Forrester, 1973). This study employs system dynamics as a methodology to estimate future electricity demand, considering the various factors involved in the relocation of Indonesia's capital city, including population and economic growth. The system dynamics model has a population subsystem and an economic subsystem. The constructed model predicted that labor and government officials were the primary drivers of migration to the city, in addition to natural population changes due to births and deaths. The model implies that the City's Gross Domestic Product (CGDP) is equal when measured using both the consumption and production approaches, as per the Cobb-Douglas model. This assumption is the foundation for projecting labor force figures while keeping total factor productivity and capital constant. CGDP is an independent variable used to forecast the electricity consumption in the city.

Supply Model

The TIMES model is a partial equilibrium optimization model. It assumes perfect foresight in decision-making and aims to minimize the total system cost through a linear programming approach (Pina et al., 2011). Demand projection of the city is entered exogenously from the system dynamic model, while other regions outside Nusantara, but also served by Mahakam Grid are not considered and deemed outside of this research boundary. This study's methodology incorporates existing plant data from a state-owned vertically integrated utility's business plan (RUPTL PLN - Rencana Usaha Penyediaan Tenaga Listrik Perusahaan Listrik Negara) 2021-2030 and cross-references it with an Indonesian power plant database to incorporate technical lifetimes of power plants (ESDM, 2021). This information, along with properties of potential new power plants such as construction time, efficiency, capacity factor, and lifetime, feeds into the TIMES model. The model prioritizes cost efficiency, discounted by 6% to the base year 2023. Moreover, the model considers emissions from fossil fuels and constraints such as renewable energy penetration target, daily solar production profile, and controlled growth for each technology.

Scenario and Pathways Development
The demand model utilizes three possibilities based on the percentage of investment that IKN will acquire by 2045. The CGDP, population, and power consumption for each scenario are derived using system dynamics and exhibit variability. Scenario 1 is the optimal situation in which IKN successfully attains 100% of its investment objectives. Scenario 2 pertains to a situation in which IKN achieves 80% of its intended overall investment. Scenario 3 depicts a suboptimal circumstance where the investment falls below IKN's planned target.

Results:The model indicates that the power system of Nusantara will, without needing any incentives, become fully renewable by 2042, driven by retiring natural gas and coal plants, in 2037 and 2042. To substitute the supply gap, hydro and solar are chosen as the most cost-effective technology. There is a sudden jump in hydro capacity at around 200 to 350 MW projected in all scenarios, which is supposed to be supplied by Kayan Hydro Plant in North Kalimantan with a total feasible capacity of 9 GW. On the other hand solar capacity addition will be incremental which peaks at 350 MWp of solar being online in 2043 and plateau afterward.

The accelerated net zero model indicates that even though fossil plants have not been retired in 2035, there is no demand supplied by these plants. This can be explained by the limited model boundary that only considers the demand from Nusantara, not the whole Mahakam Grid. The rationale would be that these plants will still be generating electricity to the Mahakam grid but not serving Nusantara's demand, instead, serving the surrounding regions.

The total carbon budget difference between the 2045 net-zero scenario and the accelerated scenario is very substantial, around 70% lower for the accelerated net-zero scenario. This difference happened because of the difference in emission peak time and level of both scenarios.

POLICY GAP

Finance
Regardless of demand scenarios, the expedited net-zero model costs 4% more than the 2045 model. The accelerated type uses less gasoline but requires more capital. Higher capital, PLN's restricted capital-raising ability, and the government's limited fiscal flexibility offer the private sector a key role (IEA, 2020). Current regulations require new projects to be at least 15% cheaper than the provincial average, which reduces private interest (Bridle et al., 2014). Indonesia also has a higher capital cost than India or Mexico. The government must prioritize policies and financing schemes that lower capital expenses.

Political
As a State-Owned Enterprise (SOE), PLN provides electricity access to the population and generates profit. However, given that PLN does not determine electricity pricing, it depends on government compensation and subsidies, which constituted 28% of its revenue or 8.5 times its profit in 2022. This dependence, combined with the vulnerability of Indonesian SOE leadership positions to corruption allegations, undermines the motivation to meet renewable energy targets (Harahap et al., 2021; PP No 23 Tahun 2022, 2022). One potential solution is establishing a more adaptable institution dedicated to managing energy and power in Nusantara's operation area (wilayah usaha).

Economic
The annual cost of power generation is approximately 2.2% of GDP in 2023, with the model suggesting a decrease to about 0.2%-0.4% by 2045. This reduction indicates a transition towards a low electricity intensity economy, a characteristic commonly associated with a state capital. Furthermore, discussions regarding establishing a new institution could potentially lead to higher electricity rates. Consequently, it remains essential to maintain a subsidy mechanism to support individuals living below the poverty line.

Environmental
Hydroelectric power, a primary renewable source intended to replace coal, may lead to land use changes on productive territories, or even result in the displacement of indigenous communities (Alsaleh et al., 2021). Similarly, solar plants also require bigger land compared to fossil plants. The model estimates 51,000 Ha of land is required. It is imperative for the government to establish adequate zoning policies to meet net-zero objectives while ensuring a fair and thorough plan for mitigating environmental and social impacts. This plan must also account for emissions resulting from land use changes (Van De Ven et al., 2021).

Technical
The policy regarding electricity operating reserves must be revised to accommodate an increased penetration of variable renewable energy sources (Ela et al., 2011). To ensure a reliable power supply for the capital, it may be necessary to install an additional, more dependable power plant or to guarantee that the renewable energy plant provides essential reliability services (EAC, 2019). As a result, a minor portion of the energy mix will need to derive from gas, diesel, or battery storage, not completely net zero. Additionally, strategies must be developed to address non-traditional risks such as cyberattacks (Glenn et al., 2016).
Conclusions:The soft-linking between system dynamics and TIMES/MARKAL enables the creation of

a comprehensive model of demand and supply projections of a new city. System dynamics encompasses the demand variable in TIMES/MARKAL which was usually regarded as a static and linear variable. System dynamics allows for the modeling of the relationship between the economic and demographic subsystems to draw a projection of the city's power demand.

In conclusion, the transition to a fully renewable power system in Nusantara presents a complex interplay of environmental, economic, political, and technical challenges. Economically, the transition underscores the need for increased private investment and policy reforms. Politically, the challenges within PLN highlight the necessity for institutional reforms to better balance the energy trilemma. Technically, adapting to higher penetration of variable renewables necessitates revisions in electricity reserve policies, the inclusion of reliable energy sources, and heightened cybersecurity measures. This comprehensive consideration is imperative for realizing Nusantara's, and other new modern cities', net-zero goals.

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Keywords: System dynamics, TIMES/MARKAL, Energy policy modeling, Nusantara, New city

[Abstract:0113] OP-127 [Accepted:Oral Presentation] [Energy Modeling » Energy Supply]

Decarbonization of aviation and motor vehicles: Effects of changing bioenergy demand on United States agriculture under climate change

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Overview:Three important developments are coming to the United States (U.S.) bioenergy sector that will change the feedstock composition potentially away from maize and towards other crops. First, an increasing number of electric vehicles reduces the long-term demand for maize ethanol, which currently uses about one-third of U.S. maize production. In the short- to medium-term, maize demand could increase if the federal government allows the year-round sale of E15, i.e., gasoline blended with 15% ethanol, as opposed to the current E10 blend. Changes in the demand for maize will have important effects on land allocation and commodity prices. Second, the heavy trucking sector could use bio-based diesel—either biodiesel blended with regular diesel or renewable diesel—as a (bridge) technology to decarbonize in the long-term. In the U.S., bio-based diesel is mostly produced from soybeans, which are grown in rotation with maize in large parts of the U.S. Midwest. And lasty, the Biden Administration has set the goal of 132.5 billion liters of sustainable aviation fuels (SAF) by 2050. There are many biomass feedstocks that can be used in the production of SAFs. Among them are various crops, agricultural and forest residues as well as energy crops such as switchgrass. Those developments in the bioenergy sector occur at the same time as changing crop productivity due to climate change. The purpose of this research is to assess the effects of various transportation policies and climate change scenarios on U.S. county-level land-use, production, and commodity prices under until 2050. The results can shape the discussion surrounding bioenergy, farm income, and conservation policies. The price effects from changes in feedstock demand under climate change can inform industry about the future profitability of various bioenergy sources. At the same time, the research also contributes to the discussion about land conservation and carbon sequestration potential given cropland re-allocation since. Examples here are the carbon sequestration ability of switchgrass, which is different compared to maize, or the possibility of switchgrass production on land taken out of production due to an increasing number of electric vehicles (LLNL, 2023).
Methods:The economic simulation model is comprised of three modules: (1) Transportation, (2) county-level agricultural production, and (3) crop yields under climate change. The macroeconomic assumptions behind the first two modules are taken from the most recent version of the Annual Energy Outlook (AEO) published by the U.S. Energy Information Administration (EIA). Specifically, four cases regarding high/low economic growth and high/low oil price evolution are used besides the so-called Reference Case.

The road transportation model projects energy consumption until 2050 based on the dynamics of the U.S. vehicle stock (Dumortier et al., 2023). Eighteen vehicle types are modelled, which are broadly separated into passenger and freight. The light-duty vehicle (LDV) market is also divided into two

regional segments to account for the Advanced Clean Cars II (ACC II) Regulations, which bans the sale of internal combustion engine (ICE) vehicles by 2035. Originally implemented in California, six additional states—representing approximately 28% of the U.S. LDV market—follow the ACC II ruling. Three road transportation scenarios are modelled until 2050. First, an exogenous increase in the market shares of electric vehicles is implemented in the non-ACC II states leading to a complete phaseout by 2050 of ICE vehicles in the LDV sector. Second, the blend limit for maize ethanol is increased from 10% to 15%. Third, the heavy trucking sector increases its use of bio-based diesel, which affects soybean demand. And fourth transportation scenario quantifies SAF production from maize (ethanol) and agricultural residues (i.e., corn stover and wheat straw) increase until 2050. Note that the scenario is implemented such that maize and agricultural residues are only covering 21.3% of the total demand for SAFs, which is the current estimate of the U.S. Department of Energy (DOE).

A county-level simulation model is applied to the U.S. agricultural sector to project various bioenergy uses—resulting from the transportation model—until 2050. The model covers barley, maize, rice, sorghum, soybeans, and wheat in 3105 counties in the contiguous United States. Large parts of the model have been used in previous publications to quantify second generation biofuels (Dumortier et al., 2017; LLNL, 2023). On the demand side, there are up to four uses for each crop, i.e., feed, non-feed, biofuels, and exports. The crop supply is modelled at the county-level with area allocation based on operating income (i.e., yield as well as output and variable input prices). The model solves endogenously for the crop prices that clear the markets. Demand and supply elasticities are based on previous literature since the estimation of many parameters—as would be required for this model—is beyond the scope of the simulation model. It also includes the supply of corn stover and wheat straw for cellulosic ethanol production.

The new addition to the agricultural model compared to the references cited previously is the modelling of yields as a function of past and future climate. There are three steps involved to model climate-dependent crop yields until 2050: (1) Linking historic climate to yields, (2) projecting yields under historic climate serving as no climate change scenario, and (3) projecting yields under climate change. Historic climate (i.e., daily minimum and maximum temperature as well as precipitation) from 1981 to 2021 is taken from the PRISM Climate Group at Oregon State University and aggregated to the county-level. For the six crops, growing degree days (GDD) and heat degree days (HDD) are calculated according to the crop-specific planting months. Besides precipitation, GDD and HDD—the latter reflecting heat stress—are important determinants of pant growth. Future climate data is taken from the Coupled Model Intercomparison Project Phase 6 (CMIP6) with seven Global Circulation Models (GCM) being used: GFDL-ESM4, HadGEM3-GC31-LL, HadGEM3-GC31-MM, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, and UKESM1-0-LL. In addition, the ensemble mean of the seven GCMs in terms of temperature and precipitation is calculated, which is common practice in climate change analysis (Aufhammer et al., 2013). The two Shared Socioeconomic Pathway (SSP) and Representative Concentration Pathway (RCP) combinations used are SSP1-RCP2.6 and SSP5-RCP8.5. Thus, the scenarios in this research are executed along the four dimensions of (1) AEO macroeconomic environment, (2) road transportation and SAF policies, (3) GCMs, and (4) SSP/RCP combinations. Each scenario is compared to a baseline with status-quo policies and electrification pathways to determine the effect of the policy/scenario on commodity prices and land-use with and without climate change. This can lead to important insights into the future availability and cost of biomass procurement for the bioenergy industry.
Results:Preliminary results are calculated for the scenarios regarding a higher market share of electric vehicles leading to a full phaseout by 2050 and the blending limit changing to 15% instead of the current 10%. The implementation of the bio-based diesel and SAF scenarios is in progress. In the AEO Reference Case and without climate change, maize prices decline by 5.3% in the scenario in which electric vehicles represent 100% of sales in 2050 compared to the baseline with a phaseout continuing on the current trajectory. The decline ranges from 3.9% to 6.3% in the other AEO cases with Low Oil Price and High Economic Growth representing the upper and lower bound. The highest increase in maize prices from increasing the blend limit to 15% is observed around 2030. At that time, the expansion of E15 market reaches the maximum and electric vehicles have not yet sufficiently penetrated the market to reduce pressure on maize prices. Without climate change and status quo policies, base area for all six crops is 71.6 million hectares in 2050. This is contrasted to the scenarios with climate change in which the area for all six crops in 2050 is increased to 84.6 million hectares. Due to the negative effects of climate change on U.S. crop yields, crop area is expanded in order clear the market also leading to higher commodity prices. Maize prices increase by 59.1% compared to the baseline without climate change. If rapid electrification of the LDV sector is added to the scenario, the price increase is lowered to 41.6%. That is, the adverse effects of climate change on the maize market are dampened by a more rapid electrification, which lowers the demand for maize ethanol. The increase in electric vehicles also leads to a lower cropland use of 82.6

million hectares, which has important implications for conservation efforts. Conclusions:This research quantifies the effects of transportation policy and climate change on feedstock supply, prices, and land allocation. There are both positive and negative crop quantity changes occurring due to policy arising at the same time of mostly negative crop supply effects. The research informs policy makers on the effects of changes to electric vehicle market shares, blending limits, and SAFs. For industry, it can serve as a long-term outlook of procurement cost of feedstock from maize, soybeans, and agricultural residues. It will also inform conservation efforts due to the interaction between transportation policies, climate change, and land use.
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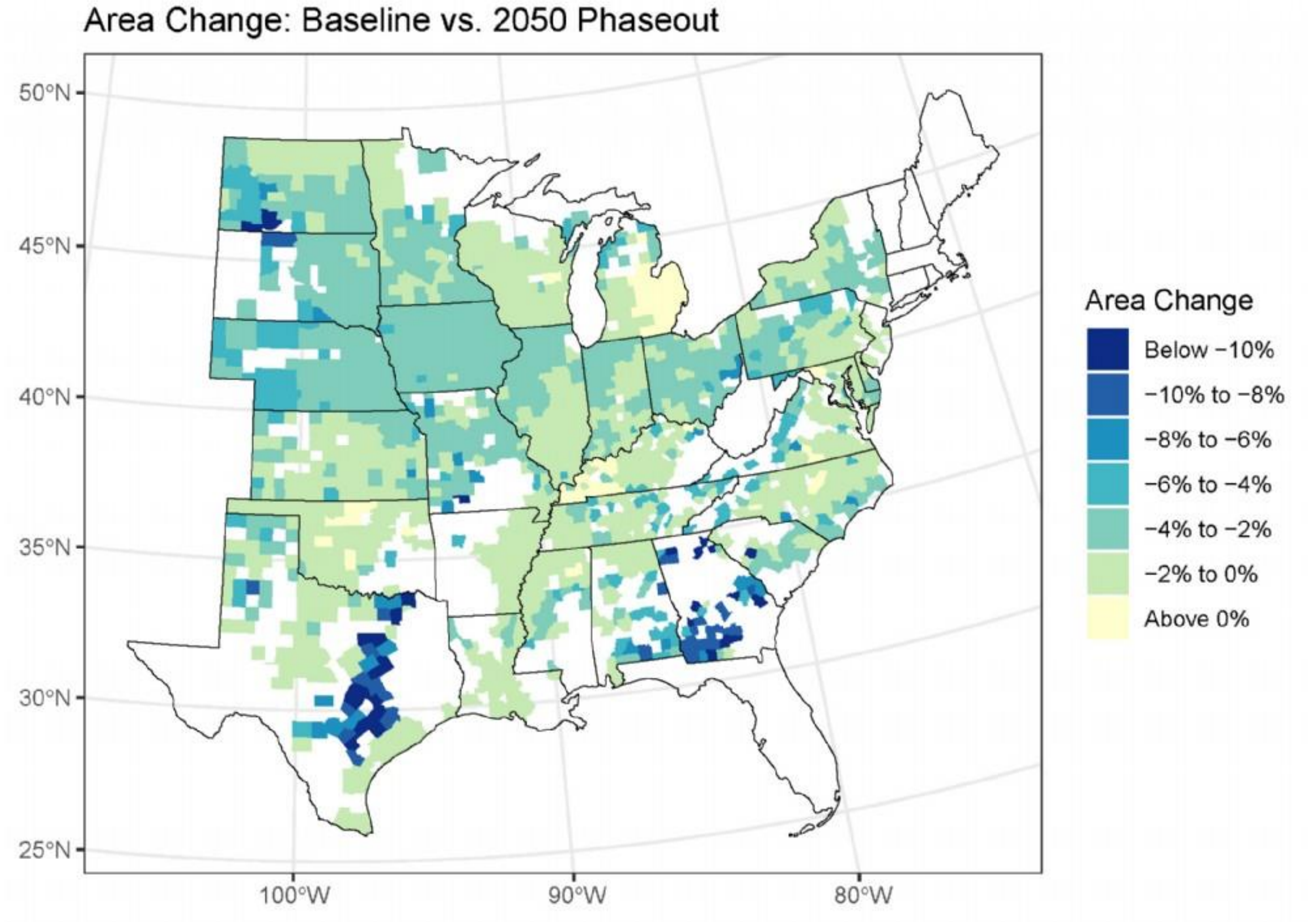
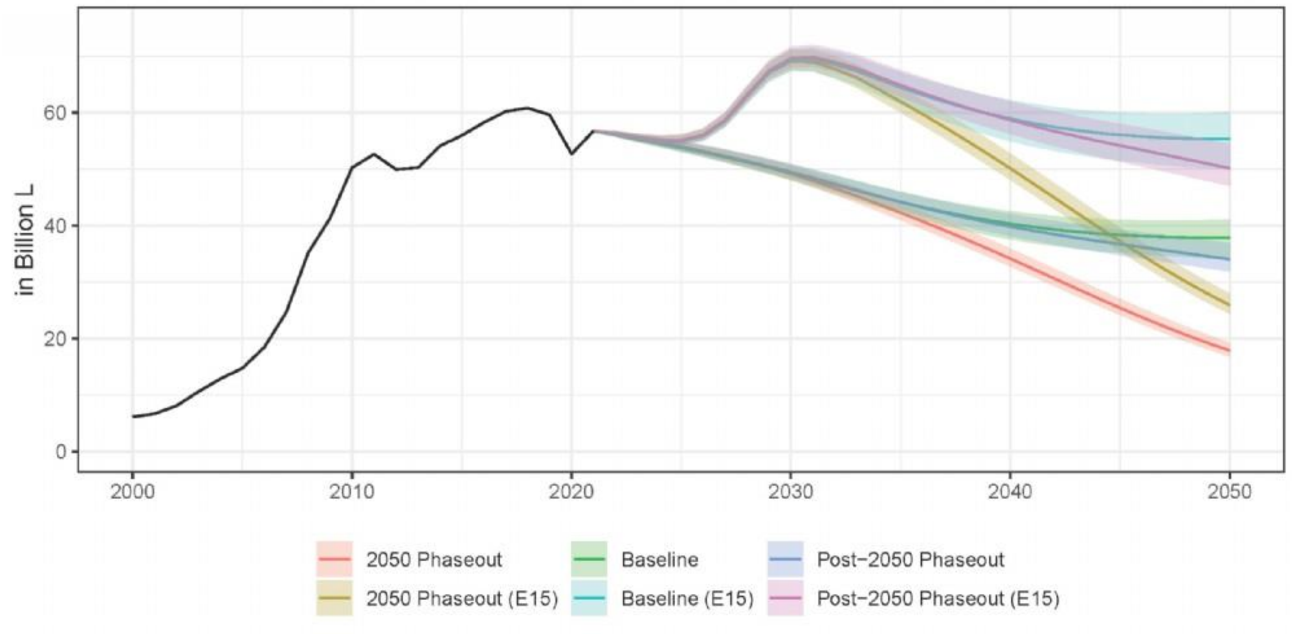
Keywords: electric vehicles, sustainable aviation fuels, biomass

Area Change Ensemble



Change in area under the phaseout of ICE car sales by 2050 compared to a phaseout on the current trajectory. The climate change scenario represents the ensemble mean of RCP8.5.

Ethanol Use



Simulated maize ethanol trajectories under more rapid vehicle electrification and increased blend limit.

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[Abstract:0299] OP-128 [Accepted:Oral Presentation] [Electricity » Demand]

Using a spatial economic and modeling time-series simulation to analyze energy, transportation, and housing implications of a megaproject in Riyadh

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Overview:The city of Riyadh in Saudi Arabia envisions rapid growth, from a 2020 population of 7.2 million reaching 15 million or more by 2030 (Alhefnawi, 2023). A spatial economic and transport forecasting model has been developed following well-established approaches, to assist in forecasting the expansion of the urban area, and in particular the spatial organization of the population, their housing, economic activity and their employment consumption, and the flows of goods and services on the transportation network. The model, called the Riyadh PECAS Model, was used to analyze the housing, travel, energy consumption, and related impacts of a proposed megaproject, The New Murabba, which is envisioned as a new downtown for the city. The model simulates energy use (residential domestic, and transportation) due to shifts in housing location, housing dwelling type, travel mode choice, and travel distance. The model predicts some of the details of housing consumption and location choices of Saudi's and non-Saudi's that provide additional insight. The non-central location of the new development could substantially increase the total quantity of vehicle-distance-travelled when compared to a reference simulation where development locations are

market-driven. Complementary investment in major public transit infrastructure could lead to a higher mode-split to transit and a corresponding reduction in transportation energy use.
Methods:We designed and built a time-series spatial economic, land-use, and transport simulation model for Riyadh, entitled: PECAS-Riyadh model, to analyze and forecast future scenarios for Riyadh city, Saudi Arabia.
This model follows the PECAS (Hunt and Abraham 2005; Abraham and Hunt 2007) framework which unites input-output theory and social accounting matrices with random utility theory (in particular, a spatial choice representation) and real-estate theory.
We used the model to investigate the impacts of a proposed megaproject, namely: the New Murabba project, which is designed to accommodate and lead future growth patterns (Abdallah 2021). Then, the result is compared with the resulting forecast to a reference case scenario where development patterns followed market forces (a business-as-usual scenario without the New Murabba project).
The Riyadh PECAS model encompasses the entire city of Riyadh. A specific layer of domestic energy use is incorporated in the modeling work to allow the system to assess the impact of land use and transportation policies and other urban interventions on the energy demand at the city level. The PECAS Riyadh model includes two categories of households, Saudi and Non-Saudi, and different categories and sizes of residential dwelling, with different energy needs. This allows the model to consider the distinct preferences for housing for the two nationality groups.
Results:The New Murabba simulation allocates the households differently by dwelling type, based on the household's preferences (Table 1).

Table 1: Number of occupied residential units by type in the two scenarios in 2030

A comparison map of the simulated number of households is shown in Figure 1. The model simulates more than 50 thousand households moving to the New Murabba project by 2030, and this trend continues until 2050. Most of the shifts are localized, shifting growth patterns from the immediate east of King Fahd road towards the new development. Figure 1 also shows that both with and without the New Murabba project the model simulates a larger total amount of development in the northeast area.

Figure 1: Change in households' allocation over time after building the New Murabba project – totals of households by scenario by TAZ with difference of households by TAZ.

The model indicates that with the New Murabba project there is more household home (domestic) energy use as electricity. The number of households is the same in both scenarios, but there is a shift in structure type, location, and space quantity, to match the increased supply in The New Murabba project. This leads to a larger demand for domestic electricity for households, to support air conditioning and other uses. Without the project more households tend to allocate in central north Riyadh for the year 2050, and with the project, they switch to the zone in the west (Figure 2). The model also indicates that the demand for electricity switches from the south, the east and from downtown to this new west location.

Figure 2: Change in domestic electricity use between the New Murabba project and the Reference scenario in 2050.
As for energy impact from transportation, Figure 3 and Figure 4 show the change in traffic congestion for a weekday PM peak hour for the year 2030, without and with the New Murabba project, respectively. The RCRC travel model indicates that the congestion on roadways near the New Murabba project could become severe without major increases in capacity on nearby roadways.

Figure 3. Level of service on roadways without the New Murabba project (i.e. the Reference scenario)
Figure 4. Level of service on roadways with the New Murabba project

With the construction of the New Murabba, there is an increase in energy consumption in typical weekday travel which is around 21,400 GJ/weekday, 6% higher than without the project, see Figure 5. To convert this difference into an annual amount, it is multiplied by 300 (to approximate a yearly aggregate total; there is less traffic on weekends), which resulted in 6.4x106 GJ/Year.
Overall, the New Murabba attracted substantial numbers of trips for various purposes, and given the non-central location of the development, this increased the average trip length and the associated energy use in travel. The reference scenario, with more growth close to the central axis, supports shorter trips lengths than the New Murabba scenario.

Figure 5. Annual weekday transport energy use for the Reference and the New Murabba scenarios for 2030

Conclusions:The Riyadh PECAS model simulates the spatial and economic impact of this project in terms of shifts in housing location, dwelling type, domestic energy use, travel energy use, and other implications of household and industry/employment spatial organization.
Findings from this simulation of the New Murabba include:
a) Households use larger dwellings in response to the increased supply of housing, increasing the domestic electricity consumption, while providing a quality-of-life benefit, especially for Saudi households who use larger dwellings.
b) With the construction of this project, housing is located in its non-centralized location. This location, in combination with being away from the Metro system, leads to more travel, leading to increased energy use, overwhelming the roadway capacity in the surroundings of this project, and potentially limiting the success of the New Murabba project in Riyadh.
c) There is a potential to expand the Metro system to the New Murabba project. This location can result in reducing congestion and transportation energy use due to the decentralization of commuting patterns and the large travel demand generated by this project.
d) Targeting optimum housing size, dwelling type, and the efficiency of the new dwellings in the New Murabba development, as part of the land-use policies in Riyadh, could improve the overall energy use at residences.

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Keywords: spatial-economic, land use, integrated transport planning

[Abstract:0340] OP-129 [Accepted:Oral Presentation] [Energy Modeling » Energy Supply]

Reflecting Uncertainties in District Heating Supply Modelling: A Comparative Analysis of Multistage Optimization Techniques

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Overview:District heating (DH) systems are increasingly acknowledged by governments, policymakers, and municipalities as a strategic solution for leveraging renewable energy and excess heat sources, given the decarbonization targets and the challenges of decarbonizing the heating sector. In the European context, policies set goals for reaching certain milestones by a target year, such as reducing greenhouse gas emissions by 55% by 2030, reaching carbon neutrality by 2050 and increasing the share of renewables and excess heat sources in DH supply by 2.1 percentage points per year. However, how the targets will be reached is not defined, and modelling comes into play at this stage.

DH modelling studies are instrumental in uncovering how DH systems can transition to carbon neutrality and assessing the impact of various parameters. Studies focus on different dimensions of DH, such as supply, demand, and network sides, as DH systems are complex. In this study, we focus on DH supply modelling. Traditionally, DH supply models often rely on scenario-based approaches to examine different decarbonization pathways, such as the Hotmaps DH Gen model [1]. Yet, these methods are typically limited to a few scenarios, each modelled independently. Such deterministic models fail to adequately capture the significant uncertainties of the future, such as fluctuations in DH demand and energy prices. Moreover, modelling studies that focus solely on the target year overlook the gradual evolution of DH systems. In contrast, multistage optimization methods consider this progressive transition, offering insights into the optimal evolution of DH systems towards a carbon-neutral supply.

Methods:This study investigates how uncertainties can be integrated into DH supply modelling, particularly in multistage optimization for transitioning DH supply to carbon neutrality. Initially, we assess existing DH supply models, looking at how they incorporate uncertainties. In the context of DH, uncertainties might arise from several factors. For instance, (new) building constructions, demolitions, renovation activities and weather years might affect the DH demand. Another significant uncertainty is the energy carrier prices.

Following the existing DH models, we extend this review to include capacity expansion models from other energy sectors, such as those presented in references [2, 3, 4], to identify methods that could potentially be applied to DH. Our analysis compares approaches used in modelling different energy sectors to understand how they consider uncertainties. These studies offer varied perspectives on handling uncertainties: Khojaste et al. [2] discuss Markov decision processes for decision-making under uncertainty with cyclostationary behaviour and illustrate examples for hydropower scheduling and offshore wind power integration. Mitjana et al. [3] introduce a multi-stage stochastic model for power decarbonization in Northeastern North America, including generation, storage, and transmission decisions with long-term uncertainties. Hole et al. [4] introduce a capacity expansion model for electricity generation and transmission in hydroelectric systems using stochastic dual dynamic programming. The paper demonstrates the proposed approach's flexibility and applicability for different case studies and sectors. By analyzing these and other relevant state-of-the-art studies in the literature, we aim to identify techniques adaptable for DH supply modelling, thereby bridging the gap between current DH modelling practices and potential advancements from broader energy modelling.

Results:The primary outcome of this study is twofold: first, a summary of the best practices in modelling uncertainties in DH supply modelling and possible improvements gathered from a cross-sector examination; second, a multistage stochastic DH supply model will be developed for a simple case based on review to showcase possible enhancements.

Conclusions:In this study, we anticipate several key conclusions that will contribute significantly to DH supply modelling. Firstly, we expect to demonstrate how integrating multistage optimization techniques can substantially advance DH supply modelling, providing a more dynamic and comprehensive understanding of DH systems' evolution towards carbon neutrality. Secondly, our research aims to bridge the methodological gaps between current DH modelling practices and the enhanced accuracy and resilience achievable by adopting methods from other energy sectors. This cross-sector analysis is likely to underscore the importance of a holistic approach in energy system modelling. Thirdly, the study is expected to identify a set of best practices for modelling uncertainties in DH systems, drawing from extensive reviews of both DH and other energy sector models. These practices should offer valuable guidance for future research and practical applications in DH modelling. Additionally, the development of a multistage stochastic DH supply model, informed by these insights, is anticipated to exemplify the practical application of advanced modelling techniques, serving as a proof of concept for their effectiveness in DH systems.

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Keywords: DH Modelling, DH Supply, Decarbonization, Multistage Optimization, Stochastic Modelling, Capacity Expansion

AuthorToEditor: The abstract is submitted based on a work in progress and its expected results. The authors will present the actual results during the conference.

[Abstract:0509] OP-130 [Accepted:Oral Presentation] [Energy Modeling » Energy Supply]

Modelling the sensitivity of the European electricity system to Belgian and German nuclear policies

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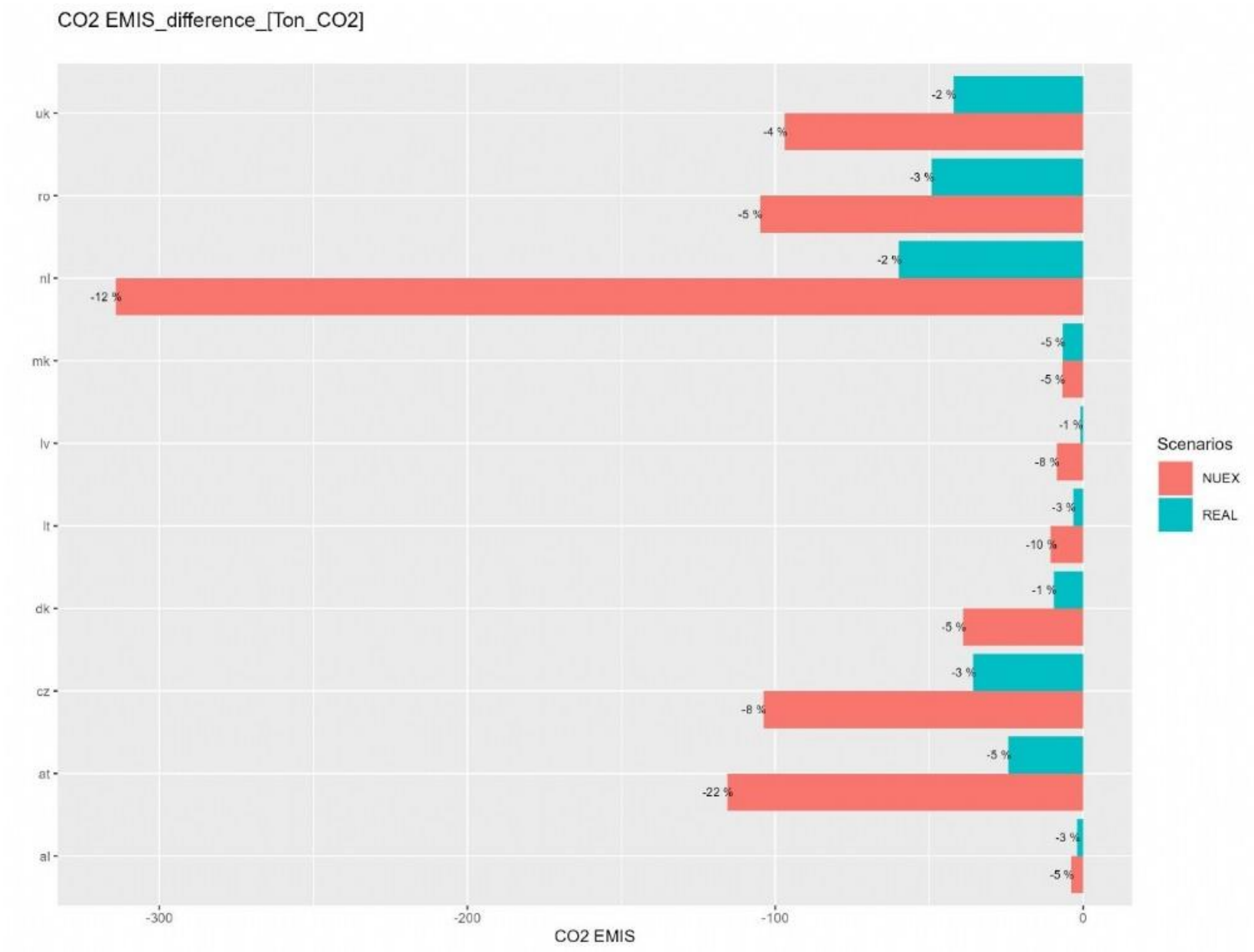
Overview:European countries are committed to reducing their greenhouse gas emissions to reach carbon neutrality, implying an energy transition in its demand and supply side. That implies an increase in electrical usage and intensifies the deployment of new renewable technologies. Electricity would, therefore, become a primary energy source in the heating, mobility, and industry sectors, replacing the current role of fossil fuels. However, energy systems based on new renewable sources (NRES) would have to deal with mild prediction of renewable sources and intermittency. Nuclear energy is a low-carbon technology that harmonises with NRES thanks to its flexibility, yet its role in the European electrical system is currently widely debatable.
Despite the benefits of nuclear power generation, some European countries agreed on phasing out nuclear power. Nevertheless, the last energy crisis was caused mainly by the COVID-19 implications, incidents in French reactors, and specifically the Ucranien invasion of Russia, which made the European governments wonder about the pertinence of current nuclear phasing-out policies. For instance, the prolongation of "Doel 4" and "Tihange 3" nuclear reactors in Belgium to 2035 and the delay of closure of "Emsland", "Isar II" and "Neckarwestheim II" in Germany until the end of winter in Avril 2023. Moreover, the phasing-out has strengthened the share of NRES in the mix and aggravated intermittency problems. That coerced the construction of new gas-based plants, increasing the dependency on external fossil fuel supplies furnished largely (greater than 55%) by Russia before the war. Therefore, the nuclear phase-out agreement is also an energy security matter, influencing insidiously European economies—for instance, the soaring gas prices in the winter of 2022-2023 due to LNG purchase instead of traditional Russian gas pipeline.
Therefore, the prolongation of nuclear reactors has a pertinent impact on the European electricity system and on European energy policy, yet the literature is limited to focusing mainly on one country and concentrating on national repercussions. Our model goes further by studying the impact of Germany's and Belgium's nuclear phase-out policies. We have chosen them because we first consider the technical viability, the location, and the potential for prolongation. This research aims to study national effects as much as international ones at the European level by modelling and analysing the impact on electric dispatching, CO_2 emission, electricity trade and operational cost at a European level. What is more, we take into account the hydro-thermal unit commitment[1], which is original in the literature regarding the topic, in our model. We also include a sensibility test on gas prices to analyse the impact of the relative merit order of gas and coal on the results.
[1] model that considers technical dispatching constraints such as minimum power, ramp-up, minimum operating time, clustering of power plants (production units), power fluctuations, shutdown and start-up of power plants and incidental as well as planned outage and maintenance.

Methods: In order to execute this study, we used the "European Electric System Modelling" ESMOD model, built on Antares-Simulator, which allows us to do electric dispatch system studies at different levels, either regional, national or European. It models the European electric system for the year 2030, covering 37 countries constituted in 53 market-bidding zones. The technical-economic data of the model is mainly based on the European Resource Adequacy Assessment (ERAA) done by ENTSO-e, which provides in a dataset the characteristics of the electric system: production capacities, load factor, net transfer capacity interconnections, stock capacities, thermal properties, planned and forced outage rate and others.
All renewable energy production and transfer capacities time series are given in an hourly time step. Demand time series are also given in an hourly time step and are partially correlated to weather conditions.
ESMOD is compliant with merit order market configuration based on marginal costs, the hourly electric trade among the countries following physical constraints and the cycles of loading and taking-off from PSP and batteries following the water usage value. Through this calculus, the operating ranges of the various means of production are determined to minimise the annual operating cost of the electric system. The CO2 emissions are calculated a posteriori by multiplying the optimised production by an emission factor for each technology.
Our study responds to different scenarios chosen to depict three energy contexts in Europe: benchmark *full closure* scenario, *real* 2 GW prolonged in Belgium and *nuclear extension* 4GW prolonged in Belgium and 4GW in Germany. As the study focuses on the impacts on the system of nuclear policy decisions in both countries, our scenarios' design focal point is on the nuclear nominal power and fossil fuel costs, giving way to a cross-sensitivity analysis.
Results: The main result of our model is to illustrate the effects of Belgian and German decisions on other European countries. Nuclear closure leads to higher demand for gas for electricity production in other parts of the system, notably Central and Eastern countries. Our model confirms the strong integration of European electricity, highlighting the relevance of European coordinated energy policies.
Conclusions: The availability of nuclear-based electricity does replace more expensive and more carbon-intensive production based on gas and coal (direct effect). It also has an indirect effect by feeding other countries with nuclear production. Nuclear energy reduces emissions and overall system costs through direct substitution by imposing first in merit order and second through indirect substitution via supplying other countries through connections. Thanks to this direct and indirect effect, nuclear energy then reduces emissions and overall system costs.
Political insights into how country-level policies can affect a system such as the European electric integrated system are one of the primary outcomes of this study. Because of the interdependence of European countries' electrical systems, political decisions and mix choices in one country do end up affecting other countries, mainly neighbouring countries but also countries with no direct connexions. In order to reach common environmental targets, this is a crucial aspect to consider during energy policy discussions.
A conclusive aspect of the present study is that interconnections are the arteries of the European electric system. These interconnections make it possible to mutualise either the advantages or disadvantages of energy political decisions made elsewhere than in one's country. This emphasises the interest in coordinating policies through European countries to reach energy independence goals and climate targets.
References: We don'y have any references

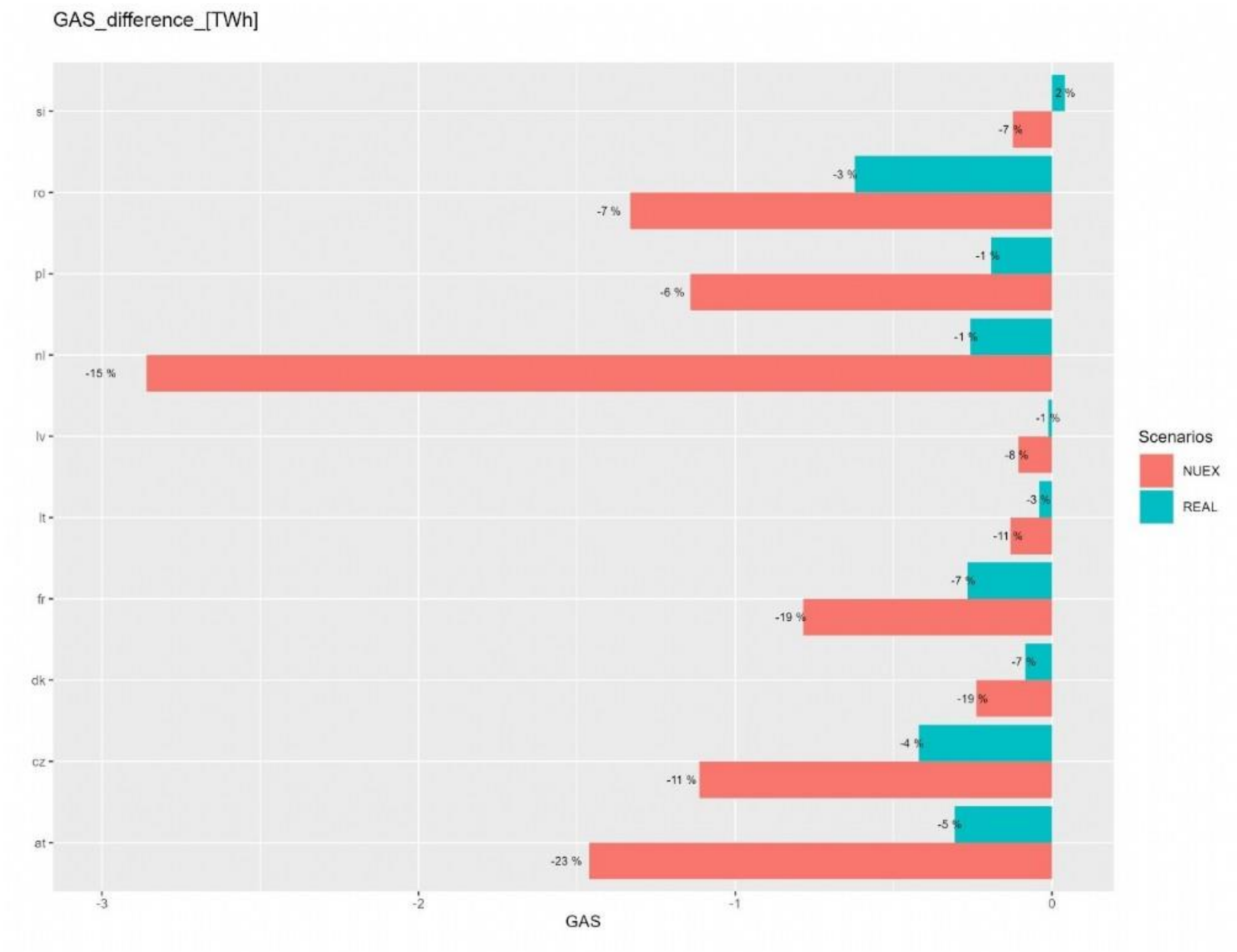
Keywords: Nuclear closure, nuclear extension, integrated European electricity system, European energy policy

Difference in CO2 emissions compared to reference scenario in Tons of C O2 and in percentage



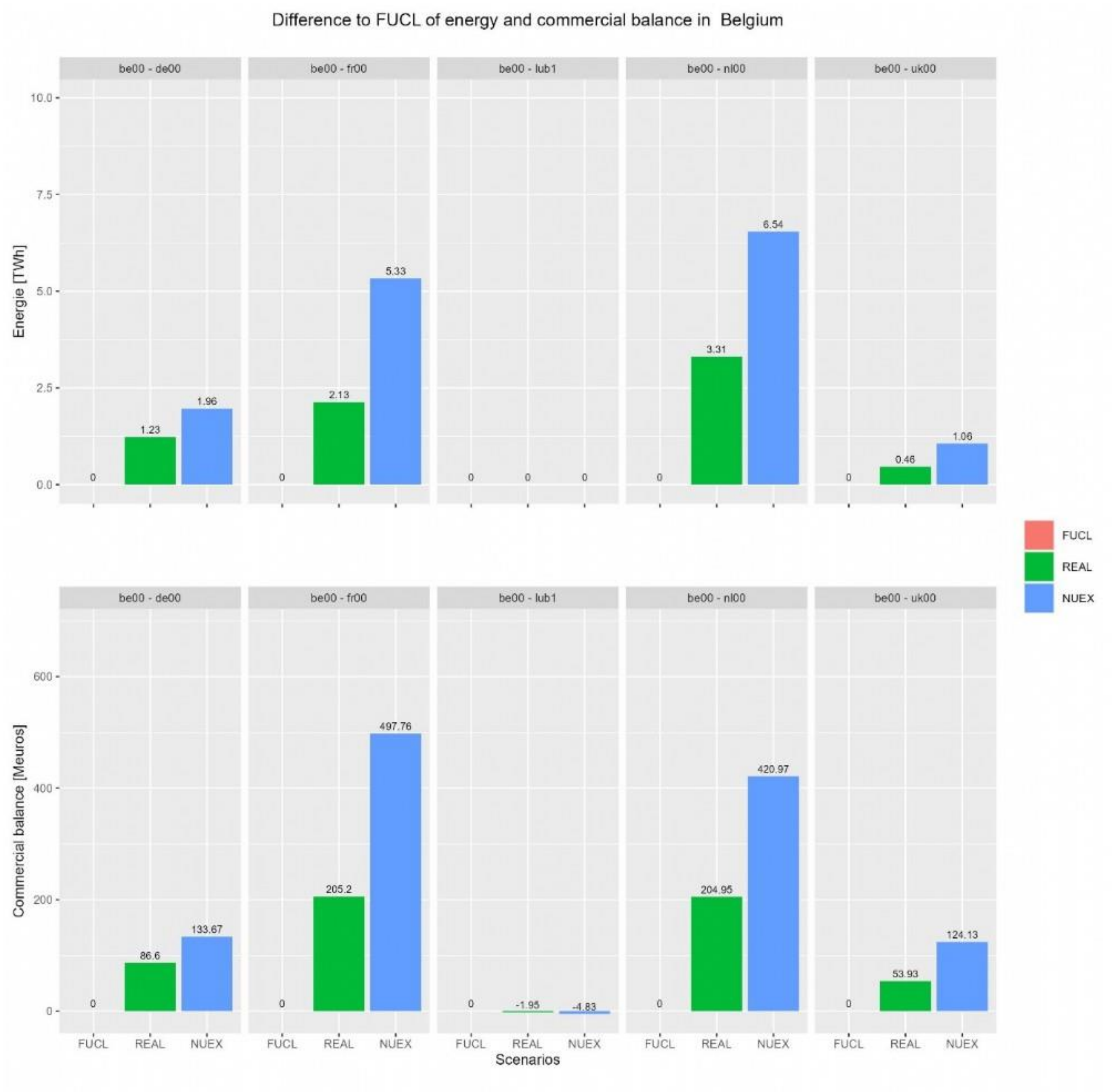
It depicts the difference in CO2 emissions compared to our benchmark scenario, FUCL.The x-axis represents the absolute difference in CO2 emissions (TCO2eq) and the y-axis indicates the ID of the most impacted countries. Additionally, we included the related weight of this difference as a percentage at the end of each bar

Difference in gas consumption compared to FUCL in TWh and in percentage



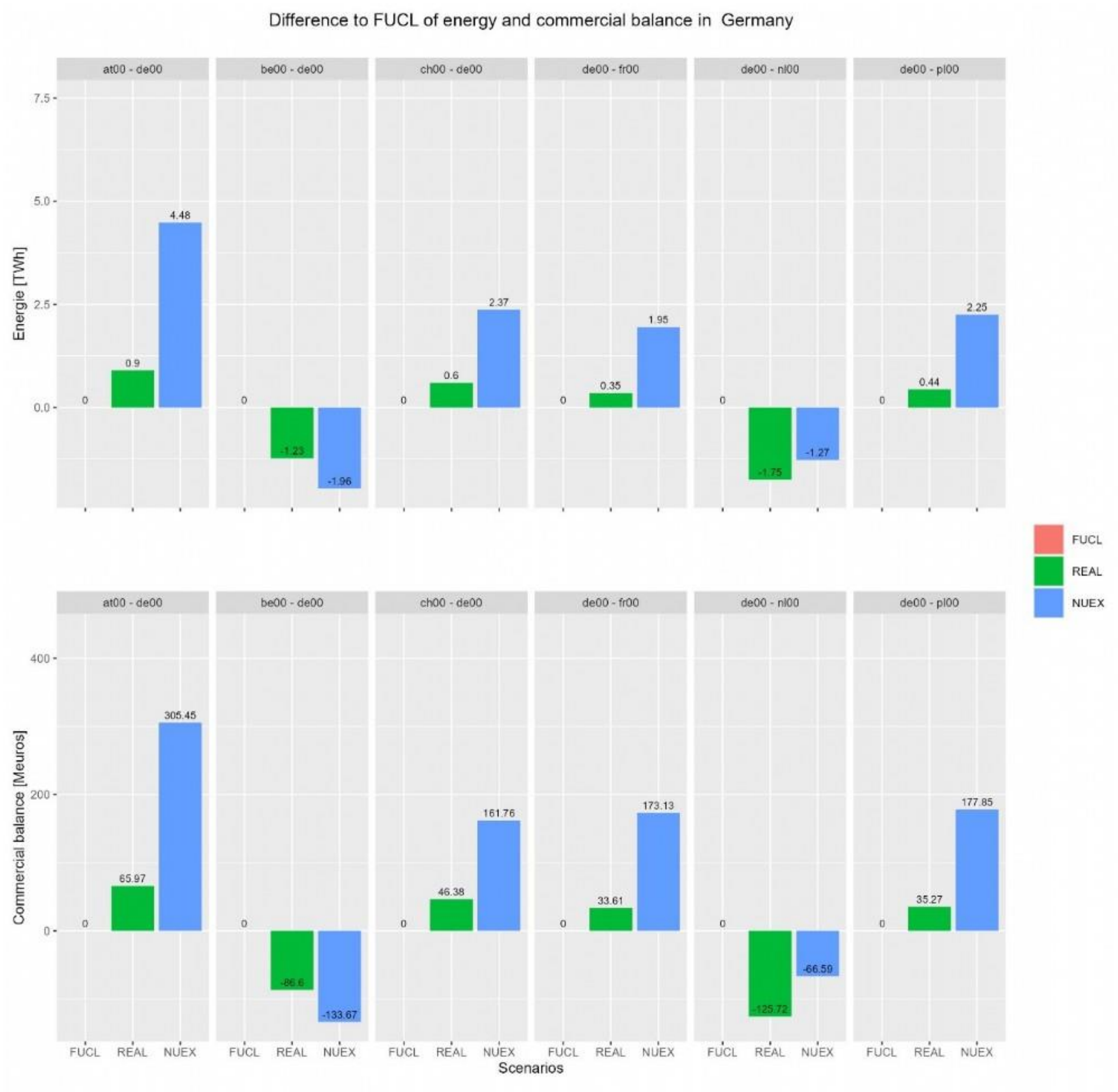
It depicts the difference in gas consumption compared to our benchmark scenario, FUCL. The x-axis represents the absolute difference in gas consumption (TWh) and the y-axis indicates the ID of the most impacted countries. Additionally, we included the related weight of this difference as a percentage at the end of each bar

Difference to FUCL scenario in energy (TWh) and commercial balance (Meuros) for Belgium



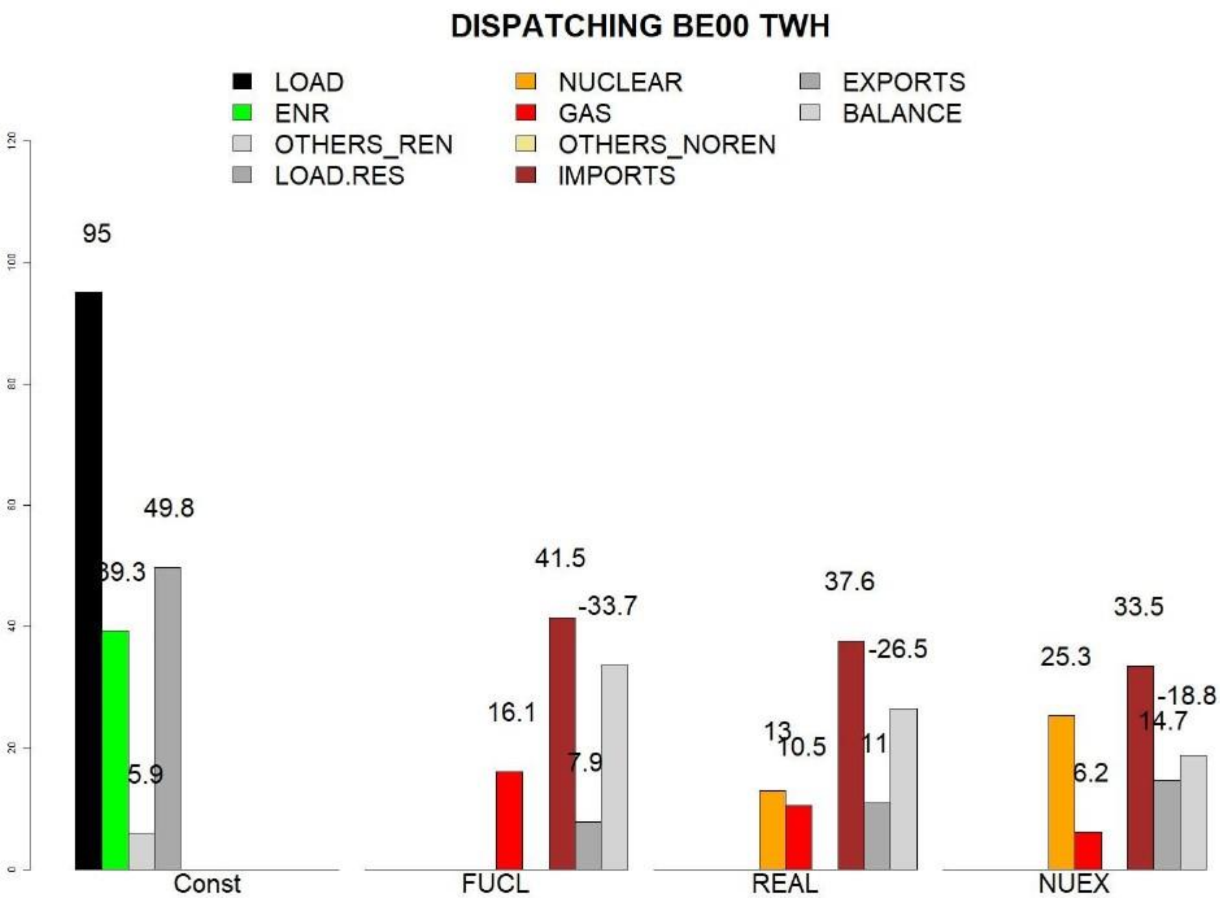
illustrates that the nuclear reactors extension in the REAL and NUEX scenarios mostly affects the exchange between France and the Netherlands with Belgium. First, the presence of nuclear plants in Belgium leads to a reduction in its imports from France, which alters the French nuclear energy export market. Second, as the exchange deviation between Belgium and the Netherlands is five times bigger than the one with Germany, we understand that the line de00-be00 has saturation problems and that Germany imports Belgium's surplus through the Netherlands

Difference to FUCL scenario in energy (TWh) and commercial balance (Meuros) for Germany



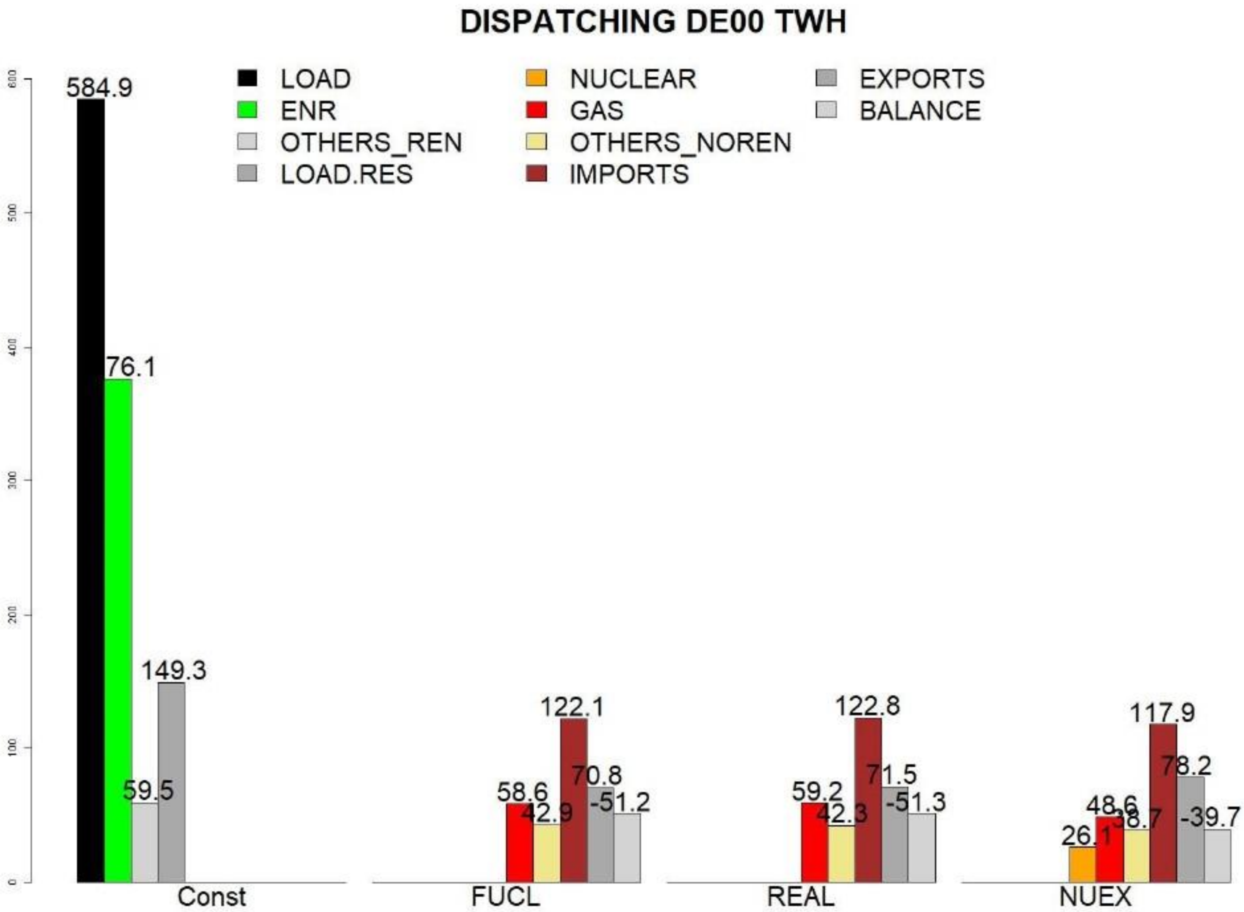
Except for the Netherlands and Belgium, the trade difference between REAL and FUCL scenario are all less than 1TWh (see green bar). This can be explained as the REAL scenario includes more nuclear capacity only in Belgium, so the effects in other countries, except in Belgium and in the Netherlands, are marginal effects caused possibly by the equilibrium of the system. The exchange difference with Belgium in REAL scenario shows that its nuclear prolongation policy would influence the German operating power planning through the reduction of gas and coal power plants activation. A trend appears when Germany mix has more capacity (NUEX), as extra energy is coming from Belgium and the Netherlands. Compared to our benchmark scenario, even in the NUEX scenario it is attractive for Germany to import electricity produced in Belgium, be it directly or through the Netherlands. By doing so, it can increase its exports (or reduce its imports) from its other neighbouring countries, most notably to Austria, and in a smaller proportion to Switzerland and Poland. That confirms the sensitivity to the energy policy of Belgium and Germany

Electricity dispatching in TWh, Belgium



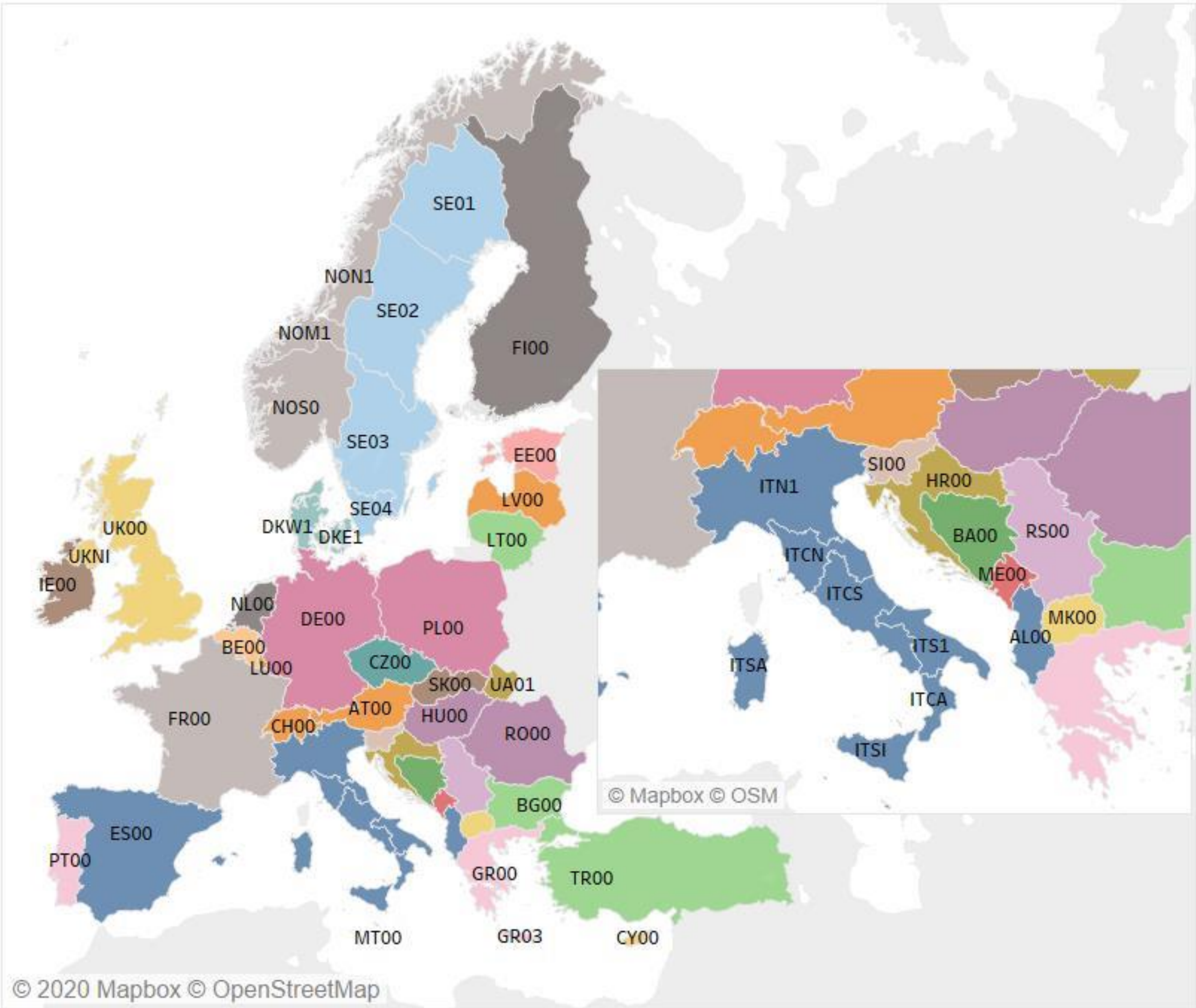
the first group of columns, "Const", features components of dispatching that are constant regardless of the scenario; they are total demand (LOAD), renewable energy production (ENR and OTHERS_REN), and residual demand (LOAD RES). In addition, the three following groups of columns represent the power production of nuclear, gas and grouped others non-renewables (Hard coal, lignite and fuel oil and DSR) technologies, the imports, the exports and the net balance for each scenario. For display reasons, we set a positive sign to imports and exports For display reasons, the positive digit means a net export country and negative a net import country

Electricity dispatching in TWh, Germany



In Germany, residual demand represents around 25% of total demand. Studying the composition of the mix through the three scenarios, we realize a decrease of the other non-renewable share in the German dispatching thanks to an increase of nuclear energy in Belgium (REAL) or in both, Germany and Belgium (NUEX). Regarding gas, the effect is not proportional to the increase of nuclear power through the scenarios. In the REAL scenario, the gas use change is marginal whereas in the NUEX scenario, there is a considerable gas use drop of 17.1%. If we put these two categories together in the FUCL scenario, they represent up to 68% of the residual demand while, they represent 55.7% in the NUEX scenario. That translates into a decrease of 18% in the use of fossil fuels in the German electric production.

Interconnections. Image taken from ERAA2021.



it deptics the mapping of our model

Hypothesis of nuclear installed capacity in Belgium and Germany for the three scenarios.

Country\Scenario	FUCL	REAL	NUEX
Belgium	0GW	2GW	4GW
Germany	0GW	0GW	4GW

Summary of major changes in Energy crisis scenario when comparing NUEX to FUCL

NUEX compared to FUCL whole system	Gas use for electricity production [TWH]	Lignite use for electricity production [TWH]	CO2 emissions [Mton]	Median marginal price [Euros/MWh]	Marginal technology
Reference costs	-35	-0.7	-5.8	FUCL: 78.4 NUEX: 77.8	GAS
Energy crisis	-21.7	-13.4	-6.5	FUCL: 177.4 NUEX: 176.3	LIGNITE

The first column highlights the fact that the decline in gas use is mainly compensated with lignite and partially with coal use. These modifications in the consumption of fossil fuels reflect the swap in the merit order between gas-based and lignite-based power plants occasioned by the soaring fossil fuels prices, especially gas. In our energy crisis scenario, lignite becomes often the marginal technology, whereas in our reference cost, gas is often the marginal technology. While both Belgium and Germany undergo major mix changes in the NUEX scenario, we looked at Germany given its position as the major economy in Europe *and due to the comprehensive utilization of fossil fuel based technologies within its electricity mix. To corroborate the change of the marginal technology, we calculated Germany's median marginal prices for both states of the world and FUCL and NUEX. These prices feature the shadow costs and confirms the swap of marginal technology as these marginal prices match with marginal costs of gas and lignite, respectively*

[Abstract:0562] OP-131 [Accepted:Oral Presentation] [Energy Modeling » Energy Supply]

Marginal Abatement Cost of Power Sector for Korea's NDC considering Stochastic Approach

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Overview:As the need for global GHG reduction efforts emerged according to the Paris Agreement, Korea announced the 2050 carbon neutrality in December 2020. As a way of reaching carbon neutrality in 2050, the NDC target for 2030 has also been greatly strengthened. Korea being one of the countries that made early adoption of ETS, plans to actively decrease the ratio of free allocation after the 4th phase (2026-2030). To establish a system for stable ETS and to provide reliable policy signals to the market, it is important to show an appropriate forecast of the carbon price. Based on the 3rd phase, 36.9% of the K-ETS allocation belongs to the power sector. For the more, with a low risk of carbon leakage, power sector is likely to face lower free allocation rate at the fastest level. In this context, we analyzed the marginal abatement cost(MAC) that achieves the NDC target by developing an energy system model that reflects the Korean power sector.
Methods:For MAC analysis, we develop a bottom-up energy system model called METER-21(Model for Energy Transition and Emission Reduction-2021), based on GAMS. METER-21 is developed in 192 time slice structure that can specify seasons, weekdays/weekends, and hourly-base time zones, with technologies defined at a plant level, which can enable sophisticated long-term optimization analysis of Korean power system. With the model, the deterministic carbon cost for year 2030 is calculated by finding a carbon cost where the cumulative emission curve for every level of carbon cost and the target emission line meets across. To take the uncertainty of fuel prices into account, we calculate stochastic marginal abatement costs according to coal and LNG using Monte Carlo simulation. Additionally, copula function is used to produce random samples of coal and LNG prices considering the correlation between the two.
Results:The MAC achieving the power sector target for 2030 is analyzed to be 41,454.8 KRW/ton and 73,889.7KRW/ton for the 5-year average and 34-year average fuel price, respectively. Since the emission varies depending on the fuel price assumption, the reduction and the carbon cost required to achieve the target also varies depending on the assumption. As shown in Figure 1-a, for less difference between coal and LNG prices, the MAC for achieving the target comes to 41,454.8/ton. On the other hand, as shown in Figure 1-b according to the assumption of a 34-year average fuel price with larger gap between coal and LNG prices, the MAC for the 2030 target increases to 73,889.7KRW/ton.
We apply random numbers that consider the correlation between the coal and LNG prices through copula in addition to independent random number generation methods. Figure 2-a and 2-b show the distribution of coal and LNG fuel prices according to independent random number generation methods that follow each distribution, and the distribution of the sample has a low circular shape as shown in Figure 2-c. When extracting random numbers considering the correlation between the two samples through copula, Figure 2-d and 2-e show no significant difference from Figure 2-a and 2-b, respectively. However, we can find that random numbers generated using copula shows a positive correlation between the two fuel prices.
If random numbers are extracted without considering the correlation between coal and LNG prices, the average MAC comes to 76.9 thousand KRW/ton with a standard deviation of 45.6 thousand

KRW/ton. The average stochastic MAC derived through independent fuel price random numbers is higher than the deterministic. When the correlation between coal and LNG prices is unconsidered, a large difference between the two fuel samples may occur more frequently than actual, resulting in an increase in MACs. On the other hand, when random numbers are extracted using Copula function, the average MAC is approximately 75.0 thousand KRW/ton, closer to the deterministic result. With the standard deviation 34.6 thousand KRW/ton, the 95% confidence interval of MAC comes to 7.1 to 142.8 thousand KRW/ton.
Conclusions:According to the target achieving carbon price analysis of the Korean power sector, the cost varies depending on the fuel price, ranging from 41.4 to 73.9 thousand KRW/ton. When stochastic MACs are calculated through Copula, a large range of 7.1 to 142.8 thousand KRW/ton is derived. From this, we can find there is a high degree of uncertainty in coal and LNG fuel prices. In addition, when random numbers are generated through Copula, the range of marginal abatement costs is reduced, making it possible to produce more realistic and accurate marginal abatement costs.
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Keywords: Marginal Abatement Cost, Power Sector, Stochastic Analysis, ETS, Energy Systems Model, Linear Programming

Figure 1. Deterministic Marginal Abatement Cost of 2030

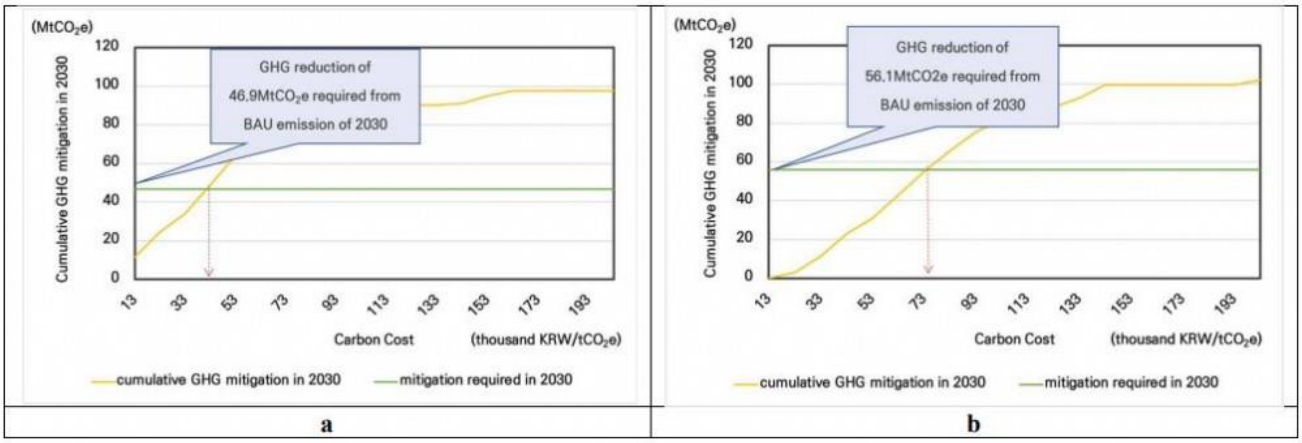

Figure 2. Fuel Price Distribution by Sampling Method

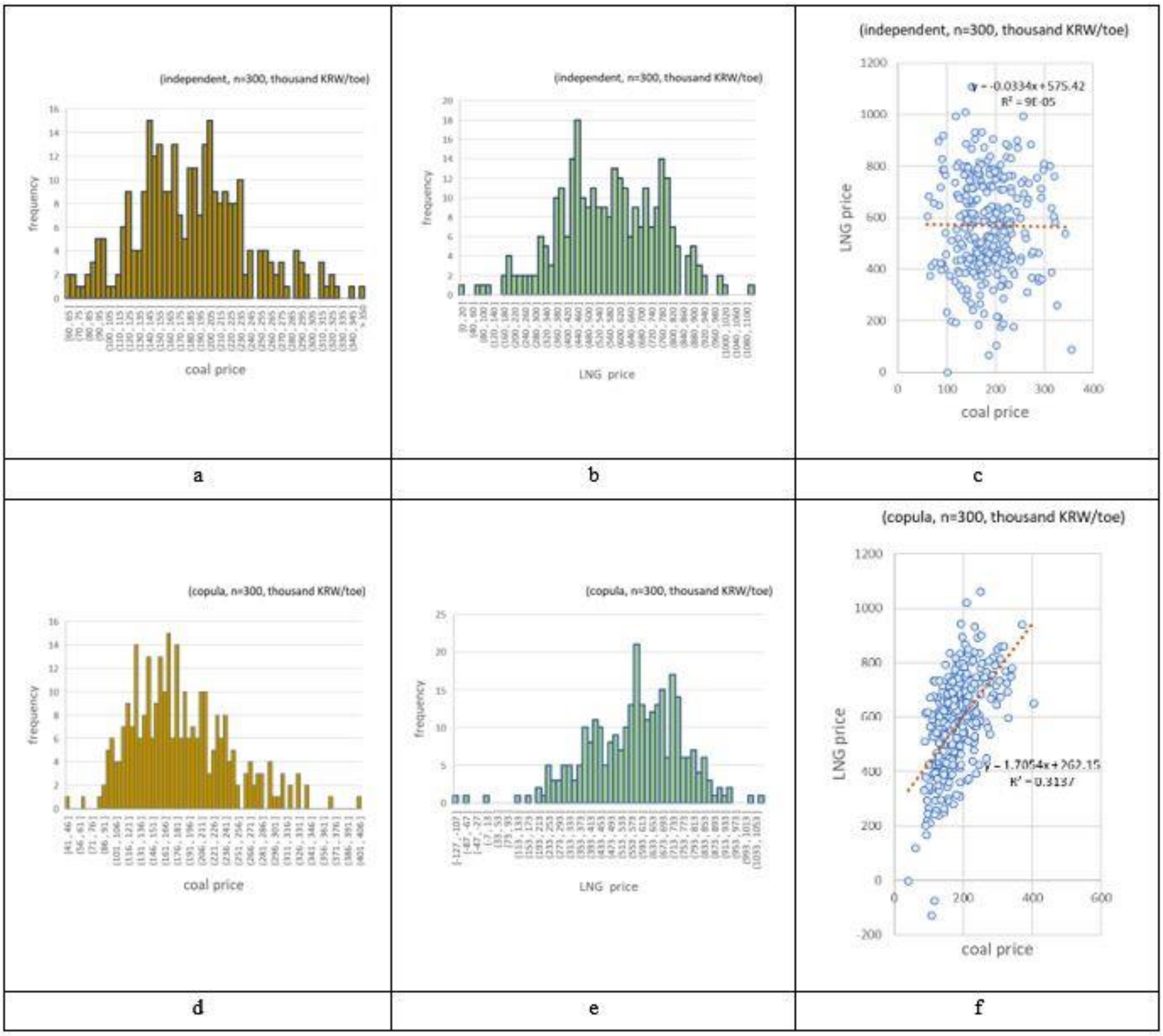

Figure 3. Stochastic Marginal Abatement Cost by Sampling Method

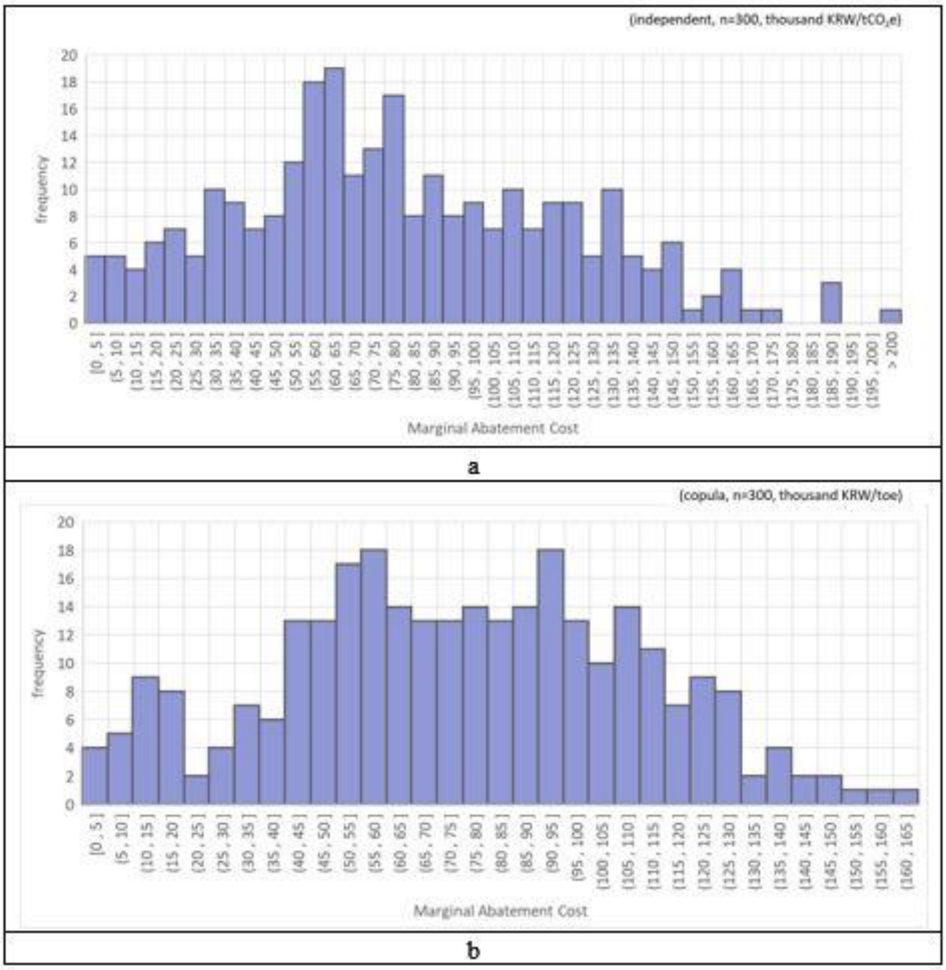

Table 1. Summary of MAC analysis

Analysis	Analysis	Fuel price	Fuel price	Fuel price	Marginal Abatement Cost	Marginal Abatement Cost	Marginal Abatement Cost	Marginal Abatement Cost
Condition(i,*)	Condition(*,j)	Coal (thousand KRW/toe)	LNG (thousand KRW/toe)	difference (thousand KRW/toe)	Average (thousand KRW tCO2e)	Standard deviation (thousand KRW tCO2e)	Number of samples (unit)	95% confidence interval (thousand KRW tCO2e)
Deterministic	Deterministic	-	-	-	73.9	-	-	-
Stochastic	Independent random sampling	185.8 (60.3~367.2)	557.4 (0.3~1,109.0)	371.6 (-269.1~957.8)	76.9	45.6	n=300	-12.6~166.3
Stochastic	Random sampling with copula	188.0 (41.3~403.4)	566.1 (-125.9~1,060.2)	378.1 (-234.0~811.3)	75.0	34.6	n=300	7.1~142.8

[Abstract:0201] OP-132 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Value of Lost Load estimation for residential sector in South Korea using lost leisure and stated preference method

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Overview:This study examines the lost load value (VoLL) for South Korea's residential sector, incorporating methods to assess both leisure value and stated consumer utility. Unlike industrial sectors with measurable value-added, the residential sector lacks such quantifiable metrics, complicating the evaluation of production loss during outages. To overcome this, the study proposes measuring lost leisure as a substitute. VoLL in the residential sector was measured using the contingent valuation method (CVM) and a time allocation model representing a leisure valuation approach. CVM results indicated higher VoLL compared to existing literature on the manufacturing sector. However, assessing the value of lost leisure using labor market data surpassed CVM results significantly, suggesting a potential underestimation of the implicit utility decrease from outages compared to leisure value derived from labor market wages. Adjustments to CVM-based VoLL estimates may be necessary to accurately reflect lost leisure during outages. Given the proportional relationship between CVM-based VoLL and retail electricity prices, modifying cost compensation in the Korean electricity market could lead to an increase in CVM-based VoLL.
Methods:This study employs two methodologies. Initially, the VoLL of the residential sector is estimated using the Contingent Valuation Methodology (CVM) as a stated preference method. The CVM methodology utilizes the Double-Bounded Dichotomous Choice (DBDC) model to ensure robustness in the estimation process (Hanemann, 1984). The DBDC model involves posing elicitation questions up to three times during the survey process and ensures robustness by setting the range in the respondent's willingness-to-pay (WTP) question (see Figure 1). Given the difficulty for general respondents to fully comprehend the concept of VoLL, the WTP for an additional payment as a percentage of the monthly electricity bill to prevent power outages is asked. Subsequently, researchers convert the WTP into VoLL (USD/kWh).
Secondly, Becker's (1965) time allocation methodology is employed to estimate VoLL through the leisure cost methodology. This approach gauges the value of leisure that could be lost in the event of a power outage by analyzing people's use of time in the residential sector. To apply this methodology, labor surveys and statistical data are utilized, with time utilization data from the labor panel surveyed in 2014 serving as specific data. Using this information, the study estimates the average leisure time and leisure value in the Korean residential sector.
Results:Following the CVM analysis, the additional monthly electricity charges necessary to prevent power outages were determined to be 8.16%. Factors positively influencing WTP included the possession of essential power facilities, the installation of solar power for homes, and an awareness of power consumption. After converting the CVM results into VoLL using the unit price of electricity and monthly electricity usage time, the VoLL in the Korean residential sector was found to be 2.76 USD/kWh.
In contrast, the VoLL using the leisure cost approach yielded much higher results. Estimating leisure time by distinguishing between the employed and the unemployed, the leisure time for the employed is approximately 3.5 hours per day, while that for the unemployed is approximately 6.49 hours. For employed individuals, the hourly leisure value is converted into an hourly wage, while for the unemployed, it is assumed to be half that amount. Based on this, the estimated leisure cost-based VoLL was derived to be approximately 5.78 USD/kWh.
Conclusions:In summary, the Value of Lost Load (VoLL) in the residential sector was estimated using two methodologies, resulting in a significant gap, with CVM yielding 2.76 USD/kWh and the leisure cost approach showing 5.78 USD/kWh. In Korea, there is a growing need to introduce VoLL as a standard for long-term power infrastructure investment. However, further research is required to establish VoLL values for benchmarking purposes. Given the disparity between the estimates in this study, determining the accuracy of either value is challenging.

Nevertheless, when comparing VoLL (1.30 USD/kWh) based on the production function of the manufacturing sector, as found in existing study of Jin et al. (2023) focusing on the manufacturing industry, it suggests that the added value produced per hour is equivalent to the hourly wage in Korea's labor market. This implies that the hourly wage might exceed the production value. Consequently, it can be argued that VoLL using the leisure cost approach has a high likelihood of overestimation.

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Keywords: Value of lost load, Residential sector, Outage, Contingent valuation, Leisure cost

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[Abstract:0212] OP-133 [Accepted:Oral Presentation] [Electricity » Storage]

Profitability of price-maker batteries in day-ahead electricity markets

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Overview:In order to reduce the absolute levels of carbon emissions, governments are promoting the development and use of renewable energy sources like solar Photovoltaic (PV) and wind electricity. However, the growth in renewable electricity sources is not sufficient to reduce carbon emissions. As the production of solar panels and wind turbines depends, unlike fossil-fueled power plants, on meteorological conditions, non-intermittent power plants might still remain necessary to balance supply and demand. Therefore, the attention is increasingly going to ways to store electricity, like batteries. Recently, the Dutch transmission system operator Tennet envisioned the installation of 9 gigawatts (GW) of batteries in the Netherlands by 2030, reflecting a strategic commitment to bolstering battery energy storage (TenneT, 2023).
Battery storage operators can generate profits by a process known as energy arbitrage. During periods of low electricity demand and/or overproduction of renewable sources, electricity prices will be low and batteries charge by storing electricity. Subsequently, during periods with high demand, the electricity price is high, and the battery is discharged, allowing the battery storage operator to sell electricity at a premium. We shed light on the profitability of batteries that use energy arbitrage and operate in European day-ahead electricity markets.
Related studies investigating the profitability of batteries in European day-ahead electricity markets, like the works Martins and Miles (2021); Komorowska et al. (2022) and Komorowska and Olczak (2023), take electricity prices as given. However, adding batteries to the electricity system affects demand and supply for electricity, potentially changing electricity prices, and thus the profitability of battery systems. We take into account these effects of batteries on electricity prices.
Methods:In order to make a revenue with energy arbitrage in the day-ahead market, battery storage

operators must buy when the electricity price is low, and sell when the electricity price is high. However, determining when to buy and sell electricity is not straightforward, as future electricity prices are not known. Moreover, the effect of the battery storage operators on electricity prices should be taken into account.

In our paper, we use a partial hourly equilibrium model of a day-ahead electricity market, with profit maximizing producers and utility maximizing consumers who both respond to market prices. By modelling the operations of the battery storage operator, we can account for the pricing implications stemming from the operations of the storage operator.

This model is calibrated on the Dutch day-ahead electricity market situation in 2023 (in terms of prices and market size), using data from the European Power Exchange (EPEX). We analyze the profitability of investments in battery storage systems with sizes ranging from 0.1 GW to 9 GW, to show the effect of having such an installed capacity of batteries in the Dutch electricity system.

The model analysis is done for a number of scenarios. First of all we look backwards, and calculate the profitability of battery systems in historic electricity markets. Then, we consider the effects of having more renewable electricity, increasing electricity demand, and higher carbon prices.

To investigate the impact of uncertainty regarding future prices, we model and compare four control strategies, that determine the timing and quantity of electricity bought and sold. For the first strategy, we assume that the storage operator has perfect knowledge of future prices. The revenues of this strategy provide an upperbound for the revenues of a storage operator. Secondly, we evaluate a strategy that is defined on two pre-defined thresholds. When the electricity price falls below the lower threshold, electricity is bought. Subsequently, when the electricity price exceeds the higher threshold, electricity is sold. The third strategy, which is similar as a strategy used by Komorowska et al. (2022), uses predefined hours to buy and sell electricity, with the selection of these hours based on historical electricity prices. These two strategies are simpler than the first strategy, as knowledge of future electricity prices is less relevant. Finally, we compare a control strategy that predicts future electricity prices. Specifically, future prices are assumed to be equal to recent prices.

Results:At the moment of writing, the electricity market model used for the analysis is not completely finished. However, we expect to shows the following results.

First of all, we compare the profitability of the four different control strategies. The first strategy, assuming perfect knowledge of future electricity prices, is expected to give the highest operational profits. It is however not clear which how the other strategies will perform. These results can be compared with the results of Komorowska et al. (2022) and Komorowska and Olczak (2023), who did a similar analysis.

However, where Komorowska et al. (2022) and Komorowska and Olczak (2023) assume electricity prices as given, we explicitly take into account the effects of the buying and selling of the battery storage operator on electricity prices. In this second part of the analysis, we also show how the operational profits depend on the amount of batteries installed. We expect the operational profits to go down as more batteries are getting installed, as the market becomes saturated. However, it is not yet clear how large this effect is, and how the different control strategies are affected.

Last, we show the effects of having more renewables, a higher demand for electricity, or higher carbon prices on the profitability of battery storage operators. These sensitivities all reflect expected developments of future electricity markets, and provide insights in how the profitability of batteries might change in the coming years.

Conclusions:In this research, we undertake a novel analysis of the profitability of batteries in the Dutch day-ahead electricity market, incorporating a crucial factor often overlooked in existing studies—the impact of storage operator operations on prices.

Our expected contributions to the field lie in the exploration the operational decisions of storage operators. By investigating different control strategies, we aim to provide valuable insights that can inform investment decisions.

Anticipating our findings, we expect a noteworthy trend: as the installation of batteries becomes more prevalent, the operational profits of battery storage operators are likely to experience a decline. This projection is important for both investors seeking sustainable returns and governments, considering to provide financial support for battery projects.

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Keywords: Battery storage system, Electricity market model, Day-ahead electricity markets

[Page: 134]

[Abstract:0268] OP-134 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Bidding on Combinatorial Electricity Auctions

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Overview:Day-ahead markets are one of the core elements of a liberalized energy system and allow energy to be traded for the next 24 hours in advance. In Europe, it is designed as a combinatorial auction where agents can bid not only on power for single hours but also on bundles of power in different hours by so-called block bids. This allows agents to express their complementarities between hours caused by inter-temporal constraints or quasi-fixed costs. However, it also complicates the bidding decision as the number of bundles feasible to an agent might be exponential regarding the number of hours. As an auctioneer constrains the number of bids by an agent to ensure a tractable market clearing problem, the question arises of which bids to select [1]. In case of a sub-optimal bid selection, agents do not achieve their maximal attainable utility, leading to an overall welfare loss. We take the agent's perspective to study the action design and give decision-support tools to place bids more effectively.
Methods:In the literature on auction design, it is studied which "bidding languages" are suited for agents to express their preferences [2]. We apply those results in the context of the electricity market and use them to explain bidding behavior found in simulations conducted in the engineering literature [3,4]. At the core of those considerations is that agents on electricity markets, like loads, storage systems, and generators, have substitute valuations due to inherent capacity and/or other technical constraints. This makes ungrouped block bids – known as OR bids in auction theory [2] – unsuited bid formats and exclusive groups of block bids – known as XOR bids [2] – the better choice. Subsequently, we study the bidding problem of an agent from a normative perspective and formulate their decision problem as a two-stage stochastic program. The aim of this program is to determine those block bids in an exclusive group that maximizes the expected utility of an agent while respecting the limit on the number of bids set by the auctioneer. By exploiting its mathematical structure (total unimodular constraint matrix), we show that it can be formulated as a linear program. We can use this model to simulate the bidding behavior of three different types of agents: a storage system, a flexible load, and a thermal generator on German day-ahead market data from 2017. This allows us to study the impact of the auctioneer's limit on the number of bids on the agent’s ability to express their preferences accurately.
Finally, we add a theoretical result to those simulation results. Applying ideas from probability theory, we can demonstrate the inherent connection between the auctioneer's upper limit on the number of bids submitted by an agent and the price uncertainty agents face.
Results:The conducted simulations and derived theorems demonstrate the complementary nature between a limit on the number of bids and the agent's price uncertainty. If the price uncertainty is low, a few bids by an agent are sufficient to effectively express their preferences and thus minimize inefficient after-market trading. If the price uncertainty is high, the market operator could increase the limit on the number of bids to allow participants to better hedge against this uncertainty. As the day-ahead market runs daily, price forecasts are pretty accurate. Our simulation results show that agents can effectively bid on the pan-European day-ahead market, thus the welfare loss caused by limit on the number of bids is negligible.

Conclusions:Complementary bidding mechanisms like block bids are getting more popular in European auctions: In addition to the day-ahead market, they are now introduced in the pan-European balancing market MARI. The auctioneer needs to decide on a limit on the number of bids submitted by each agent to keep the winner determination problem (market clearing) tractable. Our work studies the implications of this limit on the bidding behavior of a market participant. Moreover, it provides insights into the discussion on the bid formats used in electricity auctions: block bids as used in Europe or parameter-based bids as used in the US [5]. We advocate combining the parametric bid formats used in the US with the exclusive groups of block bids used in Europe. For resources that can efficiently express their preferences through available parameters, this provides the agent with a compact and straightforward way to describe complex preferences. However, it may be beneficial to use block bids for resources with different or new technology, for agents with synergies between assets, or for agents with unique operating characteristics not reflected in the parameter set. In the US, such agents are currently advised to self-schedule. The risk of selecting a sub-optimal schedule can be reduced by offering multiple different "schedules" via block bids in an exclusive group. As price information is commonly high in electricity markets since they run daily, our work provides a good argument that agents can thus effectively minimize their regret.

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Keywords: Bidding/Auctions, Electricity Market, Stochastic Programming

[Abstract:0288] OP-135 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Can Residential Demand Response Unlock New Potentials in Low Carbon Capacity Markets?

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Overview:Decarbonisation of power systems has led to the integration of a high number of renewable resources; thus, changing significantly the generation portfolio in many countries. For example, in the United Kingdom solar photovoltaic capacity totals 15 GW and generated a record of 5.5 TWh of energy between April to June 2023. However, renewable resources are highly intermittent and variable, and lead to net load variations of increased uncertainty. To maintain system reliability there is a need for sufficient energy, capacity, and flexibility, or often collectively referred to as sufficient resource adequacy. Resource adequacy has become more challenging in the energy transition because of market failures that do not promote adequate investments. Electricity markets are currently designed to dispatch generation based on economic merit order. In this regard, under current market designs zero carbon resources lead to low future electricity prices, as these will be cleared first. Furthermore, regulators impose price caps in energy markets to address potential market power issues that reduce payments to all types of resources, creating the so-called "missing money" problem. One solution to the missing money problem is the introduction of capacity remuneration mechanisms (CRMs). CRMs compensate resources for making capacity available for utilisation, regardless of the extent to which it is operated. In this regard, they provide an additional revenue stream to resources in order to ensure resource adequacy.

Historically, CRMs have typically targeted more conventional resources and have received criticism that even though they are supposed to be technology neutral due to their regulatory framework, e.g., participation rules, they do not promote the participation of demand response (DR) resources. However, an intuitive alternative to building more capacity would be to encourage DR resources. Indeed, in times of scarcity a transmission system operator can identify consumers who are willing to reduce their demand in exchange for financial compensation. Even though the system as well as consumers' benefits from DR have been broadly demonstrated and documented (see, e.g., (N. O'Connell, 2014), (Linvill, 2019)), residential DR that has great potential with the use of heating, refrigerators, air conditioning, electric vehicles and others, has not yet been fully developed.

This paper proposes the use of nonlinear pricing and in particular the priority service pricing scheme to incentivise the participation of residential DR in wholesale markets. In particular, we focus on the benefits of using such a scheme in capacity markets (CMs), which is a popular means of CRM. To this end, we introduce a refined CM product that is more appropriate in a future low carbon power system where investments in DR resources need to be incentivised by CMs.
Methods:This paper uses a multi-faceted approach. Initially, it provides a comprehensive overview of the benefits of DR participation in wholesale markets, setting the stage for a deeper investigation. Subsequently, it delves into the specific barriers that residential consumers face in engaging with DR programs, with a particular focus on CMs. This analysis is crucial for identifying and addressing the impediments to effective residential DR integration. To further this objective, the paper introduces and assesses the potential of nonlinear pricing schemes, specifically priority and multilevel demand service pricing, as mechanisms to enhance the adoption of residential DR in the capacity market. The paper then tests the proposed approach under two paradigms, i.e., as a supply or a demand resource participating in CM, to explore their suitability. Lastly, we develop simple simulation examples to demonstrate and provide insights on the proposed concepts.
Results:DR resources' participation in wholesale markets offer many benefits to the system as well as to the consumers. To this day, DR participation has been mainly witnessed by large industrial consumers. However, to be able to mitigate the variability and intermittency of renewable-based resources; this needs to be expanded in the residential sector. In this paper we elaborate on the barriers, e.g., market, political, social and technological, that residential consumers need to overcome. By identifying these we are able to propose an appropriate mechanism that can lift these. In particular, we propose the use of priority service pricing, which is a form of nonlinear pricing, that can incentivise the participation of residential DR resources. Priority service pricing offers consumers a menu of reliability and power pairs with different prices. For example, let us consider three pairs: (i) cheap power that can be interrupted frequently; (ii) power that can be interrupted in emergency situations; and (iii) expensive power that cannot be interrupted. Under such a scheme residential customers can submit their bids in wholesale either as a supply or a demand resource. The main advantages of this model are that it is simple enough; utilities control the power-reliability pairs and thus can predict better the consumer behaviour; consumers have control over their consumption and maintain their privacy; and it gives a better indication of the actual value of loss of load (VOLL). The latter is beneficial in increasing market efficiency, since usually VOLL is assumed to be known by the government or a central planner which is usually not the case.

We focus on how this pricing scheme can be implemented in CRMs and in particular capacity markets (CMs). In this regard, we also analyse the shortcomings of current CM designs and propose a set of modifications. Current CM designs involve lack of appropriate locational and temporal signals and do appropriately value the required flexibility, which is exacerbated with the deepening penetration of renewable resources. To this end, we introduce a refined capacity product that is expanded to include location, season as well as flexibility requirements. DR resources can then participate in refined CMs from the "demand side" and be as completive as traditional resources.
Conclusions:The participation of residential DR in CMs with the proposed framework from the "demand side" leads to a capacity demand curve that reflects consumers' willingness to pay for capacity since the value of reliability indicated in the reliability-power pairs is directly indicated. As a result, the reliability level implied by the capacity demand curve requirements and the cost for the required capacity levels are optimal. Moreover, the bids of such costumers include the locational information since capacity capacities in different locations have different impact on reliability differentiating the non uniform VOLL. By moving DR's participation to the demand side of the CM we are avoiding the use of baselines, the need for other customers to fund supply-side compensation,

and distortions from over-compensating demand response at the full energy prices.

However, there are some challenges associated with the implementation of priority pricing in residential DR. For instance, less advantaged consumers might exploit this scheme to reduce their energy consumption and desired reliability levels costs to what they can afford. In such circumstances subsidies need to be offered to preserve equity. Moreover, potential distortions to the retail market could be introduced as a result of lack of information of priority pricing contracts for capacity, thus making the need for information exchange between entities necessary. The advantages of this scheme will be more evident with future consumers, e.g., electric vehicle owners; however, they are still existent for a subset of present consumers. Last, the use of the priority pricing framework is not only limited to capacity markets but may be implemented in all markets to incentivise the participation of residential DR.
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Keywords: electricity market, capacity market, demand response, non-linear pricing

[Abstract:0300] OP-136 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Power Shift: Decarbonization and the New Dynamics of Energy Markets

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Overview:The paper focuses on how electricity market designs must evolve in the context of power sector decarbonization. It covers the impact of increasing renewable energy sources like wind and solar on key market segments, including day-ahead, real-time capacity, and ancillary service markets. The paper highlights the challenges posed by the variability and uncertainty of renewable sources, necessitating enhanced system flexibility. It discusses the need for markets to align incentives and value resources that can accommodate renewable integration, addressing issues like overgeneration, ramping needs, forecast errors, and transmission constraints. The paper suggests that despite the appeal of marginal cost-based dispatch in a high-renewable context, most systems maintain existing market designs while reforming operations and rules to enhance flexibility.This paper examines the profound shifts in energy markets driven by decarbonization. We analyze how the increasing integration of renewable energy sources like wind and solar is transforming the structure and operation of electricity markets. The study delves into the complexities of balancing the variability and unpredictability of renewables, emphasizing the need for enhanced system flexibility. It further discusses how market designs and operational strategies must evolve to accommodate these changes, highlighting the challenges of overgeneration, ramping needs, and transmission constraints. Our findings suggest that while existing market frameworks persist, significant reforms are essential to ensure efficient and reliable operation in a rapidly decarbonizing energy landscape.
Methods:This study employs a mixed-method approach, combining qualitative and quantitative analyses to assess the impact of renewable energy integration on market dynamics. The approach is augmented by policy reviews, offering a holistic view of the evolving energy landscape under

decarbonization pressures.
Results:The analysis reveals significant shifts in energy market operations due to increased renewable penetration. It underscores a rise in market volatility and highlight the emergence of new challenges, such as grid stability and balancing supply with demand. Our findings also show a notable need to increase in investment in grid modernization and energy storage solutions. These results higlight the complexity of transitioning to a more sustainable energy model while maintaining market efficiency and reliability.
Conclusions:The paper encapsulates the dual nature of decarbonization's impact on energy markets, highlighting its challenges and opportunities. It emphasizes the need for a strategic overhaul of market structures and policy frameworks to accommodate better and optimize the integration of renewable energy sources. There is a need for a multi-disciplinary, collaborative approach involving various stakeholders to foster sustainable energy advancements. It stresses the importance of ongoing research in developing advanced market mechanisms and technologies for grid management and energy storage, underlining the need for proactive policy interventions and market reforms. This comprehensive perspective sets a forward-looking agenda for future research and policy-making in the era of the energy transition, aiming to ensure a resilient and sustainable global energy future.
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Keywords: Decarbonization, Renewable Energy, Market Dynamics, Grid Stability, Energy Storage, Policy Innovation

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[Abstract:0403] OP-137 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Economics of grid interconnections: a heterogeneous markets’ design context

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Overview:The exchange of electricity across different countries or jurisdictions requires the existence of interconnections between the grids of the respective parties. These interconnections generally allow bi-directional trade, enabling arbitrage across markets, and their transmission capacity is always limited. This grants interconnection capacity its scarce resource aspect, and as such, the efficient allocation and utilization of this resource falls within the realm of economics, and arises as a central issue in the economics of grid interconnections.

Cross-border interconnections emerged shortly following the initial establishment of the power grid system in Europe in the early 20th century, and rapidly expanded ever since, mostly due to the benefits they provide. The extent of these benefits is largely dependent on the capacity allocation mechanism, which in turn depends on the "market state" of the interconnection. There are three possible interconnection states depending on whether or not the interconnected countries have

deregulated their power markets: both countries' power markets are deregulated, neither of the power markets is deregulated, and one country's power market is deregulated while the other is not. These different market states lead to different rules governing the interconnection and the allocation of its capacity to economic agents.

In the literature, the third state is rarely considered despite its increasing importance as several links of this type are set to be established in the near future (Tunisia - Italy, Egypt - Cyprus - Greece, Algeria - Italy...). Therefore, this investigation attempts to fill this gap by identifying how existing interconnections of this type are regulated, and providing both a theoretical and an empirical analysis of their economics under different operational scenarios.
Methods:The central research question this investigation aims to address is determining which capacity allocation mechanism or arrangement, combined with necessary regulation, leads to the most efficient usage of interconnections involving markets with heterogeneous designs, under different scenarios of possible market structure combinations. Our methodology starts by establishing an intensive review of some existing interconnections involving markets with heterogeneous design across the MENA, North America, and Europe regions, and describing, from a regulatory standpoint, how their transmission capacity is allocated, and to whom.

Then, based on the results from the first step, we appropriately classify these mechanisms into different categories. Subsequently, for each one of these categories, we identify its advantages and possible shortcomings in a comparative approach, and we model how, under assumed rationality, market participants acquire cross-border capacity, and their willingness to pay for it. We also explore the implications for the interconnection operators, whether they are profit maximisers or welfare maximisers. This analysis is conducted under different scenarios of market structure, mainly related to the level of generation provided by Independent Power Producers in the regulated market, and the degree of competition or market concentration in the liberalized market. Finally, for every analysed scenario and allocation category, we investigate the resulting utilization rate of the interconnection, and its ensuing efficiency.
Results:By analysing a set of existing heterogeneous interconnections, We have identified several categories of capacity allocation mechanisms, which are enumerated below:

_Explicit auctions for transmission capacity: As their name suggests, these are stand-alone auctions, independent from energy dispatch, that are established by either markets, or both, to allocate the existing interconnection capacity for a determined period of time and direction. Participants interested in acquiring interconnection capacity to either export or import electricity submit their bids, consisting of a volume-price pair, and transmission rights are granted to the highest paying bidders up to the existing interconnection capacity.

_Long term contracts for firm capacity: These contracts, often signed by the governments and involving the vertically integrated utility of the regulated market and the transmission system operator of the liberalized market, are utilized to transmit a set amount of electricity across the border for a relatively extended amount of time. These are largely used to take advantage of complementarity across interconnected markets. Such contracts may specify a unidirectional electricity flow, often accompanied by financial compensation (e.g. Turkey - Iraq interconnection). Alternatively, they may dictate a bidirectional flow, such as an inter-temporal swap of electricity taking advantage of different seasonal demand peaks across the interconnected markets (e.g. Ontario - Quebec interconnection).

_Implicit auctions: This category refers to those mechanisms that indirectly allocate the interconnection capacity simultaneously with the market clearing in a way that maximises social welfare. In the context of heterogeneous interconnections, they capture the arrangements where the regulated market, either through its utility or other agents, submits bids directly within the wholesale market of its counterpart where the market's dispatch and the cross-border exchange are simultaneously determined by the existing market clearing algorithm (e.g. Morocco - Spain interconnection).

_Virtual market zones: The liberalised market establishes a virtual zone representing the interconnection with the regulated market within which market participants, domestic and foreign, who wish to trade electricity across the border submit their bids. Submitted bids are considered up to the available transmission capacity level in the clearing of the liberalised market's zone, based on which capacity is implicitly allocated. Subsequently, a clearing price is determine for the virtual zone, based on which congestion costs are determined, and rents are paid (e.g. Ontario - Quebec interconnection). Therefore, this category relies on a special form of implicit auctioning.

_Arbitrageur subsidiary: The vertically integrated utility creates a subsidiary company whose sole purpose is to efficiently import and export wholesale electricity across the border by participating in the wholesale market of the deregulated country as an arbitrageur (e.g. British Columbia). This is likewise a special form of implicit auctioning of the capacity. The novelty is from the regulated market's perspective.

Our research is ongoing, we are still investigating how other similar interconnections operate with the aim of identifying additional categories of capacity allocation in such contexts. Likewise, our theoretical analysis is underway and is not included in this abstract.
Conclusions:The different capacity allocation mechanisms in heterogeneous interconnections can broadly be classified within the three families of bilateral contracts, explicit auctions, and implicit auctions. The subcategories within each family are largely set by the different ways these mechanisms can be arranged in this context, both from the regulated and the deregulated markets' perspectives, such as to whom the capacity is allocated, how are cross border bids integrated in the deregulated market's clearing etc...

These mechanisms are largely defined by the underlying characteristics of the interconnected markets, and how they compliment each other. For mechanisms involving implicit auctions, they are generally dependent on the existing market clearing rules of the liberalized market, and its transmission capacity allocation mechanism governing potential other interconnections it holds with distinct deregulated markets. That is, in most cases, the capacity allocation approach with the regulated market is a second thought, and an adaptation to how the liberalized market allocates its homogeneous interconnections' capacity. This conclusion may explain one of the reasons why these heterogeneous interconnections usually display a significantly lower degree of usage compared to the ones solely involving liberalized markets.
References:We have not included any reference in this abstract. References will be included later on once we submit the working paper.

Keywords: Cross border grid interconnections, Cross jurisdiction interties, Power market regulation, Electricity markets, Electricity industry.

AuthorToEditor: Two points to note: This paper is still a work in progress and is currently in an early stage. The results we have included in the abstract are some early insights from our investigation. Nonetheless, the paper is advancing promptly, and should be almost completed by the conference date. I, Anas Damoun, am affiliated with both the University of the Basque Country as a research fellow, and with the Oxford Institute for Energy Studies as a visiting doctoral research fellow. There was no option to include both affiliations in the submission, I therefore included myself as an author twice, each entry with one of the affilitations. Please take this into account. Regards, Anas

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[Abstract:0439] OP-138 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Benchmarking operational and quality of service parameters for electricity distribution utilities: A three-stage data envelopment analysis approach

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Overview:Reform and restructuring of the Indian power sector has evolved through phases, with an aim to improve operational and financial performance [1], [2] and [3], and encourage private investment [4]. In the first phase, the sector was opened for private and foreign investment, the State Electricity Boards were unbundled and independent regulatory institutions were established at the central as well as state levels. In the second phase, enactment of the Electricity Act, 2003, led to market reforms and greater regulatory coherence in the sector [5]. Even after two decades of restructuring and regulatory reforms in the Indian power sector, the financial health of the sector continues to hinge upon the operational and financial performance of the electricity distribution segment. The regulatory framework for tariff determination for the distribution segment is largely modelled around cost-of-service regulation with in-built targets for performance improvement [6]. The prudency check while approving the various cost of distribution utilities lacks a benchmarking approach wherein the performance targets, including incentives thereof are reflected in the tariff determined for the electricity distribution and supply. Issues like poor financial health of distribution companies, poor service quality and electricity thefts are still prevalent in the sector [7]. Overall AT&C losses for distribution utilities declined from 22.32% in 2020-21 to 17.27% in 2021-22 [8], after continued initiatives to reinvigorate the sector. As on 31st December, 2023, the total dues to generating companies by distribution companies stands at Rs 70,723.88 crore [9]. Distribution utilities differ in terms of costs, quality of supply, customer categories, network characteristics and other aspects, which affect their efficiency [10]. The difference in pace of improvement in operational and financial performance as well as the quality-of-service for the consumers across different distribution utilities needs to be analysed. Thus, it will be interesting to compare the efficiency of distribution utilities by specifically incorporating quality-of-service indicators, which have been neglected in the previous studies analysing performance of distribution utilities for the case of India.
Methods:Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) have been extensively employed for efficiency evaluation of electricity distribution utilities in different countries [10], [11]. In the present study, operational model with and without quality-of-service parameters has been developed. Three-stage DEA methodology[12] has been used to measure and compare efficiencies of 42 unbundled electricity distribution utilities in the operational model and 19 of them in the operational with quality-of-service model between 2015-16 to 2019-20. For measuring the operational efficiency four inputs, namely, length of low voltage power lines (in km), length of high voltage power lines (in km), distribution transformation capacity (in MVA), operational expenditure (in Rs crores) and three outputs, viz. gross energy sold (in MU), number of customers and transmission and distribution (T&D) losses (in %), where T&D losses is treated as undesirable output. Additionally, two quality of service determinants, namely, frequency of interruption (SAIFI) and duration of interruption (SAIDI) are used as undesired outputs in the second model. Environmental variables considered are years of reform, customer structure and ownership of utilities.
Results:The relative efficiency scores of the operational model varies from 0.48 to 1. The electricity distribution utilities with least efficiency scores are from the same state. The private utilities are the best performers which advocates the reason behind the privatization of utilities to improve their operational performance. The relative efficiency scores of the second model in which operational with quality-of-service parameters are taken, varies from 0.60 to 1. The utilities with lowest efficiency scores in the second model are same as in the first model. The coefficient of customer structure is negative and significant in both the models which signifies that efficiency increases with decrease in percentage of electricity sold to domestic and agricultural consumers. The coefficient of ownership is also negative and statistically significant, implying that private utilities are better performers.
Conclusions:The government has been taking various steps and infusing capital to improve the condition of the DISCOMs but the improvement in the condition of the distribution utilities is not as per expectation. The performance evaluation of the distribution utilities can be used to incentivize best practices and serve as a benchmark to ensure competition among the companies. The results obtained from this study would be helpful for policymakers, regulators and management of utilities to identify determinants of inefficiency and design of better strategies to improve the operational efficiency and quality of service for end consumers. This study uses a novel approach to measure and compare operational efficiency with quality-of-service parameters for only unbundled distribution utilities.
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Keywords: Indian electricity distribution, three-stage DEA, performance analysis, benchmarking

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Cost evolution of smart electricity meters: Deciphering two decades of deployment history

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Overview:Smart electricity meters are often viewed as a foundational technology for power grids that use digital technologies, sensors and software to better match electricity supply and demand while minimizing costs ("smart grids"). For this reason, public sector investments since the early 2000s have supported the rapid expansion of advanced metering infrastructure globally (Sovacool, 2021). However, while the cost evolution of other technologies has been studied (Nykvist 2015, Kavlak 2018, Eash-Gates 2020, Klemun 2023), little is known about trends in the deployment costs of smart meter programs, including the role of hardware- and non-hardware-related price drivers and technology characteristics. Here, we construct a database of smart meter rollout costs in 30 countries, covering the period 2000-2022 and a total of 110 million installed meters, and examine cost drivers and underlying changes in technology and market size. We find that per-meter costs differ significantly and consistently across countries, with no consistent cost decrease over time. Some of the persistent cost variation is explained by the non-hardware costs ("soft costs") of installation, system integration, and business process management, which may have slowed overall cost declines. While years with larger global deployment volumes achieve lower estimated per-meter costs, economies of scale effects at the level of individual rollouts are limited.
Methods:We collect cost data from project reports, cost-benefit analyses, and meter supplier websites, covering the academic, business and government literature. Overall, our dataset contains approximately 250 unique entries representing different cost components of smart meter rollouts. We utilize this data and linear regressions to study relationships between deployment years, location, market size, and technology characteristics and cost components. We also conduct content analysis to develop a set of hypotheses for the lack of cost reductions with rising cumulative deployment.
Results:We observe significant variation in per-meter project costs across countries and sites in the

same country, with the highest prices exceeding the lowest by a factor of 10-15. Price variations are driven to a similar degree by hardware costs such as meter and communications hardware, and soft costs, such as installation costs, business process costs, and system integration costs. Overall, despite 20 years of deployment history, recent AMI projects have not been deployed at lower prices than early-stage projects in the 2000s.
In projects with high soft costs, a large fraction of these costs are system integration costs and business process costs. For hardware costs, high-cost projects are difficult to explain due to the lack of cost disaggregation in original and secondary data sources. However, meter price data from supplier websites suggests that meter accuracy and communications technology choice are influential price drivers.
Economies of scale at the rollout level appear to have a minimal effect on per-meter costs. While larger meter rollouts exhibit lower hardware prices, soft costs do not decrease with larger per-project meter counts. Beyond the roll-out level, we observe a relationship between per-meter costs and annual global market size, with lower per-meter costs observed in years with larger total meter rollouts. However, this relationship does not correspond to a decline in per-meter costs over time, as the size of the global smart meter market has fluctuated.
We use content analysis to better understand the circumstances of individual rollouts and develop a set of hypotheses about the reasons for the lack of cost reduction. First, many smart meter projects were part of publicly funded demonstration programs. These projects involved many goals related to showcasing and testing AMI capabilities, with cost efficiency as a secondary goal. Second, as mentioned above, the global smart meter market did not grow consistently and is fragmented (e.g., domestic suppliers are often favoured due to privacy concerns). These factors may have limited opportunities for experience accumulation and knowledge transfer in global supply chains.
Also important is the role of project-specific, customized system integration efforts. Many AMI projects require extensive labor inputs to establish connections between databases and data management systems, including systems used for billing, outage management, and theft detection. Efforts to enable seamless communication involve extensive preparation, testing, validation, and communication between different project stakeholders (utilities, vendors, regulators, consultants). This issue is complicated by a large number of stakeholders, motivated by the exploratory nature of many AMI projects and the lack of in-house technical expertise. Contrary to other domains like electricity supply (e.g., photovoltaics) and aerospace (e.g., engine control systems), few companies have emerged in the AMI market that provide systems integration as a consolidated service. For example, while solar PV integrators offer every solar-related service except component manufacturing, comparable companies that integrate AMI components, knowledge, and skills, do not exist in the smart meter market.
Conclusions:Smart electricity meters exhibit a cost trajectory that is different from other technologies deployed in clean energy transitions; they also do not mirror the rapid performance improvements observed in the ICT sector at large. While the costs of solar PV, wind turbines, and batteries have trended downwards, per-meter AMI project costs show no clear temporal trend and continue to vary significantly across and within countries. Large contributions of soft costs to total project costs are among the likely reasons for this variation and cost stagnation, considering that these costs have slowed cost declines in other technologies (Eash-Gates 2020, Klemun 2023). Given the anticipated growth in smart grid projects, which are technological relatives of AMI projects, our work highlights the need to better monitor system integration and other customization-related costs, and identify opportunities for standardization and integrator business development.
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Keywords: smart meters, technology cost evolution, smart grids, advanced metering infrastructure, electricity metering

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An incentive based regulatory framework for regulated tariff determination of electricity generating plants

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Overview:India has a regulated tariff environment for generation, transmission, and distribution segment of the power sector, where distribution utilities procure about 85% of this regulated generation tariff to sell it to the final consumers. The Electricity Act (EA) 2003, Tariff Policy 2006, Tariff Policy 2016, and relevant tariff regulations of the respective electricity regulatory commissions sets out the framework for tariff determination for generating plants. As per Section 61 of the EA 2003, the terms and conditions for tariff determination for generation and transmission set out by the federal commission, i.e., Central Electricity Regulatory Commission (CERC), would be the guiding principles for the determination of such tariff by the State Electricity Regulatory Commissions (SERCs) and hence this motivates us to analyse the regulations at the federal level [1]. This paper reviews the evolution of regulated tariff determination framework for the electricity generation sector, particularly those for the inter-state generating plants governed by CERC. The journey for principles for tariff determination has evolved from fully cost based recovery under the vertically integrated State Electricity Boards (SEBs). Subsequent to the introduction of electricity regulatory commissions, the adopted tariff framework was based on cost of service (CoS) regulation which allowed for recovery of prudently incurred cost. Over a period of time specifically with the introduction of Multi Year Tariff (MYT) framework the regulatory commissions have adopted approach to set out performance benchmark over the control period for the determination of tariff [2][3]. The normative CoS approach to regulation with prudency check did not provide sufficient incentive for cost reduction. The adopted approach allows for cost recovery based on norms which themselves are decided based on the actual historical costs. The paper analyses the generation cost profiles of 20 inter-state thermal generating plants across various sub-heads including capital recovery, Operation & Maintenance (O&M) expenditure, depreciation, interest on loan and interest on working capital and evaluates the interplay between the norms for determination of regulated tariff for generation and the actual cost incurred by the generators across identified sub-heads. This paper sets out to answer three questions.
(i) Is there a reasonable reduction in the cost of generation, even after adjusting for cost inflation across various individual cost heads?
(ii) Are there incentives and how the incentives have evolved over the various control periods of MYT regulation??
(iii) Have the incentive/ penalty structure been able to bring about improvement in cost reduction or improvement in operational parameters??
Finally, the scope of this paper is to review the existing norms and suggest an approach for designing incentive based norm for MYT framework to promote efficient operation of electricity generating plants.
Methods:The methodological approach involves a systematic review of evolution of regulated tariff framework for electricity generating plants across 3 tariff periods i.e., 2009-14, 2014-19 and 2019-

24. This review specifically addresses the extent to which regulated entities can recover their cost relative to the norms. Generation cost profiles across various tariff sub-heads has been evaluated (after adjusting for inflation) to follow the trajectory of actual costs across the years. Further evaluation of incentive/ penalty structure was done across the three MYT regimes. The econometric analysis reveals the impact of incentive/ penalty on generation cost reduction and/ or performance improvement considering any other external factors e.g., vintage, etc.
The tariff regulation framework has evolved through various existing approaches like rate of return, sliding scale mechanism, yardstick regulation, RPI-X with price and revenue cap, etc. At present Ofgem has moved a step ahead of earlier benchmarking practices by introducing RIIO-1 (Revenue = Incentives + Innovation + Outputs) model in 2010 and then RIIO-2 in 2020 for the network tariff [4][5].
Looking at the major problem of information asymmetry, Chikkatur et. al (2007) proposed three types of benchmark norms i.e., revised performance benchmark, relative performance incentive and self-improvement incentive calculated based on median heat rates of all category group of generating plants calculated separately which is aligned with yardstick regulation; while Poudineh and Jamasb (2016) introduced "no impact efficiency" concept as a revenue neutral efficiency effect of investments under cost benchmarking for Norwegian electricity distribution companies [6][7][8].
Results:The results highlight the fact that historical performance has been perpetuated in setting the norms for current tariff regime since inception which needs a change. Absence of mandate to report actual costs lead to information asymmetry and reporting of actual costs only in the case of shortfall from the norms, for e.g. wage revision for the case of O&M cost. It is important to note that the norms themselves do not consider any efficiency factor either within a control period or between different control periods. Figure shows the O&M cost norms for various category group of plants across the three MYT periods. The linear increasing graph clearly depicts that there is no such efficiency factor embedded in the norms over the years.
Conclusions:There are incentives in some cases which are possibly sufficient (even higher than required, e.g. ramping), while in some places there is lack of sufficient incentives to achieve more efficient performance benchmarks [9]. Appropriate design of incentives which are targeted towards the key parameters require improvements. The regulatory framework should be based on the norms derived from the benchmark costs factoring efficiency improvement and appropriate incentives for surpassing the norms. The reporting of actual costs to the regulator by the regulated entities should be mandated for each cost heads to avoid information asymmetry [10]. The actuals of O&M should also be reported like the actuals of other parameters are being reported (e.g. capital costs, loan, etc.) and there should not be a differentiated treatment of O&M cost and other cost heads as far as the reporting for the actuals is concerned.
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Keywords: Incentive regulation, performance benchmark, electricity generation, regulated tariff framework

Category group wise normative O&M cost across three control periods

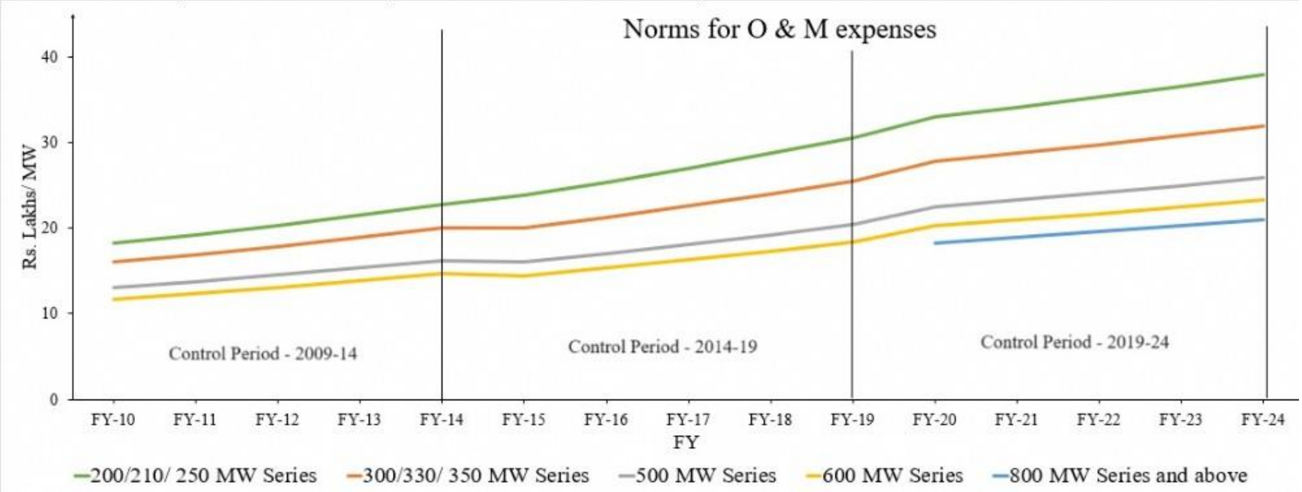

Figure shows the O&M cost norms for various category group of plants across the three MYT periods. The linear increasing graph clearly depicts that there is no such efficiency factor embedded in the norms over the years.

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[Abstract:0478] OP-141 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Alternative clearing mechanisms for regional power markets to deal with national fuel subsidies

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Overview:The design of cross-border electricity markets is influenced by economic, social and political factors that inevitably need to be addressed. One of these factors is energy subsidies, i.e. measures designed to keep electricity prices for final consumers below market levels. Though these fuel subsidies affect competition and short and long-term economic efficiency, as the recent European experience shows, the trend is not towards the removal of these subsidies, but quite the opposite.

In this context, we analyze in this paper how alternative bidding protocols and market clearing methods can deal differently with the presence of national subsidies in regional electricity markets.

This analysis is applied in the context of the Iberian electricity market, where the "Iberian Exception", a temporary fuel subsidy mechanism, was implemented in 2022-23 to mitigate the impact of the invasion of Ukraine on electricity prices.

To conduct the study, a full-scale case study simulation was developed, focusing on the Iberian-French market interaction. The different alternative market clearing designs were modelled with the

aim of assessing their different impacts on the Iberian economic dispatch and cross-border trade with the neighboring French system.
Methods:To carry out the analysis, we simulated the Peninsular and French electricity systems using a two-node short-term cost-minimizing optimization model, that mimics the behavior of a fully competitive spot market, and allows assessing the resulting short-term market prices and economic dispatch at both sides of the interconnector.

Once the model was calibrated to accurately reflect the historical pricing series, we implemented the alternative clearing mechanisms, namely:

• The initial proposal of the Iberian governments for what eventually became the Iberian exception. This proposal consisted of a two-step clearing mechanism similar to what was sometimes referred to in the past as "volume coupling".
• The proposal actually implemented in the "Iberian Exception".
• The alternative clearing mechanism, denoted as "binodal bidding", proposed by Alawad et al. (2022). This market clearing mechanism is based on allowing dual bids with different prices for local sales (which are subsidised) and cross-border sales (unsubsidised). To model this approach, virtual generators were created by duplicating the Iberian subsidized units in the French system. This way, each subsidized Iberian unit is duplicated by an identical virtual generator with the same technical characteristics (capacity, efficiency, etc.) but with different variable costs (i.e. not taking into account any subsidies). The clearing algorithm ensures that the sum of the matched energy quantities of each unit and its virtual duplicate does not exceed the maximum generation capacity of any generating unit in any period.
Results:The paper first analyzes the generation dispatches of both systems for the different cases (see figure 1): (i) the business-as-usual situation (with no subsidies), (ii) the mechanism of the Iberian exception as implemented, (iii) the initially proposed mechanism of the Iberian exception and (iv) the binodal mechanism.

This makes it possible to verify the impact on the operation of generation units in both systems. The paper compares the different market price curves and interconnection flows under each context (see figure 2), which is one of the aspects most affected by the introduction of the mechanisms.
Conclusions:This study provides valuable insights into the complex dynamics of regional electricity markets, highlighting the challenges and potential solutions associated with the implementation of national subsidies. The main findings and implications can be summarized as follows.

The mechanism initially proposed by the Iberian governments ensures that cross-border trade is not affected by national subsidies, but at excessive costs. This approach complicates the execution of the clearing algorithm by requiring a two-step clearing process, which contradicts the European intention to simplify the execution of the algorithm.

As regards the proposed alternative mechanism, it accurately reflects the real cost of production of the peninsular plants on the French market, thus avoiding the inefficient operation of subsidized technologies. In terms of market prices, the mechanism successfully reduces peaks in the Spanish market price while increasing minimum prices in the French market. The proposed alternative mechanism proves to be an attractive and viable option for introducing national subsidies in regional markets, although it has a number of drawbacks that need to be thoroughly investigated to determine its feasibility in a real-world setting.
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Keywords: Regional power markets, fuel subsidies, power trading, unit commitment, economic dispatch.

Figure 1: Economic dispatch and market prices under two different clearing mechanisms

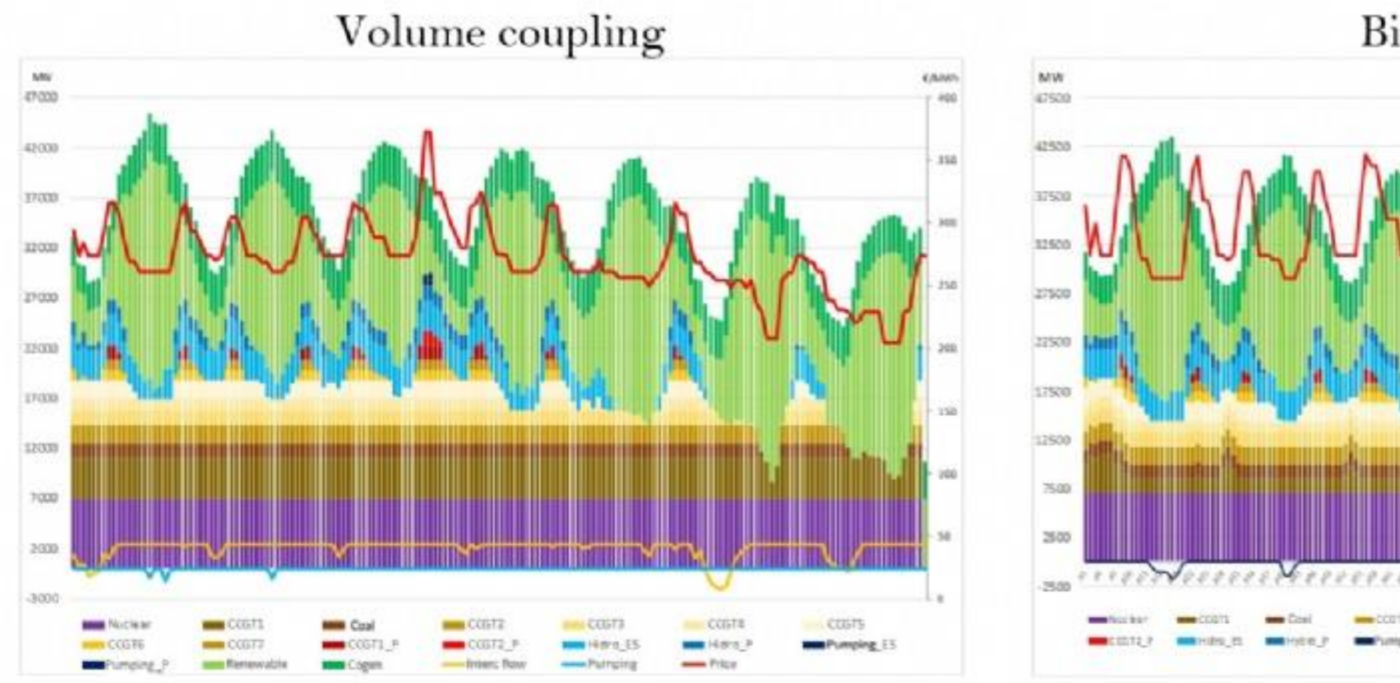

Figure 2: Interconnection flows

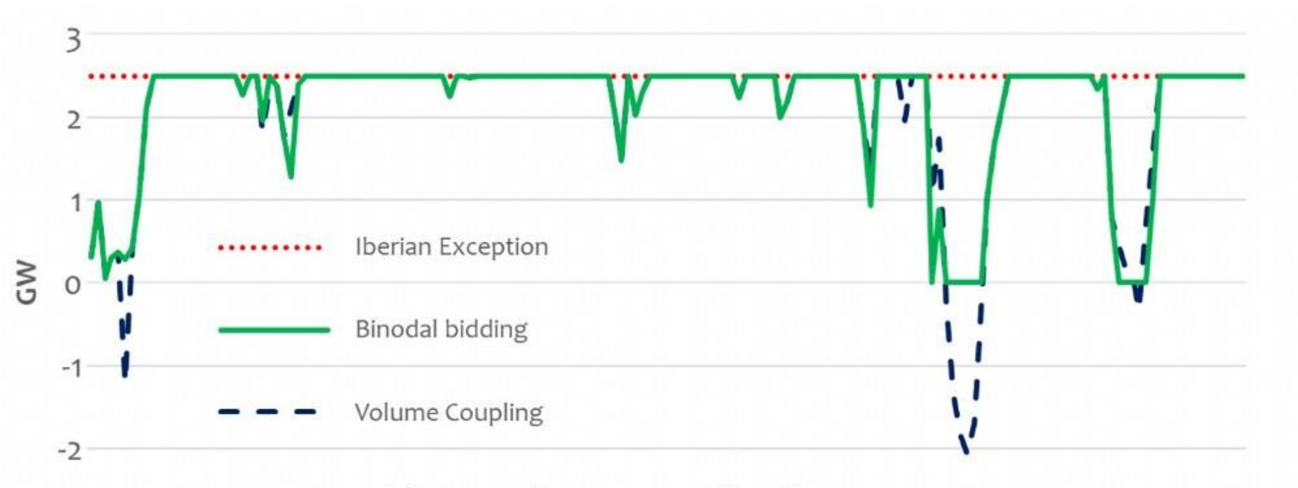

Figure 2. Interconnection flows

It shows the different interconnection flows between Spain and France with different market rules. Positive values refer to a flow from Spain to France.

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[Abstract:0053] OP-142 [Accepted:Oral Presentation] [Energy System Transition » Policy]

Energy Policy in Morocco: Analysis of the National Energy Strategy's Impact on Sustainable Energy Supply and Transformation

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Overview:The MENA region is currently undergoing a transition towards new energy systems, which aligns with the shift towards more democratic forms of government. This transition signifies a successful strategy to diversify from imported fossil fuels to domestically produced renewable energy sources, particularly solar and wind power. This research paper aims to trace the origins of the energy transformation in Morocco and propose a potential pathway towards a sustainable, low-carbon energy system.
Methods:By utilizing the Triple Embeddedness Framework (TEF) developed by Frank W. Geels, the study examines the historical, current, and future dynamics of the energy sector, as well as its interactions with the economic and socio-political contexts.
Results:The analysis identifies a distinct period following the traditional energy policy reliant on imported fossil fuels, which was prevalent around the turn of the century (referred to as "t-1"). In 2009, the introduction of the "National Energy Strategy" marked a top-down approach to incorporate large-scale renewables, primarily solar energy (referred to as "t-0"). Although successful, this approach came with high costs and relatively centralized, state-controlled governance structures,

where the existing "energy village" still dominates. However, with the significant decrease in solar costs, there has been a shift towards a more decentralized approach to renewables, exemplified by projects like the MG-Farm pilot initiatives in the region[1]
Conclusions:This period (referred to as "t+1") requires further support from a favorable institutional environment, such as net metering access to the distribution grid for all decentralized electricity generators. The paper concludes by summarizing ongoing discussions on policy instruments that are crucial for sustaining the success of the low-carbon transformation.
References:1 https://www.leap-re.eu/mg-farm/

Keywords: Morocco, Energy Policy, Renewable Energy, Triple Embeddedness Framework, Top-down Strategy, National Energy plan.

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[Abstract:0259] OP-143 [Accepted:Oral Presentation] [Electricity » Demand]

Assessing Consumer Behavior in The Adoption of Residential Solar PV Systems

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Overview:Over the last couple of decades, the electricity sector has undergone a significant transformation towards a system based on renewable energy sources, undeniably disrupting the traditional energy market. This transformation stem from a series of major changes involving significant shifts in consumer behavior, competition, the production service model, distribution channels, and government policies and regulations. It is projected that with the introduction of various new renewable technologies, the traditional energy business model will undergo a complete transformation or experience significant changes. In the new energy model, consumers, in particular, will play a more active role as relevant actors with new habits. For this reason, in the energy industry, studies on consumer behaviors and decisions as a key player are increasingly gaining importance.
Methods:In this article, we aim to identify the various factors influencing changes in consumer behavior towards distributed generation in the Chilean context. Due to the increasing role of consumers in the energy market, the academic literature has been looking and providing new evidence regarding the impact of different perceptions and constraints influencing consumer behavior in implementing a self-generation system in their homes. To address this question and contribute to this literature, we utilized the Fogg model, which posits that three dimensions—motivation, ability, and opportunity—must be present for a behavior to occur. Each of these dimensions is composed of different factors that allows to identify the consumer's behavior and it subsequent analysis. To apply the Fogg model in the Chilean energy market and understand how it is influenced by consumers, a survey was conducted. The survey includes sociodemographic data and questions associated with each of the three dimensions to better characterize consumer behavior. Among the respondents, three main relevant groups were identified. Group one considers the possibility of acquiring a self-generation system but has not done so yet. Group two has no plans to acquire one in the short term, and finally, group three consists of individuals who already possess a self-generation system. The survey was conducted from December 2021 to February 2022, and considered 362 respondents
Results:As a result of the study, the main factor of motivation, which indicates whether the behavior is desired by the consumer, showed that the dimension of motivation is demonstrated by assuming environmental responsibility. In the dimension of ability, defined as the consumer's capacity to fulfill

the behavior, the data shows a key element that differentiates individuals: the role of initial investment, which when it is considered too high prevents a potential buyer from adopting a self-generation system, despite considering its long-term saving. Regarding the dimension of opportunity, which indicates whether the behavior is facilitated or driven by the environment, consumer interest comes mainly from both groups one and three through mass media. Conclusions:As a result of the study, the main factor of motivation, which indicates whether the behavior is desired by the consumer, showed that the dimension of motivation is demonstrated by assuming environmental responsibility. In the dimension of ability, defined as the consumer's capacity to fulfill the behavior, the data shows a key element that differentiates individuals: the role of initial investment, which when it is considered too high prevents a potential buyer from adopting a self-generation system, despite considering its long-term saving. Regarding the dimension of opportunity, which indicates whether the behavior is facilitated or driven by the environment, consumer interest comes mainly from both groups one and three through mass media.
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Keywords: Renewable energies, Power sector transformation, Consumers, Behavioral changes

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[Abstract:0273] OP-144 [Accepted:Oral Presentation] [Electricity » Demand]

Estimating demand response potentials of domestic appliances

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Overview:Energy systems relying on intermittent renewable electricity generation require increased flexibility, and demand response (DR) has emerged as a promising approach to realize this flexibility. However, the available demand response potential is uncertain as it depends on the willingness to enroll (WtE) into such programs. This contribution quantifies the population-level flexibility potential of residential space and water heating as well as electric vehicles and washing machines using Japanese survey data for 1402 households. The demonstrated method is transferable and can be applied to other contexts with comparable survey data.
Methods:The analysis is based on a survey of Japanese residents, gauging their inclination towards adopting automatic scheduling for key appliances – washing machines, smart water heaters, smart thermostats, and electric vehicles – on a five-point Likert scale. The survey also collected information on socio-demographic and dwelling attributes, resulting in 1415 responses, 1402 of which were kept after screening for response quality.

We employ a four-step approach to estimate the flexibility potential of these appliances based on the participants' Willingness-to-Enroll (WtE). First, statistical tests are used to identify the drivers of WtE. Then, a binomial logistic regression of DR participation against socio-demographic and dwelling characteristics is performed to predict appliance-specific participation probabilities in a demand response program. Leveraging Japanese census data, the results of the regression are scaled to the population level. Finally, the demand response potential is quantified while considering technology-specific ownership rates and demand characteristics, both for the status quo and future scenarios.
Results:The survey results reveal a consistent willingness to enroll (WtE) in demand response programs across all four appliance categories, suggesting that individuals expressing interest in one appliance are likely to do so for others. Notably, approximately 15-20% of respondents express a "Very Likely" willingness, with smart thermostats having the lowest at 13.6% and electric vehicles the highest at 18.8%. When including those who describe themselves as "Likely," these percentages increase to a range of 42% (smart water heaters) to 50.2% (electric vehicles). A substantial portion of respondents opted for the neutral option, with only 16.1% (washing machines) to 19.8% (space heating) indicating an "Unlikely" or "Very Unlikely" inclination towards smart scheduling.
Preliminary one-way ANOVA tests, followed by Tukey's post-hoc test where statistically significant differences were identified, underscore the importance of both dwelling and socio-demographic attributes. Age, gender, employment status, presence of children, household size, dwelling size, dwelling tenure, and dwelling type all demonstrate statistically significant effects on at least one dependent variable. Being 18-29 years old, full-time employed, having children, and residing in a larger household all significantly increase the likelihood of enrollment ($p<0.0001$). These initial findings pave the way for further exploration of additional attributes and rigorous validation in subsequent analyses.
Conclusions:The current results underscore the significant role of dwelling and socio-demographic attributes in shaping the Willingness-to-Enroll. Further statistical analyses will be employed before the selection of attributes for the subsequent regression analysis. The regression outputs will used to scale the WtE estimates up to a population level, followed by a quantification of the total flexibility potential per appliance.
The results of this contribution will be helpful for energy modelers and policymakers in estimating realistic demand response potentials from different appliances and for utilities in targeting their programs. The method's transferability ensures that similar quantitative insights can be derived from survey data elsewhere.
References:Not applicable.

Keywords: Demand-side management, Direct load control, Survey, Flexibility, Willingness-to-Enroll

[Abstract:0132] OP-145 [Accepted:Oral Presentation] [Energy Modeling » Energy Supply]

Flexible Storage Commitment in Energy Management Systems under Uncertainty

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Overview:With the persistent growth of renewable energy assets in energy power systems, optimal management of storage devices during day-ahead unit commitment planning is essential. The non-dispatchable nature of variable renewable energy sources, such as solar and wind, necessitates adequate long-duration energy storage capacity. The goal is to provide ample room to the operators

for charging and discharging the storage devices in order to reduce curtailment and increase the system's reliability against stressful conditions. Energy systems with a significant long-duration energy storage must plan for week-long horizons in their day-ahead unit-commitment model, in order to better utilize this storage source. It is important to explicitly model how storage flexibility is enforced from the unit-commitment decisions to real-time operations, which is a key component in shaping the resilience and sustainability of future energy systems.

There is considerable interest in how to model and incorporate different storage technologies in the planning and real-time operations of energy utilities [1]–[5]. Energy storage systems are essential in providing both energy arbitrage and ancillary services in power systems [6], [7]. Accurate modeling of storage assets is also crucial for expansion planning and operation planning studies [8]. However, the decisions or policies passed from the day-ahead planning stage to the real-time operations do not explore the full potential of storage devices, neither in deterministic nor stochastic unit-commitment models.

Currently, the state-of-charge is committed during day-ahead planning to guarantee sufficient energy stored under stressful conditions. If left uncommitted, real-time operations would deplete all storage devices, due to their minimal cost in myopic sub-hourly operations, and would rarely recharge them because the benefits of higher storage are not accounted for in short-sighted decisions. Nevertheless, in real-time operations, the operator can deviate from the plan to mitigate curtailment and ensure the demand is met under stressful conditions. There is, thus, a disconnection between the real-time flexibility given to the operator and the strict commitment planning in the unit-commitment model.

In a stochastic unit commitment, where uncertainty in future demand and generation is considered, the optimal state-of-charge of the storage units can deviate across the different scenarios. Yet, regardless of the variation across scenarios, storage devices are still committed to a particular hourly pattern for real-time operations. Since different scenarios result in distinct optimal patterns, it is not obvious which commitment should be enforced in real time to accommodate all possible future outcomes. It would also be beneficial to inform the operators of the allowable deviations from the commitment plan during hourly or sub-hourly operations.

In this work, we investigate the pivotal role of flexibility in real-time operations enabled by large, long-duration energy storage. We do so through a day-ahead, week-long unit-commitment framework that is both stochastic and risk-averse. Our key contribution is a novel energy management system comprised of the day-ahead unit-commitment component and a real-time balancing model, which together allow us to explore the effects of different degrees of adhesion to the day-ahead plan for the storage assets. Even if a day-ahead operating plan is optimal, blindly enforcing it in real-time operations negates the immense value of storage assets that derive from their flexibility. On the other hand, an entire disregard of the day-ahead plans (crafted accounting for week-long projections) in real-time operations, results in inefficiencies derived from the myopic nature of the algorithms that typically govern this stage.

We report results for the Duke Energy system—the largest vertically integrated utility in the United States—with a total of 2.14 GW of pumped-hydro capacity. Pumped-hydro storage devices have high efficiency, long-duration energy storage, low environmental impact, and lifecycle durability. They account for 99% of the energy storage installed capacity worldwide [9]. The proposed method allows considering any energy-storage technology but is particularly useful for studying optimal operations of long-duration assets. We compare different modeling approaches and find our method outperforms the current industry approach, reducing the average operational costs and mitigating the system risk due to the uncertainty in the demand and renewables generation. This is particularly true under unexpected conditions, i.e., when the forecasts significantly deviate from the observations, as it has been seen in the past two years due to extreme weather conditions.
Methods:We address storage flexibility in a two-stage stochastic unit commitment problem with weekly storage and risk control, where the formulation uses the conditional value at risk (CVaR) to account for risk during planning [2], [10], [11].

There are several ways of utilizing the unit-commitment decisions in real-time operations. We investigate three different approaches for modeling pumped-hydro storage devices under week-long planning and enforcing the decisions during real-time operations. The first approach represents the most inflexible plan. It involves utilizing the state-of-charge as a first-stage variable, committing to operate the storage device following a fixed hourly pattern regardless of the scenario. The second approach represents the most flexible plan. It finds the optimal hourly pattern for each of the scenarios but fails to provide any guidance on what the storage operations should be in real-time when none of the scenarios is realized. We show that both extremes of complete inflexibility or complete flexibility are suboptimal and inadequate to tap the enormous potential of energy storage systems.

We propose a third approach that combines a first-stage commitment with second-stage allowable slacks or intervals around the first-stage patterns. This model is the closest to real-time operations, committing to a state-of-charge pattern while accounting for the possibility of needed variations under unexpected, extreme conditions. The commitment takes the form of an hourly pattern with allowable deviations instead of a fixed hourly value, which we term state-of-charge bands. The state-of-charge bands found by the day-ahead unit-commitment model are then passed to a balancing unit commitment for flexible real-time operations. The state-of-charge bands at each hour are not necessarily of equal width. Each band is formed by the maximum and minimum values of the state-of-charge across all scenarios in the stochastic model. See Fig. 1 for a visual comparison of the three approaches.

The state-of-charge bands are found using a data-driven approach. We set the slack in the day-ahead unit-commitment model to the highest possible value that does not change the commitment of the slow-start generators. We first solve the unit-commitment problem with no slack. Then, we make small increments to the allowable slack of the system, verifying that the optimal commitment—within the prespecified optimality gap—remains the same. The largest value of the increment before transitioning to a different commitment is the desired value for the slack.

Results: We evaluate the performance of our model by simulating the operations of the Duke Energy System in 2019 and 2022. The system's fleet, demand, and renewable generation represent data from publicly available sources. We organize our experiments in two sets: the in-sample experiments and the out-of-sample experiments. In the first set, we assume that one of the scenarios in the day-ahead planning is realized during real-time operations. While not realistic, this allows us to argue about the benefits of the proposed approach under controlled conditions. In the out-of-sample experiments, the observed scenario is a unique trace, not included in the scenario ensembles during the day-ahead planning. This represents a realistic case and simulates the usual operations in the industry.

In both cases, we compare the different approaches in terms of the cost in real-time operations. In each set, we run multiple real-time realizations and evaluate the distribution of the cost across the different scenarios. We use the average and the standard deviation as quantitative measures of the performance of each model. We also report the conditional value at risk (CVaR) to quantify the risk of a given commitment plan under multiple possible future realizations.

The simulation results show that our proposed approach reduces the expected value of the system's operating cost, as well as its variance. A summary of the results is shown in Fig. 2. The distribution of the cost with the new model has lighter tails and lower CVaR values, which indicate the increased resilience and reduced cost of the proposed plan.

Conclusions: We propose a novel modification to the stochastic unit-commitment models that reduces the operational cost and mitigate the system risks due to increased renewables by explicitly linking the flexibility in storage operations from the unit-commitment model to real-time operations. The outcomes of this research lay the foundation for the development of an innovative energy management system designed to be cognizant of storage flexibility at the unit-commitment stage and during real-time operations. The comparisons described above are also applicable to real-time models with look-ahead components, i.e., models that use updated forecasts during real-time operations. The proposed methodology can be extended to other long-duration storage technologies. Comparing the benefits of diverse storage devices offers valuable insights to utilities for resource and capacity planning, aiding them in making informed decisions for a more sustainable and resilient energy infrastructure.

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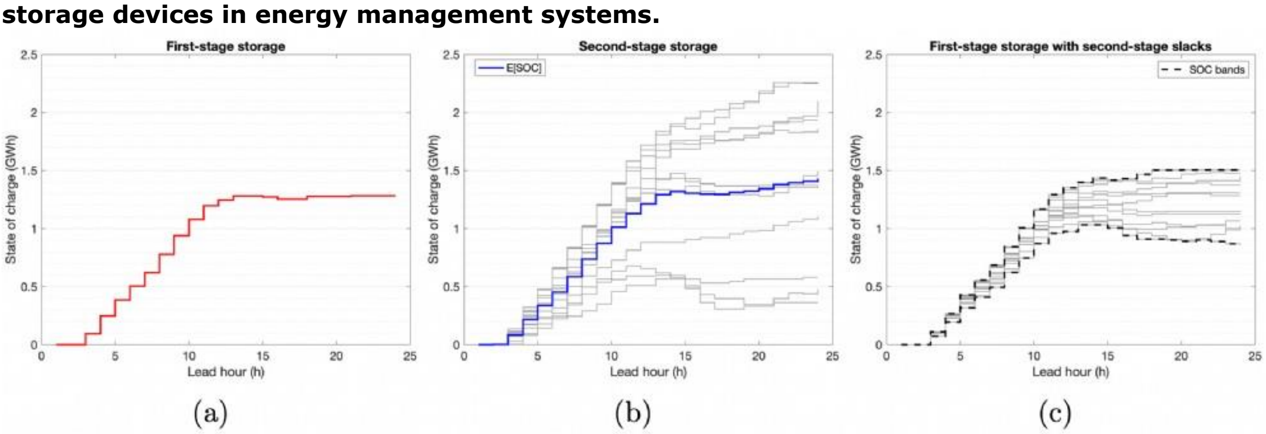
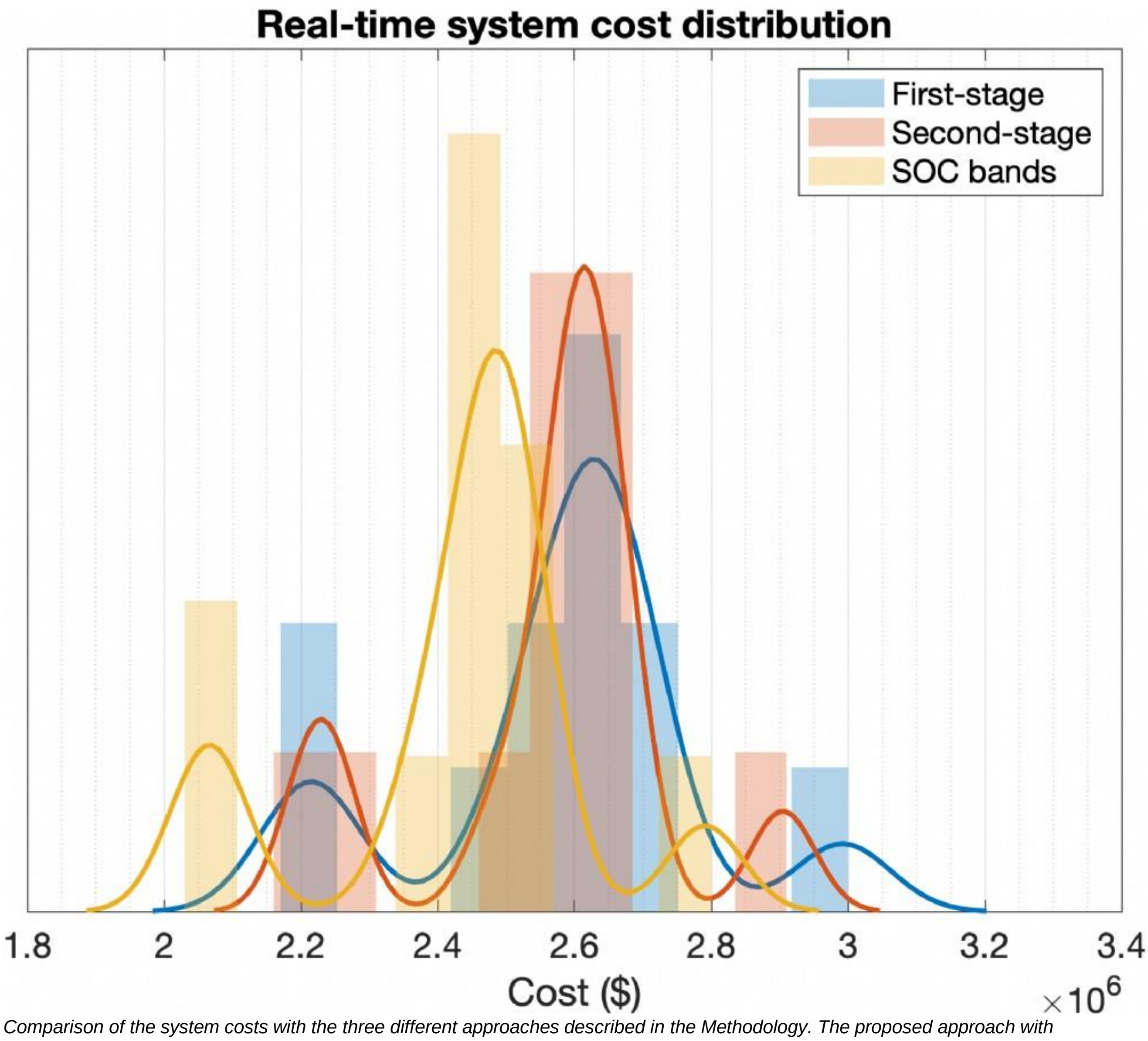
Keywords: stochastic unit commitment, long-duration energy storage, risk-averse

Figure 1: A depiction of the three approaches described in the Methodology for modeling storage devices in energy management systems.



A depiction of the three approaches described in the Methodology for modeling storage devices in energy management systems. In all cases, the storage devices are originally fully discharged. (a) The state-of-charge is a first-stage decision variable, which is the most inflexible plan. (b) The state-of-charge is a second-stage decision variable, representing the most flexible plan, but without specific guidance to the real-time operations. (c) Our proposed method identifies the state-of-charge bands (shown in dashed black lines) as guidance for real-time operations and simulation.

Figure 2: Comparison of the system costs with the three different approaches described in the Methodology.



Comparison of the system costs with the three different approaches described in the Methodology. The proposed approach with state-of-charge bands (yellow) reduces average system cost, as well as its variance.

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[Abstract:0346] OP-146 [Accepted:Oral Presentation] [Electricity » Demand]

Welfare redistribution through flexibility - Who pays?

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Overview:The pursuit of climate neutrality necessitates the decarbonization of critical end-use sectors, including industry, buildings, and transportation. Germany, in facilitating the shift to a low-carbon economy, has established technology-specific capacity targets within its national medium-term strategies. These strategies encompass not only renewable energy objectives but also specific targets related to investments in electrically driven end-use applications. Consequently, the aim for 2030 includes the deployment of 15 million electric vehicles (EV) (BMWK, 2022a) and approximately 6 million heat pumps (HP) (BMWK, 2022b). Electrification of end-use sectors leads to the growing integration of new decentralized suppliers and consumers into the existing power system. These new actors include entities such as EVs and electric heat generators with integrated storage systems. The ongoing digitalization opens promising prospects for increasing demand flexibility by temporal shifting of electricity consumption.

Several potential effects arise from incorporating this additional flexibility from the building and transport sectors into the energy system. Consumption can potentially align with the fluctuations of renewable energy, subsequently mitigating the need for backup power plants (Kiviluoma and Meibom, 2010). Flexible deployment of end-use appliances has an impact on the structure of the merit order and thus on hourly electricity prices. Prices can increase or decrease, depending on the type of flexibility being utilized and the dynamic nature of the supply and demand curves (Liski and Vehviläinen, 2023). Although the impact of the variability of solar and wind power (Hirth, 2013), sector coupling (Bernath et al., 2021), or electrolyzers (Ruhnau, 2022) on the market values of renewables has been thoroughly explored, the examination of new market entrants, especially on the consumption side, has received less attention. Compared to renewables, the technologies in the end-use sectors are not homogeneous but comprise non-homogeneous groups with distinctive characteristics.

If end consumers also face dynamic electricity prices in the future energy system, price fluctuations will strongly impact a wide range of new actors in the building and transport sectors, next to those in the energy sector. The diverse structure of demand means that the effect of electricity price fluctuations may differ across different consumers. For example, various flexibility options operate within distinct time windows and have the capability to shift electricity during varying time intervals. From the actors' perspective, the specific consumer and producer rents are likely to change as flexibility is applied.

The current literature primarily focuses on examining the system impacts of flexibility deployment, such as Härtel and Corpas (2021) or Böttger and Härtel (2022) do. However, it lacks the perspective of differentiated end consumers who are assumed to directly interact with the energy system and provide this flexibility. This academic paper aims to fill this gap by providing a profound analysis of the welfare effects of flexibility provision for various producer and end-user groups. In particular, we aim to address the following research questions:

- What is the impact of different flexibility deployment strategies on electricity prices and well as on producer and consumer rents?
- How differentiated are welfare effects in relation to different consumer groups in the building and transport sector?
- If welfare gains of end-consumers are small, to what extent do they need subsidies to provide system-oriented flexibility?

In addition to addressing these questions, this paper contributes to the existing literature in multiple ways:

- Assessment of system level impacts, including electricity price formation and total system costs, driven by different degrees of flexibility.
- Analysis of technology-specific welfare effects and their changes depending on different flexibility use cases.
- Analysis of various flexibility use cases and their welfare implications for a mid-term (2030) scenario for Germany assuming current technology-specific capacity targets.
- Development of a high-resolution dispatch model for Europe with a high granularity of end-use sectors capable of modeling the interaction of decentralized flexible assets such as electric vehicles, including Vehicle-to-X, and heat pumps combined with thermal storage with the energy system.

Methods:This paper aims to evaluate the impact of decentralized flexibility on electricity prices and technology-specific shifts in market values and average electricity costs. To assess the economic consequences of flexibility for different actors within the energy system, especially for the new market participants in the transport and buildings sectors, we enhance the existing energy system model DIMENSION by enabling a high-resolution dispatch for a range of end-consumer groups and flexible technologies.

Heterogeneity in the buildings sector is ensured by modeling various building types with differentiated heat pump profiles and building inertia. For the transport sector, we use data from the

German Mobility Panel (MOP) to generate about 300,000 mobility profiles, including information on parking location, electricity demand, and settlement type. By applying a k-medoids clustering, we define heterogeneous mobility clusters with differentiated flexibility potentials.

We apply a case study for Germany that reflects currently set technology-specific goals for the year 2030. We vary the degree of flexibility in the road transport and buildings sector within and combine them into a set of six use cases. For the road transport, we differentiate between no flexibility, demand shifting, and vehicle-to-x. For the building sector, we define one use case with only building inertia as flexibility compared to additional water storages.
Results:Related to the three formulated research questions, our results are versatile. Regarding the system effects of additional flexibility in the end-use sectors, we find that total system cost can be lowered. Effects on average electricity prices are very small, whereby applying vehicle-to-grid can reduce electricity prices slightly clearer. From the technology perspective, additional flexibility from the buildings and transport sector increases market values for PV but decreases them for all other generating technologies. Regarding electricity-consuming technologies, the average electricity costs decrease for Batteries, the Industry sector, or the building sector but increase for electrolyzers.

By diving into the specifics of the heterogeneous end-consumer groups, we find that from the perspective of the different mobility clusters, average electricity costs decrease only marginally when allowing for flexible charging, but costs can decrease significantly for some clusters when allowing for vehicle-to-x. In the case of adding more heat storage in buildings, average electricity costs can decrease significantly by up to 15 ct/kWh for the different building types.
Conclusions:The status quo of our paper lies in successfully applying the methodology for heterogeneous end-use sectors to an energy system dispatch model and generating first results to analyze. In our opinion, the paper would highly benefit from feedback from conference participants to streamline and focus on the most important aspects. Furthermore, feedback regarding the methodology and the modeling approach is highly welcome.

Additionally, as potential next steps, we would like to dive deeper into sensitivities and investigate the robustness of our results. Further, we plan to extend the discussion of the results as well as the policy implications.
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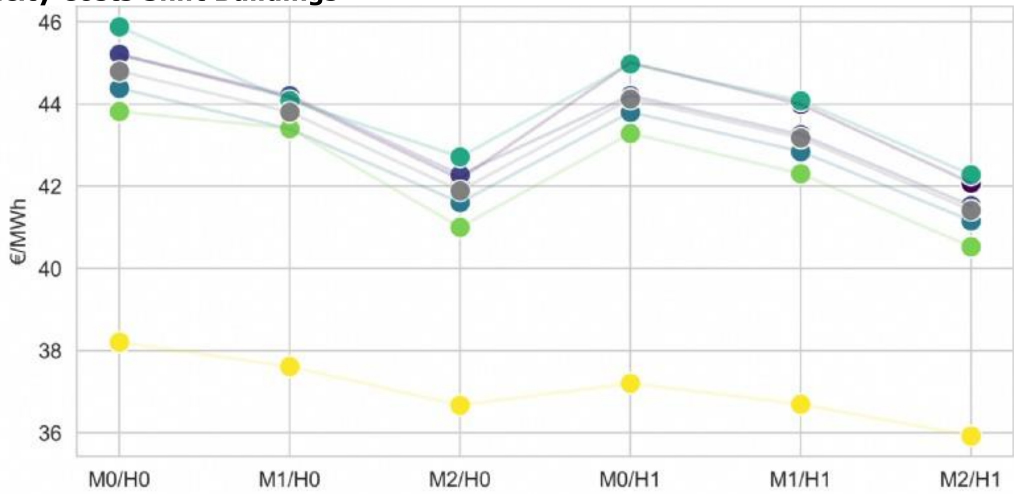
Keywords: Flexibility, Welfare effects, Energy System Modeling, Energy Transition

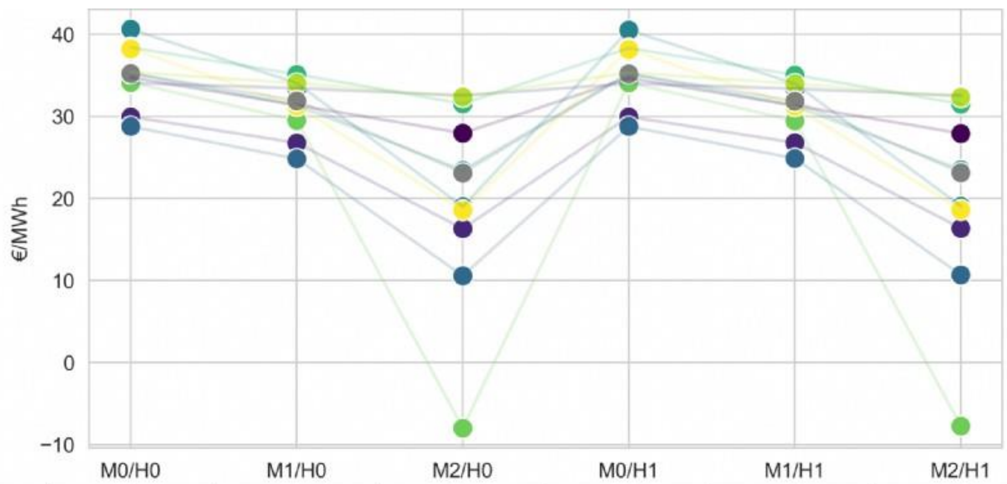
Average Electricity Costs Shift Buildings



Buildings	M0/H0	M1/H0	M2/H0	M0/H1	M1/H1	M2/H1
● Air B1	45.2	44.16	42.17	45.0	43.99	42.08
● Air B2	45.21	44.21	42.28	44.21	43.25	41.53
● Air B3	44.38	43.39	41.6	43.8	42.84	41.16
● Ground B1	45.88	44.09	42.71	44.98	44.08	42.28
● Ground B2	43.82	43.41	41.0	43.29	42.3	40.52
● Ground B3	38.21	37.61	36.67	37.2	36.69	35.93
● All	44.8	43.8	41.89	44.12	43.17	41.42

The figure shows the average electricity costs for 6 building types with different building constitutions and types of heat pumps (rows), depending on the use case for flexibility deployment (columns, see also Figure Use Case definition). The unit is €/MWh.

Average Electricity Costs Shift Road Transport



Mobility Cluster	M0/H0	M1/H0	M2/H0	M0/H1	M1/H1	M2/H1
MC1	34.75	31.38	27.96	34.68	31.32	27.94
MC2	29.96	26.78	16.34	29.96	26.8	16.39
MC3	34.05	33.44	32.56	34.01	33.39	32.53
MC4	28.78	24.84	10.59	28.78	24.88	10.71
MC5	40.61	34.07	19.01	40.5	34.0	19.07
MC6	35.27	31.34	23.45	35.22	31.29	23.5
MC7	38.4	35.13	31.54	38.32	35.06	31.52
MC8	34.16	29.52	-7.97	34.11	29.49	-7.72
MC9	35.4	34.05	32.37	35.33	33.98	32.34
MC10	38.26	31.28	18.57	38.18	31.24	18.63
All	35.25	31.92	23.12	35.19	31.87	23.15

The figure shows the average electricity costs for 10 different mobility cluster (rows), depending on the use case for flexibility deployment (columns, see also Figure Use Case definition). The unit is €/MWh.

Shifts of Market Values for different technologies

	M0/H0	M1/H0	M2/H0	M0/H1	M1/H1	M2/H1
PV	18.72	0.08	0.74	0.06	0.11	0.73
Wind Onshore	28.23	-0.25	-0.86	-0.03	-0.28	-0.86
Wind Offshore	29.31	-0.3	-1.02	-0.05	-0.35	-1.03
Power Import	43.06	-0.88	-2.46	-0.15	-1.02	-2.56
Hydrostorage	44.97	-1.17	-3.64	-0.09	-1.26	-3.7
H2-ready CHP	46.92	-1.11	-2.96	-0.17	-1.28	-3.07
Battery discharge	47.4	-1.36	-4.43	-0.17	-1.48	-4.49
PHS discharge	47.44	-1.26	-3.11	-0.17	-1.41	-3.21
H2-ready CCGT	48.4	-1.18	-3.23	-0.18	-1.32	-3.33
Gas CHP	53.44	-1.54	-4.64	-0.31	-1.78	-4.79
Gas CCGT	57.03	-1.41	-4.19	-0.23	-1.6	-4.33
H2-ready OCGT	88.98	-2.13	-7.05	-0.5	-2.62	-7.36
Gas OCGT	110.77	-5.65	-17.98	-0.4	-6.73	-18.22
Electrolysis	10.26	0.3	0.66	0.13	0.4	0.75
Power Export	20.39	0.09	0.56	0.06	0.14	0.61
PHS charge	20.51	-0.03	0.3	0.02	-0.03	0.3
PtH (central)	21.27	0.36	0.93	0.25	0.57	1.09
Battery charge	22.73	-0.19	-0.84	0.03	-0.1	-0.79
HP (central)	33.92	-0.38	-1.2	-0.08	-0.45	-1.24
Industry	34.13	-0.44	-1.29	-0.07	-0.5	-1.32
Buildings Appliances	34.46	-0.55	-1.39	-0.06	-0.61	-1.43

Colour scale: 130%, 120%, 115%, 110%, 105%, 100%, 95%, 90%, 85%, 80%, 70%

The figure shows the shifts of market values for different electricity generation technologies and shifts of average electricity costs for consumption technologies depending on the use case for flexibility deployment (columns, see also Figure Use Case definition). The unit is €/MWh.

Use Case definition

Use Cases for end-use sectors		Heating sector: Inflexible (only with buildings' inertia)	Heating sector: flexible (with additional heat storage)
Transport sector	inflexible	M0/H0	M0/H1
Transport sector	flexible (DSM)	M1/H0	M1/H1
Transport sector	flexible + V2X	M2/H0	M2/H1

The figure illustrates how we label our different use cases, for the purpose of keeping track of our different flexibility combinations. Flexibility uses cases for electric vehicles are reflected by the rows. The columns account for different flexibility assumptions regarding decentralized heating. The scenario names are written in the gray cells.

[Abstract:0382] OP-147 [Accepted:Oral Presentation] [Electricity » Demand]

Persistence of aggregate electricity demand: a lagged response to temperature

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Overview:The warming globe, doubtlessy, influences demand, as fluctuations of temperatures across seasons induce on one hand, a reduction in the necessity of heating in colder ones, and on the other they drive an increasing demand for cooling in hotter seasons [36].
Theoretical frameworks suggest that the demand for cooling increases once temperatures surpass a specific threshold (cooling state), while the demand for heating rises as temperatures drop below a certain threshold (heating state) [32], establishing a U-shaped relationship between energy demand and temperature.
Among the factors that buttress temperatures' induced swings in energy demand, residential energy demand demonstrates a heightened responsiveness [28]. The residential sector remains a significant energy consumer in most countries, accounting for approximately 30% of global energy consumption on average [21]. Moreover, residential consumption of, in particular, electricity experiences a more pronounced increase during extreme heat and extreme cold days compared to commercial and industrial demands [28].
Research by [21] suggests that a hotter summer has a greater impact than a colder winter, leading the electricity demand to skyrocket during hot seasons. Cooling devices, whose means is electricity, are increasingly used during the summer months ("colling effect"), accompanied by a reduced need for heaters in the winter [7]. The proportion of cooling in total energy usage in buildings rose from approximately 2.5% to 6% from 1990 and 2016 and today the use of air conditioners and electric fans accounts for nearly 20% of the total electricity used in buildings worldwide [13]; if not addressed, this demand for electricity is predicted to more than triple by 2050 [13].
According to [15], two main adaptation mechanisms are followed by individuals facing the need to find a new thermal comfort when temperatures change the external conditions. The first one is that individuals are more inclined to use cooling appliances on extremely hot days compared to mild days and associated to this, a larger temperature difference requires greater energy to overcome the cooling load [28]. Secondly, people tend to purchase more cooling appliances during hotter summers [15]. Following these two patterns, in literature [21], the variation of related electricity demand is distinguished into the short-term change driven by the intensity of appliance usage (intensive margin) and the long-term adjustments influenced by appliance purchases and replacements (extensive margin). The intensive margin is recognised to be the most prominent adaptation behaviour of consumers during summers [21].
A complication more arises if the choice on how to use these cooling appliances diverges from a rational use. Their use represents a quick response to external stimuli, i.e. temperatures increase, allowing individuals re-balance utility. In the study of [17] indeed, the increased frequency of use and also challenges in using appropriately is found to be negatively correlated with energy-saving purposes.
Unsound surge in electricity demand can thus be a potential consequence of relying solely on adaptive behaviours to address hard temperatures in order to maintain thermal comfort [7]. This phenomenon is referred to as electricity irrational consumption [17]. Arising from excessive and uncontrolled demand, this behaviour is suspected to persists even after temperatures return to previous levels, diverging from the principles of utility maximization; even when it is no longer as much rewarding, the strength and automaticity of this behaviour may lead to persistence [18] as the extant literature touch on [12; 16; 17; 20; 23; 25; 36].
Methods:Given the occurrence of an increase in the use of cooling devices to adapt to the hotter weather, especially by residential users, what is investigated is the effect of temperature on electricity demand. Specifically, the analysis addresses the existence of persistence in behavioural electricity aggregate demand, in the view of those theoretical models claiming individuals involuntarily enroot an irrational consumption.

The study focuses on Italy, where domestic consumption in the last ten years has represented around 20% of total electricity load [30] and summer peak load is being more and more pronounced [31].
An unbalanced panel dataset has been composed for the years 2021 and 2022; main variables:
(i) electricity load as the response variable [1]. The Italian regulator provides provincial level data on domestic load for the year 2021 and 2022. Data are presented as the average for a specific month at the specific hour, with detail for aggregated days off, Saturdays and Sundays, the economic condition characterizing the electricity distribution (either "Maggior Tutela" or "Mercato Libero"), and the power class.
(ii) Weather variables measuring thermal discomfort to explain the variations in electricity demand (ECMWF, 2023), at 0.1° gridded resolution, aggregated at provincial level.
(iii) air conditioning ownership to control for extensive margin effect [14].
The hypotheses are investigated through a dynamic econometric specification which makes it possible to study the non-linear effect of temperature on demand; the econometric model described is dynamic, using lagged variables to incorporate feedback over time as the instrument to represent the persistence of shocks.
Direct temperature variations can be represented in the empirical framework, either as the mean temperature, as Thermal Degree Days, or by defined intervals (henceforth "bins"). [8], support through evidence that the standard approach of modelling energy consumption with Thermal Degree Days cannot capture the non-linear increase in consumption when extremely high temperatures are reached. Thus, temperature bins (cut off of 3°C) are chosen for this analysis.
Results:The first result is the evidence that there is a nonlinear relationship between the electricity demand and the ambient temperature (I-Model) given by the weak positive effect of lower temperatures (within the heating state t_l0 shows an effect of 0.25), the negative effect of those temperatures in the middle of the distribution (an average of -7%) and a positive strong effect for temperatures towards the cooling state extreme (for bin t_g33 a unit increase in temperatures leads to a 40% increase in demand). This result would confirm previous literature pronouncements on the general U-shaped effect of temperatures on energy demand, including electricity demand.
Notably, in terms of coefficients size, the hotter extreme has a stronger impact than the colder one confirming the existence of a cooling effect and the growing importance on the effect that high temperatures have on demand (I-Model).
The introduction of dummy-variables lagged bins detect the existence of a persistence effect: with one hour of delay (II-Model), there is a clear positive effect of persistence for low temperatures (for t_l0 the impact is 2%), a decrease in the effect size around the middle temperature, and again, the positive persistence effect verifies more strongly (for t_g33 the impact is 6%). Persistence is particularly evident for the higher temperatures of the cooling state. In addition, III-Model shows the strength of persistence effect up to the fifth hour of delay. The magnitude of the coefficients decreases but the effect with the same patterns described above is still present.
Lastly, the details on consumer economic condition have been exploited to understand whether protected consumer (under category "Maggior Tutela", i.e. granted lower prices) would be more sensitive to temperature variations, given the lower economic incentive to save on electricity. The results (IV-Model) show that this is the case, at least for hotter temperatures.
Conclusions:The analysis confirms previous literature findings on the existence of a U-shaped relationship between temperatures and load, the stronger relationship that exists at the hotter extreme of temperature distribution and the summer season greatest impact. But mainly, a persistence effect has been detected, following the same patterns.
Limitations to this study comprise the level of aggregation of the data used (even though an exercise of load matching can be informative at provincial level, it is also indisputable that insights on the aggregated electricity demand behaviour can better be extracted from consumption data at households' level) and the period considered (years 2021-2022 exclude the years when the Covid-19 pandemic was not hitting), both to be further investigated.
In terms of policy, when evaluating the impact of AC on the electricity system, on top of the need to balance the load from the supply side, all mentioned behavioural factors must be taken into account. The increased load for electricity-powered fans or air conditioners already exerts significant pressure on the power grid. Space cooling contributes substantially to peak demand, further straining power systems up to surpassing its capacity. Such events, jeopardize the reliability and increase the risk of outages, leading to blackouts precisely when cooling and the electricity it relies on, are most essential. It must be added, in this picture, that traditionally, power systems were designed to meet the highest peak demand during winter. However, as above underlined, with climate change, demand surges are expected to shift from previously peaking season to summer.
Because consumption usually represents the largest portion of total demand in most economies, for what concern residential demand, policymakers must understand how consumers react to changes in the external environment. For energy sector operators, comprehending the factors driving electricity demand and constructing reliable forecasting models, is crucial, as well as engaging into a purposeful demand-side management which should accounts for demand peaks but also for its

persistence.
References:References are given as an attachment

Keywords: Domestic load, aggregated behaviour, temperatures, persistence, cooling, air conditioning

AuthorToEditor: Authors are 3 in total; two names are repeated to add 2 affiliations each

[Page: 148]

[Abstract:0533] OP-148 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Risk Management for Electricity Systems

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Overview:We present a usable multi-layered framework that facilitates the implementation of data-enabled recourse actions, instead of worst-case risk management, and manages prospective decisions about the system dispatch and planning, as part of a sponsored project by the Advanced Research Projects Agency, ARPA-E.
Our contributions include: (1) an asset scoring approach, grounded on financial economics methodologies for risk management, (2) data-driven algorithms to integrate the scores and risk measures into current practices for both centrally controlled and market managed systems, (3) an identification of missing mechanisms and markets, and development of new physical and financial instruments to manage the incurred risk, and (4) a design that explicitly includes current institutional and management optimization methods and practices used in dispatching power systems, without dismantling the current structures in place.
Methods:Methodologically, we use a multi-stage process. The inputs for calibration using statistical and machine learning algorithms (see e.g., Chen and Guestrin 2016) are created using a simulation of a two-settlement process. The first settlement of the optimization model is similar to a financial portfolio optimization problem where the objective (from a social welfare perspective) is to minimize costs based on information submitted by suppliers (assuming energy is delivered as specified in the submitted cost information). For centrally managed systems, the decision maker has information about the production costs. Under present operational paradigms, conventional and stochastic uncertainty-laden assets are treated on an equal footing. The proposed risk measures allow us to enrich this stage with probabilistic measures over the appropriate feasible sets for each type of asset, and these measures evolve over time. Consequently, the first stage optimization problem will be redeveloped as a ``risky asset" based portfolio optimization problem where the inputs to the optimization include asset risk measures and a probability of delivery as submitted by the asset provider (Zhao et al, 2023). In particular, we consider the problem of loan portfolio selection that has been studied using discrete probabilistic models for a variety of risk and performance measures including credit scoring-based measures as we develop here.
Results:We identify failures in handling asset risks in the form of missing information and mechanisms. To alleviate these failures, we propose third party entities to reduce information asymmetries and develop methods and services for agents who manage this risk. In addition, we develop conceptual innovative real and financial products and services for risk management that include the design of new mechanisms, short-term financial markets and day-ahead bid formats based on our risk measures, scores, and missing market analysis. We illustrate our results using the

New York electricity system with a reduction from the New York Independent System Operator calibrated to historical results (Patton 2023).
Conclusions:Our approach leverages the scoring and rating approaches used by financial institutions to quantify asset risk and the current optimization methods used in dispatching power systems to develop risk management mechanisms. We go beyond classic risk quantification, like variance and value at risk, and draw up on the aforementioned scoring and rating methodologies used in banking and finance, and data-driven statistical estimation to develop asset risk measures. The risk metrics will be grouped into normal reliable operation, resilient emergency operation, planning, and intermediate time scales. The use and impact of these risk measures is presented for both centrally managed and market driven systems. For centrally managed systems, we examine optimized multi-stage scheduling that integrates asset risk.
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[Abstract:0144] OP-149 [Accepted:Oral Presentation] [Energy Efficiency » Barriers to Adoption]

Determinants of energy-efficient appliance purchases and energy-saving behaviour of Spanish households

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Overview:Cuts in energy consumption in the household sector can come from the adoption of energy-efficient technologies and/or from energy-conservation actions by individuals at home. Energy-related purchases and investment actions require one single action at a specific time, but energy-saving behaviour is associated with a change in individuals' day-to-day energy habits. The factors that affect the decision whether to invest in EE might not necessary influence the adoption of energy-saving habits or might not affect it in the same way (Ramos et al., 2016; Trotta, 2018; Yang et al., 2016).
Under this context, the objectives of this paper are: (i) to identify, understand and discuss the factors that determine, on the one hand, the purchase of a highly energy-efficient washing machine in Spain and, on the other hand, energy-saving behaviour by Spanish consumers at home; and (ii) to test whether there is a causal effect between the purchase of energy-efficient washing machines and energy curtailment-behaviour by consumers.
The results seek to contribute to the open-ended discussion on the factors affecting both types of

energy-related action for energy conservation and to help up reflect on the effectiveness of EE policies and propose recommendations for effective, targeted measures to increase energy savings and promote energy-responsible lifestyles to reduce energy consumption in the household sector.
Methods:To that end, we use a consumer survey designed and implemented in Spain in November and December 2017 to gather data on actual washing machine purchases and energy-related behaviour in 500 households. Two econometric models are estimated: a discrete choice model to identify barriers to and enablers of highly energy-efficient washing machine purchases, and a linear regression model to estimate the effects of different variables on consumers' day-to-day energy-saving habits. A causal inference technique is used to test for any causal effect of purchasing a highly energy-efficient washing machine on individuals' energy-saving behaviour at home.
Results:We find that the decisions of Spanish consumers in regard to investments in EE and energy-curtailment behaviour are complex and shaped by many different factors, both individual (attitudes towards EE and the environment, risk attitudes, time preferences, personal experience and habits with EE and socio-economic characteristics) and political (policy measures to foster EE). This suggests that each type of action should be supported by specific targeted policy instruments, which matches the consensus in the relevant literature.
We have also determined by causal inference that purchasing an energy-efficient washing machine does not directly imply more energy-saving behaviour (in general or specifically in relation to the use of washing machines). Therefore, policies are needed that affect purchases and influence energy-saving behaviour, and ideally foster both at the same time to make them more effective.
The estimates obtained for each model and the causal inference technique can be seen in Tables 1, 2, 3 and 4 attached in the "Tables" document.
Conclusions:Various policy recommendations can be drawn from this study. When it comes to promoting both the energy-efficient technologies and energy-saving habits, provision of information could have an effect on both types of action (Cattaneo, 2019; Solà et al., 2020). We find that social norms related to EE and the environment play an important role in investment decisions. Therefore, information campaigns to raise awareness and knowledge of EE - with messages in understandable metrics (de Ayala et al., 2020; de Ayala and Solà, 2022) - and appeals to environmental responsibility can affect purchasing decision-making in regard to EE. Energy audits that tackle informational failures and increase awareness of possible improvements in EE at home could also be worthwhile (Markandya et al., 2015).
Considering EE as an important attribute in purchasing decisions is a positive driver for deciding to invest in EE, so having sales staff trained in EE aspects at the point of sale could also be useful to encourage purchasing decision-making for energy-efficient appliances (Solà et al., 2021).
Commitment and goal setting programmes on energy use and/or information feedback tools such as smart meters and energy bills with comparative information (Cattaneo, 2019; Solà et al., 2020) can encourage consumers to concern themselves with their energy consumption and energy bills, which has be seen to be key for behaving in a more energy-saving manner at home.
The EE labelling scheme for appliances also seems to be a useful informational policy option, since it has been shown to lead not just to purchases of more efficient appliances but also to a more energy-saving behaviour. The EE label is one of the cheapest and easiest ways of addressing asymmetric and/or incomplete information at the point of sale (Cattaneo, 2019; de Ayala et al., 2020; Solà et al., 2020).
Our findings indicate that economic and financial instruments can also be helpful particularly for decision-making in regard to investment in EE. Such instruments could include direct subsidies to help households defray the cost of investing in EE: we show that the Spanish RENOVE rebate programme can lead to purchases of highly energy-efficient appliances. Other financial policies could be designed instead with the aim of making access to credit easier for households (e.g. grants and loan facilities), particularly those in the lowest income brackets (we find that income has a significant, positive role in purchasing decision-making), since we find that a lack of access to loans can decrease the probability of buying a highly energy-efficient washing machine.
Economic incentives work particularly well for risk-averse consumers because they lower the upfront costs of investment (Cattaneo, 2019). In our case we find that the more willing consumers are to take risks the more likely they are to purchase a washing machine with a high EE level. To influence energy-saving behaviour, a tax on energy consumption might be useful particularly for those consumers with high income, as they tend to behave in a less energy-saving manner. A combination of tax and subsidies has been proposed by some authors to promote energy-efficient household appliances (Galarraga et al., 2016; Markandya et al., 2009).
Ideally, policy makers should take into account the heterogeneity of consumers so as to increase the effectiveness of the policies proposed, as we find that socio-economic variables can differ or have different effects for each energy-conservation action. It might be advisable to target these policies, to the extent possible, by taking into account the main socio-economic characteristics of individuals such as age, education level, occupation and income for investments in EE; and age, gender, marital status and income for energy-curtailment behaviour.

All in all, our study suggests that a combination of informational, economic and financial instruments that affect investment decisions in EE and energy-curtailment behaviours jointly or separately can be beneficial in bringing about a substantial reduction in energy consumption in the household sector. Informational instruments seem to be advantageous for both types of energy-conservation action, while economic and financial instruments are especially favourable for the adoption of EE.
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Keywords: household sector, energy consumption, energy-efficiency, purchasing decision-making, energy-saving behaviour, policy recommendations

[Abstract:0151] OP-150 [Accepted:Oral Presentation] [Energy Efficiency » Barriers to Adoption]

Informality and energy efficiency in African countries: Evidence from symmetric and asymmetric (nonlinear) panel ARDL cointegration approach

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Overview:From artisanal traders in the bustling cities of Kano and Lagos, Nigeria, to street vendors in Harare, Zimbabwe, informal economies employ and provide livelihoods for the majority of Africans. According to a recent report, about 83% of Africans and 85% of sub-Saharan Africans (SSA) are employed in informal economies (UNDP, 2022). In other report, informality accounts for between 30% to 90% of total non-farm employment, and contributes between 25% to 65% to the GDP in SSA (IMF, 2017). In light this, policy dialogue in mid-2022 by the UN discussed policy pathways towards inclusivity and sustainability in the informal economies of Africa (UNDP, 2022). The discussions underscored the need to move beyond the traditional view of the informal economy as a potential threat requiring elimination or strict control, and emphasised the potential benefits of supporting and investing in the sector as a means of fostering inclusive transformation and as a pathway to formality. The urgency for addressing the challenges of the informal sector has been further underscored by the COVID-19 pandemic. Its severe repercussions on informal activities globally have emphasized the necessity for governments to extend support to significant portions of the population that are either not covered or inadequately covered by existing social protection programs (Deléchat & Medina, 2020).

A plethora of recent studies have explored the effects of informality on energy consumption and environmental sustainability with mixed results. Informality is shown to have varied effects on environmental quality depending on the context of the analysis. For example, a positive (increasing) effect is found for Europe and China (Shahbaz et al., 2023; Pang et al., 2021) while a negative (reducing) and nonlinear effect is found for large sample of countries (Elgin & Oztunali, 2014; Basbay et al., 2016). Basby et al. (2016) also find some evidence of asymmetry in the nexus for a sub-sample of countries with low shares of informal sectors. Studies that consider the informality-energy nexus find that informality increases energy consumption and energy intensity (Benkraiem et al., 2019; Canh et al., 2021).

The potential association between informality and energy efficiency has received limited consideration. Yet, there is now a consensus among researchers and leading intergovernmental organizations that energy efficiency stands as the primary instrument for realising the Paris Agreement as reaffirmed during the recently concluded COP28 conference in Dubai. Promoting energy efficiency yields extensive benefits, encompassing energy savings, reduced energy intensity and ecological footprints (Yang & Yu, 2015). In particular, African countries stand to benefit from increased energy security, creation of employment opportunities and markets for efficiency-related products and services (Pielli et al., 2014).

Focusing on African countries, this study examines the effect of informality on energy efficiency in light of the benefits of achieving energy efficiency in Africa and of driving policy towards inclusivity and increased formality. The lack of regulatory oversight and technological advancement in informal economies could engender sub-optimal practices in energy use (Shahbaz et al., 2023). An understanding of the dynamics of informality and its impact on energy efficiency is therefore vital for crafting tailor-made policies and interventions, and this is especially important at a time when the challenges and opportunities of informality are taking centre stage in policy dialogues.

Methods:The study employs a two-stage approach. The first stage focuses on the estimation of energy efficiency using the stochastic frontier analysis technique (SFA). Within this framework, we employ the Shephard energy distance function in the spirit of Stern (2012). Likelihood ratio tests give preference for the Translog over the Cobb-Douglas specification. We therefore rely on the former specification. Energy efficiency estimations are carried out using the True Random Effects (Greene, 2005a, b) and the Random Effects (Pitt & Lee, 1981) models. While the former gives estimates of transient efficiency, the latter gives estimates of persistent efficiency. Overall efficiency, which is employed in the second stage, is a product of both the transient and persistent efficiency scores. In both sets of regressions Mundlak adjustment is used to counter potential heterogeneity biases (Mundlak, 1978). In the second stage, the symmetric and asymmetric (nonlinear) ARDL techniques are used to analyse the effects of informality on energy efficiency conditioning on the effects of technological innovation, governance quality and foreign direct investment. To the best of our knowledge, this is the first study that examines the informality-energy-efficiency nexus using the SFA technique to measure efficiency. Previous studies have employed the energy intensity measure which has variously been considered as an unsuitable measure of energy efficiency. Informality is measured using the estimates of the size of the informal sector (% of GDP) constructed by Elgin et al. (2021), which are available from the World Bank. Data on technical cooperation grants and foreign direct investment are from the World Development Indicators while data on corruption control, our measure of governance quality are from the World Governance Indicators.

Results:The following findings proceed from the study: first, we observe considerable variability and a declining trend in energy efficiency performance in the sample. The results point to a large scope for energy efficiency improvements, showing that the elimination of all types of energy efficiency could realise energy savings of up to 58%. Second, when testing for asymmetry, the results lead us to reject the null of no asymmetry in both the long-run and short-run. We therefore rely on the asymmetric nonlinear ARDL regressions in examining the long-run and short-run effects of informality and other variables on energy efficiency. The results show a decline in energy efficiency performance in response to a positive shock that increases the size of the informal economy and an increase in performance in response to a negative shock that reduces the size of the sector. Further evidence shows that negative shocks have a stronger effect on efficiency than positive shocks which goes to support our conjecture that declines in informality will have substantial effects in improving energy efficiency in Africa. Lastly on the included covariates, the results present a positive association between technical innovation and foreign direct investment and energy efficiency. This shows that technological innovation and transfers are important drivers of energy efficiency improvements in Africa.

Conclusions:Understanding the nexus between informality and energy efficiency is a critical policy issue. And it goes without saying that the implementation of measures aimed at reducing the size of the informal economy is paramount for African economies. Policies aimed at incentivising businesses to formalize operations should be a key focus. This transition can be driven by simplified registration processes, tax incentives, and financial supports in the informal economies. Recent discussions have highlighted the need to explore the potential benefits of supporting and investing in the sector as a means of fostering inclusive transformation and as a pathway to formality. Such considerations are important now than ever. International collaboration through partnerships and technical cooperation grants and foreign direct investments should be encouraged as these will contribute to technological innovations and technological transfers and enhance collective efforts to address energy efficiency challenges specific to the African context.

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Keywords: informal economy, energy efficiency, stochastic frontier analysis (SFA), nonlinear panel ARDL

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[Abstract:0367] OP-151 [Accepted:Oral Presentation] [Energy Efficiency » Barriers to Adoption]

Willingness-to-pay for energy saving measures and the impact of retrofit grant scheme

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Overview:In our study, we investigate home retrofits as a strategic approach for households to reduce energy costs through enhanced efficiency. The importance of energy efficiency in residential areas extends beyond cost savings to reducing dependence on fossil fuels, contributing to both energy security and environmental protection. In Slovenia, akin to other developed nations, the residential sector consumes a significant amount of energy, predominantly for space heating and hot water. Thus, improving insulation and heating systems in existing buildings is a crucial factor in decreasing national energy usage.

For the last two decades, the Slovenian government has been proactive in supporting these retrofit activities through financial incentives, including low-interest loans and grants, with a notable program launched in 2008. A key aspect of assessing the efficacy of such policies is understanding the homeowner's Willingness to Pay (WTP) for energy savings from retrofitting. This analysis is crucial for measuring the extent of free-rider effects, a phenomenon where households implement energy-saving measures that they would have undertaken regardless of subsidies, a concept thoroughly explained in Train (1994).Despite the importance of evaluating publicly funded programs, there has been limited examination of WTP estimates for energy savings and their implications for free ridership. Previous studies indicate that the proportion of free riders in residential energy efficiency programs varies widely, ranging from 40% to 96% (Grösche & Vance, 2009; Nauleau, 2014; Collins & Curtis, 2019).

Our study has dual OBJECTIVES: firstly, to determine the factors influencing home retrofits and thereby estimate the marginal WTP for energy savings; secondly, to evaluate the impact of free-rider effects on the social benefits of the subsidy program. This study employs a unique dataset of over 10,000 Slovenian households surveyed in 2010, 2014, and 2019, encompassing actual investment costs for four retrofit measures, estimates of the resulting energy savings, and rich data on the building characteristics and households' sociodemographic characteristics. In our study, the observed retrofit costs represent the actual expenses incurred by households for their selected

retrofit options, as recorded in the administrative dataset. For other options, the costs are estimated, differing from the approach of using attribute levels from a choice experiment as seen in some other studies (Grösche & Vance, 2009; Olsthoorn et al., 2017). Our dataset encompasses four energy-saving retrofit measures: façade insulation, heating equipment replacement, windows and doors replacements, and attic insulation.
Methods:In our comprehensive study, we utilized random utility theory to explore Slovenian households' willingness to invest in energy conservation. This theory effectively predicts choices by contrasting the benefits of different retrofitting options. To enhance our analysis, we combined real data on households' energy efficiency actions with hypothetical scenarios of possible retrofit choices. This approach builds on the Cameron's (1985) model, where he examined household behavior regarding energy efficiency retrofits, using a nested logit model to evaluate the effectiveness of financial incentives for retrofitting. Our dataset includes actual survey data on retrofit investments made by households and simulated data representing various available retrofit options. This simulated data serves as an approximation to what homeowners might estimate from consultations or available retrofit guides.

Our study utilizes conditional and random parameters logit models, meticulously selected for their effectiveness in analyzing various factors that affect retrofit decisions, such as cost, potential energy savings, building features, and socio-demographic elements. The aim is to gain a comprehensive insight into household behaviors concerning energy conservation and to assess the impact of subsidization policies. In our research, households are presented with a choice among sixteen retrofit options, representing all possible combinations of four retrofit measures, including the decision not to retrofit at all. For each option, we model the likelihood of a household selecting a given alternative, taking into consideration the attributes of each option that contribute to the household's utility. We calculate the average marginal willingness-to-pay for households that undertook a retrofit, which is then multiplied by the quantified energy efficiency improvement (in kWh/yr) of that retrofit. Further, we categorize the extent of free-riding into three levels, based on a comparison between a household's WTP and the total costs, following the methodology outlined in Collins & Curtis (2019).
Results:In our study, the model estimates from both conditional and random effects logit models produced broadly similar coefficients. As anticipated, factors such as costs and energy efficiency improvements significantly influenced retrofit decisions in each model. Investment costs had a negative effect on the likelihood of choosing a retrofit, whereas the expected energy savings positively affected this choice. Additionally, interaction effects related to building and household characteristics (such as building type, floor area, age, income, energy expenditures, and past retrofit activities) showed expected effects. The preliminary results imply preference heterogeneity with respect to the expected costs and energy efficiency improvements to be minimal. Consequently, when calculating WTP using fixed effect coefficients, the conditional logit model yielded consistent results.

Further examination of the coefficient estimates revealed notable variations in preferences based on different household characteristics. Generally, higher costs decreased the probability of selecting a retrofit. However, households with previous retrofit experience were less deterred by higher costs compared to those retrofitting for the first time. In contrast, households with higher incomes, those residing in older buildings, and those with higher energy expenditures showed a greater tendency towards more expensive options (typically including more retrofit measures). Moreover, higher expected energy savings were positively correlated with single-family homes, larger floor areas, and previous retrofitting, and negatively correlated with the age of the building, aligning with expectations.

The study reveals an average marginal WTP of € 0.412 per kWh/year across households. The lowest income group shows a readiness to pay € 0.364 per kWh/year, whereas the highest income group is willing to pay € 0.488 per kWh/year. Additionally, the average free-riding share is found to be 35.2%, calculated as the proportion of households whose WTP exceeds the actual cost of the retrofit. Notably, an increase in income correlates with a slight rise in free ridership. The free riding rate for the first income group is 30.8%, compared to 36.4% for the highest income group. It is observed that both WTP and free-riding share vary significantly across different retrofitting alternatives.
Conclusions:The Slovenian grant scheme, launched in 2008, was designed to reduce energy consumption and improve energy efficiency in residential buildings. This study evaluates the willingness of households to invest in these enhancements and examines the extent of free riding, which refers to retrofits that would have been undertaken even without the grants. Such analysis is vital for assessing the cost-effectiveness of the grant scheme.The results show that households with higher incomes not only show a willingness to pay more than those with lower incomes but also exhibit a marginally higher rate of free-riding. The WTP results align somewhat with previous findings, although being higher than Collins & Curtis (2019) at €0.127 per kWh/year but lower than

Grösche & Vance (2009) at €1.97 per kWh/year. The observed free-riding rate of 35.2% is consistent with international findings, as indicated by studies such as Alberini et al. (2014), Grösche & Vance (2009), Nauleau (2014), and Olsthoorn et al. (2017).

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Keywords: Willingness to pay, Free-riders, Energy efficiency, Retrofit

[Abstract:0500] OP-152 [Accepted:Oral Presentation] [Energy Efficiency » Barriers to Adoption]

Trigger my motivation and remove my barrier: A latent class analysis of homeowners' perception about home energy retrofit

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Overview:The effectiveness of policy interventions that aim to encourage household energy-efficiency investments is subject to the diversity in needs and preferences of householders. Following previous research in both marketing and political sphere, we use the word 'segmentation' to refer to the practice of identifying relatively homogeneous and mutually exclusive subgroups of a population (Hine et al., 2014; Smith, 1956). Segmentation analysis can complement individual-level investigation by identifying audiences that are homogeneous within each class while heterogeneous between classes (Kácha et al., 2022). By matching segmented classes of households with energy-saving interventions, the design of policy and marketing strategies can effectively target the needs and preferences of households, thereby conducing to national energy and climate targets. Furthermore, according to behavioural reasoning theory (Westaby, 2005), we assume that reasons for and reasons against undertaking home energy retrofit measures can influence homeowners' decision-making through different routes, and therefore should be addressed separately in policy interventions. Therefore, this study investigates homeowner segmentation based on their perceived motivations (reasons for) and perceived barriers (reasons against) to undertake energy retrofit measures, separately.
Methods:The study draws on data from an online survey conducted in May 2022. The sample consists

of 1011 Dutch homeowners who had experience with home energy retrofit. Latent class analysis (LCA) was conducted to identify homeowner segments. The decision to perform LCA analyses instead of cluster analyses is because the former is model-based, which allows evaluating models based on statistical indices, and generates probabilities of class membership rather than simple class assignment (Nylund-Gibson & Choi, 2018; Weller et al., 2020). Specifically, we performed LCA for a set of eight perceived motivations (see Table 1) and a set of eight perceived eight perceived barriers (see Table 2), respectively. After exploratory class enumerations were performed, we used statistical indices, substantive interpretability, and parsimony criteria to determine the final models. Furthermore, 3-step LCAs (Nylund-Gibson et al., 2019) were performed to explore the relationships between latent class memberships and the probabilities of undertaking retrofitting measures as well as the socio-demographic determinants of latent class memberships.
Results:As shown in Figure 1, we identified five segments for homeowners' motivations for (reasons for) energy retrofit: individual utility maximiser (class 1, 6.8%), immediate utility seeker (class 2, 14.7%), balanced motivation homeowner (class 3, 26.7%), environmental-financial sensitive majority (class 4, 45.4%), and environmental and immediate utility maximiser (class 5, 6.3%). As shown in Figure 2, three latent classes were identified for homeowners' barriers to (reasons against) energy retrofit, which are labelled as lack of demand (class 1, 24.3%), prominent non-financial barriers (class 2, 3.4%), and balanced financial and feasible barriers (class 3, 72.3%). The identified segments are also described according to socio-demographics and previous retrofitting behaviours. Furthermore, we found that the probabilities of reasons for segment membership and reasons against segment membership are marginally correlated, suggesting independent but complementary roles of behavioural motivations and barriers that should be addressed separately in policy and social marketing interventions.
Conclusions:The identified homeowner segmentation in terms of both reasons for and reasons against is highly differentiated and has informative substantive interpretation. We discuss the potential of using homeowner segmentation to inform tailor-made policy and social marketing interventions.
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Keywords: Energy efficiency, home energy retrofit, market segment, behavioural reasoning, latent class analysis

[Abstract:0321] OP-153 [Accepted:Oral Presentation] [Electricity » Demand]

Demand response system and private values: a SDDP-based guideline for mass deployment

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Overview:Facing the double challenge of increasing demand for electricity and massive integration of variable renewable energy sources, the power sector seeks new flexibility sources. These trends hinders indeed the ability of power systems to follow variations of supply and demand in order to balance them at all relevant time scale and at controlled costs. Among new flexibility sources, demand-side flexibility, also called demand response, is seen crucial in the following decade. Regulators and system operators foster this flexibility option due its lower costs compared with high scale deployment of batteries, power-hydro storage or with interconnections development (IAE (2022)).

Even though it implies lower infrastructure costs, demand response necessitates regulatory, economic and social efforts in order to be implemented at significant scale. In Europe, many channels are available in order to incentivize the development of demand-side flexibility and numerous actors might find an interest in it (e.g.Bureau et al. (2023), recommendations 4 and 5). Therefore, an industrial plan in order to coordinate these efforts seems required for stakeholders to deploy demand response at system scale (see RTE (2023) in France or IAE (2022)) and benefit from this source of flexibility.

However, such coordination requires from stakeholders the ability to answer the genuine question: what is the value of a new installed MW of demand-side flexibility from a specific power use ? A relevant answer should assess simultaneously and quantitatively the specifics of the considered power use, the type of service(s) for which its flexibility is intended but also the interest of all actors of the power system for this flexibility. Hence an large-scale deployment of demand response implies disaggregating the notion of demand response value and measuring these values. These indicators are the only way stakeholders would have access to the multifaceted impacts of demand response in both power systems and markets.

Demand response has been extensively studied by the literature. Nevertheless, it remains fragmented between studies of characteristics of electricity uses as flexibility sources, of demand response revenue streams, of the challenges of its integration in electricity markets and of its effects on power systems. Such state of the art is detrimental to usable policy insights as all of these aspects have to be considered in system planning. System effects are indeed closely related with the characteristics of introduced resources and with systemic flexibility needs. Resources are in turn only actually introduced and operated if their revenue is sufficient. Finally, such revenues depend directly on market designs, public aids and the correspondence between the feature they value and the specifics of the considered demand response potential.

Some authors inventory in parallel the attributes of a flexible resource, the possible uses of this resource and the properties that are valued by the different electricity markets (Bradley et al. (2013), Vicente-Pastor et al. (2018), Villar et al. (2018), Ramos et al. (2016)). However, their analysis, intended to give insights on market designs, remain mainly qualitative.

The present study seeks to follow the ambition of the last mentioned branch of the literature while adopting a more quantitative approach. We try to encompass here both the types of flexible demand, the different values and services of demand response and, above all, measurement methods for these values. Hence, such measures are given for specific, flexible electricity uses with their own technical or social constraints. The main contribution of this study lies in its holistic and quantitative approach of demand response. It synthesizes possible answers to the question of the value of making a specific power demand flexible.

Policy-wise, this study proposes methods for the valuation of demand response and insights on some flexible demands to decision-makers, whatever the dimension of demand response they are interested in. The proposed framework also evaluates potential conflicts occurring in the development of DR as some actors might have opposed valuations of the same DR potential. In other words, we build a dashboard of indicators relative to demand-side flexibilities allowing to orient the deployment of demand response capacities according to the interests of stakeholders.
Methods:First, from a literature review, we derive a series of indicators of DR values by bridging flexible electrical appliances, generic flexibility resources, flexibility needs of a power system and the actors responsible for the procurement of these services.
DR values harsh back either to system operation values (total operating cost, emissions, system imbalance), investment values (need for peak generation, possible entry of more variable renewables) or private values (profit generated by DR, market price level and volatitility). Appliances from all sectors candidate to enter large-scale demand response programs are quantified through a set of relevant attributes of a flexible resource (availability, duration, number of activation, recovery time, minimum down time, variable cost).

Then, a large-scale dispatch model accounting for a bottom-up reprezentation of DR and accounting for stochasticity in demand levels and renewables production, solved by stochastic dual dynamic programming (SDDP, see Pereira & Pinto (1991)), is presented. It serves to measure system operation values of each DR candidate and encompass day-ahead, intraday and day-to-day reserve procurement as revenue streams for DR and traditional generations. For investment values, the model is adapated in order to incorporate a first stage decision of investment in either peak generation or renewables. Finally, private values of DR resources are evaluated in this setting for a price-taker agent, price data being simulated by the operation model without DR.

The models are calibrated for 2035 France, with considerable presence of renewables, as the following decade is expected to be marked by DR large-scale deployment in Western Europe. Robustness checks are to be implemented in order to control for the initial level of DR in the system before introducing the evaluated MW, since previous works from the author underlined a possible cannibalization effect of demand response.
Results:Results of our simulation depicts contrasted values for the various demand response potentials. Contrasted among potentials as tertiary and residential potentials (mainly heating and cooling) are on average a hundred times more profitable than industrial costly load shedding potentials. Tertirary appliances seem to bring more value to the system in terms of security of supply, total operation cost and price volatility reduction than residential appliances. This may arise from the shorter delay over which residential load shifting has to be recovered and the smaller amount of allowed activations.
Conclusions:The paper contributes to the discussion of large-scale deployment of demand response, which is bound to happen in increasingly renewables based power systems. Key indicators for describing and valuing diverse demand response potentials are designed. A methodoly of assessment of these indicators is proposed in the form of stochastic linear programs solved by SDDP. It is applied in the case of 13 appliances from the residential, tertiary and industrial sector and a hypothetical 2035 French power system.

Results show that, depending on the preferred value indicator of the decision maker, the merit order of demand response potential differs with industrial load-shifting appliances displaying bigger private profits on average than residential ones yet bringing less guarantees in terms of system values (total cost and security of supply notably).

The present exercise provide a valuation framework for decision makers interested in making demand response deployment (which seems necessary in the following decade) in an economically/environnementally rational order. The framework can also lay common discussion ground for different actors of power systems (TSOs, generators, DR aggregators, retailers, regulators) to discuss and bear this deployment even if they seek slightly different objectives.
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Keywords: Demand response, Flexibility, Renewable energy, SDDP

[Abstract:0567] OP-154 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

Economic and environmental impacts of road transport electrification in Saudi Arabia: A scenario analysis

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Overview:The transport sector plays a crucial role in economic and social development. Due to strong economic development, urbanization, low fuel prices, and the lack of availability of public transport, the demand for vehicles has increased significantly in Saudi Arabia. The road transport sector is one of the main consumers of oil in Saudi Arabia (Atalla et al., 2018). Growing incomes have enabled most Saudi households to purchase private vehicles, while economic development has led to large cities with extensive road infrastructure and an extensive highway network connecting Saudi Arabia's various cities.
Saudi Arabia relies on fossil fuels to meet its transportation fuel requirements; as a result, oil demand for the transportation industry has increased. The country's high consumption of fossil fuels in the transport sector and the steady increase in the number of vehicles on the road have raised concerns about future energy consumption, economic growth, and greenhouse gas emissions. Electrification of the vehicle fleet is central to meeting key environmental, transport, and energy policy challenges. Countries around the world have set ambitious long-term targets for moving away from internal combustion engines (ICEs), with goals for large-scale adoption of electric vehicles (EVs) or timetables for the complete elimination of ICEs.
With the rapid economic growth of Saudi Arabia, road transportation is emerging as one of the largest and fastest-growing consumers of oil in the country. This study aims to project trends in vehicle growth, oil demand in the transport sector, and CO2 emissions associated with on-road transportation in Saudi Arabia. The projection of vehicles and oil demand is significant because it forces decision-makers to develop strategies to prevent more serious environmental impacts in the future. Secondly, we developed different scenarios for EVs in Saudi Arabia to determine the effect of EV penetration on future oil demand, CO2 emissions, and electricity demand.
Methods:Numerous studies have been carried out to project vehicle ownership in developed and developing countries. De Jong et al. (2004) reviewed the passenger car ownership models described

in recent literature. The authors relate vehicle ownership to specific economic parameters (typically national GDP, GDP per capita, income per capita, and/or income per household) using a sigmoid-shaped function, which assumes that the long-term trend in vehicle growth follows an S-shaped curve, with three phases: a period of slow growth at the beginning (when economic levels are low), a period of expansion and a period of saturation (when vehicle population growth approaches the saturation level). A number of sigmoid functions for simulating vehicle stocks have been demonstrated: the modified logistic function by Button et al. (1993) and Ingram and Liu (1997), as well as the Gompertz function by Dargay and Gately (1999) and Zachariadis et al. (1995). In this study, we chose to use the Gompertz function to simulate the growth of the total vehicles in Saudi Arabia.
Results:We are still working on the empirical analysis of this study.
Conclusions:Vehicle ownership in Saudi Arabia has grown rapidly due to urbanization and economic development; this trend is expected to continue in the future. Consequently, oil consumption, CO2 emissions, and other environmental problems related to the transportation sector are increasing rapidly in Saudi Arabia. However, no comprehensive research is available on the future projection of Saudi Arabia's vehicle population growth, oil consumption in the transportation sector, and associated CO2 emissions. Consequently, Saudi Arabia may not have the information needed to formulate targeted, effective policies to control vehicle population growth and the resulting increase in oil demand and greenhouse gas emissions.
In this study, we developed a model to predict the total number of vehicles in Saudi Arabia until 2050. The total number of vehicles was further divided into passenger cars, trucks and buses. To remove the uncertainties associated with vehicle growth and the potential to improve vehicle fuel economy, we developed two sets of scenarios: one for the range of vehicle growth and one for the range of potential improvements in vehicle fuel economy. Several EV scenario analyses were developed to consider the potential impact of EV penetration on future transportation oil demand, CO2 emissions, and electricity demand. By using the methodology developed in this study, we projected vehicle population, annual oil use and CO2 emissions through 2050.
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Keywords: Vehicle; oil demand, CO2 emissions, Saudi Arabia

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Spatial Distribution of EV Charging Infrastructure in Germany: An Exploratory Analysis of Determinants

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Overview: In recent years, the urgency to mitigate climate change by reducing carbon emissions has gained widespread recognition. Germany, at the forefront of climate action, aims to slash its greenhouse gas (GHG) emissions by 65% by 2030 compared to 1990 levels (BReg, 2023). Given the transport sector's failure to meet targets, the 'German climate protection law' (Bundes-Klimaschutzgesetz) mandates a 48% reduction in transport sector GHG emissions by 2030 (BfJ, 2019). Essential to this transition is the electrification of transportation, with Electric Vehicles (EVs) emerging as a promising alternative to traditional internal combustion engine (ICE) vehicles. Germany aims to reduce reliance on fossil fuels, curb emissions, and foster a cleaner future through EV adoption and the establishment of a comprehensive charging infrastructure.

The widespread adoption of EVs hinges not only on technological advancements but also on a robust charging infrastructure capable of supporting the growing fleet of electric vehicles. An accessible charging network is vital to alleviate range anxiety, boost adoption rates, and facilitate long-distance travel. Additionally, such a network stimulates investments in renewables, creates jobs, and drives technological advancements. Germany envisions deploying 15 million EVs by 2030 but faces challenges; as of June 2021, only 3% of the target had been met, with just 10% of new cars being fully electric (BMWK, 2021). Barriers include higher initial costs, limited range, and inadequate charging infrastructure (Sierzchula et al., 2014). Governments globally have implemented policies to bolster EV competitiveness and uptake (Silvia and Krause, 2016).

EV charging infrastructure plays a pivotal role in consumer decisions and adoption rates (Coffman, Bernstein, and Wee, 2017). Germany has actively promoted public EV charging infrastructure, aiming for one million public chargers by 2030 (BMVI, 2019). However, as of July 2023, only 9.7% of this target had been achieved, with 97,494 public chargers operational nationwide (BNetzA, 2023a). Achieving the 2030 goal remains uncertain, emphasizing the need for a strategic approach to charger placement and integration into daily life. The seamless integration of charging infrastructure into routines and electric grid stability are crucial for optimizing EV adoption and emission reduction efforts.

This paper aims to identify determinants of existing EV charging infrastructure distribution in Germany, focusing on factors shaping spatial allocation across regions. By examining these determinants, the paper seeks to guide evidence-based decision-making and inform interventions supporting the transition to electric mobility.

Methods: The methodology section outlines the data sources, variables, and regression model used to analyze the relationship between the number of charging stations and various explanatory factors. The level of analysis is at the postcode level and the dataset was constructed from multiple sources to capture diverse aspects influencing charging point locations in Germany. OpenStreetMap (OSM) provided crucial geographic data, including population statistic, amenity locations like supermarkets, restaurants, and service stations, categorized into four groups: 'Errands', 'Food and Beverages', 'Shopping', and 'Daily Supplies'. QGIS, an open-source geographic information system, facilitated data extraction from OSM, especially regarding the electric grid infrastructure, such as power lines, converter stations, substations, and transformers. Power plant locations and renewable energy sources were obtained from a German public authority dataset.

Variables were aggregated at the postcode level, with population density and road density serving as base variables. Amenity variables captured opportunities for charging while engaging in daily activities. Infrastructure variables included road and living street density, motorway links, train stations, and petrol stations. Electric grid variables encompassed line density, intersections, and power plant presence.

Cross-sectional regression analysis was employed to model the relationship between the number of charging stations and explanatory variables. The regression equation included the dependent variable (number of charging stations per postcode), base variables (population density and road density), amenity variables, infrastructure variables, electric grid variables, municipality fixed effects, and an error term. The methodology aimed to comprehensively capture factors affecting charging station distribution, from population density and infrastructure to amenity availability and electric grid characteristics. By leveraging diverse data sources and employing robust regression techniques, the analysis sought to provide insights into the complex dynamics shaping the deployment of charging

infrastructure across Germany.
Results:The results from the regression analysis shed light on various factors influencing the distribution of EV charging stations in Germany. We find that population density and road density correlate positively and significantly with charging station distribution, underscoring the close relationship between charging station placement and population and road networks. These results underscore the pivotal role of population centers and road infrastructure in dictating the spatial distribution of charging stations, highlighting the importance of accessibility and convenience for EV owners. The results further show that amenity variables are significant determinants of charging station counts, suggesting that proximity to essential services and daily amenities drives demand for charging infrastructure.

These findings underscore the importance of considering local amenities and consumer behavior when planning charging infrastructure. We also find that postcodes with motorway links demonstrated significantly more chargers, particularly fast chargers crucial for long-distance travel. These findings underscore the importance of strategic placement along major transportation corridors to increase highway accessibility, facilitate EV adoption for long-distance travel and address range anxiety. We also find that residential areas featured significantly fewer fast chargers, reflecting preferences for overnight charging. Conversely, the available of public transport stations such as train stations exhibited negligible impact on charging station distribution, possibly due to space limitations or commuters preferring home charging.

In terms of the impact of electric grid variables, we find that the density of electric lines used as proxy for the overall availability of electricity in a postcode is a significant determinant. The number of intersections in the grid, denoted by the count of converter stations, substations, and transformers per postcode were also found to have significant impact of the number charging stations. For example, substations and transformers appears to be significant drivers of charging infrastructure. In summary, the results highlight the multifaceted determinants of EV charging station distribution in Germany. Population density, road networks, amenity variables, and electric grid infrastructure play pivotal roles, with fast chargers notably associated with motorway links. Understanding these dynamics is crucial for optimizing charging infrastructure and promoting EV adoption.
Conclusions:The analysis of EV charging station distribution in Germany yields insights crucial for policy decisions aimed at optimizing charging infrastructure and expediting the transition to electric vehicles (EVs). Factors such as population density, road networks, amenity variables, and electric grid infrastructure play significant roles in shaping charger placement, highlighting the need for comprehensive planning and policymaking.

Population density exhibits a strong positive correlation with charging station numbers at the postcode level, underscoring the importance of catering to densely populated urban areas. Prioritizing charging infrastructure installation in urban centers can address the increasing demand from EV owners residing in these regions. Strategic placement along major transportation routes like highways and motorway links can mitigate range anxiety and facilitate long-distance travel, encouraging broader EV adoption.

Amenity variables' association with charging station distribution emphasizes the role of local amenities in driving demand for charging infrastructure. Policymakers should consider the proximity of essential services and daily amenities when planning charger placement, particularly in residential areas and locations frequented for errands and daily supplies. Partnering with supermarkets, retail outlets, and fuel stations to host charging stations can enhance accessibility and convenience for EV owners while creating additional revenue streams for businesses.

Analysis of electric grid infrastructure underscores the importance of ensuring local electricity availability and grid connectivity for charger placement. Differentiating between normal and fast chargers enables policymakers to tailor infrastructure development to meet specific needs, such as overnight charging in residential areas and fast charging along major transportation routes.

In summary, a comprehensive and integrated approach to EV charging infrastructure development is crucial. Policymakers should prioritize investment in urban charging networks, strategic placement along transportation corridors, and collaboration with local businesses and energy providers to enhance accessibility, convenience, and reliability of charging infrastructure. Furthermore, fostering public-private partnerships and incentivizing EV adoption through subsidies, tax incentives, and regulatory measures can stimulate investment in charging infrastructure and accelerate the transition to sustainable transportation systems.
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Keywords: Electric Vehicle, Charging Infrastructure, Electric Mobility

[Abstract:0617] OP-156 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

Sharing is Caring. A Choice-Based Conjoint Analysis of Wallbox Sharing Preferences in Germany

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Overview:The transition to battery electric vehicles (BEVs) in Germany is contingent upon the availability and accessibility of charging infrastructure. Public charging stations, while essential, often face congestion and are unevenly distributed between urban and rural areas. An untapped resource in this context is the private charging infrastructure, notably wallboxes owned by individuals. These wallboxes are underutilized, being used for charging their owner’s BEV only for a fraction of the day. This study explores the potential of wallbox sharing between owners ('hosts') and external users ('chargees'), aiming at enhancing the utilization of existing charging capacities and fostering a sharing economy in the BEV charging sector. Building upon this premise, the research delves into the dynamics of wallbox utilization and the factors influencing their potential for sharing.
Methods:This research employs a choice-based conjoint analysis to understand the preferences and decision-making processes of over 4,300 German individuals, divided into hosts and chargees. Each participant is engaged in 11 choice situations, evaluating wallbox sharing options based on four attributes: *sustainability* (type of charging electricity), *social well-being* (relationship between host and chargee), *cost of electricity*, and *ease of use* (level of interaction required between host and chargee). The study's design allows for a comprehensive understanding of the incentives and barriers

perceived by both groups in the sharing process. In this context, the research investigates how these attributes influence the willingness of individuals to participate in wallbox sharing.
Results:The findings reveal that both hosts and chargees prioritize *ease of use* and cost factors in their decision-making. *Sustainability* emerges as a major concern, especially when electricity from solar PV panels can be charged at the host's charging station. *Social well-being*, while less critical, shows interesting trends; participants are more inclined to share with neighbors or acquaintances than strangers. The study underscores the importance of balancing economic incentives with usability and environmental considerations in promoting wallbox sharing. Furthermore, the results offer insights into the nuanced preferences and concerns of potential participants in a wallbox sharing scheme.
Conclusions:Wallbox sharing presents a viable solution to augment Germany's BEV charging infrastructure, addressing the limitations of public CSs. The study highlights the necessity of developing user-friendly, cost-effective, and sustainable sharing models that cater to the preferences of both wallbox owners and chargees. Policymakers and industry stakeholders should consider these insights in creating regulatory frameworks and technological solutions to facilitate wallbox sharing, ultimately contributing to the broader adoption of BEVs in Germany. In conclusion, this research emphasizes the role of private charging infrastructure as a critical component in the evolution of Germany's electric mobility landscape.
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Keywords: Choice-based conjoint, private charging infrastructure, sharing economy, electric mobility, wallbox sharing

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[Abstract:0625] OP-157 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

Power system optimization for renewable energies, stationary batteries and electric vehicles

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Overview:Traditionally, power grids were made up of large power plants producing huge quantities of electricity for inflexible end consumers. However, with the rise of distributed energy resources (including distributed generation, distributed storage units, flexible loads such as heating, cooling, electric vehicles...) and the advent of "smart grids", electrical systems are facing new challenges. These distributed energy resources have an impact on grids, which were not designed to accommodate the high penetration of these new units. The power supply system is therefore undergoing a complete metamorphosis. In addition to security of supply issues, the growth of renewable energies will create periods when the marginal cost of production will be very low or zero, with the risk of momentarily negative prices or production "spills". It is also important to ensure that the increased use of electricity to decarbonize essential uses (mobility, heating) is not detrimental to the balance of the power system, but rather contributes to its optimization. Due to the intermittency and uncertainty of renewable generation, the large-scale integration of renewable generation and new loads is changing the behavior of overall consumption; such an evolution of the power system presents unique challenges and opportunities for generation facilities, consumers, aggregators and other participants in the power grid. Energy flexibility technologies could effectively mitigate the uncertainty caused by this evolution of the power system. According to the Conseil Général de l'Economie's 2020 report on power system flexibility, from 2030-2035 onwards, more general consumption flexibility will be sought for economic reasons, in competition with other technical solutions such as storage or gas-fired power plants to ensure supply-demand balance. It is important to note that electric vehicles have strong arguments as suppliers of flexibility products. They have a decent availability rate, good predictability, are able to react in seconds and supply reactive power. The development of electric vehicles and renewable and decentralized power generation are seen as key levers in the energy transition, and as tools for flexibility in the energy chain, enabling sustainable responsiveness to climatic contingencies. In this paper, we propose a strategy for coordinating flexibility technologies based on game theory and optimization, in order to improve the growing flexibility of power systems subject to variable renewable penetration.

Methods: We assume a power system made up of grid operators, energy producers (renewable and conventional), flexibility technologies and flexibility aggregators. We take into account renewable energies from solar and wind sources. We consider only bi-directional electric vehicles organized into a fleet by a flexibility aggregator that acts as an intermediary between the vehicles and the electricity market. In our model, we consider two storage technologies: bidirectional electric vehicles (V2G) and stationary batteries. Each of the flexibility and generation technologies is connected to the grid either bidirectionally (EVs for charging/discharging via charging stations) or unidirectionally to supply the grid with electricity (power generation sources, stationary batteries). Stationary batteries are also connected to renewable energy production sources. The whole system is controlled and monitored by information and communication technologies (ICT), which will enable us to improve the operation and planning of the power grid in order to optimize the system. We develop a three-level dynamic optimization model based on game theory, where we analyze the strategic investment behavior of each player. At the first level of the model, we model the investment decisions of the leader (the network operator), who decides on the level of network investment that maximizes welfare. Then, at the second level, we model the investment decisions of renewable generators who are followers of the network operator. Renewable generators invest in generation and storage capacities (stationary batteries) that maximize their expected profit. At the second level, we also model the investment decisions of flexibility aggregators, who are followers of the network operator but leaders of electric vehicles. They also invest in charge/discharge stations to maximize his expected income. And finally, at the third level, we formalize the purchasing decisions of electric vehicles (V2G) to provide flexibility in order to minimize the total cost of ownership of electric vehicles. We use dynamic stochastic modeling to formalize the choices of the actors as a mathematical program with equilibrium constraints. And the mixed complementarity problem technique is then used to solve the subproblems of the game and find the equilibrium at each step.

Results: We find that the flexibility offered by electric vehicles and stationary batteries enables networkoperators to avoid investment costs. This flexibility increases welfare and lowers the cost of integrating renewable energies into the network. Purchasing decisions for electric vehicles remain strongly influenced by the deployment of charging stations. The charging/discharging tariffs offered by flexibility aggregators modify the flexibility supply scenarios for electric vehicles. Network operators need to put in place incentive mechanisms to lower charging tariffs and offer attractive discharging tariffs to encourage electric vehicle owners to put their vehicles at the service of the network. We show that storage via stationary batteries increases producers' profits, as their surplus production is stored for future consumption or sale. On the other hand, we find that self-consumption of production does not optimize plant operation, as there is no real trade-off between consumption and sale.

Conclusions: Incentive mechanisms are necessary so that energy produced from renewable sources is consumed where there is the greatest need in order to optimize the entire system. Also a regulated market model is necessary for the deployment of electric vehicles.

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Keywords: Electric vehicle, storage, network operator, flexibility

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[Abstract:0549] OP-158 [Accepted:Oral Presentation] [Energy System Transition » Policy]

Transformation and implementation Roadmap to Smart Grid Technologies in Uganda

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Overview:Uganda Vision 2040 indicates that Uganda aspires to have access to clean, affordable and reliable energy sources to facilitate industrialization. In striving to achieve this vision, the government continue to commission a number of power plants, the recent ones being Isimba and Karuma power plants which increased the country's electricity generation capacity to 1,837 MW. Uganda's Ministry of Energy and Mineral development however, reported a decline in quality-of-service compliance performance in 2022/23 financial year. This was partially attributed to limited automation to allow timely response to faults by operators. The ministry also reported an average customer outage duration of 15.8 hours per month yet the country has excess generation capacity of 559MW (2022 performance review report MEMD). The limited automation of the grid further contributes to customers' inability to have adequate information about their consumption rate to have preference on when and how much to consume. Due to these inefficiencies, some consumers avoid electricity bills through illegal connections and vandalism, yet over 90% Ugandan households resort to biomass for their household energy needs. The purpose of this study was to recommend a strategic transformation and implementation roadmap towards transitioning Uganda's electricity sector to smart grid technologies. This was aimed at increasing access to clean, affordable and reliable energy sources as stipulated in Uganda's vision 2040.
Methods:The methodology of this study comprised concurrently triangulating qualitative, quantitative and documentary review research designs by collecting data from the major energy players in the electricity sector of Uganda. These included Policy makers (04), Regulator (01), Generators (09), Transmitters (02), Distributors (09), Support organizations (10), Industrial consumers (25), Households (144) and Consumers of own generated electricity (22). The documents reviewed included; The Electricity Act, 1999, Atomic Energy Act, 2008, Amended Energy policy of 2022, Renewable Energy Policy of 2007 and the Electricity Connection Policy of 2019. Quantitative data analysis involved using frequencies to describe respondents' responses in relation to the study variables. Qualitative data analysis was concurrently done during and at the end of data collection. This involved taking field notes and electronically recording (with respondents' permission) the researchers' interactions with the respondents. These recordings were later transcribed into written materials and thereafter summarized and memoed into patterns and themes for easy and logical interpretation.
Results:Results indicate that there is no direct policy on Smart Grid Technologies in Uganda. However the existing energy Acts and policies mention some aspects of smart grid technologies like energy mix, energy efficiency, net metering and integration of data by various players but do not put a direct emphasis on adoption of smart grid technologies. The results further indicate that sector players have adopted some aspects of smartness in the technology used. These includes Metering technologies like Yaka for the domestic and commercial customers, Automated Meter Reading (AMR) for industries, Supervisory Control and Data Acquisition (SCADA) system which is a monitoring and controlling system that gathers and analyzes real time data. The major electricity distributor (Umeme) also has an App where customers can interface electronically with the operators to pay bills, buy Yaka, check their balance and keep up to date with planned outages. The results also show that the sector has capacity to adopt smart grid technologies as it is characterized by increased

electricity generation capacity, private sector investment and generation of electricity from different sources.

Conclusions:The study findings imply that the sector players have the ability to invest in smart grid technologies to increase reliability of electricity and subsequently increase demand for electricity and offset the current high tariff rates. The study's recommended transformation and implementation Road map to smart grid technologies include the following steps;

1. Identifying potential stakeholders for smart grids in the distribution system
2. Conducting baseline research for smart grid potential
3. Piloting smart grid in a given location(s)
4. Conducting socio-economic benefits of smart grid technologies that accrue to all stakeholders.
5. Stakeholder agreement on the desired outcomes and the specific pathway for reaching SGT within a given timeframe
6. Setting timelines and milestones for achieving Smart grid technologies
7. Developing policies and regulatory framework to guide phased transition to smart grid technologies,
8. Instituting technology mandates that require the use of SGT technologies
9. Incentivizing private sector investments into SGT
10. Incremental phased adaption of smart grid technologies based on piloting learning points
11. Full adoption of smart grid technologies

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Keywords: Smart Grid Technologies, Transformation, Implementation, Roadmap

AuthorToEditor: Am looking forward for an opportunity to present this paper in the 45th IAEE International Conference

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[Abstract:0557] OP-159 [Accepted:Oral Presentation] [Energy System Transition » Policy]

The Energy Transition in Two Speeds: Path Dependencies and Segregated Network Effects in Smart Meter Adoption Decisions in Germany

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Overview:The widespread adoption of Smart meters is considered to be an important step in the energy transition in the European Union. In Germany, the smart meter adoption rate remains at around 1% in 2022, whereas the rates are much higher in many other EU countries, especially in Western Europe. While the reasons behind the adoption rates might be administrative or policy-

related, it allows us to better understand the reasons behind the (non-) adoption decisions of smart meters by households. In this article, we use the geographical and economic disparities in electric vehicle (EV) adoption in Germany to explain the adoption of EV charging infrastructure at homes, as well as the uptake of smart meters in homes.
Methods:In this article, we use a binary-outcome econometric model to utilise the geographical and economic disparities in electric vehicle (EV) adoption in Germany to explain the adoption of EV charging infrastructure at homes, as well as the uptake of smart meters in homes[1]. The results are compared with an Agent-Based Modelling (ABM) approach to test the hypothesis of segregated networks. The empirical basis of the analysis is a representative survey of 5000 households contacted in Germany that have purchased a subsidised electric vehicle between 2016 and 2023.
Results:The results indicate that the adoption rate shows significant geographic and economic disparities between states in Germany, indicating that stronger network effects and path dependencies in energy- and digital technology adoption might have led to a higher adoption rate in the west of the country, compared to the east, where network effects might be weaker.
Conclusions:The results point to the need for policies to actively address the unfair distribution of public funding in the energy transition to counter segregated network effects.
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Keywords: smart meters, electric vehicles, network effects, econometric models, energy justice

[Abstract:0643] OP-160 [Accepted:Oral Presentation] [Energy System Transition » Policy]

Quest to accelerate energy transition policy reforms in Tanzania

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Overview:Energy is essential for powering economic activities and providing a healthier and more prosperous future to all. In recent years, the challenge of environmental sustainability has attracted considerable attention and policymakers have targeted the energy sector's revolution to promote green energy consumption as an alternate source and so accelerate the energy transition process (Singh et al., 2019). With knowledge on the existing energy fuel sources in use and produces significant pollution to global environment, countries are argued to deliberately innovate and shift from traditional energy to green energy resources. Such endeavors are yet to be accommodated at the satisfactory by many states. The ongoing implementation of technology transformation from the old energy system into a more efficient one is appreciated, however, the share of green energy in the overall energy mix is still minimal (Sun et al., 2022).It is necessary to institute a revolutionary transition from traditional energy to green energy resources for the global energy system (Yu and Guo, 2023). Relevant energy reforms to signal impact at the policy level, institutional, firm, households and sector level are tested and have resulted to mixed outcomes experienced across countries. Heterogeneity in policy supporting environment and infrastructures provides fundamental differences in energy transition across countries' domain. In this paper, policy reforms to accelerate energy transition are explored and tested for their effectiveness focusing the policy environment in Tanzania. Unclean fuels accounts for 90% of the primary energy consumption in households and many Tanzanians relay on unclean fuels for cooking. Only 5.1% of households use liquefied petroleum gas, 3% use electricity and 2.2% use alternative energy sources. Use of unclean fuels for

cooking is detrimental to human health and the environment. Medical reports show that, at least 33,000 Tanzanians die prematurely every year from household air pollution caused by cooking with unclean fuels. 50% of acute respiratory infection (ARI) mortality in under-fives is due to particulate matter (smoke and soot) inhaled from unclean fuel-based household air pollution. If we don't act now to stop using unclean fuels for cooking, we will experience devastating consequences. A new study in Dar es Salaam applying a home-based cooking experiment reveals the low cost of cooking using electricity. This contrary from what is believed by many people that cooking using electricity is too costly and that people with low purchasing power prefer unclean fuels.

Methods:The study is aiming to ascertain the status and pace for which energy transition is progressing in Tanzania. At first, the study performed comparative analysis of the energy transition status. The study adopted Energy transition score from the energy transition framework – the energy transition index (ETI) (WEF, 2018). Comprehensive picture of energy transition effort in Tanzania is mirrored with the state and trajectory of energy transition at the global level. Focusing on policy, institutional, firm, household and sector levels, the study integrates measurement of energy transition with reference to the five levels to ascertain the effective policy reform needed to accelerate energy transition in Tanzania. The study approached the research into three different activities with specific methodology. At first, the study assessed status of energy transition and performed descriptive and regression analysis to established factors influencing energy transition. At this stage, integration assessment of energy transition indicators from WEF and SGD tracker platforms was performed. Second, the study performed field survey and conducted key informants' interviews. KIIs was conducted to small business operators in Urban areas of Dar es Salaam city. This surveyed aimed to ascertain energy transition possibilities at the lower level of business operations and ascertain the necessary policy reform ingredients that could benefit communities. The third, experiment at household level on cost-effectiveness of clean cooking energy. Participants performed cooking experiment using three energy sources (electricity, gas and charcoal) and compared cost per type of fuel. The experiment highlighted and made correction on perceived high cost of cooking using electricity.

Results:Results shows that, there an increase in level of energy transition across the world between 2019 and 2023. The increase in ETI has reached maximum of 78% this means that, more than 20% of potential energy transition has been achieved globally. Sixty-six countries registered positive ETI change and the increase is high for South Africa, Saud Arabia, Brazil, China and others. Countries with decreasing ETI are Tanzania, Jamaica, Brunei, Belgium, United Kingdom etc. However, large economy countries with low decreasing in ETI, they have remarkable reduced levels of energy subsidies, enhanced energy security and a strong and supportive regulatory environment to drive the energy transition (WEF, 2023). This implies that, these economies in better position to energy transition trajectories.

In Tanzania, the ETI shows that, for the 2023, the country level of energy transition has declined compared with ETI for the previous years and also in comparison with other neighboring countries. For the ETI computed in 2019 and 2023, the energy transition for Kenya has increased significantly and that for Tanzania is dwindling. The ETI for Kenya indicates an increase of index by 11% between 2019 and 2023, the ETI for Tanzania is showing a declining energy transition by 13% in same period. For year 2023, the ETI is 42.2 and 57.8 for Tanzania and Kenya respectively.

Regression analysis is performed on the factors influencing the ETI score. The hypothesis is that, energy transition is influenced by country's economic growth represented by real GDP growth rate, human development, environmental performance index, country's energy transition readiness, region of the country (Africa vs non-African). Summary statistics of the key variables by countries is shown below (Table 1). The average ETI score for 2019 and 2023 is 55.52 and 56.18 respectively. The minimum and maxim score for 2023 are relatively higher than the minimum and maximum score for 2019. This shows that, on average, the energy transition has increased globally. The average score for system performance and transition readiness is 63 and 46% respectively. The study performed significance difference between the mean ETI 2019 and 2023 by regions. The results shows that there are significance differences between the ETI for African countries and the Rest. Mean ETI for 2019 and 2023 for African were lower than the average ETI for other continents, except for the real GDP growth and change in ETI (Table 3)

Regression analysis on factors influencing ETI_2023 was estimated. The model specified based on the hypothesis that, ETI_2023 dependents on level of ETI in previous year (ETI_2019), level of system performance reached (SP_2023), human development index (HDI), real GDP growth rate, environment performance index and location of country (Africa). The model result is significant with Square 87%. Level of energy transition in the previous years and level of system performance attained and human development index influences positively the energy transition. The policy reforms should focus more on variables constituting the system performance, human development. Transition readiness variable is statistically significant influencing energy transition in the world (Table 4).

How effective is the cooking with clean cooking energy sources? To cook a 0.5kg of yellow beans, a home-based experiment performed and revealed that, electricity and LGP cooking is more time efficient than cooking using charcoal. Clean cooking energy source uses 40 minutes less time than the time used for cooking using charcoal. Cooking using electricity is no longer expensive. Electricity is the cheapest energy source for cooking compared with cost of LPG and charcoal. The cost of cooking using charcoal and LPG is more than double the cost of cooking using electricity. The experimental results unfold the low-cost attribute of electricity and surprised households in the experiments who have not been using electricity to cook believing that cooking using electricity is expensive.
Conclusions:Better awareness is needed to accelerate sustainable energy transition. Using clean cooking fuels is possible and is much beneficial in terms of cost and time and health to households. The long-term existing claims on high cost of cooking using electricity has not been backed by evidence from the field experiments. Households at their own homes, applying their cooking appliances have exhibited a least cost of cooking beans using electricity compared to LPG and Charcoal. Awareness creation by involving directly households in cooking experiments aids better understanding on how cheap the electricity for cooking is and hence an important endeavor to fast-track sustainable energy transition.
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Keywords: Green Energy Transition, energy policy reforms, energy transition index

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What is Optimal Market Splitting? Review of Clustering Techniques on Nodal Pricing

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Overview:As part of the VerSEAS research project, our team investigated multiple options for clustering nodal prices of past and future energy scenarios of the German market. In this presentation, we will compare different market-splitting techniques focusing on the most prevalent clustering algorithms and their associated heuristics. The results will then be modelled on ELMOD, a highly advanced electric market model, and compare results pertaining wellbeing, renewable energy production, line congestion and other relevant paraments of grid performance. An analytic evaluation of the different clustering techniques will complement the simulation and comment on techniques

used by regulatory institutions like National Regulatory Agencies (NRAs) and the European Union Agency for the Cooperation of Energy Regulators (ACER) with the objective of providing concise policy advice on market division schemes both for the German electric grid and other electric transmission systems.

Methods:The market results calculated with the PowerACE model (developed by KIT) are used as input of our calculation within the framework of VerSEAS. This data is used to calculate nodal prices using an optimal transmission model. This nodal data has hourly resolution over the target year and very high special resolution as well, with over 1500 nodes to describe the German transmission grid in a high granularity.

We apply a series of market splitting algorithms drawing from common practices in Sweden, and Norway, the recommendations by ACER to the German market as well as other NRAs examples. Additionally, we suggest more complex clustering methodologies like agglomerative clustering under different metrics and use each methodology to create different corresponding market divisions.

Results:The results are a summary comparison of the different grid performance parameters of the German grid under different market split scenarios. The results are calculated with ELMOD, an electric market model of the German grid with high resolution and detailed information regarding demand and energy production within Germany. The parameters used for the comparison include but will be not limited to: total system costs, CO2 emissions, renewable energies curtailment, line congestion, and pricing differences between market zones. The quantitative results will be accompanied by a a posteriori analysis of the performance of said market splitting techniques.

Conclusions:Conclusions focus on the relationship between market splitting algorithms with their associated heuristics and their effects on grid redispatch performance. The objective is to make a broad analysis of existing techniques and compare them in a realistic scenario while keeping in mind the analytic characteristics that define each of them. Furthermore, we will draw conclusions on possible policy decisions regarding the market split of the German grid as well as other possible grids.

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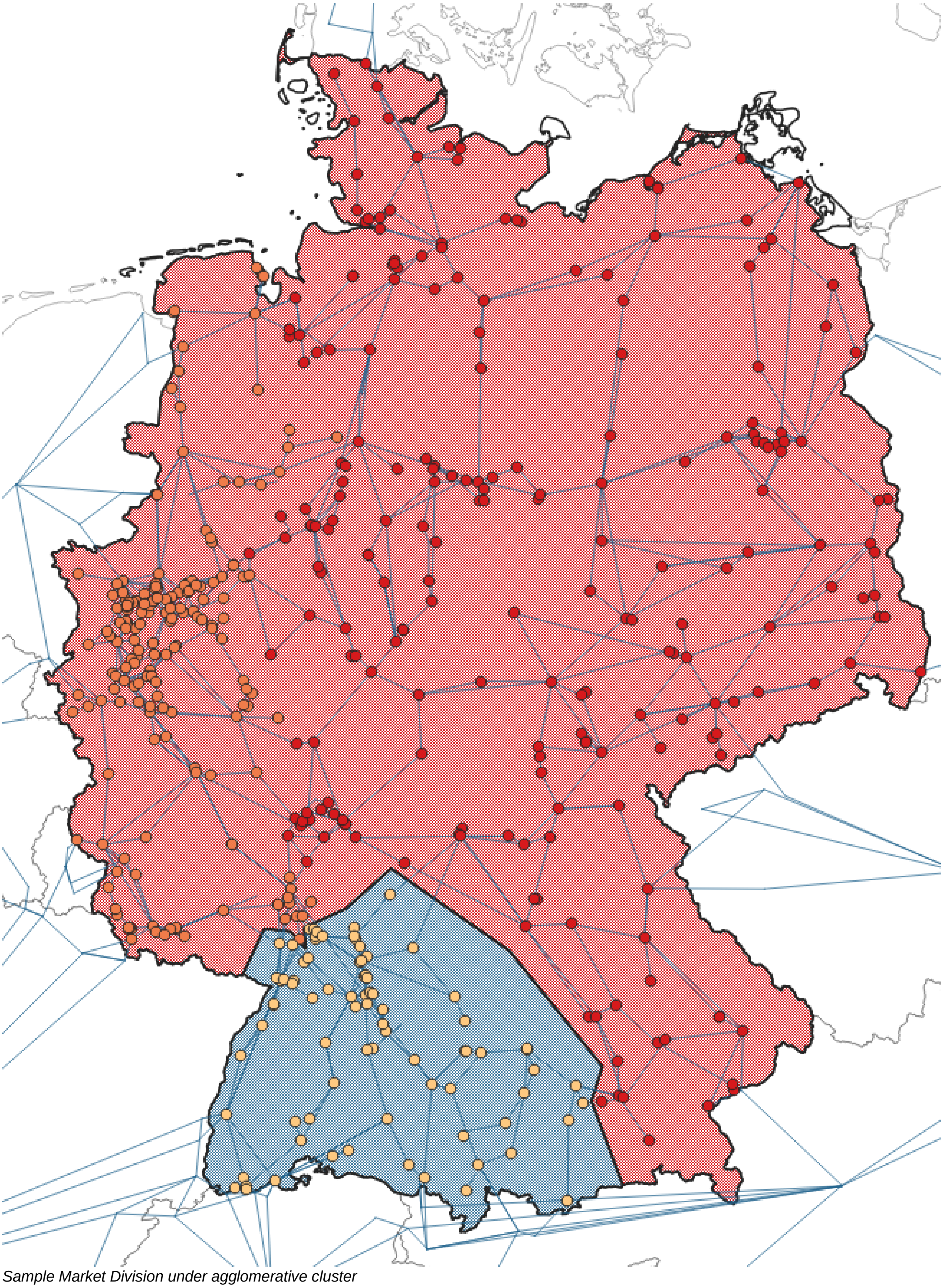
Keywords: Market Split, Energy Markets, Clustering

Sample Market Split



Sample Market Division under agglomerative cluster

[Abstract:0233] OP-162 [Accepted:Oral Presentation] [Energy System Transition » Policy]

A Review of Offshore Wind Leasing and CfD Subsidy Allocation in the UK: 1999 – 2023

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Overview:Securing a seabed lease is a key first step in developing an offshore wind farm in the UK. These are allocated via a tendering process, termed Leasing Rounds, that concludes with a competitive auction. The UK's subsidy mechanism for renewables, the Contract for Difference (CfD), is also allocated via competitive auction. The rules of these tendering processes can change significantly between rounds leading to different and sometimes unexpected outcomes. This paper provides a review of leased offshore wind development and allocated CfDs in the United Kingdom from 1999 to 2023, offering valuable insights to the policymakers responsible for delivering the tendering process and, for industry stakeholders, who must navigate it. The summary covers allocated capacity, leasing costs, and the resultant status of the lease – indicating if a site is in development, commissioning, cancelled, or decommissioned. In addition, the paper indicates the reasons why 11.8% of capacity leased between Round 1 and 3, never reached delivery. Methods:The paper compiles a detailed record of all present and lapsed lease sites, by combining data from public registries managed by the Crown Estate, the Crown Estate Scotland, and the UK Planning Inspectorate, with private sector press releases and information obtained through Freedom of Information requests. Using these records, the study then identifies broad trends within the history of leasing within the UK and, how changes in the tendering process has affected Leasing Rounds and the CfD coverage of leased sites. Results:A comprehensive overview of the status of offshore wind leasing sites in the UK is delivered, characterising each site by its current or final status. Additionally, the costs associated with leasing are illustrated for each site, including option deposits and option fees. The study investigates the ratio of sites leased compared to sites that have reached operation. An investigation of the relationship between leasing and CfD acquisition was also carried out – with seabed leases acting as the primary prerequisite for participation in the CfD Allocation Round. This includes a summary of the number of eligible participants for each Allocation Round and, a review of the time between the acquisition of a Seabed Lease and a CfD. Conclusions:This paper delivers an overview of leasing for offshore wind in the UK over the last 20 years, and its ultimate status. It reveals several trends within delivery, with capacity primarily failing to reach operation due to inhospitable site conditions, 7.5 GW, or environmental concerns, 2.7 GW. Additionally, it reveals that since the introduction of the mechanism; CfD coverage has continuously trended upwards, increasing from 17.6% of capacity leased in the Scottish Waters Leasing Round, to 48.5% in Leasing Round 3. The time between the acquisition of a seabed lease and a CfD has also gradually decreased from ~13 years for Leasing Round 1, to ~9.5 years in Leasing Round 3. It is anticipated these trends will be dampened by the failure of Allocation Round 5 to deliver any bids. Ultimately, this study provides invaluable insights that may inform the future tendering process for both seabed leasing and CfD allocation. Foremost among these insights is the importance of excluding

environmentally inappropriate sites for lease, as evidenced by the withdrawal of Scottish Territorial Waters leases following the publication of the country's Sectoral Marine Plan.
References:

Keywords: Seabed Leasing, Offshore Wind, Contracts for Difference, Natural Resources, United Kingdom

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[Abstract:0427] OP-163 [Accepted:Oral Presentation] [Energy and the Environment » Circular Economy]

Biogas- based clean cooking: A fair and Sustainable energy transition in Uganda

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Overview:Inefficient burning of solid biomass for cooking puts strain on forest resources and emits harmful air pollution into households.
Clean cooking energy is essential for achieving a number of development goals, including access to clean and affordable energy (SDG 7), reducing greenhouse gas emissions and enhancing the health of women and children. In order to expedite a just transition to clean cooking powered by biogas, affordability, Government policy (subsidies and incentives), community participation, gender equity, income equality, cultural issues, safety rules, emission standards, resources considerations need to be addressed in Uganda. As a result, this study shows that research on attaining a just energy transition necessitates multidisciplinary approaches that incorporate the social sciences, natural sciences as well as many modes of knowledge from practitioners, scientists, and various community viewpoints. Thus in order to successfully implement a fair transition to biogas-based clean cooking in Uganda, decision-makers at all levels of Government, local stakeholders, residents, and the academic community will find this research to be a valuable resource.
Methods:To summarize, the assessment of the fair and sustainable biogas based clean cooking is done by calculating the difference between the effects of a Policy scenario and a Reference case in a scenario that spans the years 2018 to 2023. The term Reference refers to a simulation in which the primary drivers of biogas –based clean cooking such as affordability, income levels, Government policy (subsidies and incentives), community partication, awareness, capacity building, access it finance, gender equity, income equality, cultural issues, safety rules, emission standards, availability of feed stocks, the number of households and demography are taken into consideration when calculating the trend in clean cooking. It covers potential driver saturation trends as well as the (residual) effects of biogas – based clean cooking put in place prior to a given reference year, or 2018 in this case, which is the year the impact modeling exercise begins. The term Policy scenario describes a situation where extra energy-saving measures that are planned or implemented beyond the relevant reference year are taken into consideration when determining the development of biogas –based clean cooking.
Results:We suggest an econometric model (time series analysis) that makes it possible to estimate substantial and consistent short-term connections between biogas – based clean cooking and sector-

specific economic indicators for a sustainable transition. From our initial findings, 60% of respondents agreed that, they do not use biogas energy, 25% use biogas for cooking and majority 55% use charcoal for cooking. Most respondents agreed that biogas is beneficial in terms of cooking, sanitation, lighting, financial gains, better livelihoods and sustainable environment. However 58% of the respondents agreed that affordability of biogas is a major determinant for adoption of the technology among other factors thus a need for incentives, subsidies, safety rules, emission standards, resources and funding from global cooperation, knowledge sharing, building capacity, gender equity,income equality which are priority factors for a fair energy transition. Additional research is still needed to evaluate the short-term and long-term drivers of a fair biogas based – clean cooking.

Conclusions:Utilizing biogas protects the environment from the damaging effects that the massive amounts of agricultural waste that are produced worldwide have on the environment and human health. Solid fuels continue to be the most popular option for cooking fuel in Uganda, despite multiple attempts to encourage the adoption of clean energy alternatives. Despite widespread availability of low cost feed stocks, biogas as a cooking energy choice is still insignificant in Uganda. In light of this gradual transition, it is imperative that evidence-based policies need to be developed, put into practice, and then reviewed again in order to encourage a faster transition to clean cooking and the accomplishment of SDG 7 and all of its numerous social benefits.

Across-sector and institutional coordination is needed to maximize advantages and prevent duplication of effort by utilizing complementarity and providing the right feed stocks to encourage cooking with biogas.

Furthermore, there is need for greater understanding and awareness of the advantages and potential of biogas based cooking among key decision makers in the public and private sectors, as well as associations that support research and regulations. In addition to influencing user choices for cooking energy, this will help various stakeholders make well-informed decisions regarding priority work areas.

Providing inventive funding or focused assistance to providers, consumers, and organizations to boost enthusiasm in cooking with biogas, so inciting behavioral shifts and ensuring long-term adoption of contemporary energy services. A creative business plan would be the pay-as-you-go model, which enable customers make installment payments.

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Keywords: Clean cooking, Biogas, fair and sustainable transition, Uganda

Presentation of results on drivers of fair and sustainable biogas – based clean cooking

Variable	Category	Frequency	Percentage (%)
Biogas User	Yes No	16 24	40 60
Energy used for cooking	Biogas Firewood Charcoal Electricity Others	10 07 22 17 07	25.0 17.5 55.0 42.5 17.5
Function of Biogas	Cooking Sanitation Lighting Hearing Others	19 02 06 02 06	61.3 06.5 19.4 06.5 19.4
Why Biogas	Financial gains Sustain Environment Live better All of the above	08 25 04 07	21.6 67.6 10.8 18.9
Biogas Adoption determinant	Finance Government Community Culture	14 09 28 05	35.9 26.1 71.8 12.8
Necessary factors for Biogas Adoption	Government policy Community innovation Technological innovation All of the above	07 11 15 14	20 31.4 40.0 42.7
Affordability relevancy to uptake of Biogas Adoption	To a large extent To a moderate extent To a low extent	21 07 08	58.3 19.4 22.2
Priority factor to transition	Gender equity Income equality Job creation All of the above	08 15 10 12	58.3 19.4 22.2 34.0
Legal requirements for a fair transition	Incentives and subsidies Safety rules Emission standards All of the above	14 11 05 13	40.0 31.4 14.3 37.1
Global cooperation needed	Resources and funding Knowledge sharing Building capacity All of the above	14 9 10 15	40.0 25.7 28.6 42.9
Relevant stakeholders	Political parties Non-Government Organisations Civil leaders Religious leaders	09 21 18 12	25.7 60.0 51.4 34.3

As a way of obtaining study insights a pilot study has been carried out using data collected via a questionnaire designed using All counted online survey tool and a non-probability method known as referral sampling was used to reach 40 respondents. The data obtained was analyzed basically to obtain descriptive statistics as presented in the following frequency table for variables that were deemed so crucial to the study. Most questions sought multiple responses from the respondents and multiple response analysis was used for analysis for such questions.

AuthorToEditor: I will be grateful if my abstract is considered for Presentaion on the 45th International Association of Energy Economics, International Conference Istanbul 2024.

[Abstract:0204] OP-164 [Accepted:Oral Presentation] [Energy and the Environment » Carbon Capture, Utilization and Storage]

Decarbonizing in the Upstream Oil and Gas Sector in Indonesia: Financing Challenges and Opportunities in Deploying CCS/CCUS Projects

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Overview:The global deployment of Carbon Capture and Storage and/or Carbon Capture, Utilization, and Storage ("CCS/CCUS”) is advancing swiftly, with North America and Europe at the forefront and burgeoning interest from Asian regions. This technology is essential to support clean energy by capturing CO2 from various industrial activities and storing it underground or repurposing it for processes in upstream oil and gas industries, such as Enhanced Oil Recovery (EOR) or Enhanced Gas Recovery (EGR).

As energy transition from fossil to renewable energy remains a challenge in Indonesia, CCS/CCUS is the technology to bridge between the need of energy source to maintain high economic growth and the need to reduce GHG emission in Indonesia. A number of desk-top technical studies on CCS/CCUS have been conducted in Indonesia as early as year 2003. A recent study indicates that the capacity of CO2 storage in saline aquifer is 572 GT CO2 and the capacity of the storage in oil and gas fields is 4.85 GT CO2. With such large capacity of CCS/CCUS, Indonesia aims to become the regional CCS/CCUS hub. The first commercialization of CCS/CCUS in Indonesia will potentially come from the upstream oil and gas industry. However, financial aspect has been the major hurdle in commercializing the CCS/CCUS.

Our analysis delves into the financial aspects of CCS/CCUS projects in Indonesia's upstream oil and gas industry, examining the complex challenges and opportunities that affect their development and feasibility. Despite facing hurdles like significant costs, extensive infrastructure requirements, regulatory hurdles, and the need for public endorsement, CCS/CCUS is gaining traction. With escalated investment and governmental support, CCS/CCUS bolsters the financial sustainability of oil and gas ventures. It strengthens their environmental standing, thereby playing an integral role in the worldwide endeavor to mitigate climate change and foster sustainable growth.
Methods:This study incorporates an extensive publications review, an in-depth policy and industrial analysis utilizing Porter's Five Forces Model, and qualitative assessments through expert interviews. In addition, this approach ensures a comprehensive and multifaceted understanding of the financial aspects of CCS/CCUS projects. The literature review component of this study lays the groundwork by identifying the primary financial challenges CCS/CCUS initiatives face. Chief among these is the daunting initial investment required to deploy CCS/CCUS technologies. This is further complicated by the Indonesian regulatory environment, which is marked by uncertainty and variability, posing a substantial risk to investors and stakeholders. The limited avenues for international funding also emerge as a significant hurdle, restricting the scope for large-scale implementation of these technologies.
Results:Building on this foundation, the industrial analysis through Porter's Five Forces provides deeper insights into the competitive environment of the CCS/CCUS sector. Porter’s model include analysis on the competitiveness of Indonesia to commercialize CCS/CCUS, particularly in the upstream oil and gas industries. Based on the model, strategies and risks to compete and become

the regional hub can be identified. This analysis examines the competitive rivalry within the industry, the potential threats posed by new entrants, the bargaining power of suppliers and buyers, and the threat of substitute technologies. This comprehensive industrial analysis is crucial to understanding the market dynamics influencing investment decisions and financial strategies in the CCS/CCUS sector.

Simultaneously, the policy analysis aspect of this study scrutinizes the existing governmental policies and regulatory frameworks. The dynamic of the policy framework compels us to analyze both ratified and drafted regulations. We evaluate the effectiveness of current incentives provided by the Indonesian government for CCS/CCUS projects, particularly for upstream oil and gas industries. It investigates how these policies influence these projects' financial viability and attractiveness to potential investors. This analysis also considers the role of international environmental policies and funding mechanisms that impact Indonesia's CCS/CCUS sector.
Moreover, the qualitative assessments through expert interviews enrich our study with current, practical insights. These interviews with industry experts, policymakers, and financial analysts provide real-world perspectives on the challenges and opportunities in financing CCS/CCUS projects. They offer valuable validation and critique of the theoretical and secondary data findings, adding depth and practical relevance to the study.
Conclusions:In conclusion, this comprehensive analysis highlights that strategic government policies targeting investments and international collaboration are crucial for the success of CCS/CCUS projects in Indonesia, particularly for upstream oil and gas industry. Understanding the industrial landscape through tools like Porter's Five Forces and aligning it with supportive policy frameworks can significantly influence the financial viability of these projects. We are hoping that our study will be beneficial for the government to set strategies to support the deployment of CCS/CCUS in Indonesia. The study advocates for future research into specific financial instruments and models suitable for the Indonesian context and for developing a more robust regulatory framework to facilitate investment in CCS/CCUS projects. This research contributes significantly to understanding the financial aspects of environmental technologies, providing valuable insights for policymakers, investors, and stakeholders in the field, both in Indonesia and in comparable international contexts.
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Keywords: decarbonization, energy transition, upstream oil & gas, CCS/CCUS, financial viability

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[Abstract:0414] OP-165 [Accepted:Oral Presentation] [Energy and the Environment » Carbon Capture, Utilization and Storage]

From Waste to Commodity: Leveraging Game Theory in the CCUS-Driven CO2 Market - A Case Study in Cyprus

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Overview:In accordance with the Paris Agreements of 2015, the European Union aims to achieve net-zero pollutant emissions by 2050, setting interim targets for 2030 and 2040 to limit global warming to 1.5°C compared to pre-industrial levels. The International Energy Agency (IEA) emphasizes the role of Carbon Capture and Storage (CCS) and Carbon Capture Utilization and Storage (CCUS) in reaching these net-zero targets. These technologies are projected to mitigate 1.6 GtCO2 annually worldwide, escalating to 7.6 Gt by 2050 (IEA, 2021). Their contribution to global emissions reductions is expected to increase from 4% by 2030 to 12% by 2050, positioning them as key solutions for reducing CO2 emissions in hard-to-decarbonize industries.

Ringrose [1] highlights the multifaceted risks of operating CCS & CCUS technologies, including climatic, legal, and economic considerations. From an economic standpoint, CO2 emissions carry a cost, and their mitigation aligns with financial incentives, thus valuing CO2 storage and potentially increasing risk acceptance. Significantly, Ringrose & Meckel [2], assert that CCS and CCUS technologies are proven, viable, and technically able to meet the Paris Agreement goals, supported

by substantial geological storage capacity. However, despite the technical feasibility, socio-economic barriers prevail, as these technologies perceived high costs and low benefits hinder their widespread adoption and implementation.

To overcome these barriers, numerous studies have been focused on providing tools to assess and optimize the whole value chain. This focus primarily addresses the utility provided by the economics of scale on the infrastructure design. For instance, Jakobsen et al. [3] developed the integrated multi-criteria CCS chain assessment tool (iCCS), which allows for flexible component selection and supports critical economic KPI evaluation. Similarly, Middleton et al. [4] presented the SimCCS model, emphasizing infrastructure connectivity and cost-effectiveness. This model prioritizes constructing a well-connected pipeline network, focusing on efficiently reducing costs through strategic CO2 routing and using source and reservoir capacities. Morbee et al. [5] and Oei et al. [6], further contributed by exploring the pan-European deployment and the complexities of the whole value chain by utilizing Mixed Integer Linear Programming for massive CCS infrastructure design.

Building on these optimization-focused studies, more recent research has shifted towards examining the dynamics of cooperation among the various stakeholders in the CCS value chain. This shift recognizes that while technical and economic optimizations are crucial, they often overlook the complex interactions and decision-making processes among independent entities. Morbee [7] pioneered their previously mentioned approach in the pan-European deployment of CCS infrastructure by analyzing the country-level negotiation process, employing a game-theoretic Shapley value approach [8]. Massol et al. [9] furthered this by delving into individual emitters' decision-making processes regarding CCS capabilities and the associated cost-sharing mechanisms. Their initial exploration of a simplistic point-to-point pipeline system was later expanded by Massol et al. [10] to include a meshed national pipeline network connecting independent industrial clusters to storage sites in Spain. The culmination of these explorations is seen in the work of Jagu and Massol [11], who applied it to Sweden. However, none of these studied the dynamics of cooperation in the CCUS value chain, where the economical use of CO2 is used to help facilitate the economics and growth of such large-scale infrastructures [1].

While several studies have attempted to assign a market price to CO2 [12], [13], treating it as a commodity with its own market price and dynamics, they often overlook the aspects of cooperation and interaction among entities involved in the CCUS value chain. For example, Agrali et al. [14] developed a model to analyze the decision-making processes of thermal power plants in Turkey. Their study compares the viability of cap-and-trade systems and the sale of captured CO2 for Enhanced Oil Recovery (EOR), emphasizing how economic incentives and market conditions shape the preferences between the two options. However, the study does not fully account for the dynamics of cooperation and interaction among the various entities engaged in the value chain.
Methods:This study explores the potential of CO2 as a marketable commodity within a CCUS or CCS infrastructure by examining the interactions among entities involved in the value chain. To accomplish this, the Jagu and Massol [11] model is enhanced by incorporating one additional optimization parameter, the utilization market price of CO2 (p_(CO_2)^U $/tCO2) in addition to the prevailing carbon price of emissions (p_(CO_2)^E $/tCO2). This will transform the model into a multi-objective optimization problem.

More specifically, the financial Total Gross Income is redefined as:

Equation_1.png

with N still representing the set of all the emitters, Q_i^E the quantity of avoided CO2 emissions of emitter i and Q_i^U the quantity of utilized CO2 emissions of emitter i. Utilization can be part of any activity where CO2 is not considered waste, such as Enhanced Recovery for CCUS and Syn-gas generation through Underground Hydrogen Storage (UHS) methanation reaction for CCU [15]. The distinction of these quantities is crucial for avoiding the double counting of CO2, and their summation should result in the total quantity of CO2 stored by emitter i.

With that in mind, the net surplus W(p_(CO_2)^E,p_(CO_2)^U,S) yielded by the deployment of CCUS or CCU technologies at a given coalition S is redefined as:

Equation_2.png

with, χ_i representing the levelized unit cost of the site-specific carbon capture unit, σ the price of the storage service provided, υ the price of the utilization service provided and C(S) the transportation cost of coalition S.

Thus, the linear programming multi-objective optimization problem to be solved is defined as:

Equation_3.png

If a solution exists, the core must simultaneously guarantee the rationality, marginality, and efficiency principles [16]. Additionally, the solution will be Pareto optimal [17] with its own Pareto Frontier of all the feasible values of the two optimized prices for the undominated coalition. Thus, a preference function must be defined to isolate a single optimal allocation representing the minimum price pair at which that coalition dominates the other coalitions.

The preference function can take the form of a logarithmic utility function of constant elasticity of the two prices, as follows:

Equation_4.png

The two elasticity parameters, ɑ and b, can be adjusted according to the specific case. For example, the elasticity of p_(CO_2)^U can incorporate engineering parameters to predict the demand for utilization, such as the amelioration of the production in an ER scheme, or the Syn-gas yield of a UHS operation.
Results:Case Study: Cyprus CCUS in Aphrodite Gas Reservoir

The methodology previously detailed is applied to a case study in Cyprus, an EU member state in the eastern Mediterranean. The selection of Cyprus is informed by its distinctive characteristics: the presence of three major ports—Moni, Vassilikos, and Dekhelia—which are significant sources of emissions due to cement and electricity production activities, and the existence of the offshore Aphrodite Gas Field, which offers a unique opportunity for implementing the CCUS framework for Enhanced Gas Recovery (EGR) in the forthcoming field's development plans.

CO2 emission data were obtained from the European Pollutant Release and Transfer Register [18], identifying five significant emitters near the three ports. Consequently, three emission nodes and one storage node—the Aphrodite Gas Reservoir, located approximately 180 km offshore of Cyprus—were considered. The three emission nodes are connected with a pipeline to Vassilikos port, which is subsequently connected with the storage node with an offshore pipeline, potentially enabling broader interconnections with nearby countries. With this information, the Pareto Frontier of the problem is being constructed (Figure 1).

Figure_1.png - Description: Multi-objective game theoretic framework – Case study in Cyprus

Regarding the utility function, the captured CO2 can be injected into the reservoir for EGR or into other layers of the field for geological storage. It is assumed that it is preferable for the emitters to utilize their emission, and the elasticity terms can, therefore, be defined as follows:

Equation_5.png

with ΔG_p being the additional production of Natural Gas (NG) due to the EGR scheme, M a scaling factor, p_NG is the NG price and p_LCoP is the levelized cost of production of the field. ΔG_p was calculated by implementing the piston-like model for gas reservoirs proposed by Giakoumi et al. [19] aligned with the data of the Aphrodite field presented by Markou and Papanastasiou [20,21].
Conclusions:This study establishes a novel approach to treat CO2 as a marketable commodity. It focuses on optimization techniques and coordination among interacting stakeholders to estimate the minimum price pair at which complete cooperation can be guaranteed. The study demonstrates the successful application of this approach in Cyprus, where emitters can utilize their emissions through EGR schemes in offshore gas fields. The same methodology can be adapted for CCU scenarios by integrating Syn-gas yields from UHS operations, which parallels the EGR approach used in this case study.
References:See attached file: Giakoumi et al. 2024 - 45th IAEE Submit.docx

Keywords: Carbon Capture Utilization and Storage, CO2 Market Dynamics, Cooperative Game Theory, Multi-Objective Optimization, Pareto Optimality

Equation_1.png

$$p^{E}_{CO_2}\left(\sum_{i\in N} Q_i^E\right) + p^{U}_{CO_2}\left(\sum_{i\in N} Q_i^U\right)$$

financial Total Gross Income

Equation_2.png

$$p^{E}_{CO_2}\left(\sum_{i\in S} Q_i^E\right) + p^{U}_{CO_2}\left(\sum_{i\in S} Q_i^U\right) - \sum_{i\in S}\left[\chi_i\left(Q_i^E + Q_i^U\right) + \sigma Q_i^E + \right.$$

Net Surplus of coalition S

Equation_3.png

$$\begin{aligned} &\min_{p^{E}_{CO_2},p^{U}_{CO_2}} \left(p^{E}_{CO_2}, p^{U}_{CO_2}\right) \\ &s.t. \quad W\left(p^{E}_{CO_2}, p^{U}_{CO_2}, S\right) \geq W\left(p^{E}_{CO_2}, p^{U}_{CO_2}, S'\right), \quad \forall S' \subseteq N\{S,\emptyset\} \\ &\qquad p^{E}_{CO_2} \geq 0 \\ &\qquad p^{U}_{CO_2} \geq 0 \end{aligned}$$

Linear Programming Multi-Objective Optimization Problem to be solved

Equation_4.png

$$U\left(p^{E}_{CO_2}, p^{U}_{CO_2}\right) = \ln\left(p^{E}_{CO_2}\right)^a + \ln\left(p^{U}_{CO_2}\right)^b$$

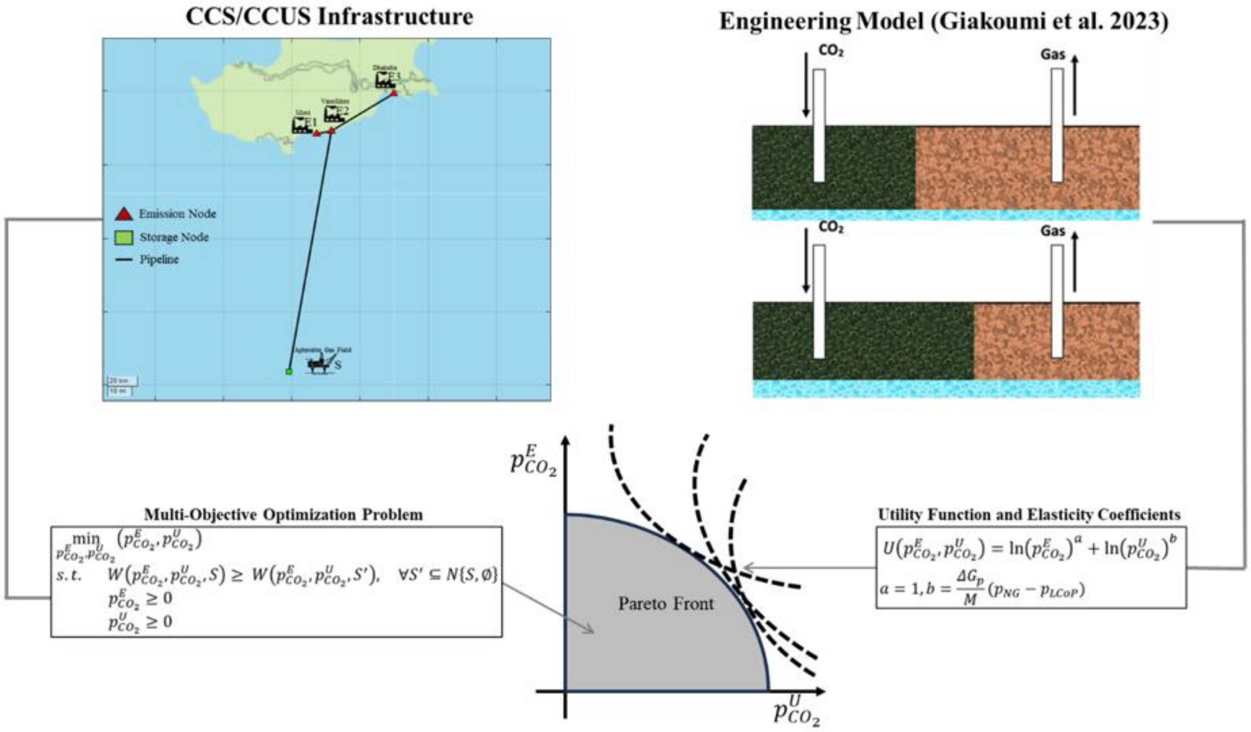
Utility or Preference Function

Equation_5.png

$$a = 1, b = \frac{\Delta G_p}{M}\left(p_{NG} - p_{LCoP}\right)$$

Elasticity Coefficients of the Utility Function for the Case Study

Figure_1



Multi-Objective Game Theoretic Framework - Case Study in Cyprus

AuthorToEditor: Since I had to include complex equations in the abstract, I also attached the Word document for your consideration. I appreciate your understanding. Thank you.

[Abstract:0548] OP-166 [Accepted:Oral Presentation] [Energy and the Environment » Carbon Capture, Utilization and Storage]

The Economics of Carbon Dioxide Removal Technologies using Equilibrium Modelling

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Overview:The Paris Agreement has set ambitious targets to limit global warming to "well below" 2°C by 2100, and to pursue measures to contain it to 1.5°C. These objectives can hardly be attained absent a sizeable deployment of Carbon Dioxide Removal (CDR) methods, such as Afforestation/Reforestation (AR), Bioenergy with Carbon Capture and Storage (BECCS), and Direct

Air Carbon Capture and Storage (DACCS) (IPCC, 2022). Integrated Assessment Model scenarios estimate that 190 to 1,190 GtCO2 of cumulative removal will be needed by 2100 (Huppmann et al., 2018; Rogelj et al., 2018). The magnitude of these deployment needs raises numerous economic and policy concerns pertaining to: the important cost of that deployment, the fierce competition for resources it may create (e.g., to acquire bioenergy resources), the societal demand for social justice, and possible threats on biodiversity, and (Fuss et al., 2018; Heck et al., 2018; Smith et al., 2016). The purpose of this study is to examine the economics of a large-scale and market-driven deployment of CDR technologies, namely BECCS and DACCS, using a spatial and dynamic equilibrium model. We investigate the optimal deployment of the negative emission technologies needed to achieve net-zero emissions and propose an adapted modelling framework that explicitly accounts for the economic interactions generated by such deployment. To achieve this, we model the behavior of key players along the supply chain, including biomass and energy producers, as well as CO2 capture, transport, and storage processes. Our approach is a year-by-year two-level, involving government subsidies to the supply chain and the setting of emission removal targets from 2025 to 2050.

Methods:Our methodology mobilizes non-cooperative game theory concepts as we model the economic interaction between agents subject to an endogenous CO2 price using a Generalized Nash Equilibrium problem à la à la Gabriel et al. (2013) or Abada et al, (2013). Our model characterizes 7 geographic zones: the UK, France, Germany, Benelux, Denmark, Sweden, and Norway. Each of these players maximize the gains related to the deployment of negative emissions technologies. A European government creates a policymaking scene to understand the best way to incentivize formation and success of CDR markets. We calibrate the model using recent data and projections to 2050 from a variety of source for biomass, energy, technology costs, storage availability...

Results:Our results provide detailed projections of the technologies that will be deployed, including their scale, geographic distribution, and projected timelines. BECCS are first being deployed and specifically in countries where biomass is available and carbon sink accessible. DACCS technologies are then being deployed first in countries with low-carbon energy mix such as Norway. In addition, our findings provide an assessment of the benefits yielded by deploying international CDR-based supply chains. Imported biomass helps countries with scarce bio resources to deploy BECCS, achieving negative emissions goals. Furthermore, from a public policy perspective, our study provides new insights into the various supportive policies that can be envisaged to unlock the deployment of these supply chains. While integrating negative emissions in the EU ETS creates playground for profitability, setting a negative emission target force coordination to avoid losses. Finally, we conclude by discussing the effect of CDR deployment in Europe on future carbon price trajectories. BECCS and DACCS negative emissions lowers the carbon price inducing unwanted effects on profitability.

Conclusions:In conclusion, our study delves into the economics of a large-scale deployment of BECCS and DACCS in Europe. This deployment is largely determined by the associated to negative emissions, making the carbon price and/or negative emissions target the most deterministic components. Coordination and international supply chains have positive effects on this deployment while it may impact populations and inequalities worldwide. Support and actions from the European government are necessary to balance the rebound effect on carbon prices.

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Keywords: BECCS,DACCS, Generalized Nash Equilibrium,Negative Emissions,Cardon Dioxide Removals,CDR

[Abstract:0569] OP-167 [Accepted:Oral Presentation] [Energy and the Environment » Carbon Capture, Utilization and Storage]

The future role of permanent carbon removal in the EU emissions trading system

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Overview:On top of deep decarbonization, carbon dioxide removal is considered instrumental to limit global warming to 1.5°C (Masson-Delmotte et al., 2018). Accordingly, policymakers consider fostering the deployment of technologies like Direct Air Carbon Capture and Storage (DACCS) and Bioenergy Carbon Capture and Storage (BECCS). In Europe, one option is to integrate DACCS and BECCS to participate in the emission trading system (EU ETS). Given the EU's climate target, the price of emission allowances in the EU ETS might increase to 300–400 USD per ton by mid-century (Pietzcker et al., 2021). At this price level, these technologies could play an important role to offset expensive-to-abate emissions, effectively creating a ceiling for allowance prices. While the availability of these removal technologies at scale is subject to high uncertainty, already the expectation of possible scenarios could affect investment decision on costly mitigation technologies well before an emission price ceiling materializes. The importance of such effects, however, is unclear.

In this contribution, we employ an extended version of the linear optimization model LIMES-EU (see below) to assess when and to what extent DACCS and BECCS can be expected to enter the system, and what the resulting impact is on emission allowance price pathways. We calibrate the model based on recent cost data for three DACCS technologies, using experience curves to project cost reductions with increased deployment. For BECCS, we consider scenarios for biomass availability and costs. Preliminary results underline that around 2050, DACCS and BECCS could indeed become an alternative solution for very high-cost mitigation options, at a volume large enough to affect the allowance prices since the 2040s due to banking.

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Methods:We utilise the numerical EU ETS model LIMES-EU, which includes a detailed representation of both supply and demand in the EU's carbon market. While the supply of allowances is modelled through the scheme's design features, including the Market Stability Reserve (MSR), demand for carbon certificates is represented through all sectors under the EU ETS' scope. More precisely, the power sector is represented in detail, considering each country as a demand node and covering 35 power generation and storage technologies. Other sectors, namely energy-intensive industry, maritime, and district heating, are represented through marginal abatement cost curves. Regarding policy and market design, we implement the EU ETS 2023 reform, setting the main system parameter up until 2030 and extrapolating most of these elements. Since the stationary cap would reach zero

by 2040, we assume that allowances can only be traded until the end of this year. This also implies that the MSR remains operational until this year. We calibrate the We assess the deployment of BECCS and DACCS in the EU ETS and their impact on the power sector by linking carbon and removal compliance markets, i.e., CDR technologies generate removal allowances within the EU ETS and thus, for every t CO2 an EU allowance (EUA) would be generated. For BECCS, we consider maximum biomass potential based on primary energy consumed between 2010 and 2020. For DACCS, we use techno-economic data for three DAC technologies combined with CO2 transport and storage, namely liquid solvent, solid sorbent, and CaO ambient weathering DACCS. The net removal costs of DACCS are based on (Sievert et al., 2024).

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Results:While the analyses are currently being finalized, preliminary findings indicate that BECCS deployment begins post-2030, with DACCS growth becoming significant after 2050. Eventually, DACCS emerges as more profitable, relegating BECCS to a marginal role. Given the DACCS electricity intensity, its deployment affects the power sector. While this impact is limited at the EU ETS level (less than 2%), in some European countries the share of DACCS electricity consumption reaches up to 20%. Long-term projections suggest DACCS as a key player, with solid sorbent DACCS showing the largest potential. However, its deployment largely hinges on global DACCS deployment, which, through technological learning, can reduce costs. Low global deployment results in minimal DACCS use in the EU ETS, whereas high deployment could nearly triple DACCS removals in the EU ETS.

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Conclusions:We discuss implications for the regulation of the EU ETS, policy support for DACCS, as well as effective climate policy mixes more generally.

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Keywords: Carbon dioxide removals (CDR), Net-zero policy design, EU ETS, Direct air carbon capture and storage (DACCS), Bioenergy with carbon capture and storage (BECCS)

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[Abstract:0198] OP-168 [Accepted:Oral Presentation] [Energy and the Environment » Environmental Markets and Taxes]

Carbon Tax impact on ASEAN energy system: an input output analysis

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Overview:ASEAN countries are heading to a net zero future. As of 2022, all of the ASEAN Member States (AMS) have enhanced or published their Nationally Determined Contributions (NDC), signifying more robust commitment on greenhouse gases (GHG) emission abatement [1]. The energy sector appears as the major contributor of greenhouse gases to climate change. Additionally, ASEAN is estimated to generate 3.7 times higher greenhouse gas emission due to the increasing demand of energy use [2]. Thus, concentrating on emission reduction in this sector is critical for governments to meet their NDC pledges. Carbon pricing mechanism emerges as an initiative that should be promoted to complement AMS's commitment in renewable energy scale-up for power generation and energy efficiency improvement.

Carbon Tax and Emissions Trading System (ETS) are two schemes frequently employed in the carbon pricing mechanism [3], and both aim to incentivise emission reduction by putting a financial burden for every carbon emitted. This study will focus on carbon tax implementation in ASEAN. By taxing goods or activities based on their emissions, the government generates carbon revenue, which can then be recycled for general spending or, ideally, green spending. Therefore, carbon tax price will be the critical indicator to show the commitment. In ASEAN, carbon tax has been or will be established in Singapore (USD 19/tCO2e in 2024 until 2025) and Indonesia (USD 2/tCO2e). Meanwhile, Brunei, Cambodia, and Malaysia are still exploring cost and benefit between carbon tax and ETS [4]. However, carbon taxes, or carbon pricing mechanisms in general, can have a regressive effect on lower-income households because the costs associated with emissions are frequently passed on to consumers in the form of higher commodity prices for goods or services. Thus, this study aims to evaluate the effectiveness of carbon tax implementation in power generation to achieve climate goals, assess economic impacts and contribute valuable insights to inform stakeholders and public discourse.

The paper will be structured as follows. Section 1 outlines the background and purpose of this study. Section 2 covers the datasets and methodology used in carbon tax impact assessment through an input-output analysis. Section 3 presents the estimation results, including discussion on energy-related tax scenario design. Finally, section 4 summarises the key findings based on the analysis and provides suggestions for further research enhancement.
Methods:We utilize an input-output analysis to assess the effectiveness of carbon taxes and its impact on the whole economy in ASEAN and its key partner countries. It captures the direct and indirect impacts of carbon tax on production, employment, and economic activities in each AMS, the ASEAN region, and its key partner countries. The analysis will be focused on shocking specific carbon tax, which is currently applied in AMS, then examining its impacts on the entire supply chain of economy within applied carbon tax countries, ASEAN region, and its key partner countries. This study applies the following tax-price scenarios:

1. Carbon Tax: USD 2/ton CO2e (Indonesia's rate)
2. Carbon Tax: USD 3.75/ton CO2e (Singapore's 1st term rate)
3. Carbon Tax: USD 7/ton CO2e
4. Carbon Tax: USD 19/ton CO2e (Singapore's 2nd term rate)
5. Carbon Tax: USD 40/ton CO2e (World Bank suggestion)

This study employs the most recent version of the Inter-Country Input-Output (ICIO) table published by the OECD in 2022. This table delineates the economic interdependence among 76 countries across 45 industries. In alignment with the objectives of this research, the 2020 OECD ICIO table has been appropriately adjusted.
Results:The impact of several carbon tax scenarios on the power production sector, ranging from USD 2/ton CO2e to USD 40/ton CO2e, yields various outcomes. At the lowest tax-rate scenario of USD 2/ton CO2e, a moderate 10-15% reduction in output is expected, along with a marginal 5-8% increase in production costs for industries related to power generation. This leads to a small 5-10% increase in revenue for the electricity producing sector. As the tax rate rises to USD 3.75 per ton CO2e, the direct effects become more obvious, with a 15-20% drop in output. Concurrently, related industries suffer a modest 8-12% increase in production costs, resulting in a notable 10-15% growth in revenue. A further increase to USD 7/ton CO2e results in considerable decreases in output (20-25%) and a major 10-15% increase in production costs, resulting in a noticeable 15-20% gain in revenue for the power generation industry.

At higher tax rates of USD 19/ton CO2e and USD 40/ton CO2e, the direct effects become more significant, with a 25-30% and 30-35% decrease in production, respectively. At the same time, production costs rise significantly, ranging from 15-20% to 20-25%. These higher tax rates result in a significant gain in revenue for the power production industry, with predictions predicting a 20-25% increase for USD 19/ton CO2e and a 25-30% increase for USD 40/ton CO2e. These findings shed light on the complex dynamics of tax rates, sectoral adjustments, and revenue implications, offering a thorough knowledge of the possible effects of carbon taxing on the power generation sector. Conclusions:In summary, the input-output analysis reveals a transformative impact of carbon taxation on the power generation sector in ASEAN. The observed shifts in output and revenue underscore the potential for sustainable practices. As policymakers navigate these findings, prioritizing equitable distribution and targeted support for sustainable initiatives is imperative for effective climate change mitigation strategies.

This study assumes that the technological input structure, represented by the input coefficient in the input-output table, does not immediately change as energy prices rise (short-term economies). Also, changes in the industrial sector (such as energy prices) have no immediate impact on consumer behaviour or manufacturing operations. As a result, applying a general equilibrium model to conduct further study will assist in addressing the assumptions inherent in dealing with the medium- to long-term economy.

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Keywords: Carbon tax, ASEAN, Power Generation, Decarbonisation

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[Abstract:0242] OP-169 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Energy Shocks and Business Cycles]

Asymmetric effects of oil prices on Saudi Arabia's non-oil trade balance. Insights from NARDL and Autometrics

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Overview:This paper examines the potential asymmetric in the effects of oil prices on Saudi Arabia's non-oil trade balance are. Applying the Non-linear Autoregressive Distributed Lags (NARDL) and Autometrics to the data spanning 1988-2022, our analysis reveals that oil prices exert an asymmetric impact on the non-oil trade balance, both in the long- and short run. An expansion in an upturn of oil prices reduces the non-oil trade balance through heightened imports, whereas the impact of a downturn in oil prices on the balance is statistically insignificant. Methods:Long-run parameter estimations

It is noteworthy that one of the assumptions that Cho et al. (2019) made to resolve the asymptotic singularity issue is that $E(\Delta Xt)$=0. Meaning that cointegration is determined between Yt, which is an integrated series with time drift and Xt, which is an integrated series without drift. Thus, it is crucial to test whether a population mean of ΔXt is zero, before implementing this two-step estimation method suggested by Cho et al. (2019). Importantly, Cho et al. (2020) show that if $E(\Delta Xt)\neq 0$, then the same asymptotic singularity issue comes back. Therefore, Cho et al. (2020) extended the two-step estimation approach of Cho et al. (2019) to accommodate the non-zero population mean of ΔXt. This extended approach is also effective if the mean is zero. The approach involves the following procedures: (i) regress $Xt+$ on intercept and time trend and do the same for $Xt-$. (ii) collect the residuals of these equations and name them, say $Zt+$ and $Zt-$, respectively. (iii) regress Yt on $Zt+$ and $Zt-$, as well as intercept and time trend, preferably using FMOLS. (iv) construct $\hat{ECT\_At}$ using the long-run coefficients/parameters estimated in (iii) and finally, estimate equation (6.7) to obtain the short-run coefficients and speed of adjustment.

Short-run parameter estimations

We have estimated the NARDL in equation (6.7) using OLS within the general-to-specific (Gets) framework using Autometrics – a machine learning modeling algorithm (Ericsson, 2021) in the PcGive toolbox of OxMetrics 8.0 (Doornik, 2009, chap. 4; Doornik and Hendry, 2009). Autometrics utilizes computer technology for model selection within the Gets method. The process involves several steps outlined by Hendry and Krolzig (2005), among others. Initially, the general unconstrained model (GUM) is specified based on a combination of theory- and data-driven approaches. If the GUM passes diagnostic tests, it is considered congruent; otherwise, supersaturation is performed to address post-estimation issues. The next step involves multiple-path reduction of the GUM, utilizing a tree search to identify a final model among terminal models.
In line with the guidance provided by Hendry (2020) and Castle et al. (2021a, b, c), we integrate supersaturation into the estimation process. It is important to highlight that Autometrics' supersaturation feature allows for diverse indicator saturations, including impulse indicator saturation (IIS) for outliers, step indicator saturation (SIS) for location shifts, trend indicator saturation (TIS) for trend breaks, and designated indicator saturation (DIS) for specific shapes. Utilizing Autometrics for model selection, with tight significance levels and bias correction, proves valuable as it accommodates outliers, shifts, omitted variables, incorrect distributional shapes, non-stationarity, misspecification, and non-linearity.
Incorporating different saturation types significantly increases the number of regressors. Autometrics tackles this issue by employing a block search method for saturations. Monte Carlo simulations indicate that Autometrics surpasses other machine learning methods, including LASSO, in retaining pertinent regressors and excluding irrelevant ones, demonstrating superior performance in small sample cases. Additionally, Autometrics provides the flexibility to treat specific regressors as unrestricted, offering advantages over traditional and alternative machine learning methods.
Results:To identify whether we should apply the two-step estimation NARDL developed by Cho et al. (2019) or extended version of it proposed by Cho et al. (2020), we tested if the population mean value of opr can be zero. The null hypothesis of population mean is zero cannot be rejected as the sample t-statistic is 0.61 with the probability value of 0.54 for 19990-2022 period. Therefore, the first method above can be used. We estimated equation (6.9) with FMOLS and the associated coefficients in equation (6.8), which are obtained using equation (6.10) are reported in Panel B of Table 3. We also estimated the long-run symmetric effect of opr on tbn for the comparison purposes using FMOLS, and the results are reported in Panel A. Table 4 documents the results of the asymmetric and symmetric estimations. One may believe that the long-run impact of the oil price on non-oil trade balance is asymmetric based on the test findings reported in Panel C of Table 4: (i) The null hypothesis of no cointegration between tbn and the regressors including opr cannot be rejected in the symmetric model, as the probability value from the Engle-Granger test statistic is 0.36. (ii) The null hypothesis of no cointegration between tbn and the regressors including opr_p and opr_n can be rejected in the asymmetric model, as the probability value from the Engle-Granger test statistic is 0.05. (iii) the null hypothesis of symmetric impacts of opr_p and opr_n on tbn can be rejected at the 1% significance level in favor of the alternative hypothesis of asymmetric effect.

The short-term estimation results from Autometrics
We constructed the equilibrium error correction term ECT_At using the estimated long-run coefficients in Table 3 following the methodological discussion in the previous section:
$ECT\_At = tbnt - (-35.95 - 0.43 opr\_pt - 0.07 opr\_nt - 0.79 reert - 1.56 ydt + 3.62 ydt)$
We then formulate a GUM of NARDL in equation (6.7) using one lag value of all the variables including ECT_A and contemporaneous values of the regressors and estimate it for 1990-2022. The estimated initial GUM passes all the post-estimation tests for autocorrelation, serial correlation, normality, heteroscedasticity, and functional misspecification. However, it cannot pass the recursive estimation tests for stability, as illustrated in the figure below.
Apparently, recursively estimated residuals are slightly unstable in 2018, although they are desirably around the zero line (the first graph). For the same year, Chow one-step ahead forecast test and Chow breakpoint test indicate instability in the estimated coefficients of the initial GUM, as the second

and third graphs illustrate, respectively (Chow, 1960; Brown et al.,1975). Since a statistical congruency of the GUM is recommended, this instability issue must be resolved. We fix/retain all the regressors in the initial GUM of NARDL and run Autometrics with the option of Saturation estimation from Outlier and break detection section with the Target size of 1% to see if the initial GUM needs to take any dummy variable. This target size is not so small and hence, the chance of picking up many dummy variables is quite high (see the discussions in Castle et al., 2021a, b, c). We include all types of saturation in the estimation, that is, Impulse indicator saturation (IIS), Step indicator saturation (SIS), Differences IIS (DIIS), and Trend saturation (TIS). This is to enable Autometrics to account for any kind of outlier or break that happened in the period under consideration and matter for the relationship that $\Delta tbnt$ establishes with the regressors in the short run. Autometrics add three dummies to the initial GUM specification. They are one DIIS taking one and negative one in 2018 and 2019, respectively, and two SISs taking unity till 2005 and 2007, respectively and zero otherwise. The post-estimation tests do not show any problem with autocorrelation, serial correlation, normality, heteroscedasticity, and functional misspecification. Figure 4 illustrates the recursive estimation tests for stability.
Apparently, the saturations selected by Autometrics resolved the instability problem of the initial GUM, as the estimated residuals and coefficient show stability.
Conclusions:We found the evidence that Saudi non-oil trade balance responds to the oil prices asymmetrically in long- and short-run. The upturn of oil prices decreases the non-oil trade balance. This can be attributed to increased imports of goods due to higher government and private income, as well as the appreciation of the Riyal. On the other hand, oil prices' downturn might potentially improve the balance, but it was found to be statistically insignificant in our sample. However, this impact was not statistically significant, probably due to the scale effect, where non-oil merchandise exports are considerably lower than merchandise imports. Both effects can be explained theoretically and are consistent with stylized facts of the Saudi economy, such as small share of non-oil export of goods in total, a considerable share of import in aggregate demand. In addition, we found that the real effective exchange rate and domestic income are negatively associated with the non-oil trade balance, while foreign income is positively related. Finally, it was found that any deviations of the non-oil trade balance from the long-run equilibrium relationship are temporary and correct back to this relationship.
Key policy implication from this research is that the authorities may wish to implement measures leading to the expansion in the exports of the non-oil goods. Investment and financing opportunities of oil revenues can be considered among other measures. Moreover, further localization measures should be designed and implemented as the share of goods import in Saudi aggregate demand is large.
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AuthorToEditor: The critical problem here is that ARDL developed by Pesaran and Shin (1999) and NARL developed by Shin et al, (2014), like many other single-equation based method, assume that there is only one cointegrated relation between the dependent variable and regressors and the regressors are note mutually cointegrated. If this assumption is violated, then the methods crash down (see the discussion in Shin et al., 2021 inter alia). To address this, we utilize the reduced rank cointegration method within the Vector Equilibrium Correction (VEC) modeling framework developed by Johansen (1988) and Johansen and Juselius (1992). The literature suggests that the ARDL method provides more consistent estimates in small sample sizes when compared to other methods, as noted by e.g., Banerjee et al. (1993), Pesaran and Shin (1999), Pesaran et al. (2001), and Enders (2015). In addition, Chudik et al. (2017) affirm the validity of the ARDL approach, regardless of whether the regressors are considered exogenous or endogenous. We employ the non-linear autoregressive distributed lag (NARDL) model developed by Shin et al. (2014) for the estimation of the asymmetric effect in the long- and short-run. However, for the long-run estimations, we followed Cho et al. (2019) and employed the two-step estimation NARDL, not the

Shin et al. (2014). This is because, as Cho et al. (2019) argue the NARDL method by Shin et al. (2014) is subject to asymptotic singular matrix issue. Note again that employing two-step estimation NARDL is the methodological merits of our research over many other studies using the NARDL method.

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Transitioning to Net-Zero: Macroeconomic Implications and Welfare Assessment

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Overview:We assess the macroeconomic and welfare implications of carbon mitigation strategies using an environmental Dynamic General Equilibrium model. The economy uses energy from both green renewable technologies and fossil fuels. We set an emission reduction target in line with the Paris Agreement and analyze the welfare and macroeconomic impacts of various strategies, including (1) raising the domestic price of fossil fuels, (2) implementing a subsidy on green investment funded through lump-sum taxes, (3) imposing taxes on emissions with rebates to households, and (4) utilizing emission taxes to support green investment. Our model provides a framework for evaluating the welfare consequences of various carbon mitigation strategies, emphasizing the need to balance the short and long-term effects of incentives for investment and innovation in green technologies, as well as taxes and other policies designed to reduce carbon emissions. Methods:We assess the transition towards a low-emissions economy using an environmental Dynamic General Equilibrium (eDGE) model. These models are specifically designed to capture the relationship between climate change and economic growth, drawing inspiration from earlier works such as Nordhaus (1991) (see Annicchiarico et al., 2021, and Annicchiarico et al., 2022, for two recent surveys).

Our model provides a framework for assessing the macroeconomic and welfare implications of different carbon mitigation strategies, highlighting the importance of balancing the short and long-term effects of incentives for investment and innovation in green technologies, taxes, and other policies aimed at reducing carbon emissions. To the best of our knowledge, this is the first attempt to carry out this comparison in a consistent way.

In our model, the production of goods and services utilizes energy from either environmentally friendly renewable ("green") technologies or fossil fuels that generate CO2 emissions, commonly known as "dirty" or "brown" technologies. Energy producers employ specific capital to generate this input, resulting in CO2 emissions with different intensities depending on the use of these technologies.

By considering the more realistic case of emissions being dependent on a particular type of energy production, we enrich the relationship between carbon generation and aggregate output, allowing emissions reductions to be achieved not only by reducing output but also by changing the combination of inputs. In addition, the model takes into account the transformative potential of technological advances to reduce the prevalence of brown energy and improve the overall efficiency of the energy mix. This aspect of our research aligns with the works of Fried (2018) and Nakicenovic and Swart (2000). Furthermore, we acknowledge the pivotal role that investment in green energy capital plays as a key driver of this transition (see Jackson and Jackson, 2021).

As a numerical illustration and an example of our model's application, we calibrate it with data from the Spanish economy, which ranks among the four largest countries in the EU. Specifically, we set an emission reduction target consistent with the Paris Agreement and analyze the welfare and macroeconomic effects of different strategies, such as increasing the domestic price of fossil fuels, implementing a subsidy on green investment financed by lump-sum taxes, levying taxes on emissions rebated to households, and using emissions taxes to finance green investment. These policies are strategically designed to mitigate emissions and incentivize the widespread adoption of green technologies. In this context, our study aligns with recent literature, including Marron and Toder (2014), the International Monetary Fund (2019), Semmler et al. (2021), and Delgado-T\'ellez et al. (2022). For Spain, Freire-González and Puig-Ventosa (2019), using a CGE model, explore the environmental effects of taxing the production of electricity by fossil fuels compared to taxing all forms of electricity production.
Results:Our main findings can be summarized as follows. Front-loaded environmental policies intended to mitigate carbon emissions may prove effective in achieving the intermediate 2030 Green Deal target, although they are insufficient to meet the 2050 Net Zero Emissions (NZE) target without a substantial increase in welfare costs. Alternatively, green investment subsidies require more time to deliver a significant reduction in emissions compared to other policies. Contrary to other mitigation policies, subsidizing green investment leads to an increase in energy intensity per unit of output due to the upsurge in green energy production. A one-time, front-loaded increase of nearly 60\% in fossil fuel prices to discourage their use achieves over 80\% of the NZE target, although increasing fossil fuel prices incurs the highest welfare costs in both the transition to 2050 and in the long run. Emission taxes emerge as the most preferable policy in terms of welfare during the transition to 2050, although green investment subsidies yield substantial welfare gains in the very long run, even without a globally coordinated emission reduction policy. Reallocating revenues from carbon taxes toward green investment subsidies yields the most balanced welfare effect between the short and long run. To achieve the NZE target by 2050, we need a linear increase in emissions taxes to reach a level of \EUR*227* per ton of carbon by 2050 and stabilize afterwards. The average welfare loss resulting from this policy, in terms of equivalent initial consumption, stands at a manageable -0.44\% from 2019 to 2050, however, it rises to -19.11\% in the very long run, covering the period from 2019 to 2200.

In the absence of an internationally coordinated strategy, the temperature is projected to increase by 1.8 degrees Celsius above pre-industrial levels by 2050 and by over 3.5 degrees Celsius by 2200. In a coordinated scenario the temperature remains below 1.5 degrees Celsius by 2050 and reverts to almost pre-industrial levels by 2200. The positive impact on welfare of a coordinated policy becomes evident, although it takes several decades to materialize. In the very long run, average welfare may increase by over 50\% between 2019 and 2200 in terms of equivalent initial consumption, as the world economy avoids the damages of climate change.
Conclusions:In this paper, we have proposed an environmental dynamic general equilibrium model to assess the welfare effects of energy transition policies, such as those geared to reduce carbon emissions through environmental taxation, investing in green technologies, or a combination of both. Starting from a central scenario characterized by a trend of environmentally friendly technological progress, zero-emission taxes and incentives to green investment, as well as current oil prices, we have simulated the effort required to achieve NZE under different mitigation strategies and assessing their welfare and macroeconomic consequences.

Maintaining or accelerating current emission-saving technological progress would reduce carbon emissions by one third by 2050 with respect to 2019. Policies heavily front-loaded to rapidly mitigate carbon emissions may demonstrate effectiveness in reaching the intermediate 2030 Green Deal target. However, they fall short of meeting the 2050 Net Zero Emissions (NZE). For example, a once-and-for-all subsidy on green energy investment of approximately 60\% on green energy investment, equivalent to 2.6 percentage points of GDP per year in government budget costs, would result in reaching 92\% of the intermediate 2030 target but only 80\% of the 2050 NZE target.

The welfare effects significantly vary between the short to medium and the very long term, particularly among different mitigation policies. Thus, elevating fossil fuel prices to deter their usage results in the highest welfare costs in both the transition to 2050 and in the long run. Conversely, emissions taxes prove to be the most favorable policy in terms of welfare during the transition to 2050, while green investment subsidies exhibit substantial welfare gains in the very long term, even without a globally coordinated emissions reduction policy.

To attain Net Zero Emissions (NZE) fully, a gradual increase in the carbon tax to a steady state level of \EUR*227* per tonne of carbon (at 2010 prices) is needed. The average welfare loss resulting from this policy is calculated at a very manageable -0.44\% in terms of equivalent consumption during the period 2019-2050. However, it escalates to -19.11\% in the very long run (between 2019 and 2200). When the government reallocates revenues from carbon taxes towards green investment subsidies, the required increase in the tax to achieve the emission target is significantly lower. Additionally, this policy leads to a more balanced welfare effect between the short and long run.

Our findings highlight the significance of global coordination in mitigation policies. Through a simple exercise, we demonstrate that a coordinated policy possesses the potential to entirely reverse the long-term adverse effects of emission taxes, transforming them from negative to largely positive impacts. This transformation occurs via a substantial reversal in the global temperature trend.

Overall, our paper underscores the utility of eDGE models for assessing the welfare and macroeconomic consequences of various mitigation policies across different scenarios and assumptions, particularly in light of the uncertainties surrounding energy transition, technological advancements, and climate change.
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Keywords: carbon emissions, green energy, brown energy, energy transition, welfare

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Energy prices and disaggregated household inflation: The Greek case

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Overview:Since the early 2021 the European economies are suffering from unprecedented inflation pressures, which are primarily fuelled by price spikes in the energy markets, due to the Russian invasion in Ukraine. Extreme inflation due to energy price spikes can cause significant loss of income, which can subsequently cause reduction in household consumption with detrimental effects on well-being, redistribution of income and economic development. Even more, inflation causes wealth redistribution effects as it erodes the real value of nominal assets, while it does not affect assets in real values.
There are ample studies on the impact of energy prices on headline and core inflation, which some recent ones to include those by Wong (2015), Conflitti and Luciani (2019), Binder and Makridis (2022), Kilian and Zhou (2022), Abdallah and Kpodar (2023), among others. These aforementioned studies, though, focus on aggregate inflation.
However, there are studies, even from the late 70s, which show that the distribution of inflation rates across different households are significantly different and they tend to vary over time (Michael, 1979; Hagermann, 1982). In the more recent decades Hobjin and Lagakos (2005) investigate inflation inequality in the US and show that increases of cost of living seem to be higher for the group of elderly citizens. Moreover, poor households seem to be more sensitive in gasoline price changes relatively to higher income households. Kaplan and Schulhofer-Wohl (2017) is a more recent study that focuses again on the US inflation at household level due to the occurrence of high degree of heterogeneity in the distribution of household expenditures. In their study, they find that lower-income households face remarkably higher inflation, which provides evidence that different policy measures should be taken across households. Regarding the studies that examined this inflation inequality, a very recent study by Weber et al. (2022) concludes that the impact of realized inflation is much higher on low income, low education, and Black households.
It is also important to mention the studies focusing on the inflation inequality in Europe (see, for instance, Crawford and Smith, 2002; Noll and Weick, 2006; Colavecchio et al., 2011, among others), showing that there is indeed cross-household inflation dispersion.
Against this backdrop, the aim of the current study is twofold, namely, to investigate the impact of energy prices on disaggregated inflation by household type, as well as to assess the predictive ability of the former to the latter inflation rate. The research focuses on Greece for the period 2009 – 2022 (168 monthly observations). The choice of Greece stems from the fact that it is the country that has been heavily impacted by the energy crisis caused by the war in Ukraine and its economy has not been fully recovered from the 2010 debt crisis. We can just highlight that between June and October 2022 Greece's inflation rate was hovering at more that 11%, with the overall inflation rate for the 2022 to land at just below 10%. Several anecdotal evidence from various media claim that low-income households experienced more than twice this rate. Thus, this study aims to conduct an analysis that will examine whether the country has experienced significant household income discrepancies and which is the magnitude of such potential inequalities among different household categories.
Methods:More specifically, in our study, we use monthly data from the Household Budget Survey (HBS) of the Hellenic Statistical Authority to generate the inflation rates by household types, where the latter are classified into both social and economic criteria (e.g., income level, household composition, occupational status, etc.). We further use a set of explanatory variables, which are grouped into three blocks, namely, the Greek-specific (domestic) factors, the global factors and the energy specific factors. For the energy-specific factors we consider the Brent crude oil prices, the EU natural gas prices and wholesale electricity prices. We also consider retail energy prices with or without taxes, i.e., the diesel and unleaded 95 pump prices in Greece. The domestic and global factors have been chosen so to represent the main drivers of inflation, including the cost-push,

demand-pull and uncertainty factors.
We start our analysis from the in-sample estimation by employing a Dynamic Model Averaging (DMA) approach, initially proposed by Koop and Korobilis (2012), which is based on combinations of time-varying parameter (TVP) model specifications. In this regard, we develop different model specifications that take into consideration solely the domestic, global or energy factors, as well as specifications that combine all these factors. Based on the DMA methodology, we assess both the probability that the best model that explains household inflation includes the energy variables, as well as the magnitude of the effect of the energy factors, so to identify any cross-household inflation differences.
Results:Tentative results show that models which include the energy factors present a persistently higher probability to explain the household inflation rates. Even more, we find that there are important cross-household differences, with households at the lower income levels, as well as with more dependent members (children under 16 years old, 1 parent with children under 16 years old, etc.) to receive a more severe impact from the energy prices. The main impact is driven by the crude oil prices.
Subsequently, we use the DMA framework to proceed to real out-of-sample forecasts, for up to 12-months ahead, for the inflation rates by household type. We use the first 100 observations for our training period and the remaining ones compose the out-of-sample period. We find that the predictive gains from the energy prices are higher for households that are impacted more severely by these prices, as these were identified from the in-sample analysis.
Conclusions:Our findings provide valuable input to policy makers for more targeted decision-making processes with the aim to alleviate income and wealth discrepancies that arise due to the different impact of energy prices at the different household inflation rates.
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Sectoral and economic wide implications of post and pre-combustion introduction to the Scottish Chemicals industry

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Overview: Policymakers have increasingly acknowledged the indispensability of industrial activities in a low-carbon society due to the close connection between industrial production, employment, and economic development (Pisciotta et al., 2022). However, despite the relevance of the industrial sector in pursuing net-zero objectives and strides made in decarbonising transportation, heat, energy, and agriculture across several countries addressing emissions in heavy industries poses distinct challenges (McLaughlin et al., 2023). Research indicates that negative emission technologies such as carbon capture, utilization and storage can be an option.
Recently, CCUS has enjoyed substantial global attention across several countries exploring options for decarbonising the heavy industries. In the UK, through the industrial decarbonisation strategy (UK Government, 2021), an ambitious target has been set to deliver on an emission reduction of 3 MtCO2 per year through CCUS alongside 20 TWh of fuel switching to low-carbon alternatives. In 2023, the 'Powering up Britain' announcements (UK Government, 2023), demonstrate UK's commitment towards using CCUS) as a key technology to promote industrial decarbonisation. However, across the UK's industrial clusters, there are different plans on how to implement CCUS, particularly in relation to the carbon capture component and where/when it will take place. For the industries involved, the implications of carbon capture in terms of equipment (capital) requirements and inputs from different sectors, e.g., build facilities to produce zero carbon fuels, upgrade equipment to operate with alternative fuels, etc. (Agyeman et al., 2023), differ depending on whether it takes place pre-combustion, replacing current fuels with zero-carbon alternatives, or post-combustion after the production process using current fuels. These capital and intermediate inputs requirements may in turn have different implications on the competitiveness of industries implementing CCS technology.
In the literature, studies have addressed carbon capture and storage technology predominantly using technoeconomic analysis at industry level. The relevant extant literature points to general efficiency loss when implementing different carbon capture technologies due to additional energy consumption on one hand and additional capital and operation cost on the other hand resulting from the operating the carbon capture component of CCUS (Boa Morte et al., 2023; Davoodi et al., 2023). However, the economic implications of these net efficiency losses and additional capital requirements, especially on the industrial sector and broader economic impacts, have not been sufficiently explored in the literature. Therefore, this paper investigates the sectoral and economy-wide implications of introducing post and pre-combustion carbon capture in the Scottish Chemical industry as an industrial decarbonisation strategy.
Methods: The paper uses a regional computable general equilibrium model (AMOSENVI) of Scotland, as a devolved region of the UK. The model is calibrated using a 2019 Scottish Social Accounting Matrix (SAM) which has all the Scottish economic sectors aggregated into 30 sectors and where petrochemicals, inorganic chemicals and other chemicals sectors are separately identified. A CGE modelling approach was used as CGE models are ideally placed in capturing the sectoral and economy-wide implications of price changes emerging from shocks to the economy, including the introduction of decarbonisation policies. Here, the introduction of CCUS to the Scottish chemical industries involves sectoral responses to the additional cost implied by CCUS introduction, hence making a CGE model the appropriate tool to explore how these sectoral responses will be transmitted to the rest of the economy.
The introduction of CCUS into the Scottish chemicals industry is modelled considering the additional capital and energy costs required to build and operate the CCUS equipment, with particular focus here on the carbon capture component. Therefore, compared to a situation without CCUS implementation, the chemicals industry will use more capital and energy to yield the same level of production. Table 1 is derived from Agyeman et al. (2023) and displays the assumed additional capital and energy requirement of different CCUS technologies for a typical chemical sector.
In the model, we translate the additional capital and energy inputs requirement into capital and energy inputs efficiency losses in the production process.

Table 1: Post and pre-combustion additional CCS capital and energy inputs requirement for chemical industries
CAPEX relative to industry Core Asset Value
Additional Energy Requirements
(Additional relative to combustion energy input)
Natural Gas
(Feedstock or heat) Electricity

Post-combustion CCS	+40%	+30%	+4%
Pre-combustion CCS	+50%	+20%	+3%

Source: Agyeman et al. (2023)

For the analysis, we consider different scenarios of introducing CCUS to the Scottish chemical industry. The first scenario assumes a deployment of post- and pre-combustion CCUS in the Scottish chemical industry independently of what is happening in the rest of the UK. This assumption implies that the cost of CCUS in the Scottish chemicals industry is only reflected in the Scottish chemical industry production costs, while competing chemical imports/exports costs from/to the rest of the UK and the world remain constant. In the second scenario, it is assumed that all the chemical industries in the UK adopt the same CCUS approach, hence facing the same increase in their production cost which is reflected on the price of their outputs. The third and fourth scenarios consider different funding options to support CCUS implementation costs.

Results: We analyse the long-run changes against an unchanging baseline, provided by our SAM data, for a range of policy relevant sectoral and economy-wide indicators, following the introduction of post and pre-combustion CCUS for the different scenarios.

Our results indicate that the implementation of CCUS to Scottish chemical industries could have negative sectoral and economy-wide implications irrespective to the technology and the scenario considered, with a higher negative impact associated with pre-combustion CCUS introduction. For instance, considering the scenario 1, the Scottish GDP could decrease by 0.11% and 0.15% following the introduction of post-combustion CCS and for pre-combustion CCUS respectively, compared to the original GDP level. The additional capital and energy required to set and operate CCUS facilities increases the chemical industries' production costs, introducing upward pressure on the price of their output. The competitiveness implications of said price increase led to reduced demand for the Scottish chemical outputs, domestically and particularly in export markets, and in turn drive a decline in their production level. Alongside the CCUS-driven decline in the chemical activity level, we observe a decline in the total employment in Scotland decreasing by a rate of 0.04% and 0.05% corresponding to 871 and 1152 full time employment (FTE) net jobs loss for post-combustion CCUS and pre-combustion respectively for the Scenario 1, where Scotland is the sole adopter of the CCUS technology in the UK.

Our results also show that the UK-wide implementation of CCUS could lead to smaller negative impacts in Scotland compared to the scenario where Scottish Chemical industries are the sole adopters. This is achieved via eliminating the price differences between Scottish and RUK Chemical industries, protecting the exports to RUK and eliminating the substitution of Scottish chemicals for RUK imported ones. Hence, some level of Scottish Chemical activity is preserved. However, we still observe chemicals activity losses associated with the wider decline in economy-wide activity in Scotland, where sectors require less inputs from the Chemical industries, and as a result of competition with ROW chemicals where we do not assume the introduction of CCUS and therefore the cost of chemicals remains unaffected.

Conclusions: We have conducted an analysis of the introduction of Carbon Capture, Utilisation and Storage (CCUS) to the chemical industry in Scotland. Our preliminary results indicate that the implementation of CCUS may have negative implications for industry competitiveness due to the additional capital and energy requirements, regardless of the CCS technology or scenario. This may result in a decline in Scottish chemical activity, which will ultimately lead to a reduction in the Scottish GDP and total employment. However, our analysis also suggests that if CCS is implemented UK-wide, it may have a lower negative impact than if Scottish chemical industries were the sole adopters. The UK-wide adoption of CCS would eliminate the price differences between Scottish and RUK chemical industries, protecting their exports to RUK and removing the substitution of Scottish chemicals for RUK-imported ones.

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[Page: 173]

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Implemented energy policies with co-benefits: CO2 mitigation and budget revenues. Case study from Saudi Arabia

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Overview:Like any other economy, sustainability goals are crucial for Saudi Arabia, as outlined in Saudi Vision – a strategic development plan of the Kingdom. Recognizing the importance of striking a balance between economic development and environmental protection, the Kingdom aims to transform into a modern and diversified economy, reducing its dependence on oil, while also promoting environmental sustainability by reducing carbon emissions and promoting renewable energy sources. They are highlighted in the strategic policy documents of the Vision, such as the Fiscal Sustainability Program, the Financial Development Program, the National Transformation Program, the National Renewable Program, the National Environment Strategy, the Saudi Green Initiative, the Middle East Green Initiative, the Circular Carbon Economy National Program.
A number of initiatives and targets have been identified in the above-mentioned programs in achieving economic and environmental sustainability. This research work considers two important ones: energy price reform (EPR) and the goal of increasing the share of renewables in electricity generation capacity to 50% by 2030 (while the other half coming from natural gas).
EPR is an important component of the Vision 2030 plan as highlighted in the Fiscal Sustainability Program. It increases domestic prices of energy products to the levels of references international market prices with the aim of achieving efficient use of energy resources while proving government budge with additional revenues. Table 1 documents reformed prices for various energy products that were implemented in 2015 and 2018.
Table 1. Energy prices in Saudi Arabia.
From an energy and environmental perspective, another key component of Vision is to increase the share of renewable energy in electricity generation capacity to 50%, with another half to come from natural gas by 2030. We call this “50/50 policy” for brevity.

This research assesses to what extent carbon dioxide (CO2) emissions and the government’s non-oil and oil revenues have been affected by these two initiatives. Put differently, we examine how these two indicators would evolve if EPR and the “50/50 policy” were not implemented. For this purpose, we conduct a counterfactual scenario analysis using a model called KGEMM.
Methods:KGEMM–KAPSARC Global Energy Macroeconometric Model is a general macroeconometric model augmented with energy and environmental sectors. It is a hybrid model in two senses: (i) it incorporates intermediate and final demand representations of the input-output model (IOM) into the macroeconometric framework. The IOM elements give the KGEMM sectoral granularity, as unlike

standard macroeconometric models, it can examine demand at the level of sectoral economic activities. (ii) the model is semi-structural, as it brings together theory-based and data-based approaches rather than being fully structural or purely data-driven (e.g., Pagan 2003a, b; Hendry, 2018). The KGEMM represents the economic, energy, and environmental interactions of Saudi Arabia through nine blocks, as Figure 2 illustrates.
KGEMM's Energy block has detailed energy demand relations by energy product (i.e., crude oil, diesel, HFO, gasoline, kerosene, LPG, natural gas, electricity) and customer (i.e., industry, agriculture, utility/power generation, households, commercial, government, and others). CO2 equivalent emissions of the above-mentioned energy demand relations are calculated in the Emissions block of the model. Details about the KGEMM can be found in Hasanov et al. (2020, 2023).

Figure 1. Schematic illustration of KGEMM.

Note: The figure is uploaded as a separate file
Source: Modified from Hasanov et al. (2023).
Results:Scenario design
We designed three scenarios. Scenario 1 assumes that neither EPR nor a "50/50 policy" is implemented in the Kingdom. Scenario 2 adopts the implementation of a "50/50 policy", and Scenario 3 undertakes the implementation of EPR. Table 2 details the scenarios.

Table 2. Description of the Scenarios.

Title	Name	Description
Scenario 1	No EPR and no "50/50 policy".	The assumptions are: - Energy price reforms were not implemented in 2016 and 2018. - The energy prices for 2016-2030 would be the same as those in 2015. - "50/50 policy" is not implemented for 2016-2030. - The economy will function in 2023-2030 as it did in 2022.
Scenario 2	Only the "50/50 policy", no EPR.	The assumptions are: - Energy price reforms were not implemented. - "50/50 policy" is implemented. - Crude oil, diesel, and HFO use in the power generation sector is reduced gradually to zero by 2030, and natural gas and renewable are increased accordingly.
Scenario 3	Only EPR, no "50/50 policy".	The assumptions are: - Energy price reforms were implemented in 2016 and 2018. - No "50/50 policy" was implemented for 2016-2030.

We assumed that additional oil export revenues of the saved energy from domestic consumption due to the given reforms will be injected into the economy. This means that aggregate demand will rise leading to expansion in economic activities which will require more fossil fuel to consume and consequently CO2 emission will increase. Thus, the simulations results will be the net outcome of these two opposing effects. This implies that if the additional oil revenues will not be injected back into the economy, then the magnitudes of CO2 reduction would be higher than those obtained below. Moreover, we assumed 43% of efficiency in the power generation sector of the Kingdom based on expert opinions and literature surveys.
Results of the analysis
The initial results of the counterfactual scenario analysis are recorded in Tables 3 and 4. To make the results more policy-relevant, we report them in two time horizons: Table 3 documents the results for 2016-2023, the past period, and Table 4 reports the results for 2024-2030, the future period.
Table 3. Deviation of the scenarios from Scenario1, average of 2016-2023, %

Scenario	Total CO2 emissions	Government oil revenues	Government non-oil revenues
Scenario 2	-4.5	1.9	1.8
Scenario 3	-17.3	18.3	32.5

Table 3. Deviation of the scenarios from Scenario1, an average of 2024-2030, %

Scenario	Total CO2 emissions	Government oil revenues	Government non-oil revenues2
Scenario 2	-4.9	4.0	1.4
Scenario 3	-13.5	18.1	32.9

The results from Scenario 2 show that CO2 emissions in the Kingdom would be higher by an average of 4.5% in 2016-2023 and 4.9% in 2024-2030 if "50/50 policy" were not implemented compared to Scenario 1. In addition, the government oil revenues would be on average 1.9% lower than that in Scenario 1 in 2016-2023 and accordingly, 4.0% lower in 2024-2030. Non-oil revenues would also be 1.8% and 1.4% lower than those in Scenario 1, respectively.
The implementation of the EPR in Scenario 3 resulted in an average reduction in CO2 emissions of

17.3% in 2016-2023 and 13.5% in 2024-2030 compared to Scenario 1. In addition, the policy led to an increase in state oil revenues by 18.3% in 2016-2023 and 18.1% in 2024-2030. Non-oil revenues of the state budget have also increased by 32.5% in the past period. The simulation shows that the impact of EPR on state non-oil revenues will be 32.9% higher on average in Scenario 3 than those in Scenario 1 in 2023-2030.
Conclusions:This study analyzes the counterfactual scenarios of implemented policies, i.e., EPR and "50/50 policy" using a general macroeconometric modeling framework. The objective is to illustrate how CO_2 emissions and the government's oil and non-oil revenues would evolve if these policies were not in place. To this end, we simulated three scenarios. The initial results show that both policies contribute to CO_2 reductions while providing additional revenues.
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Keywords: Energy Price Reform, renewable energy, macroeconomic impact, CO_2 emission, budget revenue

AuthorToEditor: Thank you for organizing the conference and opportunity to share the studies of the researchers.

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[Abstract:0428] OP-174 [Accepted:Oral Presentation] [Energy Finance and Trading » Corporate Strategy and Investor Oversight]

Green Investments Path: Environmental Performance through Strategic Ambidexterity

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Overview:Numerous regions across the globe are currently facing the negative consequences of climate change, which are mainly caused by human activity. Organizations have been increasingly pushed to prioritize environmental and social factors due to growing demand from institutions and consumers (Asiaei et al., 2023). The principal causes of global warming are the increasing levels of greenhouse gas (GHG) emissions worldwide, which result from poor energy use, harmful consumer behaviours, and excessive manufacturing. This conclusion was reached by the Intergovernmental Panel on Climate Change (IPCC) in 2023. As a result, firms have made commitments to reduce their GHG emissions, improve their environmental performance, and address the negative effects of this worrying trend shown in recent decades.
The concept of green innovation emerges as a proactive measure to tackle the environmental consequences of pollution (Chen, 2008). Green innovation refers to the specific actions taken by organizations to adopt product, marketing, and organizational innovations that have a good impact

on the environment (Woo et al., 2014). This can be demonstrated by actions such as conserving energy or reducing material use (Dangelico, 2016). Kraus et al. (2020) suggest that green innovation can enhance companies' environmental performance by a maximum of 27%. Moreover, Yang et al. (2022) highlight that green innovation plays a crucial role in promoting a sustainable economy. In addition to the positive environmental effects of implementing green business strategies (H. Lin et al., 2021), green innovation is acknowledged as a feasible approach to improve firms' financial performance (Benkraiem et al., 2023, Shuwaikh et al. 2023). This comprehensive strategy not only tackles environmental issues but also enhances the long-term financial viability and competitiveness of firms in the modern context.

This study is groundbreaking because it is the first to investigate the connection between ambidexterity, green innovation, and environmental performance in the specific context of Corporate Venture Capital (CVC) investments. The fundamental idea is based on the belief that corporations can utilize ambidexterity strategies to "acquire" green innovation by implementing CVC programs and making investments in entrepreneurial ventures. As a result, these "acquired" green innovations can be utilized to improve the environmental performance of the parent companies, making them more sustainable, in line with customer expectations, and compliant with environmental and social regulations.

Our study analyses data from 126 CVC investors between 2002 and 2021. It contributes significantly to the ongoing discussion on the most effective way to achieve ambidexterity. Our research supports the use of a sophisticated approach where companies strategically combine exploratory and exploitative CVC investments, demonstrating dynamic ambidexterity to improve their environmentally friendly innovation. We argue that relying exclusively on static ambidexterity can hinder companies' green innovation endeavours, unless it is accompanied by a simultaneous implementation of dynamic ambidexterity. This work highlights that the simultaneous application of both static and dynamic ambidexterity has a synergistic effect on firms' green innovation.

The findings of our study have broader implications that go beyond a simplistic binary perspective. This research challenges the notion of completely disregarding the concept of static ambidexterity, as suggested by Gibson & Birkinshaw (2004) and O'Reilly & Tushman (2008). The findings support the idea of combining static ambidexterity with dynamic practices in order to maximize the benefits of ambidextrous CVC investments. Our analysis confirms that the negative impact of static ambidexterity becomes stronger over time, while the dynamic and combined effects show improvement. The results of our study highlight the ability of corporate investors to strategically utilize ambidexterity in their CVC activities. By doing so, they can effectively use this approach to obtain the green innovation needed to make significant improvements in environmental performance. This discovery highlights ambidextrous CVC investments as a strategic opportunity for corporate investors to improve their environmental reputation by incorporating green innovation. Through the implementation of ambidextrous CVC investments, companies strategically avoid potential penalties from investors (Lee et al., 2015) while simultaneously enhancing their financial performance.

Methods:The hypotheses discussed are tested under the empirical setting of CVC investments. Hence, to conduct this study, we use U.S. firms that have made venture capital investments between 2000 and 2019 and have invested in green innovation from 2000-2021. U.S. firms are the most active in terms of VC investments (Benkraiem et al., 2023) and we focus on 2002-2021 as Refinitiv Eikon only provides environmental data from 2002 onwards.

Firstly, from Refinitiv Eikon, more specifically from the Private Equity screener, we downloaded firms that made at least one CVC investment. Secondly, from PATSTAT, we extracted firms with green innovation. When applicable we consider the parent firm name. Then, we merged the two data sets, matching firms that have CVC investments and green innovation. In the matching process, we assumed that each CVC investment made is going to benefit from corporates' green innovation in the subsequent periods. Then, from Refinitiv Eikon, we extracted financial, accounting, and environmental data which was added to the merged dataset. The final sample comprises 126 CVC firms, 638 CVC investments and 7780 observations.

Results:This work examines three crucial concepts - ambidexterity, green innovation, and environmental performance - with the objective of providing valuable insights to address current difficulties. The study is motivated by the urgent necessity to tackle present problems and the lack of empirical research on the integrated examination of these ideas in the context of CVC investments. Our research reveals the significant role that ambidextrous CVC investments play in helping corporate investors acquire green innovation. Dynamic ambidextrous CVC investments are particularly successful in boosting organizations' ability to capture green innovation. The study recommends maximising the investment in both exploratory and exploitative CVC activities simultaneously. This investment strategy has been shown to have a consistently favourable effect on green innovation over the following three years.

In contrast, a fixed ambidextrous strategy is observed to have an adverse influence on green innovation, reinforced by a declining trend that indicates a worsening effect over the subsequent three years. The study advises against corporations adopting a rigid perspective of ambidexterity

alone, highlighting the negative impact of maintaining a balance between exploratory and exploitative CVC investments. A significant contribution arises when companies integrate both static and dynamic approaches to ambidexterity, resulting in synergistic effects that exceed the favourable impact of dynamic ambidexterity alone. This highlights the suggestion that companies should utilize both types of ambidexterity in their CVC investments, with a focus on the importance of a comprehensive strategy. Environmental performance is now considered a vital measure that demonstrates companies' commitment to reducing their ecological footprint. We show that corporate investors can improve their environmental performance by efficiently utilizing the green innovation resulting from their ambidextrous CVC investments. Moreover, our analysis demonstrates that the influence of present green innovation on environmental performance persists over a period of time.
Conclusions:This work examines the influence of various ambidexterity tactics on green innovation among corporate investors. It explores how these investors might improve their environmental performance by acquiring green innovation through ambidextrous CVC investments. The study reveals that American corporate investors, totaling 126, can successfully leverage green innovation by making ambidextrous investments with entrepreneurial companies. Although static ambidexterity has negative effects, corporate investors who pursue dynamic ambidexterity or a combination of dynamic and static ambidexterity show enhanced outcomes in green innovation. The research demonstrates a clear connection between the green innovation of corporate investors and their enhanced environmental performance, particularly in terms of reducing GHG emissions. The study contends that ambidextrous CVC investments serve as a gateway for corporate investors to elevate their environmental performance through the strategic acquisition of green innovation. This research provides significant insights for company managers, regulators, and government bodies, delivering practical knowledge for establishing environmentally friendly practices in corporate investment strategies.
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Keywords: GHG emissions, corporate venture capital, ambidexterity, environmental performance, corporate strategy

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Carbon financial risk and corporate leverage changes: Insights from China

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Overview:In recent decades, the unprecedented influences of global climate change have aroused great concern in society. As of May 2022, carbon dioxide concentration climbed to around 421ppm, the highest level in over four million years. The excessive carbon emissions have aggravated the greenhouse effect, making global surface temperature 1.09℃ higher than in 1850-1900. If not properly addressed, the global economy in 2050 will be about 3% smaller than the baseline projections. Under such severe situations, carbon financial risk, a new systemic risk exactly reflecting these adverse impacts of carbon emissions on society, has become an emerging and urgent issue.

In the stock market, this new carbon financial risk usually refers to the uncertainty from a brown economy to a green economy. As the leading participants in economic activities, the listed companies are the main stakeholders in the climate change crisis. On the one hand, high-emissions companies will be covered by severe regulatory interventions, thus directly imposing extra business costs. On the other hand, the frequent occurrence of destructive weather will lead to a sharp revaluation of financial assets, which indirectly causes asset loss and leakage. Therefore, high-emissions companies will have a challenging green transition process, inducing a higher carbon financial risk. Based on the risk premium theory, if facing higher carbon financial risk, companies will usually have a lower stock price at present and a higher expected return in the future. That is, the stock price difference between the present and the future can and will compensate for additional green transition risk loss, indicating a carbon premium-higher stock returns for high-emissions companies.

Nonetheless, an interesting and thought-provoking question is how companies will respond to carbon financial risk. Currently, few studies have explored the effect of carbon financial risk on corporate governance, including capital structure changes, investment and acquisition decisions, and competitive advantage strategy. In order to offset the increasing carbon financial risk, companies need to carry out more carbon-efficient activities, thus potentially leading to changes in operating and financial structure. However, this will be a considerable challenge for high-emissions companies due to the huge sunk cost. Therefore, a trade-off will be between carbon financial risk management and corporate governance.

As can be seen, the potential influence of carbon financial risk is still obscure and unclear ex-ante. This study is interested in exploring the effect of carbon financial risk on corporate leverage changes and the short-term economic consequences, using the panel data of Chinese A-share listed companies from 2009 to 2019.
Methods:The sample data includes 4,528 company-year pair observations, which cover 444 unique Chinese A-share listed companies from 2009 to 2019. All basic financial data are obtained from China Stock Market Accounting Research database. There are several reasons for using this sample data. (1) The sample period is from 2009 to 2019 so as to reduce the potential impacts of the 2008 financial crisis and the COVID-19 pandemic. (2) Since the "ST" and "*ST" symbols refer to some evident and significant business problems, these companies are excluded so as to alleviate the possibility of extreme data values. (3) Due to the fundamentally different business structures in some industries, such as financial industries, companies of these industries are excluded from the sample data. (4) Linear interpolation and entropy weight methods are employed to handle the missing values. Those that cannot be addressed will be excluded from the sample data.

There are several ways to evaluate and estimate policy and project effects between different groups, among which the difference-in-differences (DID) model has been widely used. Following Cui et al. (2021)-type approach, this study employs the DID model to observe how companies will respond to the external carbon financial risk. Under the counterfactual framework, the DID model can evaluate the changes in the dependent variable between the treated and control groups. 101 ETS-covered companies and 343 non-ETS-covered companies will be chosen according to the covered regions and industries of China's carbon ETS pilots. Therefore, as for 101 ETS-covered companies after 2013, the carbon ETS implementation will set to 1.

The independent variable is carbon financial risk, which is measured by the interactive form between carbon beta and carbon ETS implementation. The dependent variable is total corporate leverage, which reflects the corporate internal distress situation. This variable is measured by the ratio of the percentage changes in earnings per share (common share) to the percentage changes in sales revenue. That is, a small change in turnover will lead to a large change in earnings per share. Furthermore, total corporate leverage can be divided into operating leverage and financial leverage.
Results:For specific illustration, carbon financial risk can decrease total corporate leverage by 14.26, equivalent to 4.2% calculated by its value ranges. Second, since total corporate leverage can be divided into operating leverage and financial leverage, they are also taken as the dependent variable in columns (3) – (4). The results show that companies will decrease both operating and financial leverage to deal with external carbon financial risk. In a statistical sense, the effect of carbon financial

risk on financial leverage is more sensitive than operating leverage.

When environmental pressure increases, the carbon financial risk becomes relatively high. It is found that companies will reduce the overall internal leverage to alleviate this distress. This conclusion is consistent with Nguyen and Phan (2020). They found that Australia's ratification of the Kyoto Protocol can reduce corporate financial leverage, while our conclusion goes further by revealing the changes in total leverage. In response to the increasing external carbon financial risk, companies are encouraged to reduce and replace the usage of carbon-intensive technologies. The transition from a high-emission state to a low-emission state will lead to changes in the capital structure, such as lowering the optimal leverage ratio. Consequently, total corporate leverage will get reduced, thus alleviating corporate distress effectively.
Conclusions:As an essential part of carbon finance, carbon financial risk refers to the uncertainty during the transition process from a brown economy to a green economy. To deal with this new systemic risk, companies must take appropriate actions. This study explores the relationship between external carbon financial risk and corporate leverage using the panel data of Chinese A-share listed companies from 2009 to 2019. It reveals the direct impacts, heterogeneity effects, potential mechanisms, and economic consequences based on the classical DID model. The results and conclusions remain the same after several robustness estimations, including parallel trend test, PSM-DID estimation, MCMC-DID estimation, IV-DID estimation, and placebo test. The main conclusions are as follows:

(1) Carbon financial risk combines the micro-risk characteristics and macro-realistic pressure after using the quantitative financial method. In response to the external carbon financial risk, companies must reduce the total corporate leverage by 14.26, which is equivalent to a 4.2% reduction if calculated by value ranges. (2) The overall effect of carbon financial risk on total corporate leverage differs among listing ages, industries, and credit offset ratios. However, there is no noticeable difference among property rights, geographical regions, and allowance allocation methods. (3) Companies can decrease fixed assets (operating leverage) and asset-liability ratio (financial leverage) to deal with the external carbon financial risk. By comparison, financial leverage will work better since it can be adjusted according to different development stages in a short time. (4) Under the increasingly severe carbon financial risk, companies will eventually reduce their investment activities as economic consequences.

This study contributes to the literature by broadening the understanding of the role of finances in corporate governance. We will put forward the following policy recommendations based on the above conclusions.

(1) With the increasing intensity of environmental regulation, companies should actively manage carbon financial risk. Due to its systematicness and conductivity, companies in all industries have various degrees of carbon financial risk. Besides operating and financial measures, it is suggested that companies must strengthen internal risk awareness. For example, recording, tracking, and managing carbon footprint will be useful and helpful in transforming into a green business pattern. (2) Companies should conduct orderly management according to their business situation. Different companies should adopt various management measures. Companies must proceed cautiously from the long-term perspective, whether the operating instruments or the financial measures. For example, since those high carbon-intensity companies suffer more pressure in the transformation process, they will need a quick and effective way in a short time. (3) In the global climate change, the government should make up some supporting policies to help companies. Companies will change their business strategies when dealing with external carbon financial risk, such as the tax shield benefits, optimal financial ratio, and short- and long-term investments. To support and accelerate the transformation and upgrading process, the government can appropriately formulate a package of green financing and investment policies.
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Financing for the Brown

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Overview:In combating climate change, sustainable investors worldwide are pivoting towards green assets. However, the headlong rush into green investment avenues uncovers a complex dilemma. Firstly, this narrowed focus potentially overlooks rich opportunities in wider, diverse markets, questioning the long-term financial sustainability of such strategies. Secondly, the overwhelming push towards green assets inadvertently elevates the financial strain on 'brown' firms. This not only exacerbates their carbon footprint but also ironically dilutes the very environmental benefits sustainable investing aims to achieve (Hartzmark & Shue, 2023).
While endorsing green businesses is pivotal, the real transformational leap manifests when investors steer 'brown' enterprises toward green horizons, thereby amplifying both environmental and financial gains. Indeed, leading institutional investors are taking a hands-on approach to shape corporate sustainability practices in recent years, besides directly investing in green assets. This active engagement manifests in their efforts to enhance firms' climate performance and reduce carbon risks. By uncovering the synergy between mitigating climate impacts and optimizing financial returns through guiding 'brown' firms to adopt greener strategies. Our study explores the prowess of institutional investors to ingeniously intertwine environmental stewardship with profit-making by reshaping brown firms into green beacons.
Methods:We explore how institutional investors capitalize on carbon risk premiums by driving traditionally 'brown' firms towards greener practices. First, we identify corporate carbon risks through a long-short portfolio based on firms' relative carbon emissions for Chinese listed companies from 2009 to 2021, drawing methodologies from Görgen et al. (2021) and Huij et al. (2021). We then document evidence that institutional investors hold more stocks of firms with higher carbon risks. To ensure the robustness of our findings, we tackle potential endogeneity using an instrumental variable (IV) approach. In particular, we instrument corporate carbon risks using the average carbon risk within a similar provincial context but from diverse industries, an approach adapted from Chang et al. (2015). This IV impacts institutional investors primarily due to the parallelism of carbon risks in their vicinity, sidestepping industry-related spillovers. This inclination towards stocks with higher carbon risks seemingly diverges from the mainstream advocacy for green transition. We now turn to investigate the rationales for institutional investors to hold brown firms.
Results:Progressing further, our research underscores that institutional investors intensify their surveillance on high carbon risk firms. Evidence suggests heightened site visits to these firms' headquarters, declined occupy by large shareholders, and increased media scrutiny. We also identify that these investors play a pivotal role in reducing information discrepancies for firms with high carbon risks by amplifying analyst coverage, curtailing insider trading activities, and diminishing debt financing costs. Intriguingly, while a firm's carbon risk might be subject to an existential threat from institutional investments, our data indicates that these firms refrain from prioritizing immediate profits at the detriment of sustainable growth. Such findings underscore the rigorous oversight of high carbon risk firms by institutional investors, setting the stage for their evolution into low carbon risk entities. Moreover, our analysis further illuminates that institutional shareholder engagements bolster a firm's ESG performance and transparency in carbon-related disclosures, effectively ensuring that financing brown firms, in fact, reduces their carbon footprint.
Finally, we delve into the nuances of how carbon risks influence institutional investors' stockholdings

across varied shareholder profiles and external stimuli. One key observation reveals that augmented investments predominantly emanate from pressure-averse, long-term institutional shareholders who prioritize enduring rewards. Concurrently, we discern that institutional shareholders' responsiveness to carbon risks amplifies during pivotal moments like the adoption of the Paris Agreement. Such reactions are especially evident within carbon-heavy industries constrained by green credit policies and in firms recognized by carbon neutrality-centric sectors within the capital market. Consequently, broader societal climate consciousness, targeted industry-specific climate regulations, and prevailing market anticipations concerning climate issues seemingly intensify institutional investors' dedication to championing green transitions within firms.

Conclusions:This study fits into three strands of literature. First, we enrich the growing literature on carbon risks and the associated risk premium. Existing literature has shown the existence and impact of carbon risks (Balachandran & Nguyen, 2018; Bose et al., 2021; Nguyen & Phan, 2020; Oestreich and Tsiakas, 2015). Our study complements this body of research by examining how institutional investors explore the carbon risk premium associated with the green transition of brown firms. Second, we add to the literature about risk management. Carbon risk involves comprehensive strategic and operational exposure to unexpected changes during the transition from a brown to a green economy (Görgen et al., 2021). However, little is known about their participation in carbon risk management. This paper shows that carbon risk is a significant factor when institutional investors make investment decisions since they desire for long-term premiums associated with carbon risks. Finally, our findings have significant implications for practice as they contribute to the understanding about the roles of institutional investors. In this paper, we highlight the external monitor and information role of institutional investors. In the absence of public governance, institutional investors should take more responsibility for engaging with their portfolio companies. Through visits, research, and analysis reports, institutional investors help firms mitigate agent costs and alleviate information asymmetry that improves the governance and financing ability to address carbon risks. These roles could better guide institutional investors to participate in firms' sustainable development, which aligns with the carbon neutrality strategies of allocating financial capital to green transition without using extra fiscal resources.

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Keywords: Institutional investor, brown firm, carbon risk premium, information

[Abstract:0434] OP-177 [Accepted:Oral Presentation] [Energy Finance and Trading » New Trading Technologies]

Analysis on the clean energy investment network – focusing on the Middle East and North Africa

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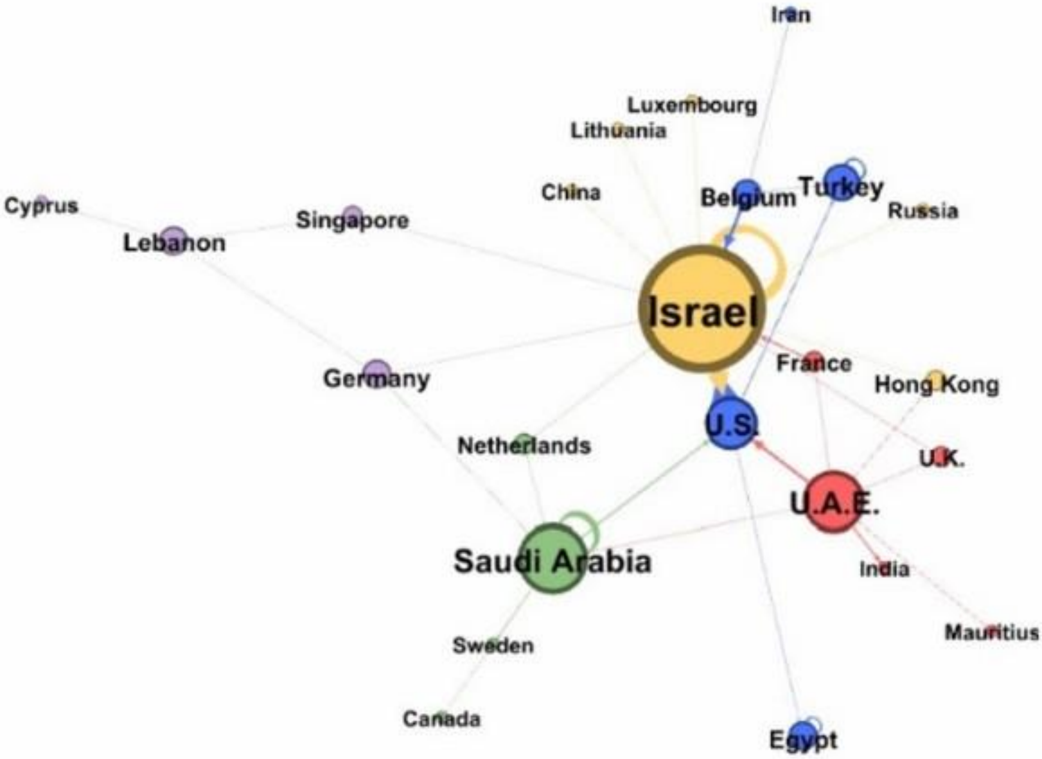
Overview:This study analyzes the network of clean energy investments in the Middle East and North Africa (MENA), aiming to assess the influence of individual nations and understand the interconnectedness through investment flows. As MENA countries intensify their strategic investments in clean energy to diversify their economies and reduce greenhouse gas emissions, international interest and foreign investments in the region's clean energy sector are surging, complicating inter-country relations (IRENA, 2023). Utilizing a social network approach, the research examines 634 clean energy firm investments in the MENA region over the last decade. The period of analysis spans from 2014 to 2023 and dissected in five-year intervals to compare shifts over time.
Methods:This study utilizes Social Network Analysis (SNA) to decipher the intricate network of clean energy investments within the MENA region. By conducting a quantitative analysis of 55 nodes (countries) and 634 edges (investment links), we calculate betweenness, closeness, and eigen centrality to assess the significance of each nation and computes the modularity of the nations to categorize clusters within the network.
Results:Over the past decade, centrality analysis revealed Israel, U.A.E., Saudi Arabia, Tunisia, and Egypt as pivotal in MENA's clean energy investments. While Israel consistently maintained high centrality both before and after 2019, notable increases in centrality were observed in U.A.E., Saudi Arabia, Tunisia, and Egypt, with U.A.E. and Saudi Arabia showing significant growth in Eigen centrality and Tunisia and Egypt marking substantial gains in Closeness centrality within the MENA region.
Globally, key collaborators in the clean energy investment network were identified as the U.S., the U.K., China, and Singapore. Modularity findings unveiled major collaboration clusters: Israel with Western countries, Tunisia and Egypt with China, the U.K., Saudi Arabia with the U.S. and European countries, and U.A.E. with Asian and European nations.
Conclusions:This study highlights the key roles and dynamic interactions within the MENA clean energy investment network, pinpointing pivotal nations like Israel, U.A.E., and Saudi Arabia, and identifying major global collaborators. The findings, derived from SNA, offer insights for shaping future strategic initiatives in the region's evolving clean energy sector.
References:International Renewable Energy Agency (IRENA). 2023. Renewable energy markets: GCC 2023

Keywords: Clean Energy Investment, Network Analysis, Middle East and North Africa(MENA)

Figure 1 Global clean energy investment network by modularity before (upper) and after (lower) 2019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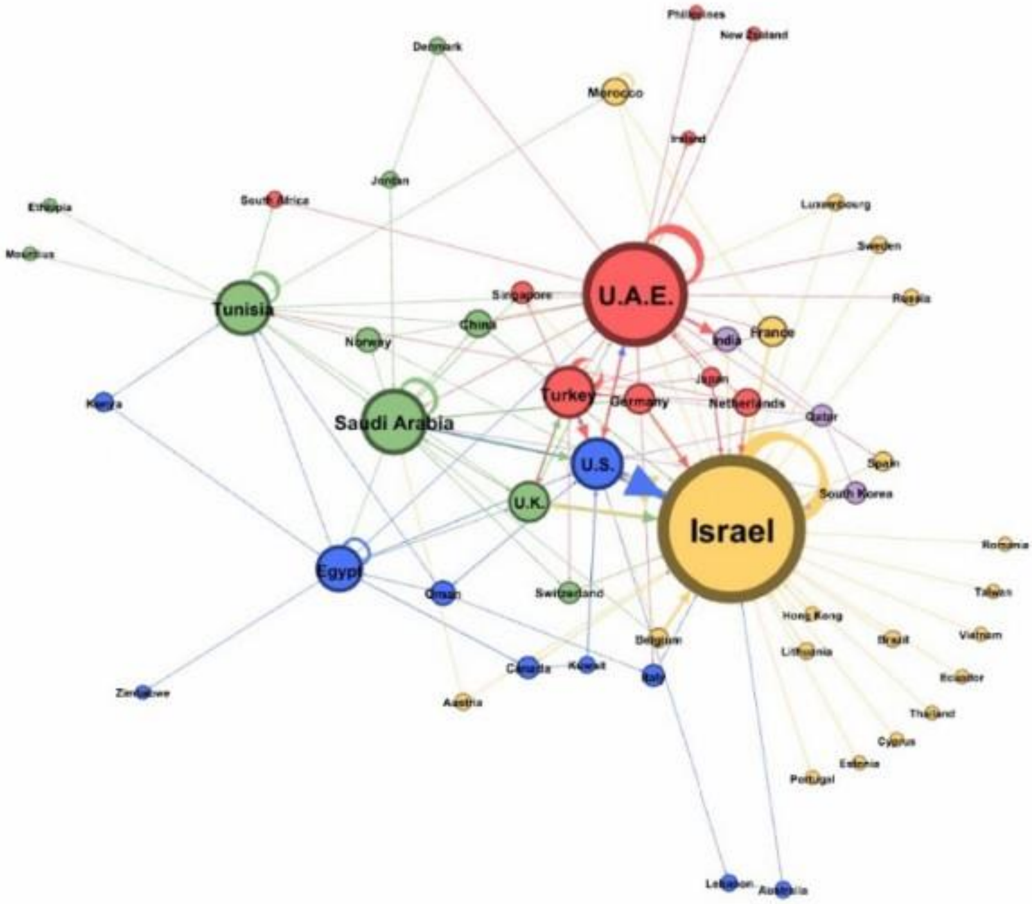
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Taiwan
Oman
Switzerland
Hong Kong
Vietnam
Belgium
Brazil
Lithuania
Ecuador
Canada
Kuwait
Italy
Zimbabwe
Austria
Thailand
Cyprus
Estonia
Portugal
Lebanon
Australia

Table 1 Top five MENA countries by betweenness, closeness, and eigenvector centrality

Betweenness Centrality		Closeness Centrality		Eigen Centrality	
Country	Value	Country	Value	Country	Value
Israel	972.126	U.A.E.	0.594	Israel	1.000
U.A.E.	601.943	Israel	0.567	U.A.E.	0.853
Saudi Arabia	246.158	Saudi Arabia	0.535	Saudi Arabia	0.497
Tunisia	167.960	Tunisia	0.494	Turkey	0.448
Egypt	83.368	Egypt	0.475	Egypt	0.290

[Abstract:0449] OP-178 [Accepted:Oral Presentation] [Energy Finance and Trading » New Trading Technologies]

An investment strategy of energy listed companies based on community division

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Overview:Energy-listed companies play a key role in energy trading and energy economy. It is an important part of energy market. With the continuous development of the economy and the progress of new energy technologies, the investment in energy-listed companies is receiving more and more attention. The stock trading of energy-listed companies as the most direct way to invest, has the widest audience. However, the stock price of the energy-listed companies tend to show great volatility and it is difficult for investors to grasp and predict. Therefore, we need to portfolio to diversify risk as it says Do Not Put All Your Eggs in One Basket. Then, how many baskets do we need and how to allocate these eggs is the focus of all investors and also the research problem in this paper.

In this paper we calculated the correlation coefficient of stock price and construct a correlation network of global energy listed companies under different thresholds. By using the community division algorithm of complex network, 332 listed energy companies are divided into several communities. We select one stock from each community from the previous and take it as the portfolio the following year. For the allocation of investment capital, we use genetic algorithm to optimize the allocation of weights and obtain the optimal allocation plan in each investment circle and use it in the next investment circle. The results of the combination of network community and genetic algorithm show that the threshold of 0.65 is a mutation point of the network structure, but the mutation point does not mean highest return. Generally, the investment portfolio based on network community division can yield higher return than a randomly picked stock. The results from this study could facilitate investment decisions.
Methods:In this paper, we use the community detection of complex network method as the investment portfolio chosen method. The nodes of the complex network are 332 listed energy companies and the connections are the relations of the daily returns between two listed energy companies. After we have the time series of daily returns, we use the Pearson correlation coefficient to calculate the correlations between two daily return series. In this paper, to build the rate-related stock network of energy listed company, we take 322 energy companies as the nodes, take the relationships between daily return of the stock price as the edge and take the correlation of the daily returns as the weights of the edges.

We establish the stock network of energy listed company and use the theory of division of complex networks to divide stocks into relatively independent communities. Then, we select the best stocks

of each community from the previous year as the portfolio of the next year.

Communities in a complex network refers to a subset of nodes that are made up of network nodes. The connections between subsets are sparse, while the connections the nodes of one subset are very dense. Companies from the stock network of energy listed company may also split into small communities. Inside the communities, companies have close relationship while the relationships between companies from different communities are relatively loose. Modularity is a measure of how well a network is partitioned. The large modularity means obvious differentiation of the network.

After selecting the stocks to be invest in the portfolio, in order to maximize the return, we need to distribute the capital among different stocks because of the differences of the stocks prices, trends and other factors. In this paper, genetic algorithm is used to optimize the weight of capital allocation.
Results:First, the number of communities of different year show different increase trend. Especially, they have different mutation points. In the 2018 and 2019, the number of communities of the networks show a slow and fluctuating upward trend with the increase of the threshold. While the number of communities in 2020 and 2021 show a clear upward trend when the threshold is below 0.6-0.65 and a downward trend thereafter.

Second, some stocks appear frequently in different portfolio such as SNP (8 times), EEP (8 times), and TSO (6 times). They seem to be important building blocks of a portfolio.

Third, The ratio of gaining positive returns is 58%. The threshold 0.60 gained highest average return but the threshold 0.70 gained more positive returns.
Conclusions:In this paper, we use the community division of complex network to select portfolio from energy listed company and use genetic algorithm to allocate the capital weight of the stocks. Generally, it is a useful way to invest. The portfolio selected based on the community division can gain higher return than a randomly picked stock. The threshold of 0.65 is a mutation point. The communities will disperse before the mutation point with the increase of the threshold value, but will gather rapidly after the mutation point. However, mutation point does not mean highest return. The threshold lower than mutation point gives higher return. In the portfolio selected under different threshold, there are some stocks appear frequently and they are obviously important building blocks.
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Keywords: Energy listed company, investment strategy, community division

[Abstract:0152] OP-179 [Accepted:Oral Presentation] [Energy Modeling » Integrated Assessment Modeling]

The Path to 2060: Saudi Arabia's Long-Term Strategy for GHG Emission Reduction

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Overview:Oil-producing countries like the Kingdom of Saudi Arabia (KSA) face the dual challenge of mitigating climate change and their economic dependence on oil revenues. Saudi Arabia is also a signatory to the Paris Agreement. It has updated its NDC commitment to reduce greenhouse gas emissions by 278 million tons of carbon dioxide equivalent by 2030. In the lead-up to COP 26 and joining the global efforts, under the umbrella program of the Saudi Green Initiative, Saudi Arabia announced its pledge to achieve net zero emissions by 2060. Saudi Arabia's efforts to reach net-zero emissions are significant because it is a major player in the global energy market. Its commitment to renewable energy and reducing its carbon footprint sends a powerful message in its shift towards a more sustainable future. While there have been studies that look at the impact of individual initiatives, such as energy price reforms, on the overall emissions in the Kingdom, there is a lack of detailed analysis in the context of the long-term implications of these initiatives and what would it take to achieve net-zero Greenhouse Gas (GHG) emissions by 2060. Hence, this study is an attempt to understand the implications of achieving net zero emissions on the overall energy system of the country.

Methods:This study uses a modified version of the Global Change Analysis Model (GCAM v6.0), an integrated assessment model representing the behavior and interactions between the energy systems, water, agriculture and land use, the economy, and the climate (Calvin et al. 2019). For this study, we have separated Saudi Arabia as a separate energy-economy region, i.e., GCAM–KSA includes 33 energy-economy regions (32 original regions plus KSA). In addition to a reference (i.e., 'No Policy’) scenario, we look at three different policy scenarios using GCAM-KSA. Choosing these scenarios aims to see the long-term impact of various policies and mitigation efforts on Saudi Arabia’s energy system.

Furthermore, for all the scenarios, we assume a growing economy and an increasing population of Saudi Arabia, with per capita income reaching USD 37000 (2020 prices) in 2060 and a 60 million total population. We include the impact of COVID-19 on the GDP growth rate in 2020 and the recovery after that in 2025 as per the International Monetary Fund (IMF) projections. After that, the population and GDP growth rate aligns with the SSP2 assumptions for the growth rate from the shared socioeconomic pathways database.

For other energy-economy regions except for Saudi Arabia, in the emissions-constrained NDC continued and NZ 2060 scenario, we assume the fulfillment of NDC and net zero targets of other regions as reflected in the NDCs scenario from (Iyer et al., 2022). This assumption includes various countries' commitments during COP 26 and the continued ambition scenario presented by (Ou et al., 2021).

Results:In the case of the Kingdom, we show that achieving Net-Zero GHG emissions by 2060 requires increasing ambitions. Our assessment shows that achieving NZ 2060 requires deploying various decarbonizing technology options, such as a high share of renewables for power generation, electric and fuel-cell vehicles, electrification of industrial processes, and carbon capture and removal technologies like CCUS and DAC.

While the transition to renewable and clean energy technologies will be central to the net zero GHG emissions by 2060 strategy, integrating carbon dioxide removal (CDR) measures will be a crucial part of the strategy for Saudi Arabia. Hydrocarbons will likely remain a part of Saudi Arabia’s energy mix for a long time due to the legacy of carbon-intensive industries and their use in hard-to-decarbonize sectors. These sectors will consequently continue to emit GHGs, necessitating carbon removal technologies to offset these residual emissions. Our analysis shows that to reach net zero GHG emissions by 2060, Saudi Arabia must deploy CDR measures to remove 371 MtCO2 per year from the atmosphere to offset the overall GHG emissions in 2060.

Conclusions:In conclusion, achieving economy-wide net zero GHG emissions in Saudi Arabia by 2060 is a complex and challenging endeavor. It requires concerted efforts across all sectors of the economy. While decarbonizing electricity generation and improving energy efficiency in buildings offer significant emissions reductions, the complete decarbonization of the industrial sector remains challenging. Transforming the transport sector through fuel efficiency standards, EV adoption, modal shifts, and changing consumer behaviors can also contribute substantially to emissions savings. Acknowledging the role of CDR technologies in offsetting residual emissions is essential. As some sectors may continue to rely on hydrocarbons, deploying CDR technologies becomes crucial to achieving the net zero goal. Continued research and development in CDR solutions will be necessary to enhance their effectiveness and scalability.

The successful achievement of net zero emissions in Saudi Arabia will also require a collaborative effort involving the government, the private sector, and society at large. It will necessitate policy support, regulatory frameworks, financial incentives and public awareness campaigns. International collaboration and knowledge-sharing will also be invaluable in accelerating progress and leveraging global best practices.

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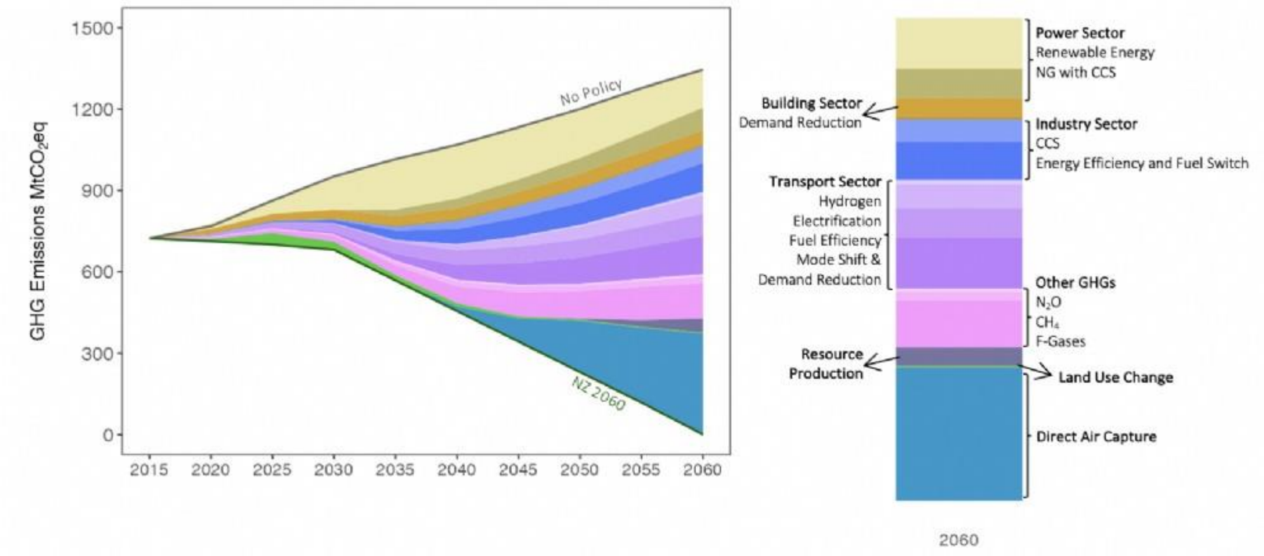
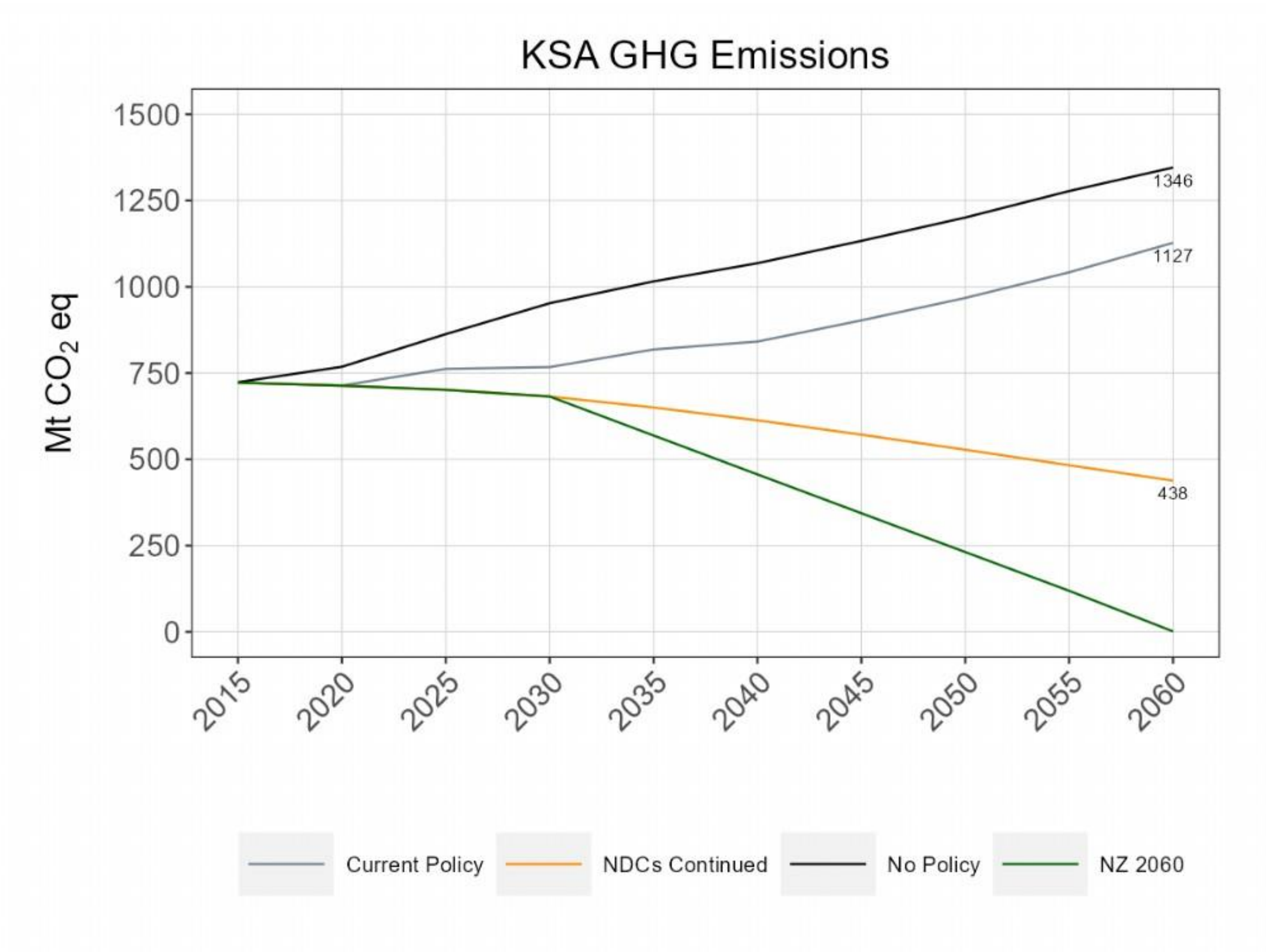
Keywords: Net Zero, GHG emissions, Saudi Arabia, GCAM-KSA, Scenario Analysis, Climate Change

Breakdown by sector and contributing factors in each sector to achieve net zero GHG emissions from the No Policy baseline by 2060



Reaching net zero GHG emissions by 2060 would require enhancing current ambitions



[Page: 180]

[Abstract:0127] OP-180 [Accepted:Oral Presentation] [Energy Modeling » Forecasting and Market Analysis]

Modelling the Long-Term Oil Demand Emerging from Petrochemical Feedstocks World-Wide

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Overview:Oil is presumed to remain the fuel with the largest share in the energy mix over the forecast period, led by demand from transportation and petrochemicals. Combined, oil and gas are still expected to make up more than 50% of the global energy mix by 2040. The Petrochemical sector has experienced a high growth rate for the last twenty

years (4% annual). Demand growth in industry is driven mainly by the petrochemical sector, with demand forecast to increase by 4.5 mb/d from 2017–2040, from all regions in the world. The strong performance of the petrochemical industry is expected to require additional volumes of natural gas as feedstock.
In this context, we want to model the demand for the main feedstocks, Naphtha, Ethane, LPG, Other petrochemical feedstock products for the 8 regions of the world. A total of 30 equations were estimated for price and income elasticities of demand in the short and long term. The results were found to be satisfactory with good econometric properties and significant coefficients enabling price and income elasticities to be estimated in the short and long term. In sample simulations showed small percentage errors across all equations. An aggregate world equation was also estimated and compared against the aggregation of regional simulations, with the latter found to track history better in sample than a single econometric world equation.
Methods: We model demand functions for 9 regions and four feedstocks as function of prices and GDP and other exogenous variables, with annual data in the period 1971 2020. We cast a ARDL model with lag = 1:

$$\ln(X_{ij}) = a_0 + a_{ij} \ln (p_{ij}) + b_i Y_i + \Sigma_k c_{i,k} Z_{i,k} + d_{ij} \ln(X_{ij,t-1}) + e_{ij} \quad (1)$$

where:

j = Naphta, Ethane, Lpg, Other oil products

i = World, OECD Americas, OECD Asia Oceania, OECD Europe, Africa and Middle East, Non-OECD Americas, Non-OECD Europe and Eurasia, Non-OECD Asia (excluding China), China (P.R. of China and Hong Kong, China)

X_{ij} = quantity demand, by product and region

p_{ij} = prices, by product and region

Y_i= Real GDP, by region

Z_{ik} = other exogenous variables, by region: population, gdp per capita, percentage of urban population

Results: We obtain good and robust econometric results. We validate the estimations with in-sample forecast for the last two periods. We performed the estimation excluding the last two periods of the sample and then we run out of sample forecast checking whether our dynamic simulation is consistent with historical data of the last two years. We use the root mean squared error or as check. We compare our results with the existing international sources like the OPEC Report and the IEA World Energy Outlook.

Conclusions: This paper has shown the methodology as well as the results for the long-term forecasting model of the oil demand emerging from the Petrochemical Sector per region. The general structure of the model comprises four main products: Naphtha, Ethane, LPG, and Other petrochemical feedstocks products and eight regions of the World: OECD America OECD Europe, OECD Asia and Oceania; Middle east and Africa, Latin America, Eurasia, Asia excluding China; and China.

We have estimated a total of 30 equations because for two particular regional data the estimation was not possible due to lack of data. We note that the results are quite satisfactory, noting that there are good econometric properties of all the equations estimated. We have conducted significance tests and all the coefficients are significant, so it is possible to estimate both price and income elasticities, with the dynamic specification, in the short term and long term. We have conducted the in-sample simulation of all the equations, finding good results in terms of percentage error of the simulation, which is small for all the equations. In particular, the dynamic simulations show a percentage error in the order of 1 - 3 % for most equations, with only some values between 5 and 12% for Naphtha and Ethane in OECD Asia OECD Europe and Eurasia.

We have also estimated an aggregate world equation and compared the results of that simulation with the results of the aggregation of the regional simulations. We find that the aggregation of the regional equations tracks better the historical data in sample than a single econometric world equation. This is an indication that disaggregating the analysis at the regional and product level of the demand for petrochemical feedstocks is a valuable direction of analysis.

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Keywords: Oil Demand, Petrochemical Demand, Demand Modeling

[Abstract:0619] OP-181 [Accepted:Oral Presentation] [Energy Modeling » Integrated Assessment Modeling]

Paradigm shift in long-term decarbonization Scenarios? A review and results of an in-depth analysis of current IPCC data

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Overview:A steep cost decline for the generation of renewable energy, combined with recent advancements in storage and flexible technologies mainly driven by batteries and renewables-based hydrogen, drive a paradigm shift in energy systems across the world. As a consequence, renewable energy today dominates investments in electricity generation systems (Ram et al. 2022). Next to this paradigm shift towards renewable energies, we however see an increasingly uncertain energy system. For example, the recent Covid pandemic and the Ukraine war, underline the importance of long-term energy scenarios in providing guidance to industry and policymakers with regards to potential future decarbonization pathways (Bistline et al. 2023; Intergovernmental Panel On Climate Change (Ipcc) 2023). Since the beginning of long-term energy planning, nuclear power has played a particularly important role, both due to expected technical progress, and the difference in real cost developments (Steigerwald et al. 2023). However, a recent paper from the Integrated Assessment Modelling (IAM) community and scenarios with updated cost assumptions of renewables, in particular for solar pv and energy system integration costs, point in the opposite direction. In fact, there seems to be evidence that due to high costs, nuclear power could be phased out in the coming decades, which we explore in more detail in this Paper (Luderer et al. 2021; Löffler et al. 2017; Teske 2018; Jacobsen 2020).
Methods:We build a sophisticated dataset of recent IPCC Reports (Huppmann, Daniel et al. 2019; Byers, Edward et al. 2022) to compare the latest developments with advanced statistical methods. We observed a change in the distribution of the integrated assessment models between the Huppmann (2019) and Edwards (2022) datasets, where the focus of scenario generation is now on the Messageix framework and discuss how these translate into relative and absolute contributions in long-term decarbonisation scenarios. We clearly identify two groups: 1) Models that conclude a rising share of nuclear including their drivers (37-39% of models reviewed), implying a steep increase in absolute power plant capacities, supported by several international energy organisations. 2) A second group of models which consistently find a decreasing share of nuclear power, leading to very high shares of renewables in the global energy mix.
Results:Within the first group of models, some key assumptions warrant further review. First, assumptions for cost digression for nuclear technologies seem to be overly optimistic, whereas renewables costs seem to be overstated. Second, nuclear is often modelled as a baseload technology while flexibility options for renewables-based systems are underestimated. Third, we find an inconsistency in the International Energy Agency`s (IEA) annual World Energy Outlook (WEO); specifically, IEA maintains the highest share of nuclear in its current Net Zero Emissions scenario (NZE) while at the same time confirming that nuclear power is most expensive way to provide electricity (IEA 2021). This is confirmed by independent market analysts (Lazard 2023).
Conclusions:We observe that the total number of scenarios for integrated decarbonization assessment models increased, while the number of scenarios with an increasing share of nuclear decreased. This is likely due to the fact that cost assumptions continue to be adjusted to better reflect reality. We see the continuous need of a critical assessment and update of long-term scenarios, both with respect to cost assumptions and other variables including for example, emission intensity or land use. The modelling efforts for a largely decarbonised energy system only just begin!
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Keywords: IAM, IPCC, Model, Nuclear, Renewables

[Abstract:0535] OP-182 [Accepted:Oral Presentation] [Energy Modeling » Integrated Assessment Modeling]

Policies, biomass availability, and technical feasibility: what hinders the decarbonization of the global cement industry?

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Overview:The global cement industry is the second-largest consumer of products by tonnage, surpassed only by water. In 2018, it produced an estimated 4.3 Mt (IEA, 2022), primarily utilized in constructing buildings, bridges, and roads through the transformation of cement from water and gravels. The production process involves decarbonation of limestone at temperatures exceeding 900°C, releasing calcium oxide (clinker) and carbon dioxide (CO2), known as process CO2 emissions (Bataille et al., 2018). High temperatures make cement production challenging to decarbonize, typically relying on fossil fuels and contributing to significant combustion CO2 emissions (McKinsey&Company, 2018). Cement plants operate for extended periods (averaging 40 years), increasing the risk of stranded assets (IEA, 2020; Liang and Li, 2012).
The cement industry, deemed a "hard-to-abate" sector, was responsible for 2.1-2.5 GtCO2 emissions globally in 2019, with 60% attributed to process CO2 (Bashmakov et al., 2022). Carbon capture and storage (CCS) emerges as a crucial technology, competing with alternative measures like electrification, energy and material efficiency, circularity, biomass utilization, hydrogen, clinker content reduction, and alternative aggregates. Various studies assess the competitiveness and

technical feasibility of these measures, considering factors such as the cost of CO_2 mitigation, levelized cost of cement production, potential GHG reduction, and technological readiness level (Bataille et al., 2018; Habert et al., 2020; Leeson et al., 2017; Rissman et al., 2020; Sahoo et al., 2022; Supriya et al., 2023).
Negative emissions through biomass and CCS (BECCS) have shown promise in mitigating cement industry emissions. Life cycle assessments demonstrated the potential for negative carbon footprints with biomass substitution rates up to 80% (Cavalett et al., 2022; Yang et al., 2021). However, uncertainties persist in biomass substitution rates and rotation periods (Tanzer et al., 2021).
Research predominantly focuses on national decarbonization pathways, with limited attention to regional and global levels. Negative emissions strategies are critical, according to studies in China and Japan, but sustainability concerns around biomass management exist, particularly on a global scale. Integrated assessment models (IAMs) highlight a consensus on increasing material efficiency, but global strategies involving carbon removal are not extensively discussed.
This study aims to fill research gaps by assessing the technical feasibility and potential contributions of carbon removal to global cement industry decarbonization. Various policy scenarios, technical cases, and sensitivity analyses are explored to understand challenges hindering the widespread adoption of net-negative cement strategies. The analysis spans both global and regional perspectives.
Methods:The analysis employs TIAM-FR, a bottom-up optimization model developed by Mines Paris – PSL. It comprehensively represents energy systems, including sectors like electricity, transportation, industry, agriculture, and residential areas, and encompasses various energy technologies, from fossil fuels to renewables and nuclear power. TIAM-FR's notable features include its capacity for granular examinations of regional and global energy dynamics until the end of the century. With 15 represented regions, the model offers temporal resolution, providing detailed year-by-year depictions of the energy system. This Reference Energy System (RES) delineates energy forms, technologies, and end-uses.
We enhance TIAM-FR with a detailed representation of the cement industry, now disaggregated into three steps: optimizing the fuel mix for cement plants, processing energy and limestone to produce clinker, and further processing clinker with aggregates to produce cement. The base year (2018) is represented globally based on IEA's energy balances for energy flows and cement demand. Energy consumption is disaggregated for each region in TIAM-FR based on solid, gaseous, and liquid fuels. Heat and electricity are isolated due to their incompatibility with conventional kilns. If fuels are processed in cement plants with carbon capture units, the captured CO_2 is accounted for in the RES. This captured CO_2 can be stored or utilized in various conversion processes, for instance by mineralizing steel slags and fly ashes that can be subsequently used in cement.
We a reference scenario (REF) to serve as a benchmark for comparing mitigation scenarios. The REF incorporates current country pledges from Nationally Determined Contributions (NDCs). It assumes no global emission trading system among model-defined regions.
The aggressive NZ70 scenario commits all countries to achieving net-zero emissions by 2070, supplementing their NDCs. This ambitious target, if achieved, could limit global temperature rise below 1.5°C. In NZ70, regions can trade emissions from 2030 onwards. The CM0 scenario enforces NZ70 but adds a constraint for the cement industry to achieve carbon neutrality by 2050. A global GHG trade system for cementitious emissions is assumed from 2030.
The study adopts the second Shared Socio-economic Pathway (SSP2) and explores decarbonization of the cement sector with additional cases related to land use. Three biomass cases (Low, Mid, High) consider different land use conversion levels, efficiencies, and costs. Sensitivity analyses focus on biomass substitution rates and rotation periods for negative emissions in the cement industry. The REF scenario projects global demands according to SSP2-4.5 and both NZ70 and CM0 scenario are based on SSP2-4.5 (Fricko et al., 2017).
Results:First of all, whatever the policy or biomass potential considered, the global cement industry tends to use the full potential of biomass for firing its kilns. So, when allowing a substitution rate up to 80%, the cement industry seizes the opportunity and takes full advantage of that. This strategy allows to generate massive amounts of carbon removals that can be used to compensate for both residual cementitious emissions and other hard-to-abate industrial emissions. Therefore, constraining the substitution rate of biomass makes the transition costlier, with lesser carbon removals, thus delaying the carbon neutrality of the global cement industry. In Figure 1, we show across REF and NZ70 scenarios how the substitution rate impacts the year at when the global cement industry reaches decarbonization. Across all substitution rates, the average delay of net-zero achievement between REF scenarios and NZ70 scenarios is of 6, 4, and 3 years delay respectively for the High, Mid, and Low cases. However, the net difference is more substantial when comparing cases with low substitution rates. Besides, in the REF scenario, carbon neutrality is only achieved in 2050 or before with substitution rates above 45% in the Low and Mid cases, and 65% in the High case. This underlines the insufficiency of current climate policies and technical progress related to biomass use in the cement kilns if the goal of the Global Concrete Association (GCCA, 2022) to reach

net-zero by 2050 is to be attained. However, if the world paves the road to global decarbonization in 2070, then, cement net-zero emissions is achieved with biomass substitution rates higher than 40%.

Across all scenarios, the zero year is delayed by 10 to 18 years when comparing the lowest substitution rate (25%) with the highest (80%) for a same policy and biomass potential. Surprisingly, the more pessimistic the biomass potential, the earlier the carbon neutrality is achieved in the cement industry; on average 4 years difference. In other words, the global cement industry employs more biomass and generates more negative emissions when biomass management is constrained by lower potentials and higher costs. However, the global generation of cumulative negative emissions from BECCS across all sectors is reduced in the Low and Mid cases. Regarding the periods of biomass rotation, the sensibility to the net-zero year is not significantly pronounced: at worse, it delays the target by up to 2 years.

Figure 2 show the economic benefits that can be brought with bioenergy and CCS developed massively in the cement industry in the long run.

Additional results examine critically how the transition of the cement industry is achieved in terms of carbon removals, technology penetration, final energy use, clinker-to-cement ratios, and cement content. This analysis is conducted regionally and is eventually compared to the roadmap proposed by the GCCA.

Conclusions:Regardless the policy scenario and the biomass potential, bioenergy combined with carbon capture in the cement industry represents a promising mitigation measure. As biomass availability increases, the cement industry generates more negative emissions to what is needed to achieve the net-zero target.

In the NZ70 and CM0 scenarios, even when 25% substitution rate is assumed, the cement industry achieves its decarbonization for any biomass case and rotation period assumed. However, it is not the case for the REF scenario. This implies that the main parameter hindering the decarbonization of the cement industry is policy.

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Keywords: Cement, Integrated Assessment Model, bioenergy, Negative emissions, CCS

Figure 1: Year when carbon neutrality is achieved as a function of biomass substitution rate for different policies and biomass potentials

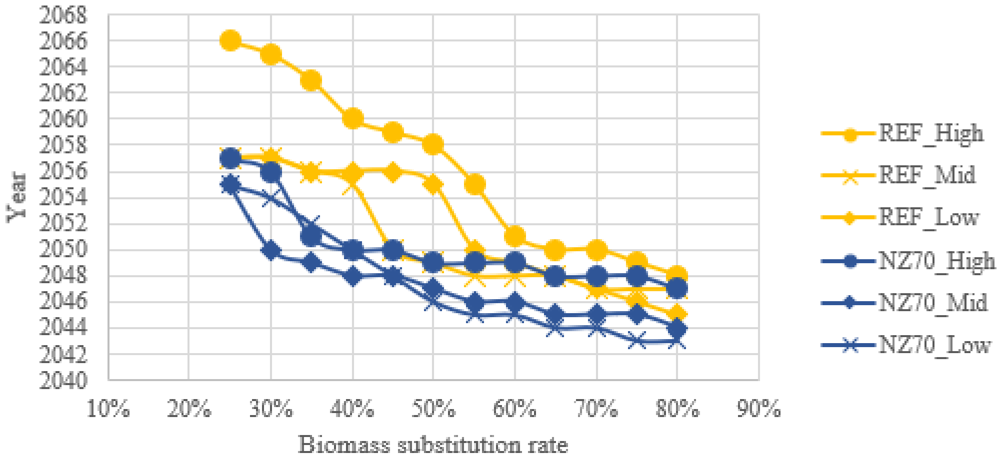

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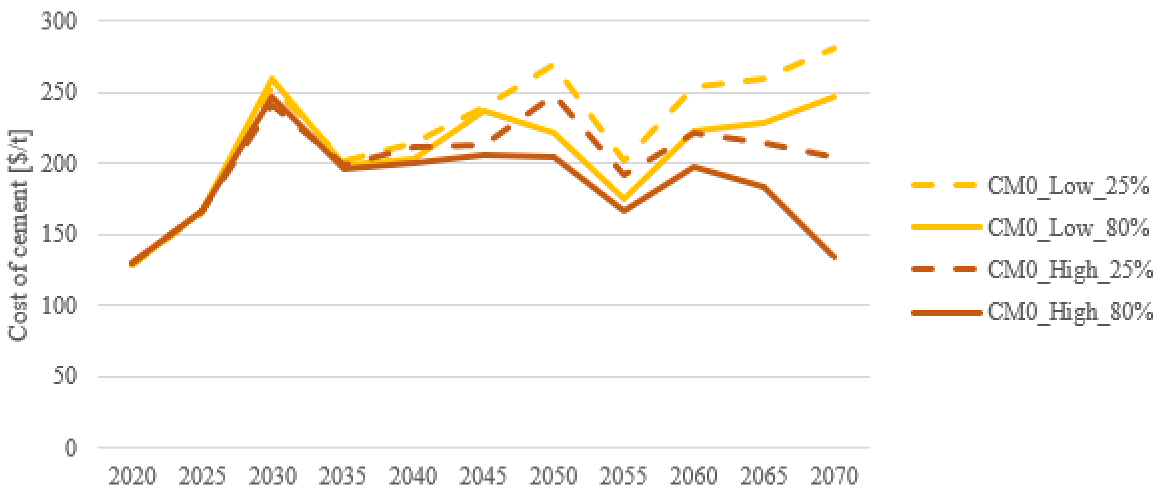
Figure 2: Average global marginal cost of cement in the CM0_High and CM0_Low scenarios with different substitution rates



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[Abstract:0560] OP-183 [Accepted:Oral Presentation] [Energy Modeling » Integrated Assessment Modeling]

Materials and water needs in a decarbonizing world, a long-term analysis based on TIAM-FR

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Overview:In the face of climate change, achieving net zero greenhouse gas (GHG) emissions by the end of the century is necessary to curb global temperature rise [1]. Governments worldwide are committing to reach this objective between 2050 and 2070, with 97 parties from 101 countries setting a net-zero target as of January 2024 [2]. Transitioning to low-emitting energy sources, decarbonizing transport fuels, and implementing Carbon Dioxide Removal measures in hard-to-abate sectors will contribute to meeting these objectives [1]. However, the widespread adoption of these solutions will impact material requirements, particularly metals. Power generation and transportation are projected to generate increasing metal flows, due to a growing demand within the framework of decarbonization scenarios by 2050 [3], [4]. In the transport sector, this intensification will be synonymous with a net rise in the volume of needed materials [3]. Concurrently, the industrial sector is using an increasingly diverse amount of mineral elements [5].

Indeed, metals are notably required in electric vehicles (cobalt, lanthanum, lithium, copper), fuel cells (platinum, palladium, rhodium), wind turbines (aluminum, copper, platinum, nickel, neodymium, dysprosium, terbium), photovoltaic solar panels (silicon, cadmium, indium, gallium, nickel, copper, silver) [4], [6]. Countries like Western nations, China, and India are competing to lead in low-carbon technology sectors, aiming to secure their materials supply. Governments generally seek strategic autonomy, which implies accelerating metal production in national territories and expanding and diversifying cooperation with exporting countries [6].

This evolution in material needs may entail more complex energy geopolitics due to the multiple supply chains and geographically unequally distributed deposits and refining capacities. Numerous

reserves of metals and metalloids used in renewable energy production technologies are more geographically concentrated than oil reserves – except tellurium, copper, and silicon [7]. In addition to reserves concentration, material refining capacities concentration can pose a risk of supply chain disruption, thus delaying the adoption of low-carbon technologies. This was the case in 2010-2011: during the so-called rare earth crisis, China restricted its rare-earth elements (REE) exports to Japan following a dispute in the East China Sea. China accounted for 97,3% of worldwide REE refining and 81% of Japan's REE imports in 2011. Therefore, this episode disturbed Japanese REE-depending industries, in particular the car industry [8]. One can also mention the aggravation of the risks linked to mining activity expansion, such as the rise of local conflicts involving non-state actors [7].

As a result of the aforementioned changes, critical and strategic material studies have attracted a growing interest since the 2000's [4]. This has translated into an increasing number of public policies on these materials. Establishing strategic plans and listing minerals of particular interest for a country's economy form part of these policies. For example, the European Union (EU) published its Critical Raw Materials Act in 2023, which sets a strategy to ensure the supply of critical materials. In addition to extending the EU's existing list of critical raw materials, this Act also sets a list of raw materials considered strategic for Europe's green and digital ambitions [9].

Increasing metal and material needs will call for expanding mining activities, implying geopolitical and policy mutations and environmental damages. In this study, we assess the growing impacts of the energy transition on material demand and their resulting externalities on the environment (GHG, pollutants, water needs) and link it to current geopolitical issues. We intend to calculate the amount of materials available for energy transition needs if certain regions are subject to water restrictions.
Methods:This work aims to determine the stress on several materials in the framework of different energy transition scenarios, using long-term modeling. We will employ the TIAM-FR model (TIMES Integrated Assessment Model, French version), a bottom-up optimization model from the TIMES model family (The Integrated MARKAL-EFOM System) which is itself developed by the International Energy Agency's Energy Technology System Analysis Program (ETSAP). It allows exploring the future technological pathways of the energy industry according to various user-set constraints.

We develop worldwide scenarios towards net-zero emissions throughout the century. We gather the model's inputs from in scientific literature. The first set of scenarios will be constrained by national carbon emissions targets and/or worldwide temperature augmentation targets. A second set will be constrained by water consumption, as one can expect possible water restrictions in regions in a hydric stress situation. The model will provide an optimal energy mix respecting the established constraints for each scenario.

Then, we will conduct a post-processing analysis to determine the stress these scenarios will represent on chosen materials. This study will be limited to copper, nickel, lithium, cobalt, and REE because they are the most prevalent in the literature.
The analysis will focus on the following technologies: photovoltaic solar panels, concentrated solar power, onshore and offshore wind turbines, electric vehicle batteries, carbon capture and storage processes, and green hydrogen-producing technologies.
Results:This study's outputs are twofold.

Firstly, for each climate and water-constrained scenario, we will discuss the evolution of regional energy systems, notably focusing on the installed capacities of needed low-carbon technologies, and the associated energy resources. We will highlight the amount of water consumed by the system, according to the climate constraints, by sectors, and by regions. This will underscore regions where hydric stress might hinder mining activities.

Secondly, our post-processing analysis will determine the amount of studied materials needed for studied low-carbon technologies in each scenario and their repartition by TIAM region. Thus, we will assess the stress the energy transition might induce on mineral reserves, and which minerals might face shortages disturbing low-carbon technology supply chains.
Conclusions:This study highlights the energy transition's material needs, using a long-term optimization model following climate and water-constrained scenarios. Materials and water supply are crucial for the energy transition, and result in more complex geopolitical issues. Indeed, it leads to international competition, policy evolution, local tensions and environmental damages. We intend to provide insights on the matter to assist decision-making.

We will compare our results with the current geopolitical context to emphasize potential future tension areas. They will most likely concern regions with already intense mining activities. Then,

based on the model's results, we will put forward recommendations for political decision-makers. These recommendations may cover investments in mineral and technological substitutes, cross-border mineral cooperation, and strengthening low-carbon technology supply chains.
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Keywords: Energy transition,Materials,Water,Integrated Assessment,Modeling

[Abstract:0054] OP-184 [Accepted:Oral Presentation] [Energy Modeling » Integrated Assessment Modeling]

Improving accuracy of energy system models for an efficient energy transition: basis-oriented aggregation and machine learning

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Overview:Power System Optimization Models (PSOMs) are widely used for planning and policy-making toward sustainable and clean energy systems. However, due to real-world power systems' spatio-temporal size and technical complexity, PSOMs can result in computationally intractable problems. Computational intractability in PSOMs stems from the multiple dimensions they try to represent, e.g., the technical details, the uncertainty concerning the system's demand and generators' availability, the spatial representation, or the granularity and length of the time horizon. To overcome this, modelers apply aggregation techniques to approximate full PSOMs through reduced-size ones. One subset of such techniques is time series aggregation (TSA), which aims to replace a full hourly or even sub-hourly PSOM with a smaller model using a simplified time dimension, maintaining, at least to some degree, the accuracy of the results.
The aggregation techniques can be classified into a-priori or a-posteriori methods. A-priori methods rely exclusively on the input data space, e.g., demand time series, capacity factors of renewables, etc., and have little regard for the optimization model performance or its structure; on the other hand, a-posteriori methods also include information from the PSOM's structure in the TSA process, i.e., results from partial runs, relaxations or surrogate models.
This work presents the results of applying a recently developed a-posteriori method called Basis-Oriented time series aggregation to real-world models. It extends it by removing the need for a dual solution of the full PSOM and using machine learning techniques on previous runs to identify approximate partitions of the input space of a model with an unknown solution. The advantage of the Basis-Oriented approach is that it has been proven, mathematically, to be an exact aggregation of the full PSOM, measured as the difference between the aggregated and full models' objective function values. By extending it through machine learning, we address the main limitation of its use: requiring a dual solution and relying on previous runs. This extension makes the Basis-Oriented approach suitable to improve the computational tractability of operational models, which, despite not being as challenging as expansion ones (i.e., Mixed Integer Programs), still pose challenges to modern computing platforms.
Methods:We used as a starting point the results obtained from [1], which proved that for any transport problem with ramping constraints, an exact partition of the full PSOM can be performed; one of the critical results showed that, given a particular solution, we could split the hours into two sets: hours that are intrinsically linked with others because a time-linking constraint is binding (i.e., ramping) and hours that are temporally independent when no time-linking constraint is (i.e., only max line transfers or generation capacities). Then, the challenge lies in identifying this hour-splitting in a particular instance of a model without running it. To address this, we performed synthetic model runs for a simplified transport model of the Austrian power system and its neighboring countries in which we have 15 nodes, ten representing each Austrian Federal State and splitting Tyrol into two and five corresponding to Germany, Hungary, Slovenia, Switzerland, and Italy; also, we aggregated each generation technology into a single power plant for each node; finally, to avoid, at least for now, the complications of storage in hydro power plants, we subtracted a typical yearly profile from the demand, leaving the model only with variable renewable energy sources and ramp-constrained resources; this formulation, albeit simple, takes a couple of minutes to run hourly for a full year and is not far away from what is done by modelers analyzing real-world systems. Next, we perform additional runs of this model, adding a random perturbation to each run's demand and capacity factors using sampling from a Weibull distribution and storing their dual solution. Then, using these solutions, we split the hours into two sets: those in which at least one ramping constraint of any resource is binding and those in which no ramping constraint is; note that from [1] we know that every hour where no ramping constraint is binding can be solved independently without regard for the others. After that, we perform a classification task with a support vector classifier feeding only input data as features to the machine learning model. Some features used were: net demand of the hour (demand minus variable renewable energy sources), the demand of previous and following hours, and the ratio between the demand difference in two hours and the max ramping rate. Finally, using the trained model on a test dataset, we assess the accuracy of the partition by running each hour as an independent model and comparing each hour's objective function value with the complete, temporally linked model.
Results:DISCLAIMER: These results, albeit satisfactory, are still preliminary as we are still working on improving our classification model and testing its generalization performance under additional runs previously unknown to the classifier.

After applying the partitioning procedure using the full model solution, we found that, on average, the number of periods with non-binding ramping constraints was around 80% of the total (around 7000 hours out of 8736); however, they amounted to 50% of the total objective function cost; this means that the hours where ramping is binding constitute half of the cost, but only correspond to 20% of the time. Also, because of the temporal independence of the non-binding periods, model size can be reduced by at least a factor of 80% and highlights one potential application of our approach: parallelization of power systems optimization models; it is known that the worst-case running time of a linear program is cubic with respect to the number of variables, this means that when we manage to partition a model in two without losing any accuracy in the solution, we will achieve a worst-case computational improvement by a factor of four. Concerning the ex-ante identification of the partitioning through machine learning, we use a support vector machine with linear kernel and input features presented in Table 1 and the training-test split of the dataset (80%-20%, respectively); the results are summarized in Table 2. So, for this particular power system model, we can identify ex-ante which periods are temporally independent with an average accuracy of 89% in the test dataset; also, when running the partitioned models (one for temporally independent hours and other with ramps binding), we get an error of 1,5% measured as the relative difference between the objective function values of the full and split models. These results mean that by partitioning the model into two, we retain 98,5% accuracy while achieving a four-fold computational improvement assuming a worst-case running time.

Conclusions:In this work, we presented a methodology that leverages insights from recent research, namely basis-oriented aggregation, and expand it using machine learning techniques to make it useful in a real-world setting. Our findings show that temporally-linked periods are only a slight fraction of the total number of periods but have an outsized weight in the total objective function value; so, they become significant when trying to approximate full PSOM. Another result from our research is that one can estimate ex-ante using only information from a couple of previous runs, which periods are temporally independent of others. Achieving this has noticeable computational improvements because of the cubic worst-case running time in solving linear programs, and it allows us to identify extreme periods more easily without relying on expert knowledge about a particular power system. Also, because of the improvements in computational tractability, it becomes faster to make multiple runs of a PSOM. This aspect is essential considering the weather-dependent behavior of most variable renewable energy sources. Finally, as future work, we are working on further reducing the time dimension of a given PSOM by finding representative hours among the already identified partitions; another avenue of future research is developing a similar methodology for expansion problems, initially for its relaxed formulation and later for the integer one. The challenge with integer programming comes from its combinatorial nature and the fact that we must discard much of the theoretical machinery of duality available in traditional linear programs.

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Keywords: power systems optimization models, variable renewable energy sources, linear programming, machine learning, time series aggregation

Table 1

Table 1: Input data for classifier

Input	Description
cf	Capacity factors for variable renewable energy sources in per unit terms
max_vres_gen	Maximum available energy from variable renewable energy sources
demand	System demand
net_demand	System demand minus maximum variable renewable energy available
vres_demand_ratio	ration between *max_vres_gen* and *net_demand*
net_demand_lag_1	Lag 1 of net *net_demand*
net_demand_lead_1	Lead 1 of net *net_demand*
demand_lag_1	Lag 1 of *demand*
demand_lead_1	Lead 1 of *demand*
max_vres_gen_lag_1	Lag 1 of *max_vres_gen*
max_vres_gen_lead_1	Lead 1 of *max_vres_gen*
vres_demand_ratio_lag_1	Lag 1 of *vres_demand_ratio*
vres_demand_ratio_lead_1	Lead 1 of *vres_demand_ratio*

Table 2

Confusion matrix (normalized) - Test dataset

		True value		
		Positive	Negative	Total
Predicted value	Positive	0.75	0.07	1424
	Negative	0.04	0.15	323
	Total	1369	378	1747

[Abstract:0445] OP-185 [Accepted:Oral Presentation] [Electricity » Reliability]

The Economic Challenges of Incorporating Consumer Reliability Preferences in Electricity Markets with Capacity Requirements

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Overview:The reliability and resiliency of electricity power systems in general and electricity markets in particular are being questioned. Recent major blackouts and close calls have occurred worldwide, such as separate blackouts in France and England in 2019, Texas (ERCOT) in 2022, the U.S. Mid-Atlantic region (PJM) in 2022, California in 2022, and Canada in 2023. Many factors, including

insufficient resource adequacy, cause blackouts. Inadequate generation was a significant factor in the blackout in ERCOT and the near blackout in PJM.

Electricity capacity mechanisms are employed worldwide to ensure resource adequacy. Resource adequacy is having sufficient electricity capacity to meet demand based upon a specified resource adequacy requirement. Typically, utilities or system operators use probabilistic resource adequacy models to determine the capacity necessary to satisfy the resource adequacy requirement. Historically, resource adequacy models used to set capacity requirements have made three fundamental assumptions. First, they modeled independent generation failures, i.e., the failure of one generation unit is not caused, linked, or correlated with any other generation units. Second, with some exceptions, the modeled generation units are dispatchable, i.e., their output can be adjusted up or down to match changes in electricity demand. Third, for the most part, demand does not respond to prices, i.e., it is invariant to wholesale electricity prices.

These three assumptions no longer hold. Dependent and correlated outages are substantial and significantly impact resource adequacy and reliability. These outages included weather conditions, operational and maintenance practices, fuel availability, output correlation with wind farms and solar panels, regulatory actions, and cybersecurity. The substantial anticipated increase in renewable resources due to decarbonization means that weather conditions combined with the variability and non-dispatchability of wind and solar photovoltaics make the first two resource adequacy assumptions untenable. Finally, introducing and increasing energy storage, microgrids, and load control devices means that demand and behind-the-meter resources will grow and be more price-responsive. Increasing flexible demand is necessary to accommodate increasing shares of variable solar and wind reliably and economically.

This paper focuses on demand response by investigating if and to what market structures and mechanisms can accommodate individual and varying customer preferences – reliability tailorization – consistent with the underlying resource adequacy models.
Methods:The electricity regulator is assumed to be a social welfare maximizer. Generators are profit maximizers, and the electricity market is assumed to be perfectly competitive. Electricity retail consumers are price takers and have different VOLLs. The system operator efficiently implements the regulator’s policy. It is assumed that due to high transaction costs, few individual electricity consumers have the necessary metering and associated equipment to be disconnected in real time based on their VOLL. Similarly, the system operator cannot selectively disconnect individual retail customers and, therefore, does not know the VOLL for each retail customer (i.e., retail meter).

The base case is all consumers must purchase their prescribed share of the total capacity required to satisfy a loss of load probability requirement. When there is insufficient available capacity to meet the inelastic demand, the system operator implements a prescribed load-shedding procedure without knowing individual consumers’ VOLL. Two alternative cases are examined. One allows individual consumers to opt out of the capacity requirement, i.e., optional capacity requirement. Another provides for consumers to sell back their capacity purchased to the system operator during power shortages.
Results:The overall efficiency of each case and their relative costs are analyzed. The qualitative results find that three critical factors drive these results. First, the accuracy of the underlying reliability model is vital. Its accuracy to the actual reliability of the power system determines the value of the capacity requirement for society and the individual consumer. Second, when consumers can opt out of purchasing capacity and not be provided electricity during power shortages, the costs and efficacy of the enforcement mechanism are essential. Likewise, the compensation for selling back capacity to the system operator determines whether such an approach is efficient and its relative efficiency to the alternatives considered.

The ability of retail electricity consumers to tailor their reliability and resiliency preferences in electricity markets is limited. Electricity markets with capacity requirements are optimal only under restrictive assumptions of a single VOLL for all consumers, power outages caused by independent generation failures, accurate estimation of generation availabilities, and non-strategic behavior by generators, system operators, and electricity consumers. Allowing electricity consumers to tailor their reliability purchases is limited by the high transaction costs associated with the metering, telecommunication, and disconnection/enforcement costs. However, subject to sufficient monitoring and enforcement, it is welfare-enhancing. It would enable low VOLL consumers to avoid paying for capacity they do not need. Under what conditions opt-out customers are required to disconnect is a crucial determinant of the expected cost. However, the generation resource adequacy framework must be a sufficient starting point for analysis as long as consumers have sufficiently accurate information regarding the probability of experiencing a power outage with and without purchasing capacity.

The significant results and their intuition are the following. First, if the capacity requirement is too high or too low, the outcome is not least cost and, therefore, not social welfare maximizing. Second, the associated capacity requirement is inefficient if the underlying LOLP model does not accurately reflect the physical system, namely the causes of power outages. Third, allowing individual consumers to opt out of the capacity market can enhance efficiency.
Conclusions:To analyze if and how retail electricity consumers can tailor their welfare-enhancing reliability needs in an electricity market with a capacity requirement requires assessing whether the current resource adequacy framework is sufficient. If so, the analysis can proceed by considering various approaches and their welfare-enhancing conditions. Unfortunately, several essential reasons suggest that the resource adequacy reliability framework is insufficient, and therefore, if consumers can opt out of their capacity requirement, it may reduce social welfare.

There are numerous avenues for further research. One is revisiting this discussion in the context of energy-only markets such as ERCOT, Australia, Alberta, and New Zealand. Second, implementing tailored resource adequacy policies in a real power system or market needs further investigation to develop specific rules, including market monitoring and manipulation. Third, the political economy of capacity market gradations requires research. Finally, broadening the notion of reliability to include resiliency, particularly in increasing the amount of variable and intermittent generation resources such as wind and solar photovoltaics, is essential.
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Keywords: reliability, capacity requirements, demand response

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[Abstract:0458] OP-186 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

The long-lasting misalignment between electricity market price and electricity system cost: a quantified analysis in France

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Overview:Over the 2010 decade significantly low levels of electricity prices have occurred in Europe, preventing producers to cover their costs and leading the electricity sector to advocate for compensatory market measures such as capacity mechanisms in several countries. On the contrary, the years 2021-2023 and especially the year 2022 have seen an unprecedented price rise, during

which electricity prices were lastingly higher than production costs, in particular in France where spot prices reached 500 €/MWh on average in August 2022 and forward prices reached 1000 €/MWh in 2022 for delivery periods in 2023. Within this context, the present paper aims at documenting the gap between electricity system costs and electricity market prices over the past decade, and explores market design measures aiming at reducing this gap in the future on a mid-term horizon.
Methods:In order to assess electricity system costs in France, the paper establishes a detailed review of the existing power mix, and documents past and present costs (CAPEX and OPEX) for every technology involved, based on an extensive literature review (IRENA, BNEF, IEA) and an expert review between all stakeholders in the electricity system (suppliers, producers, electricity and gas distributors, NGOs, think tanks…). While the tracking of past capacity commissioning allows to account for investments, data on past operation of the electricity systems allows to estimate variable costs.
To establish mid-term projections, future investments and evolution of electricity consumption are modelled in a scenario based on national objectives in the National Low-Carbon Strategy (NLCS). The operation of the electricity system is simulated through a stochastic adequacy model ANTARES software (explicitly described in Doquet, M. et al., 2011; Sanchis, G., et al., 2015; Alimou, Y., et al., 2020) at mid-term horizons.
We also explore the effect of potential market design measures to realign prices paid by consumers with system costs, whether with Contracts for Difference or long-term contracts (PPA), using a simplified approach.
Results:The results of the electricity system cost assessment for the past decade establish a significantly stable trend compared to price variability. From 2012 to 2019, before the covid and energy crises, the electricity system cost was stable at around 60€22/MWh (with +/- 5% variation), against a 35-60 €22/MWh range for the spot price, alternatively above or below the system cost. During the energy crises in 2021-2023, the French electricity system cost varied between 70 €22/MWh and 110 €22/MWh, with higher variability due to gas prices, to the unavailability of a significant part of the nuclear fleet, and a low availability of hydropower on top of the nuclear crisis and gas price crisis. However, the spot price varied between 120 and 285 €22/MWh (annual average), showing a much more important volatility, in comparison with which electricity system costs appear remarkably stable. Such stability in the French electricity system costs is structurally due to the high part of fixed costs mostly due to the high proportion of nuclear power in the electricity mix. Projections to mid-term horizon show a persistence of the gap between electricity system cost and market prices. The assessment of the presence of long-terms contracts such as contracts for difference on nuclear/variables renewables/hydropower shows a convergence that is all the more strong as the covered volumes are high.
Conclusions:Structurally, the volatility of commodity prices and especially fossil fuels prices leads to think that on a day-to-day basis, market prices have a high probability of not converging with electricity system costs, especially in systems with a high share of fixed costs as in the French electricity system. Market design measures such as CfD or increased amounts of long-terms contracts thus seem crucial to reduce that gap.
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Keywords: electricity system costs, electricity price, market design

AuthorToEditor: Our PhD candidates Kevin Favre and Arnauld Guillotin are actually affiliated to two institutions each: Kevin FAVRE, 1 & 3 Arnauld GUILLOTIN, 2 & 4 but by default, we used the university affiliation for the submission (3 and 4). Also, if possible, we would appreciate if the outcome of the submission were sent to both the presenting author (Marie-Alix DUPRE LA TOUR) and the first author (Bianka SHOAI-TEHRANI).

[Abstract:0474] OP-187 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Consumer data markets for a smart grid

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[2]Essec

Overview:In a smart grid, prosumer data is an essential input of aggregator business models. Aggregators bundle several Distributed Energy Resources (DER) to provide energy and power services for the electric system. DERs technologies might be of diverse types, such as heat pumps, rooftop solar panels, home energy management systems, and Electric Vehicles (EV), among others. These technologies might be distributed in a geographical and ownership sense, i.e. at different locations and each with a different owner. Prosumer data enables DER aggregators to predict the technical feasibility and willingness of prosumers to concede the control of their energy resources for the provision of services such as demand response, energy production, and ancillary services that aggregators can monetize in power markets.
To access prosumers' data, Aggregators can either buy the data from prosumers or a data intermediary (direct acquisition) or obtain the data for free to provide the prosumer with a specific service (indirect acquisition). An example of direct data acquisition is when a data intermediary such as Facebook sells the prosumer's data to a third party such as Cambridge Analytics, while an example of indirect data acquisition is through smart meters, which collect data on electricity consumption from performing the metering and billing services. Most economic analyses of aggregators have assumed that the aggregator can get the data of the prosumer behavior for free. This research has emphasized the potential of computational techniques (machine learning, stochastic optimization, etc) and adequate regulation to maximize the economic efficiency of DER but has ignored the incentives and costs of the prosumer to share their data.
Therefore, to close this gap in the literature, our article seeks to answer the following research question: Under what conditions do markets for consumer data are efficient to have on a smart grid?

Methods:In this paper we develop an analytical microeconomic model to show analyzing the efficiency of having markets for prosumers' data
Results:Our results show that if aggregator gets the information for free might limit the value derived from DER. Two factors might make this happen: first, when a prosumer share their data, they compromise their privacy, therefore, this might create reluctance to share their data with several parties; second, depending on the technological portfolio of the aggregator assets,
Conclusions:if a prosumer shares data only with one aggregator, there is a risk of moral hazard in the sense that aggregators might use prosumers data to maximize the returns on their portfolio instead of prosumers value. Therefore having markets for prosumer data increases the efficiency of smart grids.
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Keywords: Data markets, smart grids, decentralized energy resources

AuthorToEditor: At this stage this is a working paper, that I will continue to improve for the conference.

[Page: 188]

[Abstract:0485] OP-188 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Stackelberg competition with endogenous entry of intermittent producers

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emlyon business school

Overview:We study an industry where entrants with an intermittent production technology compete with a dominant incumbent, as in electricity markets with the advent of renewable energy sources. We characterize the Stackelberg equilibrium with free entry (Etro 2008) under real-time and uniform pricing for small entry cost. Both the incumbent and entrants operate in equilibrium if efficiency differences are small enough. Welfare is Pareto-superior with Stackelberg leadership and real-time pricing as compared with simultaneous moves and with uniform pricing.
Methods:Economic model of energy investment
Results:We study the Stackelberg equilibrium with free entry, generalizing prior analyses to allow for both intermittence and cost asymmetry. Both the incumbent and entrants operate if efficiency differences are not too large, whereas otherwise the market tips in favor of one technology or the other. This equilibrium with accommodation is Pareto-superior to a simultaneous-move benchmark, suggesting it can be beneficial to preserve historical leadership in such industries. We also compare these outcomes with the equilibrium under uniform pricing, which is prevalent in retail electricity markets. Accommodation is associated with monopoly output levels in this case, and that if efficiency differences are not too large then switching from uniform pricing to RTP is Pareto-improving in our setting.
Conclusions:Our model builds upon to the analysis of energy mix and investment incentives in perfectly competitive markets of Ambec and Crampes (2012). Our two propositions extend their

characterizations of equilibrium under RTP and uniform pricing to a potentially relevant imperfectly competitive market structure. The results we get mirror theirs, particularly regarding the joint use of both technologies if efficiency differences are not too large. In addition our model corroborates the intuition these authors express regarding possible benefits of moving from uniform pricing to RTP in imperfectly competitive markets.

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Keywords: Dynamic pricing, Free entry, Intermittence, Renewable energy, Stackelberg leadership

AuthorToEditor: Thanks for your consideration!

[Page: 189]

[Abstract:0598] OP-189 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Externalities in the joint operation of hydro cascades: An assessment of the performance of different market-based solutions

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Overview:As it is widely known from the economic literature, markets can be a very efficient way of aggregating information and incentivizing actions from different agents in order to achieve the most socially desirable final outcome – as opposed to relying on a central planner to aggregate information and direct actions from each of these agents one by one. Particularly in the context of the energy sector, liberalized electricity markets have been extremely successful in promoting a more efficient operation and planning of electricity sectors worldwide.
However, a key underlying assumption necessary for decentralized markets to be truly efficient is the absence of externalities – or, said in another way, each agent should fully internalize the financial impacts of the choices they make. One practical type of situation in which this assumption is clearly violated is the case of cascaded hydro power plants in the same river (and different owners): if the hydro plant located higher up in the river chooses to use most of the incoming water to produce electricity (or, conversely, to keep more water stored in its reservoir and only turbine a smaller share of inflows), this will certainly influence the amount of water available for other hydro power plants downstream. However, in "classic" unmodified implementations of electricity markets, the upstream plant's owner's remuneration only depends on the amount of electricity produced by the upstream

plant, such that its influence on the operation of the downstream plants is an externality. There are several solutions to this problem, such as the possibility of bilateral case-by-case negotiations and/or the creation of various types of cooperation and risk-sharing agreements (which have been common in practice between hydro producers in the same cascade in several countries, such as in Norway, Brazil, and the Columbia river in Northwestern USA). However, with the possibility of climate change altering the underlying conditions of existing agreements and a desire to manage conflicts even in contentious cases (including examples in which the cascade is split into two by a border crossing), it becomes increasingly important to look more closely into possible systematic schemes for handling hydro cascade externalities.

Methods:For the analyses of this paper, we first introduce a "parameterized" version of a cascaded hydro system describing the key features of an electricity market, along with an indication of how a real-world system can be tuned to such a parameterized version. Among the key parameters of this idealized representation are the target net demand to be served, the cost of supplying this demand with non-hydro generation assets (typically representing thermal plants' fuel and operating costs), the cost of curtailing demand if needed, the probability distribution of hydro inflows, and the conversion curve for the two hydro plants (one "upstream" and one "downstream"). Note that the conversion curve is a nonlinear function, showing diminishing returns (i.e. a lower efficiency in the conversion of water resources into electricity). In addition, this model also allows for increasing the number of "identical" parallel cascades in order to assess how the equilibrium is affected as the number of agents increases. While this representation of multiple identical cascades is not very realistic in practice, it allows for an examination of the properties of this equilibrium as the number of competing agents in the market increases. In particular, it is possible to show that, in the presence of externalities, the market equilibrium will not converge to the social optimum even in the competitive limit as the number of agents approaches infinity.

This parameterized hydro system is then tested against three main mechanisms, taken from the literature: (i) a shared ownership model, in which agents in practice share ownership of all plants in the same cascade; (ii) a wholesale water market in which agents downstream must pay upstream agents in accordance with the amount of water that is sent downstream; and (iii) a virtual reservoir model in which the management of the upstream reservoir is driven by bids submitted by the agents (these bids can be handled completely in parallel with the "standard" electricity market bids). The virtual reservoir model in particular, even though it has been first proposed in Brazil in 2002, has had limited presence in the academic literature, for which this paper brings an important contribution. Note that, if transaction costs for agents to communicate and negotiate with one another are negligible, one can expect that even in the absence of any explicit mechanism for handling externalities the agents would bilaterally and voluntarily coalesce into an agreement (that would likely essentially emulate one of the three solutions above). This is in line with the classic economic result of Coase's theorem.

Results:The paper demonstrates that, as expected, the distance between the social optimum and the market equilibrium decreases as the number of "firms" increases (in this paper's case, each "firm" is one of the identical copies of the cascade created). This result is quite robust even to changes in the cascade's key defining parameters.

By changing the cascade parameters, one can find conditions in which the magnitude of this "cost of anarchy" is smaller or greater. The "cost of anarchy" represents the difference between the socially optimal result and the market equilibrium result in a condition of maximum externality (that is, when transaction costs are too high and thus no bilateral agreements between the agents in the cascade can be reached).

Conclusions:This paper explores various types of agreement between hydro power plants belonging to the same cascade that could be implemented, either as bilateral agreements negotiated directly between the agents or as "facilitator mechanisms" introduced and encouraged by a central entity. These analyses allow for making qualitative recommendations regarding each of the strategies evaluated. The shared ownership model is perhaps the simplest and most intuitive, but it has the downside of increasing market power (as the number of bidding entities decreases if both companies in the same cascade bid as one) – which also could create an incentive for agents negotiating bilaterally to prefer this scheme. The wholesale water market has good theoretical properties, although a practical downside is relying on an "oracle" that both agents must agree to in order to determine water prices in real time. The virtual reservoir model could be an effective conceptual approach for handling externalities, with Brazilian cascades a promising case.

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Keywords: electricity market design, liberalized electricity markets, economic externality, hydro cascades, hydro cascade agreements, water resources

[Abstract:0538] OP-190 [Accepted:Oral Presentation] [Electricity » Power System Planning & Management]

Climate change impacts on flexibility needs in the future European electricity market

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Overview:The transition of the Austrian electricity system to a secure and sustainable future in times of climate change brings a broad spectrum of challenges and opportunities to the political debate, whereby timely decisions on the way forward are of central importance. On the one hand, the demand for energy and especially electricity is expected to change significantly due to new demand patterns influenced by climate change and increased sector coupling. On the other hand, a considerable transformation process is required on the supply side for achieving the decarbonisation targets. Both in Austria and across the European Union, the electricity supply will be based on renewable energy sources (RES), which will serve as the main pillar for a carbon-free electricity supply in the future. This paper provides an overview of the approach taken in the SECURES (Securing Austria's Electricity Supply in times of Climate Change) project [1] and some key findings. Thematically, the paper describes the electricity sector modelling carried out with an analytical focus on security of supply, which is considered from a system adequacy perspective. The need for flexibility is therefore assessed for the future electricity system in Austria and for Europe as a whole, whereby the effects of climate change are highlighted, taking extreme events into account.
Methods:The planning and operation of electricity systems are increasingly influenced by climate change, and the consideration of the influence of meteorological conditions has become more important due to the increasing share of weather-dependent RES. The SECURES project analyzed the challenges and opportunities for the electricity system of tomorrow to ensure a reliable, sustainable, and cost-efficient electricity supply under climate change. A combination of detailed climate and energy system modelling and intensive stakeholder dialogue formed the basis for this. On the energy side, various steps were necessary to carry out the analysis of decarbonization needs and climate impacts on the Austrian electricity sector of the future in the European context. In the following, we focus on the modelling of the electricity sector as such. The open-source energy system modelling tool Balmorel [2] was used for the modelling. This model is a partial equilibrium model for analyzing electricity and district heating from an integrated perspective. In this study, the basic

structure of the model was extended to include various flexibility options. Geographically, the modelling included Austria and other European countries (i.e. the EU plus Switzerland, Norway and the UK) to accurately represent the interconnectivity of the European electricity system. In terms of time, the focus was placed on specific years in the near (2030) and medium (2050) future, while modelling was carried out for the whole year with an hourly resolution. The scenario design focused on combining two different transformation paths with different climate scenarios: a Reference (REF) scenario with moderate decarbonization ambition and strong climate impacts and a Decarbonization Needs (DN) scenario, presuming full decarbonization across Europe by 2050 combined with moderate climate impacts. The analysis focused on security of supply, in particular system adequacy based on a flexibility analysis of the residual load (RL). In addition to determining the need for flexibility [3], the modelling also showed how this flexibility can be provided in a cost-efficient manner. For example, additional investments in certain flexibility options on the supply and demand side as well as for storage and, to a limited extent, for the cross-border grid infrastructure were permitted in the modelling, although there are differences between the scenarios and years.

Results:In the following, we provide a brief outlook on the results of the flexibility analysis using Austria as an example. In the course of the presentation and the paper, a comparison will be added as to how the situation in Austria differs compared to Europe as a whole.

Figure 1 allows for a comparison of the calculated flexibility demand for Austria, broken down by time period for all scenarios and years analyzed (2030, 2050). A strong increase in flexibility demand can be seen when comparing the years 2030 and 2050, as well as with increasing decarbonization ambitions (DN vs. REF). For medium to long-term flexibility, the increase is in line with demand growth. However, short-term flexibility increases faster - the significant use of variable RE plays a key role here. Furthermore, the modelling reveals the following patterns in the corresponding provision of flexibility:

- Demand response in households, the service sector and in industry as well as e-mobility contributes to balancing short-term fluctuations in RL.
- Batteries show a similar pattern to flexible consumers and help to cope with massive short-term fluctuations, especially under the DN path. They are a key asset during extreme weather events such as heatwaves.
- Hydropower reservoir and pumped storage enable flexible utilization in all time ranges. The utilization patterns show that the contribution of pumped storage is typically higher in the short to medium term, while the opposite trend applies to hydro storage, which helps to even out seasonal imbalances and the annual balance of RL. Both are important for coping with extreme weather events.
- Cross-border electricity exchange remains a central pillar of flexibility in Austria's future electricity market, both to utilize surpluses and to compensate for deficits. In modelled years with extreme weather events, however, the contribution is lower than in normal weather conditions.
- Heat storage and hydrogen storage are essential system components of a decarbonized energy system. For example, hydrogen storage enables a flexible and system-friendly operation of hydrogen electrolysis, which in turn help to cover flexibility requirements on different time scales and in the event of critical weather extremes.

Conclusions:The energy transition towards decarbonization is indispensable from a societal and environmental viewpoint but challenges in energy system planning come along with that: With higher amounts of weather-dependent generation, short-term fluctuations in corresponding electricity generation grow strongly, requiring large amounts of system flexibility to ensure the match between electricity demand and supply in every hour. The yearly balance of residual load is however decreasing with ongoing decarbonization ambition.

Extreme weather events driven by climate change are of key relevance for future energy system planning, affecting at European scale both the short- and the long-term needs for flexibility. It appears consequently indispensable to consider climate impacts appropriately in future energy planning.

Funding

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References:[1] Schöniger, F., Resch, G., Suna, D., Formayer, H., Pardo-Garcia, N., Hasengst, F., Totschnig, G., Maier, P., Leidinger, D., Nadeem, I. & Widhalm, P. (2023): Securing Austria's Electricity Supply in times of Climate Change; Final report of the ACRP12 project SECURES (2020-2023). www.secures.at.

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Keywords: climate change impacts, European electricity system, flexibility analysis, security of supply

Figure 1: Scenario comparison of flexibility demand, broken down by different time periods, in Austria

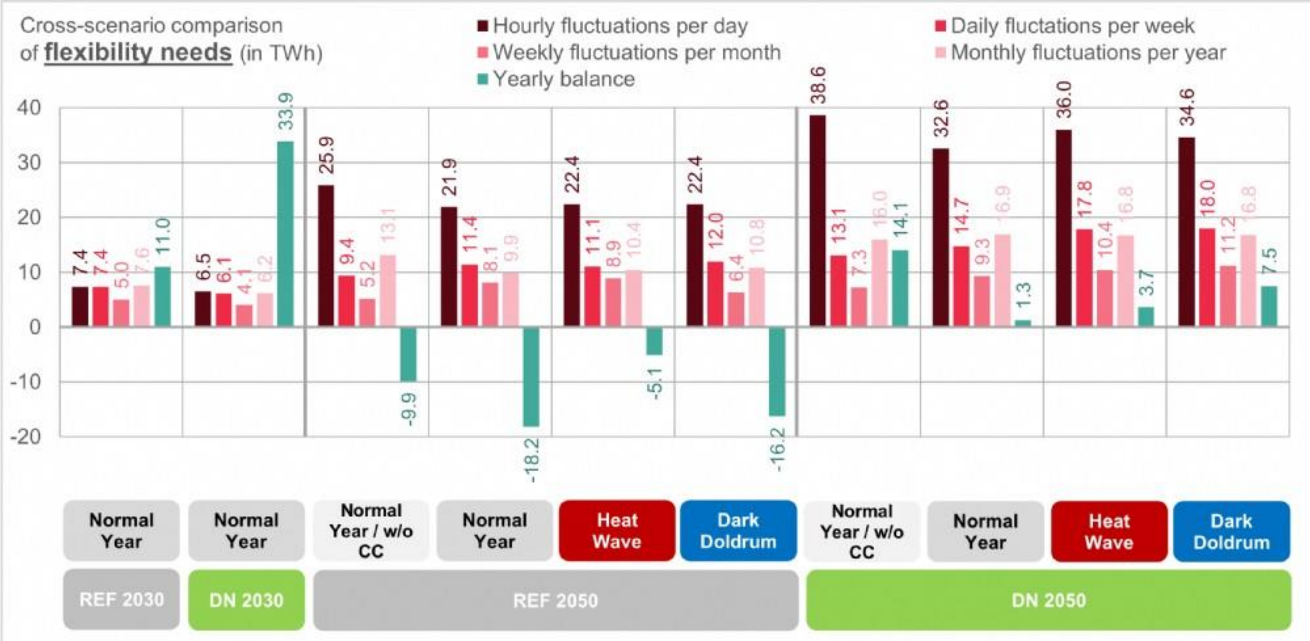

Figure 1 allows for a comparison of the calculated flexibility demand for Austria, broken down by time period for all scenarios and years analyzed (2030, 2050).

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[Abstract:0472] OP-191 [Accepted:Oral Presentation] [Electricity » Storage]

Multicriteria analysis forenergy storage technology valuation: economic simulation of energy scenarios in islands grids

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Overview:This study investigates the system benefits of the integration of energy storage technology to support variable renewables integration. The case study is the French island of Guadeloupe, where power specificities are the high share of fossil fuels, i.e. diesel and coal, and the significant seasonal variability of the load. An optimisation model is built to test energy scenarios targeting 100% renewables on the island such as to minimize the waste of energy, i.e. the power curtailed, subject to hourly supply-demand balance. Short term and long term duration storage technology are compared through seven sizing scenarios involving underwater isothermal CAES and lithium-ion batteries. A multicriteria analysis is done to evaluate which sizing scenario best fits policies and targets in terms of renewables' integration support, curtailment avoiding, and utilization factors of storage. This frame of analysis re-evaluates the method of energy storage valuation into a

multidimensional systemic approach where storage is considered through environmental impacts, technical requirement and economic efficiency.
Methods:The analysis is separated in two steps, first an optimisation model is built to minimize the waste of energy on the island. Then, the optimisation results are studied through a multicriteria analysis. The optimisation model is used with seven storage sizing scenarios, based on ADEME's baseline energy mix scenario for 2030, where energy storage technologies are allocated between lithium-ion batteries and underwater I-CAES storage such as every combination of storage technologies offers the same capacity (550 MWh of capacity in this case) (Chotard et al., 2019). The model uses linear programming implemented in Python using Pyomo package with the Glpk solver. The model is dynamic with 8,760 time slices. The results are the flow of the electricity generated by each technology and the flow of charged and discharged electricity by both storage technologies, on an hourly basis. In order to mimic the dispatch of electricity generation on the island of Guadeloupe the model minimises the annual system flow of produced and stored energy. The power market equilibrium is set every hour, and the order of entrance for each generating technologies is constraint to follow the political target of the island which ensures a minimum of 70% renewable energy in its electric mix (Direction de l'environnement, de l'aménagement et du logement de la Guadeloupe, 2017).
The optimisation results are analysed using a multicriteria analysis method called Analytic Hierarchy Process (AHP). This method, developed by Saaty in 1980, is a tool used to hierarchically structure a decision problem. This method helps to expose the relationship between factors used in the decision making process through a scoring procedure of said factors (Saaty, 1990). In this assessment the factors are represented by the optimisation outputs, organized under three dimensions: environmental impacts, technical outputs and economic parameters. Each output are assigned a numerical weight in regards to public policies and targets in terms of renewables' integration support. Storage sizing scenarios are then ranked according to the weight distribution. Three weight distribution are analysed then agregated to mimic an even preference between all studied dimensions. The impacts of storage technology and size choice are then analysed by looking individually at each dimension.
Results:After the analysis of the optimisation results, the preferred scenarios according to the AHP method would be the one where only batteries are installed on the island. On the opposite side, the scenario where only I-CAES are installed is the one with the lowest score. By looking closely at the three studied dimensions, it appears that the scenario where only I-CAES are installed is the best in terms of environmental impacts, in the matter of CO2 emissions and volumes of electricity injected to the grid from renewables power plants, despite having the lowest overall score. Regarding the technical dimension, batteries offer a better performance (based on volume of curtailed energy, energy loss related to round trip efficiency, capacity factors and usage factors), which translate a power to energy ratio best fitted for Guadeloupe energy system peculiarity, where the I-CAES power to energy sizing is not optimal.
Conclusions:We conclude that the incorporation of AHP method in the assessment of prospective electricity mix allow a better identification of the drivers which are key to the selection of a suitable mix. By virtue of public policies, detailing the analysis under three dimensions enhanced the results readability and bring to light scenarios weaknesses and strengths, which can be used to complement accuracy of the political target in decision making process. By means of optimisation modelling, the study shows that a significant energy curtailed saving required large installed capacities of energy storage. Concerning storage technology, the difference between peak loads and renewable availability in islands territories is such as it required high power delivery as much as long term duration discharge. The power to energy ratio has to be thought in advance to avoid the installation of an oversized storage plant, according to local peculiarity such as frequency of shut down and start up due to weather hazard, or intermittency of energy inflows (e.g. shut down in Guadeloupe island lead to energy losses up to 15% of gross consumption) (OREC Guadeloupe, 2019).
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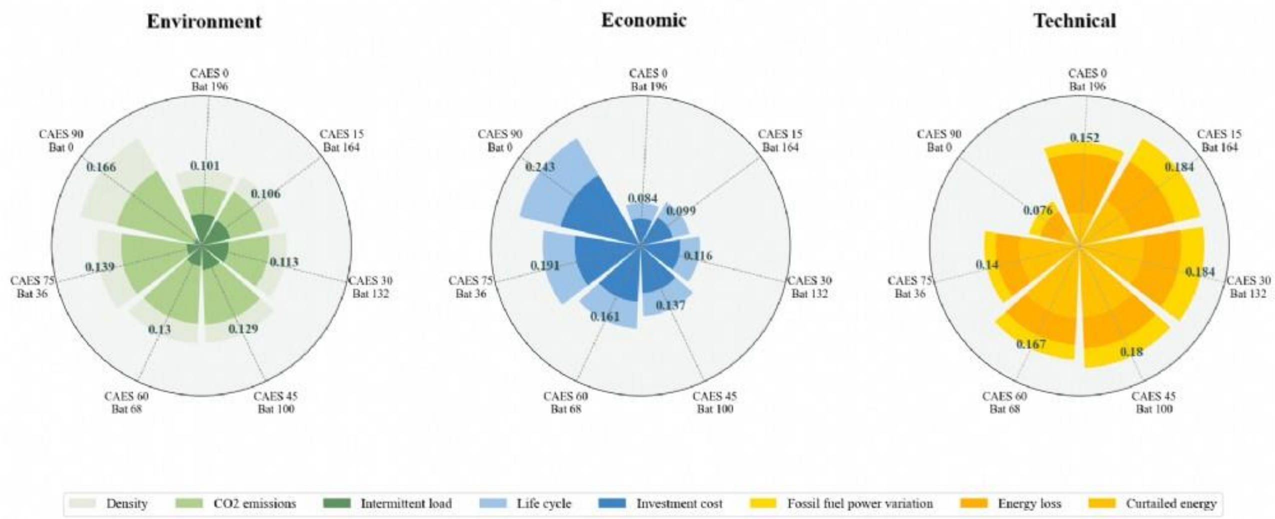
Keywords: Energy storage, insular grid, CAES, Lithium-ion battery, multicriteria analysis

Analytic hierarchy process results; aggregated scores for every dimension



Results of the analytic hierarchy process analysis

Objective function of the optimisation model

***Equation 1**. Objective function of the optimisation model*

$$Minimize\ f(w) = \sum_{t=1}^{T}\left[\left(\sum_{p} Q_t^p * \omega^p + \sum_{s}\left(Q_t^s * \omega^s + Q'^s_t * \omega'^s\right)\right) + |\partial'_t| * \omega^\partial\right]$$

Q_t^p: volume of produced electricity by the power plant p in time t
Q_t^s: volume of discharged electricity by the storage plant s in time t
Q'^s_t: volume of charged electricity by the storage plant s in time t
∂'_t: equilibrium variable (difference between supply and demand of electricity)
ω: merit-order related coefficient applied to each variable

Objective function of the optimisation model

Storage sizing scenarios

Underwater I-CAES		Lithium-ion batteries		Overall storage	
Power (MW)	Capacity (MWh)	Power (MW)	Capacity (MWh)	Power (MW)	Capacity (MWh)
0	0	196	550	196	550
15	90	164	460	179	550
30	180	132	370	162	550
45	270	100	280	145	550
60	360	68	190	128	550
75	450	36	100	111	550
90	540	0	0	90	540

Storage sizing scenarios

[Abstract:0049] OP-192 [Accepted:Oral Presentation] [Electricity » Reliability]

A sythetic review of energy poverty in africa: spatioeconometric analytic paradigm

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Overview:This paper shall presents a review of theory, concepts, and methodologies of energy vulnerability arisingfrom ongoing doctoralresearch which is at proposal stage, in the city and rural districts in zamfarastate, Nigeria. The systemic review of academic and empirical literature on incidence of energy poverty in assessing different theories and methodology within the field of energy studies.the multidisciplinary and dimensional nature energy deprivations need further scientific and academic justification through spatio econometric analytisc and applications. Traditionally, the link between electricity service sustainability, household energy behaviors and energy service are unseparatable for sustainable development.understanding the household structural dynamics and policy implications of energy vulnerability arising from the context energy injustice in Nigeria become obvious. This will be by investigating multidimensional indicator combined with social dimension variariables, enabling to identify different energy-deprivation households especially arising from inadequate clean energy(electricity) services in the study area. The study shall links the city and rural district statistical levels in zamfara state, Nigeria. Based on sustainable development goals no. 5, 7 &11 determinants, this paper shall explores city and rural district statistics by following an area-based approach and assesses its energy poverty distribution, Using energy deprivation analytics which shall be built on as determining factors to help to pinpoint the urban and rural areas where energy-poor households and vulnerable customers are more prone to be located. The results shall show the perspective and percentage of households at risk of energy poverty with the various identified spatial clusters and local interdepedency suggest the effective policy framework for energy service and energy sustainability in future energy poverty alleviation program in Nigeria and beyond.
Methods:the paper shall leverage from scientometric analysis and biblography to explore the available empirical and theoritcal literatures currently in the fields of energy/fuel poverty as the case may be.the novertlty arising from this conference paper shall be, that majority of available documented studies are arisinf from Global North and in particular, The UK and Republic of Ireland and Scotland within the context of EUROPEAN union. However, the AFTER math of energy crisis in the 1970 and late 1980s has sig=gnificant brought out this social problem that was political ill conceive in breat britain after sveral social movements agitation and radical academia interllecual intervention in the later part of 1988 and early 1990; Kudos to scalars like Brenda Boarman her PhD Doctoral thesis and seminal publicatios.
in this aerly stage of my exploratory analysis, such academic centre piece and several other policy documents within and aruond the golbal North and very few from Global south epecially from Latin America, SOUTH asia, Eastern europe and Balkan corridors due to the climatic nature of their geograhic settings (Bortz, Pablo G. and Annina Kaltenbrunner 2018).
web of science,scopus and peer review journasl including emprically unpublished PhD Thesis and MASTER dissertatations has been rigirously explore.to have identify the Research Gap. certainly, SSA aFRICA fron all dvelopment indices/indicator are vulnerable to electricity poverty
Results:the scientometric and bibblographic analysis reveiw literature within the the feild of energy poverty has clearly revealed several shortcoming in terms theoritical and methodological applications

sepecially when contexualising and try to definr the energy poverty in dveloping coutries trajectories.the literature has explicitly unveil the need for futher research especially in SSA despite the libelisation of most state uitilies entreprises for efficiency and competitative service delivery system(Cumbers, Andrew and Franziska Paul 2022).. only very few sucess stories were recorded in this regard with much far over reaching bottle necks arising from complex social.cultural, institutional.ploitical and enevronmental externalities beyound the local governabce structures (Cardinale, Ivano and Jochen Runde 2021)
the multi national and multilateral organisations were left with no ant other options, then to further reveie the macro economic policies and leading rates within the midst of global economic ressession and energy crisis and COVIC 19 KATARINA.
Conclusions:There the need to balance the energy povrerty predicaments through analysing the institutional and participatory analysis in both qualitative qnd quantitative assessments including fragmatic approch in SSA.The use of spatoeconmetric analytic shall vividly outlined the traditional weakness of econometrics models and statistical analysis that is limited to binary operations.

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Keywords: Energy poverty, spatio econometric models, Energy wellbeing, SDGs no. 5,7 &; 11, Zamfara

AuthorToEditor: indeed energy poverty pheminun has become, a global social concern. Howverm the academic and conceptulisation of tts unversal defintions is still subject to alot politically and internanationally motivated issue. the relevance to IAEE is this global discourse shall unevil alot good owen in the fiels of energy and fuel poverty especially in SSA Countries where its ha sbeen established to the highest underserviced electricity acess household across the globe. let make IAEE 2024 A REALITY AND UNIVERSAL through AFRICAN NARRATIVES.

[Abstract:0460] OP-193 [Accepted:Oral Presentation] [Electricity » Power System Planning & Management]

Analysing flexibility needs and provision in a future European energy system in 2050

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Overview:The analysis focuses on the requirements and availability of system flexibility in Europe's decarbonised electricity sector of the future (2050). The residual load (RL), defined as the difference between the (inflexible) load and the sum of electricity infeed from variable renewables (i.e., wind, solar PV, run-of-river hydropower), serves as the basis for the evaluation of flexibility needs. Hence, four scenarios were formulated to show the relevance of individual flexibility options in further detail. Of the EU27 countries, Germany and Spain have been selected to show the results of the modelling in detail, but all EU27 countries have been modelled. Germany, as the largest economy in Europe and located in the centre of the continent, has a varying number of neighbouring countries with which it exchanges electricity. Its future electricity generation is highly dependent on wind power. Spain, on the other hand, has a much lower electricity demand, has only a few neighbouring countries to trade electricity with, and will have a very large number of solar power generation units.
In brief, there are four scenarios that focus on different flexibility options in an energy system with almost 100% renewables. The BASE scenario serves as a reference, and all results will be compared to this scenario. The TRANS scenario enables more endogenous investment in transmission line capacities. The REN scenario offers the possibility to apply additional renewable energy assets. The demand response (DR) scenario considers additional flexibility on the demand side. An additional scenario, named "BASE-HighPV-lowWind", has been created to address the potential issue of a delayed uptake in wind power, compensated by a stronger uptake of PV. Accordingly, the expansion of PV capacities by 2050 has been increased, while the expansion of wind has been decreased in comparison to default.
Methods:The modelling in this study is done using the energy system model BALMOREL which is an open source, partial equilibrium model analysing the electricity and heat sector. BALMOREL uses linear programming in GAMS to optimize the desired objective function. It is a deterministic bottom-up model that optimises the dispatch of generation units and the investment in new units in an energy system. The model framework allows a range of temporal and spatial resolution; therefore, in this study, hourly resolution of one year and an analysis on country level was used.
We used the model for hourly generation dispatch and investment in new generation units across the different scenarios. The hourly dispatch enables us to assess the flexibility needs and provision of different technologies as descripted later. The possibility to invest in new generation units enables the model to build an optimized energy system to meet the flexibility needs of a decarbonised energy system.
The assumptions about electricity demand and projections for the supply side are based on a detailed modelling exercise on future electricity sector trends in Europe. This was performed within the Horizon 2020 project AURES II (Auctions for Renewable Energies II), as outlined in Resch et al. (2022).
In order to determine the need for flexibility, the residual load (RL) is used as an indicator. The residual load was computed as the difference between the demand for electricity and the generated power of photovoltaics, wind and hydropower (run-of-river and reservoir power plants). RL can be positive, negative, or zero. Positive RL indicates a temporary deficit in generation, negative RL indicates a temporary surplus in generation, and zero RL indicates a balance between generation and consumption. The flexibility needs calculation is based on RL determination, using the method proposed in (Andrey et al., 2019). This method analyses the dynamics of RL on a daily, weekly, and annual level. Monthly flexibility needs are also included, as per (Suna et al., 2022).
Results:As previously mentioned, modelling was conducted for all EU27 countries. The results will be discussed in terms of flexibility needs and provisions for Germany and Spain. Results show that different flexibility sources are of relevance to best cope with corresponding timeframe-dependent needs:
• For short-term (hourly to daily) fluctuations in RL, the use of battery systems has proven to be the most feasible solution to best cope with these.
• The system-friendly production of hydrogen (H_2), in combination with H_2 storages to allow for

that, has demonstrated beneficial outcomes in most analysed countries, matching specifically long-term flexibility requirements (i.e., seasonal imbalances in RL).
• Expanding the transmission grid is an inexpensive and efficient method to offer flexibility across all timeframes. Moreover, a well-established transmission grid can benefit scenarios that involve increased renewable capacities.
• The impact of demand side response is limited to short-term (hourly) flexibility because of its technical properties. But in energy systems with high PV generation, this hourly energy shifting potential appears very useful.
The results can be seen in Figure 1 for Germany and Figure 2 for Spain.
Conclusions:In summary, the study underscores the importance of tailoring flexibility solutions to the specific temporal characteristics of renewable energy generation. Battery systems excel in addressing short-term fluctuations, hydrogen (H2) production and storage prove beneficial for long-term flexibility, and a well-expanded transmission grid serves as a versatile solution across all timeframes. The limited impact of demand side response on short-term flexibility is acknowledged, but its significance in high PV generation scenarios is highlighted. These findings contribute valuable insights to the development of effective energy policies and infrastructure planning for Germany, Spain, and other EU27 countries.
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Keywords: Flexibility, Energy transition, Energy system modelling

Figure 1

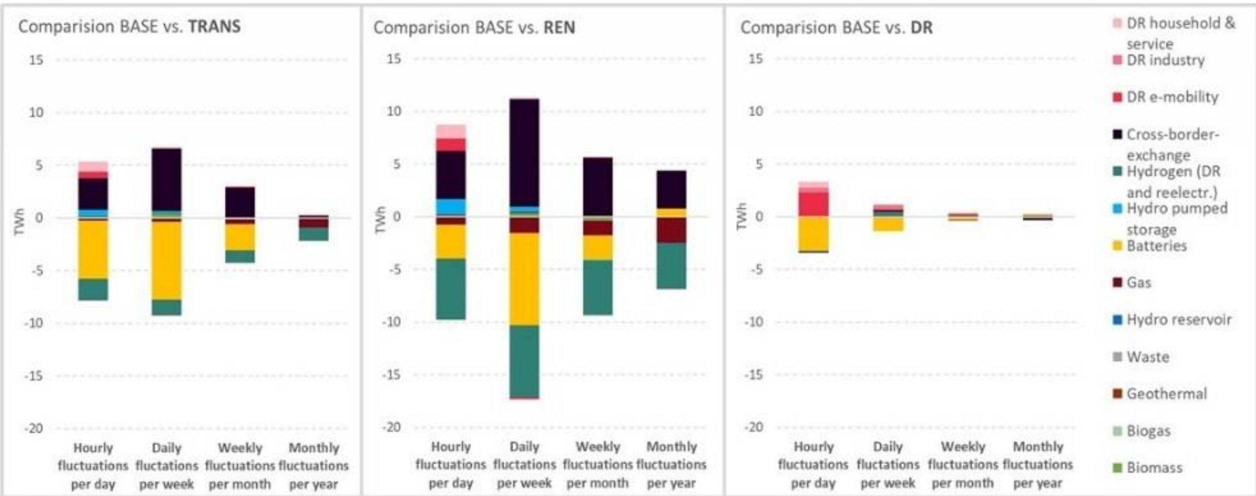

Figure 1: Changes of flexibility provision between the base scenarios and the TRANS (left), REN (middle) and DR (right) scenario for Germany (DE)

Changes of flexibility provision between the base scenarios and the TRANS (left), REN (middle) and DR (right) scenario for Germany (DE)

Figure 2

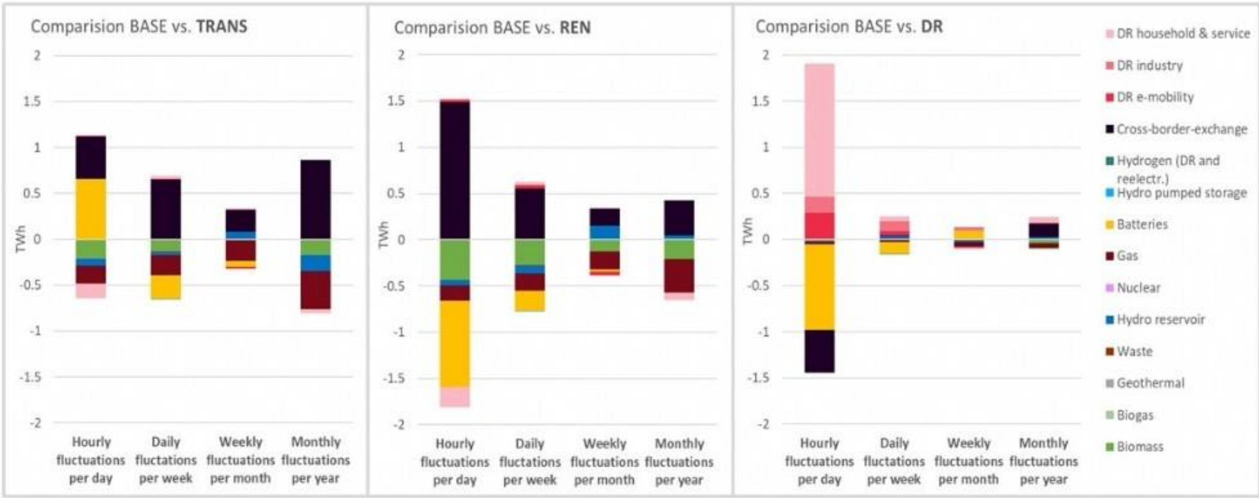

Figure 2: Changes of flexibility provision between the base scenarios and the TRANS (left), REN (middle) and DR (right) scenario for Spain (ES)

Figure 2: Changes of flexibility provision between the base scenarios and the TRANS (left), REN (middle) and DR (right) scenario for Spain (ES)

[Page: 194]

[Abstract:0586] OP-194 [Accepted:Oral Presentation] [Electricity » Power System Planning & Management]

The effects of slicing shifts on the generation of representative periods for electricity generation expansion planning

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Overview:Electricity Generation Expansion Planning (GEP) is concerned with determining the least cost schedule for installing and retiring electricity generation units to satisfy the electricity demand for the next several decades. With the increased importance of renewable energy technologies whose productive power outputs depend on uncertain and variable weather conditions, it is imperative for GEP models to consider a high temporal resolution that accounts for the weather variability and the operational details of the electricity system. At this level of temporal details, GEP models, represented as Mixed Integer Linear Optimization Programs, become computationally intractable. Existing literature commonly resorts to selecting representative periods with enough temporal resolution to overcome computational intractability. Generating representative periods based on an existing full data set of electricity demand and capacity factors for renewable energy technologies generally follows a three-stage approach (Hoffman et al., 2021):

(i) Normalizing the original data to transform it into the same order of magnitude
(ii) Slicing the normalized data into sequential distinct slices representing each a single operational contiguous unit, for example a day, or a week

(iii) Clustering the slices into separate groups each represented by a single operational unit – representative period, weighted by the size of the cluster.

When slicing the data, little attention is given to the starting or the ending position of the slices and calendar slices are generally arbitrarily considered (such as calendar days to represent an operational unit of 24 hours). We analyze the effect of modifying the starting position of the slices of data while preserving their sizes on the results of the selection of the representative periods and then the GEP model outputs.

Methods:We undertake our analysis based on representative periods of length 24 hours. We consider one year of hourly electricity demand, and wind and solar photovoltaic capacity factor data. After normalizing the data, we apply 24 different approaches to slice the data as follows: the first approach considers slices starting at hour one of calendar day one and of length 24 hours each. The second approach considers slices starting at hour two of calendar day one and of length 24 hours each and so on. The 24 separate approaches cover all the 24-hour slicing possibilities of the same full data.

Once the 24 sets of slices are produced, we test different clustering algorithms on each one of them with various configurations of the number of clusters and operational parameters of the clustering algorithms. We consider k-means, k-medoid and hierarchical clustering to generate the resulting representative periods. We end up with 24 sets of representative periods for each clustering configuration. We then conduct statistical analysis on the generated representative periods comparing the accuracy of their representation of the full dataset and analyzing the differences in representation caused by the shifting operation of the slices.

Afterwards, we develop two versions of a GEP model, a simple single node model that does not consider unit commitment constraints and a more detailed model incorporating unit commitment constraints. We consider the Reliability Test System - Grid Modernization Lab Consortium (RTS-GMLC) dataset (Barrows et al., 2020). We generate 24 slices of the dataset and then populate associated sets of representative periods. We run the two GEP models based on a greenfield development considering four types of generation technologies: gas-fired power plants, PV plants, wind plants and battery storage. We then compare and contrast the outputs of the GEP models for the different sets of representative periods.

Results:In our preliminary results, we show that the sets of representative periods generated under the same clustering conditions for the 24 sets of slices are not the same, although share many similarities. Differences are mostly observed in the representations of the wind capacity factor profiles. We note that the statistical differences between these sets of representative periods decrease with increasing number of clusters.

When considering the two versions of the GEP models, we particularly consider the build schedule for the power plants along with the value of the objective function representing the net present value of costs of the system. For the simple GEP, we notice that the results are not the same for the different representative periods generated for the shifted slices but approach each other as the number of clusters increases. The differences in the optimization results increase for the more detailed GEP model.

Conclusions:Our present work sheds light on one of the many components involved in the generation of representative periods for the GEP. Our preliminary results show that the way slicing is undertaken, even when the slices considered are of the same size and the original dataset is identical, can have implications on the selection of the representative periods and the outputs of the GEP models. As part of our ongoing and future work, we are considering the impact of slice shifts on multi-zonal GEP models and the importance of considering stochastic GEP models that account for the various uncertainties and variations possible in the steps required for the generation of representative periods.

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Keywords: electricity planning, representative periods, clustering, optimization

[Abstract:0469] OP-195 [Accepted:Oral Presentation] [Energy Efficiency » Other]

Assessment of socioeconomic impacts of energy efficiency in multi-family buildings: case of Lithuania

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Overview:Energy efficiency is a relevant measure for the security of energy supply as it reduces dependence on energy imports, including fossil fuels [1]. It will be treated as a significant energy source in the context of climate neutrality by 2050 [2]. Sustainable economic development is positively associated with increased energy efficiency [3]. Health and wealth improvements, poverty alleviation, industrial productivity and competitiveness increases, etc., are also related to energy efficiency [4]. On 13 September 2023, the European Parliament and the Council revised the Energy Efficiency Directive [5] and updated the binding energy efficiency target for the European Union. It requests to reduce energy consumption by at least 11.7% in 2030 (in comparison to 2020) to consume not more than 763 Mtoe of final energy and not more than 992.5 Mtoe of primary energy in that year. Later, final energy consumption should be reduced by 1.9% annually [5]. Lithuania committed to increasing energy efficiency by 0.8% annually from 2020 to 2030 and up to 2050 unless the European Union binding target is achieved [6]. Total energy saved by energy efficiency measures is 27.28 TWh by 2030 [6]. The Long-Term Renovation Strategy of Lithuania plans improvements in the energy efficiency of the building stock, one of the country's largest energy-consuming sectors. It aims to reduce the annual primary energy consumption of the building stock to 16.2 TWh (by 60%), the annual consumption of primary energy from fossil fuels in the building stock to 0 TWh (100%), and the annual CO2 emissions of the building stock to 0 MtCO2 (100%) [7]. Responding to commitments taken by the country, this research aims to assess the socioeconomic impacts of energy efficiency measures implemented in multi-family buildings to justify the expediency of recent political ambitions.
Methods:The scenarios for improving energy efficiency in multi-family buildings are developed based on policy documents and a detailed analysis of the existing situation in multi-family buildings [6; 7]. They refer to a high-priority group of buildings (energy performance class ≤ D), which are planned to be renovated by 760 units per annum during 2021–2023, 1086 units per annum during 2024–2030, 1083 units per annum during 2031–2040 and 1043 units per annum during 2041–2050 in a way that at the end of the period, all multi-family buildings are renovated to energy performance class C [7]. This is equivalent to 42.24 million m2 of total area of renovated multi-family buildings. Investment depends on the area of a building, i.e., 323 EUR/m2 if a multi-family building is < 1000 m2, 249 EUR/m2 – if it is 1000-5000 m2, and 186 EUR/m2 – if > 5000 m2 [7]. Investment is financed by a soft loan for 20 years with an interest rate of 3% [7]. Primary energy savings vary from 88 kWh/m2 per annum to 143 kWh/m2 per annum [7]. The assumptions allow for estimating energy savings (TWh), household expenditure savings (billion EUR), and investment requirements (billion EUR), which are inputs in the developed model. The Lithuanian version of the general equilibrium model CleanProd [8] assesses the socio-economic impacts. Among the advantages of this model is its level of detail (the basic version covers 64 commodity groups), its relatively simple structure, and the fact that it uses the most up-to-date information available in the public domain (the FIGARO database [9; 10] and Eurostat non-financial transactions statistics [11] are used to construct the social accounting matrix). For this research, the social accounting matrix is further disaggregated by energy product (individual energy products are identified instead of the aggregated D35 category), allowing the model to reflect energy efficiency measures and assess the broader economic impacts associated with the application of these measures. The mapping of the scenarios in the general equilibrium model is carried out based on the resource flows associated with the efficiency improvement process, following the methodological principles used in the impact analysis of scenarios of energy policy developments [12].
Results:Seeking to renovate a high-priority group of multi-family buildings in Lithuania, 10.5 billion EUR (at current prices) should be invested between 2021 and 2050. Investment subsidy makes 40%.

As households use soft loans, their loan payment will be 8.4 billion EUR at current prices. Due to improved energy efficiency in multi-family buildings, the primary energy savings will be 142 TWh during the validity of energy efficiency measures. District heat savings will be the highest (80 TWh). Savings of household expenditure from primary energy savings will be 10.9 billion EUR at current prices.

The results obtained when assessing socioeconomic impacts are not definitive. While housing renovation processes increase value added and employment in the construction sector, the overall impact on the national economy depends on broader factors. The situation in Lithuania is specific in this respect, as the vast majority of multi-family dwellings are heated by district heating. Around two-thirds of Lithuania's heat is produced from renewable energy sources, significantly using local biomass resources. Thus, heat savings also mean less use of local resources and, thus, less value added to the respective economic activities. This contrasts with the situation in the first decade of the 2000s, when heat production was dominated by imported fossil fuels (natural gas), and any economically feasible reduction in their consumption positively impacted the trade balance and other economic indicators.

On the other hand, biomass for energy is not the highest-value option. Although there is currently a lack of appropriate price signals, the attractiveness of alternative uses of biomass for energy production is likely to increase as the decarbonization process continues, allowing for higher value-added creation in other activities. However, the results of the simulations carried out in this study focussing on energy efficiency programmes, highlight the critical impact of the cost-effectiveness of the renovation projects themselves and the importance of the widespread use of local resources, not only in the energy sector but also in the renovation process, as the positive socio-economic impact of energy efficiency is most pronounced in scenarios with relatively fast payback of the renovation projects and with construction practices oriented towards the use of local resources.

Conclusions:Lithuania makes efforts to increase energy efficiency in multi-family buildings by implementing energy efficiency measures. The socio-economic impact of energy efficiency programs in multi-family dwellings is not straightforward. It depends, among other things, on the energy structure before the projects' implementation and the projects' cost-effectiveness.

In the case of Lithuania, the impact of renovation on job creation and GDP growth is limited by the fact that district heating is currently based mainly on using local resources, which provides added value. Nevertheless, it is clear that energy consumption is not and cannot be an end in itself. In this context, comprehensive energy efficiency programs should focus on reducing energy resource consumption cost-effectively and increasing the value added in related economic activities.

On the other hand, renovation programs for multi-family dwellings can also be seen not as investment projects but as necessary measures to keep them habitable. In this case, payback and socio-economic effects play a lesser role in the decision-making process, but exploiting potential synergies allows for maximizing the socio-economic effects considering a wide range of other circumstances.

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Keywords: Energy efficiency, impact assessment, multi-family buildings, case study

AuthorToEditor: Dear Scientific Committee, On behalf of the Co-Authors, I would like to propose an abstract for evaluation to take part in the IAEE2024 Conference. Best regards Viktorija Bobinaite

[Page: 196]

[Abstract:0285] OP-196 [Accepted:Oral Presentation] [Renewables » Other]

Impact of renewables development on profitability of onshore wind and solar in Lithuania

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Overview:The global energy market is shifting towards green energy production to achieve a sustainable future. Lithuania, along with many other countries, has committed to a net-zero carbon emission target by 2050, in line with the Paris Agreement's goal to limit the global warming effect. Lithuania is actively developing energy policies to move towards renewable energy sources (RES). According to the National Energy Independence Strategy (NEIS) [1], 45% of Lithuania's total electricity consumption should come from RES in 2030, and by 2050, RES generation should increase to 80% of the country's total load and become the main source of electricity. Given that in 2021, RES electricity accounted for 21% of the country's total electricity consumption [2], it can be assumed that RES capacity will increase significantly in the future. As RES capacity increases in Lithuania and an upward trend of growth is expected in future, a phenomenon known as the price cannibalization effect emerges and impacts on electricity prices [3]. When weather conditions are favorable, wind and solar power plants over-supply the grid, and this excess flow of energy creates a supply-demand imbalance and decreases in electricity prices. Lithuania needs to ensure the profitability of RES electricity generation in order to achieve the objectives of NEIS. Lack of profitability may make it difficult, if not impossible, to finance solar and wind projects in the future, as they can be damaging. Therefore, this research aims at providing insights on price cannibalization effect of renewables and profitability of onshore wind and solar PV technologies in Lithuania.
Methods:The steps of research (Figure 1):
I. The long-term price foreacasting based on Plexos model
II. RES generation and load growth based scenarios development
III. Formation of assumptions (RES capacities, national load, gas price, ETS prices, new electricity generation capacities, interconnections and etc.)
IV. Evaluation of price cannibalization effects (forecast of electricity market price, RES capture prices, RES capture price factors)
V. Insight on profitability of onshore wind and solar PV technologies

The price cannibalization effects of penetration of solar and onshore wind technologies were assessed based on Prol et al [4].
The capture price (CP) is defined as solar and wind generation-weighted electricity prices, which reveal how much income RES producers receive per electricity unit. It is the ratio between the amount of revenue and total quantity of forecast generation of RES technologies over a certain period, be it

a day, week, month or year.
The comparison of the CP with the average electricity market price demonstrates an absolute price cannibalization effect of RES technologies, respectively. Subject to an absolute price cannibalization effect, the CP is less than the average electricity market price. Based on [4], the relative price cannibalization effect of RES technologies is estimated by dividing the CP to the average electricity market price, which historically was decided by the power plants using natural gas. The CPF is a capture price factor. If the CPF<1, then it is said that relative price cannibalization effect is equivalent to 1-CPF.
The profitability of RES technologies is decided by comparing the income generated by RES technology with their cost. Income generated by solar and wind technologies are equivalent to the estimated CP. Based on research carried out by [5], the levelized cost of electricity (LCOE) of solar and wind was taken as a measure to represent cost. In this way, RES technologies are considered profitable, if the CP is above the LCOE in the long-term.
Results:The scenarios for RES capacity and national load growth were outlined based on the national energy targets for 2030. Five different scenarios were defined for Lithuania taking into account High, Mid and Low values of key indicators (Table 1).

Increasing solar and wind capacities in Lithuania will cause the price cannibalization effect in the country during the following decade (Figure 2).
Conclusions:In 2030, only the Low RES & High Load scenario in Lithuania can ensure a profitable CP, otherwise, electricity producers will loose money on every MWh of RES electricity generated as the LCOE will be higher than the CP. Innovative strategies could help to address this problem by increasing market flexibility and restoring the financial viability of RES. Solutions such as green hydrogen production at peak times, the deployment of BESS and the creation of expanded electricity export interconnections are essential.
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Keywords: Wind, solar, development, profitability, capture price, capture price factor

[Abstract:0082] OP-197 [Accepted:Oral Presentation] [Energy Efficiency » Industrial Processes]

Drivers of Industrial Energy Consumption in the Philippines: A Decomposition Analysis

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Asia Pacific Energy Research Centre (APERC)

Overview:The Philippines is one of the fastest-growing economies in South-East Asia. Recovering from the shocks brought by the COVID-19 pandemic, its GDP (PPP 2017 USD) in 2021 grew 5.7% from 2020 (World Bank, 2024). According to the World Bank, the Philippines is getting back on track on its way from a lower middle-income economy to an upper middle-income economy (per capita income range of US$4,466 -US$13,845) (World Bank, 2023). Following the previous Administration's ("Build, Build, Build") program, the current government takes on the underlying theme of transforming the economic and social sectors and institutions for a prosperous, inclusive, and resilient economy (DOE, 2021). One of the strategies of this transformation plan is revitalising the industry sector, to generate more quality jobs and competitive products (NEDA, 2023). As such, the industry sector will continue to rely on large amounts of energy to ensure the achievement of the goal. With this development, this paper's objective is to analyse the drivers of energy consumption in the industry sector in the Philippines, especially after the COVID-19 pandemic.
Methods:For the purpose of this study, the final energy consumption (FEC) of the construction, mining and quarrying and manufacturing sectors (except manufacturing, n.e.c) of the industry were included. Data used in the analysis were from the EGEDA (EGEDA, 2023) database expressed in petajoules (PJ). Definitions follow that of the International Recommendations for Energy Statistics (IRES) by the United Nations (UN).

• To conduct energy decomposition the equivalent measure of the level of activity of energy consumption is needed, in this case, the gross value added. (GVA). GVA adjusted to PPP 2017 US dollar disaggregated by economic activity were taken from the Philippine Statistics Authority (PSA). The base year used in the analysis was 2005.

• Decomposition method represented by Logarithmic Mean Divisia Index (LMDI)-I Formula by B.W. Ang: $\Delta E_{tot} = E_T - E_0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int}$ where ΔE_{tot} represents change in energy consumption, ΔE_{act} change in consumption due to activity, ΔE_{str} due to change in structure and ΔE_{int} due to intensity effect.

Results:In 2021, the energy consumption in the industry sector rebounded robustly by 10.3% (261.39 PJ) from the 2020 levels. True to its ambition of expanding its infrastructure, the construction industry propelled the energy consumption growth in the industry sector with a staggering 40.3% increase between 2020 and 2021, followed by the iron and steel industry which grew by 28.9% in the same period. Both industry sub-sectors were key in the infrastructure development. Among the sub-sectors of manufacturing, non-metallic mineral products accounted for 21% of the total energy consumption in the industry, over-taking energy consumption in food and beverage, which maintained a 20% share in 2021. In terms of fuel, coal grew by more than 30% in 2021, while electricity was the largest fuel consumed in the industry sector with almost 40% of the total fuel consumption in 2021. With the huge increase in energy consumption in the industry sector, CO_2 emissions reached 12,634 kT-CO_2 in 2021 or a 17% increase from 2020.
By decomposition, it can be observed that energy intensity has reduced by more than 160 MJ/USD (PPP constant 2017) in 2021. If energy intensity did not come into play energy consumption in the industry sector would have increased by more than 200 PJ in 2021 due to the recovery of the sector after the pandemic. Intensity improvements from food and beverage, non-metallic minerals and basic metals contributed largely to the reduction of energy consumption in the industry sector (Figure 1).

Conclusions:The decomposition method allows for analysing the drivers of energy consumption in the industry sector. If the economy continues to envision more infrastructure development in the future, it needs to enhance its programs in the sector. Ensuring the best available technology in the sector ensures the best production of goods, better work performance and provision of services.

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Keywords: decomposition analysis, drivers of industrial energy consumption, energy intensity

[Abstract:0398] OP-198 [Accepted:Oral Presentation] [Energy Efficiency » Energy Production and Transformation]

Identification of technological returns to scale of solar power plants in China: a convex nonparametric least-squares approach

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Overview:Solar power is considered as the best alternative to fossil fuel and the most promising solution to combat climate change by the academic community and the governments worldwide due to its abundant resources, low environmental pollution and convenience to foster energy self-sufficient (Xu et al., 2020). The installed capacity of grid-connected solar power increased by 21% in the world in 2021 while China contributes the largest share of over 33% (IEA, 2022). Incentivized by the unprecedented development of solar power, China has taken it as the pilar generation form to achieve the ambitious targets of peaking carbon emissions by 2030 and carbon neutrality by 2060. According to the 14th Five-Year Plan for modern energy system, China plans to build a new power system dominated by renewable energy and formulate a series of polices to boost the development of non-fossil energy, in particular solar power. Despite of its ambitious vision of gradually decrease the share of fossil fuel in power mix, the development of renewable energy faces many difficulties including grid availability and power stability. Yu et al. (2021) argue that the efficiency distortion resulting from the incommensurateness between power generation and its corresponding installed capacity has become a serious challenge to the sustainable development of the renewable power. Simultaneously, China's non-technical costs of solar power are much higher than that of the world average (IRENA, 2022), implying that the inefficiency comes from poor management and inappropriate policy mechanism. Along with the deepening market-oriented reform and the increase of renewable power absorption, the operational efficiency improvement and scaling up production of solar power plant is far more urgent than ever before. A reasonable and objective assessment of the operation efficiency and the type of returns to scale of solar power industry can not only provide valuable information for station location and efficiency improvement of power plants, but also serve as a tool for feasibility analysis and effect estimation of relevant policy reforms (Mostafaeipour et al., 2016).

The current investigation of performance of solar power plants in Qinghai implies the universal high efficiency of large-scale power plants, which comes from the management advantages of large enterprises, and the economies of scale of centralized power generation. Does this finding mean that the solar power industry in Qinghai is in a phase of increasing returns to scale? Is Qinghai provincial government making the right decision to continue to promote the construction of future concentrated photovoltaic bases? The identification of development stage of the industry is crucial, as this macro perspective analysis is the basis for scholar to determine of basic assumptions for efficiency evaluation and guides policy formulation and corporate efficiency improvement. The study is based on an analysis of the scale of the solar power industry in Qinghai, by proposing a new objective approach to identify the current technological returns to scale type, to determine the development stage of the industry, and to verify whether this conclusion can be supported by statistical tests. The study will analyse the dynamic evolution of returns to scale type for individual plants, and make judgements about the future development trends of the solar industry.

Methods:Returns to scale (RTS) is a crucial question and challenge in any study of productive efficiency, while only a few studies have focused on the identification of the RTS at the technology (dataset) level. The development of a reliable test procedure for examining returns to scale is important for both economic and statistical reasons. The identification of the technological returns to scale vastly influences the DMUs' efficiencies evaluated by any DEA model. Wrong identification results in statistically inconsistent estimates of efficiency, which may be a loss of statistical efficiency.

In early practice, technology returns to scale (TRTS) were determined by subjective methods, which relied on expert opinion and were therefore likely to be incorrect. A series of hypothesis tests proposed by Banker (1996) was the earliest objective method to identify TRTS. However, the distribution of inefficiency must be assumed, otherwise it will lead to a bad performance with wrong distributional assumption. Bootstrap procedure introduced by Simar and Wilson (2002) is proved to yield tests whose sizes are much closer to the nominal size than Banker's tests, while the results will be too often in favor of VRS estimator, and will resulting in low efficiency of calculation as dimensions of inputs and outputs increase. Besides, Alirezaee et al. (2018) explored a data mining-based angles approach, which yielded somewhat useful results empirically, but lacked a formal statistical basis. We propose an objective approach based on formal statistical tests for testing hypotheses regarding TRST, which eliminates the need to make assumptions about the distribution of inefficiency, and performs well with both small and large samples. The study is based on examinations of the statistical properties of DEA in two perspectives. Banker (1993) identified conditions under which DEA estimators are statistically consistent and have a maximum likelihood (ML) interpretation. Kuosmanen (2008) established formal links between DEA and to convex nonparametric least squares (CNLS) regression, showing that DEA is a sign-constrained special case of CNLS. For samples where returns to scale are at different stages, the key parameter α in CNLS will satisfy the following sets of constraints respectively:

Variable returns to scale ⇒ α is unconstrained; Constant returns to scale ⇒ $\alpha=0$; Non-increasing returns to scale ⇒ $\alpha \geq 0$; Non-decreasing returns to scale⇒ $\alpha \leq 0$.

By Wald test, the study can estimate whether the corresponding constraint group holds without the need to make prior assumptions about the inefficiency distribution, and thus determine whether the identification of TRTS is statistically significant (Kodde & Palm, 1986).

Results:Over time, we did not find significant changes in the type of returns to scale within our study window. China's solar power industry in Qinghai Province stays at the stage of increasing returns to scale, which suggests that China is far from the over-investment in the current stage of solar power boosting. This explains the necessity of the construction of a new 10.9 GW large-scale intermittent power base project that was launched in Qinghai in 2021. In order to further explore the potential areas that can be exploited to inform the location of new power plants, we further subdivided the dataset according to geographic characteristics to explore their respective types of returns to scale. The power plant clusters in near city and near county groups show constant returns to scale, which implies that they are constrained by the potential of the insolation resource and available land area. For sparsely populated areas, groups under different insolation conditions show increasing returns to scale. Specifically for individual plants, we find that the type of returns to scale depends on the installed capacity and is not significantly correlated with the labor input and the utilization hours. This implies that the universal high efficiency of the large-scale power plants comes from the management advantage and the economies of scale of centralised power generation (Zhou et al., 2021).

Conclusions:We propose an objective approach based on formal statistical tests, based on a convex nonparametric least-squares approach, to identify the technological returns to scale of solar power plants in Qinghai Province, China. Compared with Simar & Wilson (2002) and Banker (1996), our approach shows better computational performance and robustness. There is no need to make assumptions about the distribution of inefficiency, and large sample properties of estimator with meaningful statistic.

Compared with previous studies of returns to scale for only individual power plants (Sueyoshi & Goto, 2017), this study better identifies the macro returns to scale characteristics exhibited by the regional power generation industry or a class of power plant clusters, and this kind of study provides a better focus point for policy formulation. According to the performance of power plants in recent years, the solar power industry in Qinghai Province, China, has the potential for sustained growth. Under the dual pressures of securing energy supply and low-carbon development, there is a need to sustain the development of utility-scale solar power in the northwestern region, represented by Qinghai Province, in order to fully utilize its desertified land resource advantages. Although the abundance of solar power resources will have an impact on efficiency of plants, their distribution will not limit the potential for industrial scale expansion. It is worth noting that while expanding the scale of production, care should be taken to avoid redundant inputs of labor and to enhance the utilization of generating units to improve efficiency. The amount of labor in the sector of renewable power generation is mostly driven by the quality rather than quantity.

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Keywords: Data envelopment analysis, Returns to scale, Solar power, Energy efficiency

[Abstract:0488] OP-199 [Accepted:Oral Presentation] [Energy Efficiency » Energy Production and Transformation]

Flexible operation of combined heat and power fuel cells in energy systems dominated by intermittent renewables

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Overview:Fuel cell combined heat and power (CHP) systems, where waste heat generated during the electrochemical process is captured and utilized, offer the promise of a highly efficient, sustainable and reliable generation technology able to serve power and heat demands. Currently, adoption of fuel cell CHP systems is mainly obstructed by comparatively high specific investment costs, that are expected to drop in the future due to economies of scale [1]. As the primary power supply of many energy systems is shifting towards intermittent renewable energy sources, the role of CHP plants in the future energy landscape is likely to evolve. Because energy systems increasingly rely on fluctuating solar and wind power, there is a growing need for additional flexibility on the supply and the demand side. Dispatchable generation of CHP units can satisfy this need and supply power in times of low solar and wind power output. This in turn requires a change from the traditional paradigm, where either heat or power demand is the sole determinant of operation, to a more flexible operation schedule mainly determined by dynamic electricity prices, representing the time-varying scarcity of power in the grid. Flexible operation of CHP units has been the subject of multiple studies, such as [2], [3] and [4]. While these studies focus on sophisticated modelling of the technical aspects of flexible CHP operation, such as process simulation models, the representation of marketing the cogenerated power is often simplified with deterministic dynamic electricity prices or fixed feed-in rates. Therefore, this study aims to evaluate the performance in terms of achievable contribution margins of multiple fuel cell CHP systems in varying configurations (in combination with heat storages and/or power-to-heat units) operated in small district heating networks under consideration of participation in the electricity spot market with detailed representation of optimal bidding and

dispatch and short-term price uncertainty and compare it with the performance of a typical internal combustion engine (ICE) CHP. Furthermore, this study identifies which technical limitations of CHP units most significantly affect the capability for flexible operation.
Methods:The performance of CHP portfolios in a future energy system dominated by intermittent renewables is evaluated by calculating contribution margins for the future year 2030. The analysis follows a four-step procedure: First, long-term hourly day-ahead and quarter-hourly intraday auction price timeseries are generated for the 2030 European DE-LU price zone based on the methodology presented in [5]. Second, daily short-term price forecast scenarios are generated as described in [6] which serve as input for the third step, where a recursive two-stage stochastic programming model, similar to [7], is used to calculate the 2030 contribution for each CHP portfolio with default technical parameters, representing current, state-of-the art phosphoric acid fuel cell (PAFC) and solid oxide fuel cell (SOFC) CHP systems and a reference ICE CHP. And lastly, a sensitivity analysis varying technical constraints (e.g., Power-to-Heat ratio, minimum power and heat output, minimum standstill and operating time, ramping constraints, discrete operating points) is conducted to determine which technical constraints have the biggest impact on the ability to operate the system flexibly.
Results:As this is a work in progress, only expected results can be shared at the current stage. It is anticipated that extending the CHP system to a portfolio including heat storages and power-to-heat units has a high impact on achievable contribution margins. Heat storage units facilitate the retention of surplus heat for future use, while power-to-heat units allow for the utilization of excess electricity produced by the CHP and the use of grid electricity, when dynamic tariffs based on spot prices make it economically advantageous, to generate heat. In regard to the sensitivity analysis, it is expected that decoupling power and heat generation from each other has the biggest, while varying the ramping constraints the least impact on resulting contribution margins.
Conclusions:The transition to energy systems dominated by intermittent renewables incentivizes the flexible operation of CHP portfolios. For the year 2030, the contributions margins for various PAFC and SOFC CHP portfolios and a reference ICE CHP are determined under assumption of short-term price uncertainty and consideration of technical constraints via a stochastic portfolio optimization model. Furthermore, technical parameters of the PAFC and SOFC systems are varied to determine which technical constraints have the largest impact on flexibility potential.
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Keywords: Combined heat and power, Fuel cells, Stochastic optimization, Flexibility, Unit commitment

[Abstract:0438] OP-200 [Accepted:Oral Presentation] [Energy Efficiency » Industrial Processes]

Solar Energy Supported Compressor Waste Heat Recovery System

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Overview:Considering that traditional energy resources are both limited and cause serious environmental problems, energy efficiency is gaining great importance day by day. The European Union also shows great sensitivity towards energy efficient systems, recycling of waste and reducing the carbon footprint, and the green deal is the most important agenda item. Energy efficiency aims to save resources by reducing energy consumption, reduce energy costs and minimize environmental impacts, and reuse waste energy. In this way, the goal of reducing the carbon footprint can be achieved.
In this study, pre-heated fluid is provided to systems that heat a fluid by consuming fossil fuels, using waste heat or alternative energy sources (such as heat and electricity produced from the Sun). This approach aims to eliminate or greatly reduce the use of fossil fuels required to obtain the necessary hot water, depending on the user's demand. Mains water is passed through the solar water heating system and preheated and directed to the boilers.
The waste heat energy resulting from the heating of the screw air compressor oil used for compressed air production in the factory was used to reach pre-heated water to higher temperatures. In case of high water consumption and if water at a sufficient temperature cannot be obtained, a resistance water heating system that works with electrical energy produced and stored from solar panels comes into play.
The heated water is finally passed through the combi boiler and given to the system. If all these systems cannot produce sufficient hot water, the natural gas central heating boiler comes into play. This system contributes to effective cooling of the compressor oil and also provides additional energy savings by reducing the load on the oil cooling system. The energy savings resulting from the hybrid system obtained by the joint use of waste heat energy and solar energy were analyzed and reported.
Methods:In this study, mains water is preheated in tanks with the energy obtained from solar panels. Mains water heated by solar energy reaches an average temperature of 40 °C in winter and up to 85 °C in summer. Mains water heated by solar energy is filled into a boiler made of stainless steel with an internal volume of 1 m³ and a pressure resistance of 4 bars, and hot water is used from here. The oil inside the screw air compressor increases due to heating caused by friction. The temperature of the oil usually reaches the temperature range of 75-85 °C, depending on the operating frequency of the compressor, and therefore it needs to be cooled. Before the project, the heat of the oil used for both lubrication and compressor cooling was released to the atmosphere through the radiator. In the installed system, the heated oil is first directed to the heat exchanger and then to the radiator for final cooling. Both hot oil from the air compressor and preheated mains water come together in the exchanger. The oil coming from the compressor, which is in the temperature range of 75-85 °C, transfers its heat to the mains water in the heat exchanger and drops to the temperature range of 65-70 °C. Meanwhile, this cycle continues until the water temperature in the boiler reaches the oil temperature.
The compressor oil, which is cooled a little in the exchanger, is then directed to the radiator, cooled further and fed back into the compressor. With the help of the 3-way valve in the boiler, if the mains water temperature reaches the oil temperature, the exchanger cycle is not performed and the hot water is kept in the boiler, and the compressor oil is sent directly to the radiator for cooling. When the mains water temperature drops, the cycle is activated again. This system works fully automatically. When the steam pressure created by the hot water in the boiler rises to 4 bar, the safety valve is activated and the excess pressure is released. In this context, the waste heat generated during the cooling process of the heated compressor oil is utilized by heating the mains water as well as directing the compressor oil to the radiator at lower temperatures. Thanks to this method, operating the radiator fan at a lower speed reduces electricity consumption, and at the same time, extra energy savings are achieved by preventing the use of natural gas for mains water heating.
In addition to all these systems, there are 2 pieces of 304 stainless steel resistance in the boiler. If all these systems cannot bring the water to the desired temperature, these resistors come into play to provide the desired water temperature. In addition, these resistors are supported by 5 solar panels with a value of 455 Watt/peak. The electricity produced by solar panels is stored in 2 lithium-ion batteries with a capacity of 5 KW. This system has a charging/discharging system. Batteries charged under inverter control use the energy converted to mains voltage in resistors, also with the support

of the inverter. Automation is used in all these systems. The hot water accumulated in the boiler is passed through a combi boiler and used as shower, scullery and heating of the employee locker rooms and production offices within the factory. If the water temperature coming from the boiler exceeds or equals the combi boiler set value, the combi boiler delivers water directly without being activated. If the water temperature remains low, the combi boiler is activated. The water that decreases in the boiler comes from the solar energy system and is transmitted back into the boiler, ensuring the continuity of this cycle.

Results:As a result of the design, natural gas consumption to obtain hot water used in factory employee showers, scullery and heating of the 2 offices has been eliminated. At the same time, the natural gas consumed to obtain hot water used in radiators to heat employee locker rooms and production offices has been significantly reduced. Energy efficiency reports in the installed system can be calculated daily from the automation system and viewed in the system.

Savings Report

Compressor minimum datas

Yearly Working Time 3.600 h

Heated Fluid Flow Rate (Mains Water) 2.500 kg/h

Heated Fluid Inlet Temperature 50 °C

Heated Fluid Outlet Temperature 60 °C

Saving

Received Heat Energy (heat energy transferred to mains water) 29,6 kW

Received Heat Energy (at 75% capacity) 19.092 Kcal/h

Lower Thermal Efficiency of Natural Gas 8.250 m^3/kcal

Boiler Efficiency 95%

Natural Gas Equivalent 2,43 m^3/h

Annual Natural Gas Savings 8.769,53 m^3/yıl

Natural Gas Unit Price 12 TL/m^3

Yearly Money Savings 105.234,37 TL/yıl

Euro Exchange Rate 32,88

Yearly Money Savings 3200,56 €/Yıl

Conclusions:• Consumption of natural gas to produce hot water in the combi boiler is eliminated.

• A temperature of 20 °C above the outlet water temperature accepted in the calculations made at the beginning of the project was consistently achieved.

• Sufficient hot water production has been provided for all areas where hot water is intended to be used simultaneously.

• The operating frequency of the oil cooling radiator has been reduced and the electricity consumed has decreased.

• Carbon footprint has decreased by both eliminating the use of fossil fuels and reducing electricity consumption.

• The amount of waste heat thrown into the air has been reduced.

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Keywords: waste heat energy, solar energy, energy recycling, hybrid design

Boiler system

AuthorToEditor: In our study, the solar energy and waste heat recycling hybrid system was designed by Sağlam Metal R&D center. A patent application has been made for this study. The system works efficiently in our company.

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[Abstract:0453] OP-201 [Accepted:Oral Presentation] [Energy Efficiency » Policy and Regulation]

Does the heat transition need regulatory policy instruments?

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Overview:In recent years, regulatory instruments for achieving climate and energy targets in the building sector have been the subject of controversial debate in various countries and at various political levels, such as the "Minimum Energy Performance Standards" in the European Buildings Directive, the Building Energy Act in Germany and the Renewable Heat Act in Austria. In all of these cases, the result of the political debate was that the stringent regulatory requirements originally discussed, such as refurbishment obligations or boiler replacement requirements, were ultimately not implemented legislatively or at least in a much lower intensity.

The following questions arise in this context, which we analyse in this article:
(1) What are the effects on energy demand and the energy mix if regulatory instruments are dispensed with in the building sector?
(2) What does this mean for the achievement of energy and climate policy objectives?
(3) What social implications are associated with the implementation or lack of stringent regulatory instruments in the building sector?

The work was carried out as part of the projects "Pathways for Energy Efficient Heating and Cooling" [1] on behalf of the European Commission "Transitioning buildings to full reliance on renewable energy and assuring inclusive and affordable housing" [2] as part of the ACRP and the LIFE Project EPBD.wise – "Effective implementation of the EPBD in line with short-term and long-term policy requirements".
Methods:We analyse these issues from both a European and an Austrian perspective by developing scenarios with different stringency of regulatory instruments using the techno-socio-economic bottom-up building stock model Invert/EE-Lab (www.invert.at or e.g. [3]). The scenario results are analysed with regard to the effects on the achievement of energy and climate policy objectives (for EU-27) and social implications (for Austria). This is followed by a discussion of the results and the underlying assumptions and, in particular, what a change in some of these basic assumptions in the model could mean for the conclusions.
The regulatory instruments we consider are, firstly, the obligation to replace heating systems that can be operated with liquid or gaseous energy sources and, secondly, the mandatory refurbishment of buildings that do not meet a certain energy efficiency standard.
We combine these two core elements of possible regulatory requirements in different variants to form scenarios and supplement them firstly with assumptions regarding the increase in CO2 pricing and secondly with possible subsidy regimes to finance refurbishment measures on the building envelope or the heating system.
To analyse the social implications, we distinguish between different groups of actors, which differ in terms of ownership (owner-occupied vs. rented, whereby we also distinguish between privately rented housing units and non-profit and municipal housing developers), building type (single-family house vs. multi-family house, in the latter case built before vs. after 1945), income and - in the case of owner-occupied property - the age of the owners.

Results:Firstly, the results show that even scenarios with relatively high CO2 prices or subsidy regimes do not achieve the level of building refurbishment and the associated energy savings that would be the case with regulatory requirements. In the first case, the savings achieved from 2020-2050 are around 37%, in the second case around 43%.
Secondly, the share of liquid and gaseous energy sources in 2050 in the EU-27 is significantly higher in the scenario without regulatory intervention (over 30% of final energy demand) than with mandatory boiler replacement targets (less than 8% of final energy demand).
This means that either the energy and climate targets will not be met if the remaining demand for liquid and gaseous energy sources is not covered by renewables, or that the system is characterised by high variable, consumption-dependent costs for coverage by renewable gases and liquid fuels. This leads to increased susceptibility to price trends for these energy sources and therefore reduced resilience.
In the case of Austria, the cost analysis by stakeholder group shows that residents of rented flats and low-income households in particular have to expect rising running costs in scenarios without a corresponding regulatory policy, as the proportion of refurbished buildings in this segment in particular is significantly lower than in scenarios with a strong regulatory policy.
The results are essentially due to the following points: Firstly, it has been shown in the past that decisions in the building sector are not always made by owners on a purely rational basis, i.e. that the most cost-effective decisions in purely economic terms are not always taken. Secondly, there are substantial uncertainties regarding the possible development of energy prices, which further complicate an economically sound rational decision. Thirdly, there is a pronounced investor-user dilemma in the area of rented flats and, fourthly, there are also difficulties in making decisions based on majority decisions in the area of apartment blocks.
Conclusions:Without stringent regulatory policy instruments, as have been the subject of intense political debate in recent years, it appears difficult to achieve the postulated energy and climate policy objectives at Austrian and European level on a resilient, crisis-proof and socially balanced path that is characterised by a high level of energy efficiency and therefore low running energy expenditures. Regulatory policy can therefore be seen as protecting vulnerable groups in particular from rising energy prices and the costs of renewable gases.
Only if a combination of advice and refurbishment coaching, transparent and credibly communicated paths to energy and CO2 pricing and legal measures, particularly in tenancy and condominium law, succeeds in reducing the above-mentioned barriers could purely economic incentives, i.e. without regulatory law, lead to similarly effective and socially balanced target achievement paths in the building sector. The policy decisions at EU level, in Germany and Austria observed in recent months make it seem necessary to focus more on these measures as long as there are no political majorities in favour of corresponding regulatory requirements such as the decommissioning requirement for fossil heating systems or refurbishment obligations.
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Keywords: Buildings, decarbonisation, policy instruments, EPBD, scenario modelling

[Abstract:0499] OP-202 [Accepted:Oral Presentation] [Energy Efficiency » Policy and Regulation]

Boosting long-term-oriented thinking to promote home energy retrofit: A choice experiment

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Overview:In the built environment sector, enhancing energy efficiency through energy retrofitting is a key strategy to mitigate climate change. Despite efforts made by local municipalities to offer technical and financial support, the rate of home energy retrofit remains low. The decision to undertake home energy retrofit is complex for homeowners. It involves high upfront financial and non-financial costs, as well as various benefits over the long term (Broers et al., 2019; Wolske et al., 2020). Substantial costs and ambiguous benefits can prevent homeowners from investing in retrofit measures. Moreover, existing research and policy interventions have rarely accounted for the nonfinancial costs of energy retrofitting such as hassles and cognitive efforts.
Methods:We conduct a discrete choice experiment (DCE) with between-subjects treatments to understand homeowners' preferences for non-financial attributes of home energy retrofit, as well as the effectiveness of a scalable behavioural intervention that aims to boost homeowners' long-term-oriented thinking. As shown in Table 1, in the DCE, recruited homeowners are presented with a series of decision-making scenarios where they must choose their preferred investment option from two alternatives, alongside the option to maintain the current status quo. For each retrofit package, we provide information on five attributes: upfront financial cost, savings in energy bills, time investment, disruption during implementation, and the potential to generate domestic electricity. Furthermore, as shown in Figure 1, we design a boosting intervention (Hertwig & Grüne-Yanoff, 2017; Hertwig & Ryall, 2020) in a way to provide information on both financial and non-financial benefits over the lifetime of an energy retrofit project, from immediate personal benefits after installation to long-term societal contribution. The DCE is embedded in a survey questionnaire, in which information is collected on individual's time preference (Falk et al., 2018), energy literacy (van den Broek, 2019), investment literacy (Blasch et al., 2017), cognitive reflection (Andor et al., 2019), previous energy retrofitting experiences, and socio-demographics.
Results:Data will be collected in February and March 2024. 1,200 Dutch homeowners are expected to be recruited through Panel Inzicht, a professional survey panel in the Netherlands. We expect that the utility of implementing home energy retrofit decreases as upfront financial cost, time investment, and disruption during implementation increase. However, energy bill savings and the opportunity to be gas-free as well as generate domestic electricity will increase the utility of implementing home energy retrofit. Furthermore, we expect that boosting long-term thinking will reduce the negative effects of upfront investment cost, time investment, and disruption on individual utilities, thus increasing homeowners' preferences for energy retrofit investments. In addition to the hypothesis-testing analysis, two exploratory analyses will be conducted to provide additional inferences. First, we will employ mixed logit models to explore householder segmentation, which can potentially explain heterogeneity in the effectiveness of the boosting intervention. Second, we will investigate the willingness to pay space to explore trade-offs between upfront financial cost and non-financial attributes.
Conclusions:This study will contribute to understanding the role of non-financial attributes in household energy retrofit decisions. Furthermore, evidence will be provided on the effectiveness of a scalable informational intervention in boosting long-term-oriented thinking and increasing preferences for home energy retrofit. Findings of this study will provide policy implications on the extent to which non-financial factors are important determinants of energy retrofit decisions, as well as the effectiveness of scalable informational intervention in complex investment decision-making.
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Keywords: Energy efficiency, home energy retrofit, transaction costs, time preference, choice experiment

[Abstract:0070] OP-203 [Accepted:Oral Presentation] [Transportation » Trucking, Shipping, Rail, and Aircraft]

Comparison of Proposed Market-based Measures to Reduce Greenhouse Gas Emissions from International Maritime Bunker Fuels

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Overview:The volume of international maritime trade has significantly increased from the twentieth to twenty-first century due to the globalization of the national economy of many countries and their economic growth. As a result, greenhouse gas (GHG) emissions from international maritime bunker fuels have increased dramatically and accounted for about 2% of the total GHG emissions in the world in 2021.
The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) requested the International Maritime Organization (IMO) to address GHG emissions from international maritime bunker fuels since no treaty or agreement existed to reduce GHG emissions from international shipping. IMO members discussed market-based measure (MBM) proposals at the IMO's Marine Environment Protection Committee (MEPC). As of May 2013, seven types of MBMs have been submitted to the IMO (GHG Fund, Efficiency Incentive Scheme (EIS), Port State Levy (PSL), Ship Efficiency and Credit Trading (SECT), Penalty on Trade and Development, Rebate Mechanism for a market-based instrument for international shipping, and Global Emissions Trading System (ETS) for international shipping).
At the MEPC, developing countries advocate that the UNFCCC's principle of "Common but Differentiated Responsibilities (CBDR)" be considered in the future MBM and that developed countries be mainly responsible for reducing GHG emissions from international shipping. On the other hand, developed countries assert that the future MBM should be applied to all ships based on the IMO's principle of "No More Favorable Treatment (NMFT)". Then, in 2010 the nine criteria, such as cost effectiveness and administrative burden, were proposed in the IMO to evaluate GHG emissions reduction measures. H. Psaraftis (2012) evaluated and compared MBM proposals with eight of the

nine criteria and additional criteria. However, H. Psaraftis (2012) did not include the NMFT principle as one of the criteria for this research. Y. Shi (2016) analyzed MBM proposals with nine criteria and the CBDR principle and NMFT principle. Nevertheless, Y. Shi (2016) did not compare MBM proposals with these principles.

Methods:Comparative analysis: Comparing and evaluating seven types of MBMs submitted to the IMO by four criteria, the principle of Common but Differentiated Responsibilities (CBDR), No More Favorable Treatment principle (NMFT), cost effectiveness, and administrative burden. The IMO documents are supplementally referred to for this comparative analysis.

We used the CBDR principle and NMFT principle as standards for this study because these are ideological and subjective criteria that show conflicts between developed and developing countries in the IMO. We also adopted cost-effectiveness, and administrative burden out of the IMO nine criteria because these two criteria are more practical and objective than the other nine criteria such as incentives to technological changes and feasibility.

Results:As a result of the comparison and evaluation, we assume that both developed and developing countries can agree upon no MBM proposal as it is. However, the GHG Fund and Efficiency Incentive Scheme (EIS) show relatively high evaluation by this comparison analysis, even though they still lack conclusive points.

Conclusions:So far, there is no perfect MBM proposal at the IMO. However, if appropriate revisions are given to seven types of MBM proposals, especially to the GHG Fund and EIS which show relatively high evaluation by four major criteria by negotiating parties, both developed and developing countries may be able to agree with the future MBM. A more detailed analysis will be conducted in the near future.

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Keywords: International bunker fuels, greenhouse gas emissions, market-based measures, the principle of common but differentiated responsibilities, no more favorable treatment principle

Table 1: Seven MBM proposals and 4 criteria

	CBDR	NMFT	Cost effectiveness	Administrative burden
GHG Fund	△(Relatively considered)	○(Considered)	○(High)	△(Medium)
Efficiency Incentive Scheme (EIS)	×(Not considered)	△(Relatively considered)	○(High)	△(Medium)
Port State Levy (PSL)	○(Considered)	×(Not considered)	×(Low)	×(High)
Ship Efficiency and Credit Trading (SECT)	×(Not considered)	○(Considered)	×(Low)	×(High)
Penalty on Trade and Development	○(Considered)	×(Not considered)	×(Low)	△(Medium)
Rebate Mechanism for a market-based instrument for international shipping	○(Considered)	×(Not considered)	△(Medium)	×(High)
Global Emissions Trading System (ETS) for international shipping	△(Relatively considered)	△(Relatively considered)	×(Low)	×(High)

[Abstract:0394] OP-204 [Accepted:Oral Presentation] [Transportation » Trucking, Shipping, Rail, and Aircraft]

Towards deep decarbonization: Financing of CO2 transport in Europe

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Overview:By adopting the EU Green Deal, the Climate Change Act, and subsequent proposals to increase climate targets for 2030, carbon capture, and storage (CCS) play a critical role in the EU's decarbonization efforts.1 However, deploying CCS at scale will require the development of gigaton-scale CO2 transport infrastructure.2 Building this infrastructure requires the mobilization of finance for capital-intensive transport assets, which requires a good understanding of transportation costs. Prior techno-economic studies on CO2 transport rarely incorporate the unique financing cost involved, despite transport assets being capital-driven. Previous CO2 transport research, though highlighting the crucial role of finance, adopts a one-size-fits-all discount rate across modes and regions,2–6 overlooking the distinct cost of capital among nations7 and between private and public financing.8 Consequently, for CCS to effectively contribute towards deep decarbonization in Europe, it is essential to determine which transport assets should be financed, by whom - public or private entities - and to understand how these financing decisions will affect transport costs.
To address these questions, our study derives the levelized transport costs of different CO2 transport modes under different financing structures, namely public, private, and regulated private financing. More specifically, we analyze the impact of the cost of capital on transport costs for all transport assets. We also consider the impact of efficiency on the cost of CO2 transport by analyzing how different financing structures affect not only the initial investment but also long-term operational efficiency and subsequent transport costs.
Methods:We qualitatively assess suitable financing structures for CO2 transport based on academic literature and by drawing analogies to other infrastructure networks. We then compile input data to calculate levelized transport costs for different transport assets. This data includes both technical and financial input data. To account for differences in financing costs, the levelized transport cost is calculated for each transport asset and each cost of capital associated with the different financing structures. In addition, we triangulate our results through structured interviews with industry experts, focusing on the cost of capital and the levelized transport cost of projects already deployed in the industry. Finally, we explore opportunities to improve the cost and operational efficiency of CO2 transport by considering best practices from other infrastructure networks.
Results:Our results indicate that for operationally intensive modes such as trucks and trains, the financing structure has a minimal impact on costs. However, for capital-intensive modes such as pipelines, ships, and barges, transport costs vary between different financing structures. Preliminary results show that publicly financed pipelines transporting 1 MtCO2/year are the most cost-effective, with costs ranging from €25-50/tCO2 over 300-700 km. Our study also highlights the substantial impact of fluctuating interest rates (0 to 5%) on projected costs. This is particularly pronounced for capital-intensive transport modes such as pipelines, where financing costs can account for more than 50% of total transport costs in high interest rate scenarios.
Conclusions:Our results suggest that for capital-intensive CO2 transport assets, the choice of financing structure - public, private, or hybrid - has a substantial impact on transport costs. In an environment of rising interest rates, financing costs can account for more than 50% of total transport costs, particularly for pipelines. The impact of these interest rate fluctuations highlights the critical need for policymakers to consider these variations when formulating support policies for CO2 transport. The findings are valuable for policymakers and private infrastructure investors in understanding the influence of financing structures on CO2 transport costs. In addition, our findings provide relevant data on CO2 transport costs that can contribute to cost estimates for CCS and

negative emission technologies and help assess their role in achieving net zero emissions.

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Keywords: CO2 transport cost, Infrastructure financing, Climate Policy

[Abstract:0305] OP-205 [Accepted:Oral Presentation] [Transportation » Trucking, Shipping, Rail, and Aircraft]

A maritime sector in transition - Learning from past and present sectoral energy transitions

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Overview:The maritime sector currently contributes to an estimated 2.3 percent of the total CO_2 emissions with a forecasted contribution of 13 percent total CO_2 emissions by 2050, stressing the need for rapid decarbonization. In response to the potential catastrophic impacts of climate change, there is a growing call to shift the maritime sector toward cleaner fuels such as hydrogen (or its derivatives). This paper aims to address the question of how lessons from previous energy sector transitions can accelerate and enhance the effectiveness and efficiency of the maritime sector decarbonization process. Drawing insights from historical transitions such as the adoptions of renewables in the electricity sector and the ongoing transition from internal combustion engine vehicles to electric vehicles, we propose a conceptual model for the maritime sector transition.
Methods:Using both an indicative and deductive approach, we put forward a conceptual framework that distills lessons learned from these industries and investigates their applicability to decarbonize the maritime sector.
Results:Key lessons from the electricity sector highlight the importance of early policy support for renewable capacity development, while highlighting the unintended consequences in electricity market design. For road transportation transition, a key insight highlights the need for a simultaneous

and comprehensive shift rather than a sequential one, with infrastructure development playing a pivotal role in either helping or hindering a successful transition. Conclusions:Ultimately, this conceptual framework will showcase potential pathways for the transition of the maritime sector to alternate fuels such as hydrogen. References:not applicable

Keywords: Transition, Maritime Sector, Decarbonization, Electricity Sector, Electric Vehicles, Hydrogen

AuthorToEditor: a detailed reference list will be included in the final submission.

[Page: 206]

[Abstract:0306] OP-206 [Accepted:Oral Presentation] [Transportation » Fuel Cell Vehicles]

Is the Hydrogen Fuel Cell truck a better option to ride? A decision support with a real options approach

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Overview:The transformation of current production and consumption patterns and energy supply to reduce greenhouse gas (GHG) emissions are priority sectors. In particular, the production of electricity can be decarbonized by using energy sources with low or no GHG emissions. Cleaner mobility by 2050 based on hydrogen technology takes on its full strategic value when political decision-makers and consumers anticipate a reversal in the evolution of the various parameters, upsetting the pre-established order in terms of economic performance. To describe this phenomenon, it will therefore be necessary to obtain information on the evolution of the prices of electricity, hydrogen, fuels used and long-term demand. For instance, factors that influence the rate of adoption of hydrogen fuel cell truck technology include the benefits it brings, the presence or absence of substitute or complementary products (diesel, electric trucks), the ease of use (presence of hydrogen refuel stations), the regulatory framework that increase the benefits of adoption (financial incentives, subsidies), the costs of adopting the technology (relative price of hydrogen fuel cell trucks) and uncertainty about the usefulness of the technology (reducing carbon emissions, NetZero 2050). Therefore, a more comprehensive analytical framework should simultaneously incorporate the short-term uncertainties associated with the operation of hydrogen and fuel cell technology, storage and the necessary infrastructure, and the associated long-term uncertainties such as market developments, investment in low-carbon assets and financing costs. In our paper, we use a real options approach and we assess the regulatory uncertainty in terms of subsidy and the speed of adoption of fuel cell trucks in France. With a continuous-time model and dynamic programming method we determine the optimal timing and scale of investments in hydrogen infrastructure, influenced by dynamic subsidy policies and adoption rates of fuel cell hydrogen trucks. Methods:The literature on the hydrogen as a vector for energy transition is significant and encompasses a variety of disciplinary fields. In economics there is a noted increase in the literature studying the economics of green hydrogen projects, as illustrated by the reviews of Vandewalle et al. (2015), El-Emam and Ozcan (2019), Lynch et al. (2019), as well as those by Glenk and Reichelstein (2019) and Jiang, Deng, and You (2019). Nonetheless, some of these works are already obsolete due to the rapid evolution of cost reductions. It is therefore necessary to understand how these reductions impact past and current studies. More recently, using short-term (2020-2040) and long-term (2030-2050) scenarios, Khan et al. (2021) present a detailed framework of discounted

costs to determine the costs of hydrogen produced by renewable energies, as well as the sensitivity to various techno-economic parameters. One of the main limitations of these studies is that they do not account for the dynamic nature of uncertainties regarding hydrogen pricing, electrolyzer's costs, and other parameters, such as life cycles or load variation capacity. Furthermore, Li and Mulder (2021) and Hesel et al. (2022) analyze the evolution of hydrogen markets within a perfect competition framework. Michalski et al. (2017) explore the German energy transition, evaluating hydrogen production technologies and storage solutions, indicating hydrogen's significant role in mobility and its potential to mitigate wind curtailments and peak energy loads. Wu et al. (2021) identify and analyze obstacles to HFCV growth in China using a novel method, providing targeted recommendations to overcome these challenges. Gandhi et al. (2022) investigate the construction of a green hydrogen economy, assessing the project's feasibility against variable cost and market conditions while Moon et al. (2022) identify consumer trust as a significant barrier to HFCV adoption in South Korea, advising policy enhancements to promote these vehicles. Chen et al. (2023) and Wang et al. (2023) focus on optimizing hydrogen energy infrastructure and vehicle adoption, emphasizing economic benefits and the potential to reduce carbon emissions. These studies leverage models like NPV and LCC to assess the viability of hydrogen projects, especially in combating wind curtailment and enhancing the economic and environmental potential of fuel cell electric vehicles (FCEVs) by 2030. Similarly, Abadie and Chamorro (2023) analyze the economic viability of wind-based green hydrogen production in Spain, using Monte Carlo simulations to highlight its competitiveness, despite some overlooked factors. Choi and Kang (2023) present an economic and environmental analysis of hydrogen use in the steel industry, providing insights for GHG reduction and cost estimation. Harichandan and Kar (2023) explore Indian consumers' attitudes towards HFCVs, highlighting the need for comprehensive government policies that address both demand and supply-side incentives.

We contribute to the previous literature by considering two strands of literature. More precisely, we use a real options approach combined with literature from the field of diffusion of an innovation, by introducing uncertainty in a standard Bass model (1969). The Bass model provides a framework to understand how new products or technologies are adopted over time within a market. The model considers two main types of adopters: innovators, who are influenced by the product's attributes and their own knowledge, and imitators, who are influenced by the adoption choices of others. On the other hand, Real Options Theory, offers a method to evaluate and manage the uncertainty and flexibility inherent in investment decisions. It treats investment opportunities as options, giving the investor the right, but not the obligation, to undertake certain business decisions, like deferring, abandoning, expanding, or staging investments. The real options theory and the innovation diffusion model in the energy sector have been explored in several studies. Rout (2009) addresses the uncertainty in learning rates of energy technologies, underscoring the need for policy support to mitigate this uncertainty and facilitate technology diffusion. Recently, Li et al. (2020) study with real options the investment in hydrogen-fuel infrastructure in the Netherlands under uncertainty on in the existence of the infrastructure.

We adapt the Bass model, tailoring it to better represent the spread of adoption of hydrogen fuel cell trucks in France. Using a dynamic programming approach in continuous time and considering gradually two types of uncertainty (on the regulatory framework and on the infrastructure) our study provides stakeholders with a set of options for constructing flexible strategies to deal with uncertainty in the field of mobility, including hydrogen-based technologies.

Results:The Bass model of diffusion of innovation and real options theory can be linked when analyzing the uncertainty surrounding the regulatory framework and the availability of infrastructure, particularly in the context of fuel cell hydrogen trucks or energy systems like hydrogen fuel stations. We model the subsidy policy as a stochastic process to reflect its uncertainty over time. This parameter affects both the cost structure of adopting hydrogen trucks for fleet owners and the investment in hydrogen fueling infrastructure. Furthermore, we use the Bass model to determine the adoption rate of hydrogen trucks, incorporating the effect of subsidy uncertainty. The subsidy level modifies the parameters in the Bass model, reflecting how financial incentives influence early adopters and followers.

Through dynamic programming methods, we develop decision rules based on real options valuation for when to invest in infrastructure, considering the current state of subsidy policy, observed adoption rates, and market feedback. We conduct sensitivity analysis, and we show that the regulatory changes can significantly impact both innovators and imitators' willingness to adopt fuel cell hydrogen trucks. For instance, favorable regulations might accelerate adoption by reducing perceived risks or improving the technology's perceived benefits. On the contrary, the uncertainty in the regulatory environment introduces volatility, which increases the value of waiting to invest. Firms may delay investments in new infrastructure or in the production or the use of hydrogen trucks until regulatory outcomes become clearer. Moreover, we show that the availability of the infrastructure, seen in our model as a series of sequential investments, influence the use and the adoption curve for hydrogen trucks. The value of waiting to invest (defer option) is influenced by the volatility of the subsidy, while the potential market size (determined by the Bass model) affects the value of expansion options.

Conclusions:Our paper provides insights into how subsidy uncertainty impacts the strategic deployment of hydrogen fueling infrastructure and the adoption of hydrogen trucks. Furthermore, it helps stakeholders identify optimal investment strategies under different subsidy scenarios and market responses, ultimately guiding policy and investment decisions in the hydrogen truck ecosystem. For the French case, according to our Bass model including variables such as the coverage of refueling stations and the relative price of hydrogen trucks based on subsidy, it is very likely that trucks will account for 20% of the government in 2050, even with low innovation and imitation coefficients. However, if a higher share of the market is to be achieved, the innovation and imitation coefficients will have to be manipulated, and a significant subsidy policy will have to be put in place to sell hydrogen trucks and ensure that they are adopted by both innovators and imitators.

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Keywords: hydrogen trucks, subsidy, infrastructure, real options, adoption rate

[Page: 207]

[Abstract:0400] OP-207 [Accepted:Oral Presentation] [Energy System Transition » Electricity]

Valuing Transmission Investments in the European electricity market

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Overview:Expanding the electrical transmission system is crucial to achieve the European decarbonization goals by 2050. Therefore, governments, regulators, and transmission system operators have to make or evaluate plans that call for investments in the transmission grid to meet those goals. These plans, however, often assume that investments in the transmission grid which are optimal for Europe as a whole are also optimal for consumers, producers, and transmission system operators in individual countries. But what if this assumption turns out to be false? How closely do socially optimal transmission expansion plans align with what is privately optimal for consumers, producers, and transmission system operators at the national level?

This question is particularly important given the fast penetration of renewables in the European electricity system and the associated demand for flexibility that the transmission system can supply. Planned investments in transmission capacity and storage are interdependent with planned investments in generation capacity, conventional as well as intermittent. But what if the benefits of local investments in transmission capacity accrue transnationally across Europe while the costs are confined to the locally based TSO, consumers, and producers? Will their private incentives be sufficient to realise planned transmission capacity expansion? Without sufficiently strong private incentives, investments in the transmission system may not be forthcoming and the demand for flexibility will have to be met by other investments or curtailment of demand to meet European decarbonization goals.

In this paper, we provide answers to these questions by using transmission-constrained European power market model, COMPETES. COMPETES is a large-scale optimization model that computes the optimal investment and operational decisions for power generation, transmission, and storage minimising the total power system costs whilst accounting for the generation and cross-border transmission constraints. COMPETES includes 33 European countries represented by an electricity network with 21 nodes and 47 links, as can be seen in the Figure 1 below.

INSERT FIGURE 1

Our contribution to the literature complements insights provided by ENTSO-E and other national organisations that make plans and/or evaluate plans that call for investments in the transmission grid. While they offer insights on what investments may be needed to meet European decarbonization goals with a social planner in charge, we provide insights on what transfers may be needed to align these social incentives with private incentives and how we can allocate of the costs of transmission

capacity expansion as much as possible to the beneficiaries in order for the plans to be in everyone's interest and to receive broad support.
Methods:To answer our question we make use of a model-based-experiment. We make use of COMPETES which endogenously calculates the least cost transmission, generation, and storage capacity investments. COMPETES uses a two-period optimization approach as described in [Ozdemir et. al. 2018]. Investors of transmission and conventional generation submit their investment decisions in the first stage (i.e., 2030) and the resulting generation is dispatched in future electricity markets in the second stage (i.e., 2050). The model minimises total operation and investment costs in the electricity system subject to:

1. Power balance constraints: These constraints ensure demand and supply is balanced at each node at any time;

2. Generation capacity constraints: These constraints limit the maximum available capacity of a generating unit. These also include derating factors to mainly capture the effect of planned and forced outages to the utilisation of this plant;

3. Cross-border transmission constraints: These limit the power flows between the countries for given NTC values;

4. Storage constraints: These constraints represent the operation of storage during the day by charging and discharging;

5. Demand shifting: These constraints represent the shifting of demand within a day from higher to lower price hours.

We first solve for the optimal transmission capacities between nodes in 2050 given the input assumptions of ENTSO-E's Global Ambition scenario [ENTSO-E, 2022] up to 2030, which we consider as our benchmark. In order to analyse the impact of individual transmission links on the benefits of producers, consumers, and TSOs in each country, we limit the capacity of individual links to a fraction (i.e, 0%, 20%, 40%, 60%, and 80%) of their optimal capacity in the benchmark and solve the model again for the constrained optimum. By comparing the producer surplus, the consumer payments, and the net congestion rent between the optimum and the constrained optimum, we provide insights into the extent to which private incentives from consumers, producers, and TSOs may differ from the incentives of a social planner and how this affects the opportunities to realise the optimal transmission capacity for 2050.
Results:Figures 2, 3, and 4 are examples of how we will analyse the results of our model based-experiment for a hypothetical line between node A and B that are part of a larger network.

Figure 2 shows the congestion rent of the TSO that owns the line between two nodes, nodes A and B in our example, as the capacity restriction is loosened from 0% to 100% of the optimal capacity.

[INSERT FIGURE 2]

Figure 3 shows the change in the consumer payments at node A and at node B, and the sum of the changes in the consumer payment at all the other nodes as the capacity restriction of the line is set at 0%, 20%, 40%, 60%, 80%, and 100% of the optimal capacity.

[INSERT FIGURE 3]

Figure 4 shows the change in the producer surplus at node A and at node B, and the sum of the changes in the producer surplus at all the other nodes.

[INSERT FIGURE 4]

In this particular example, there is a conflict of interest between consumers, producers, and the TSO. The producers at node A and every other node except B do not want line AB to be built. It lowers their producer surplus. The producers at node B have a much lower (marginal) cost of production in this example and will outcompete some producers and lower the rents of other producers. These producers are supported by the consumers at node B who will have a much higher electricity bill if line AB is built. The other consumers at every other node do want this line to be built. The TSO will build this line, but only to 50% of the optimal capacity.

What this (hypothetical) example illustrates is that a line that is beneficial for Europeans on average, will be opposed by producers at one node and consumers at another node, and that the incentive for the TSO to invest is not strong enough as it cannot appropriate all the benefits of the line.

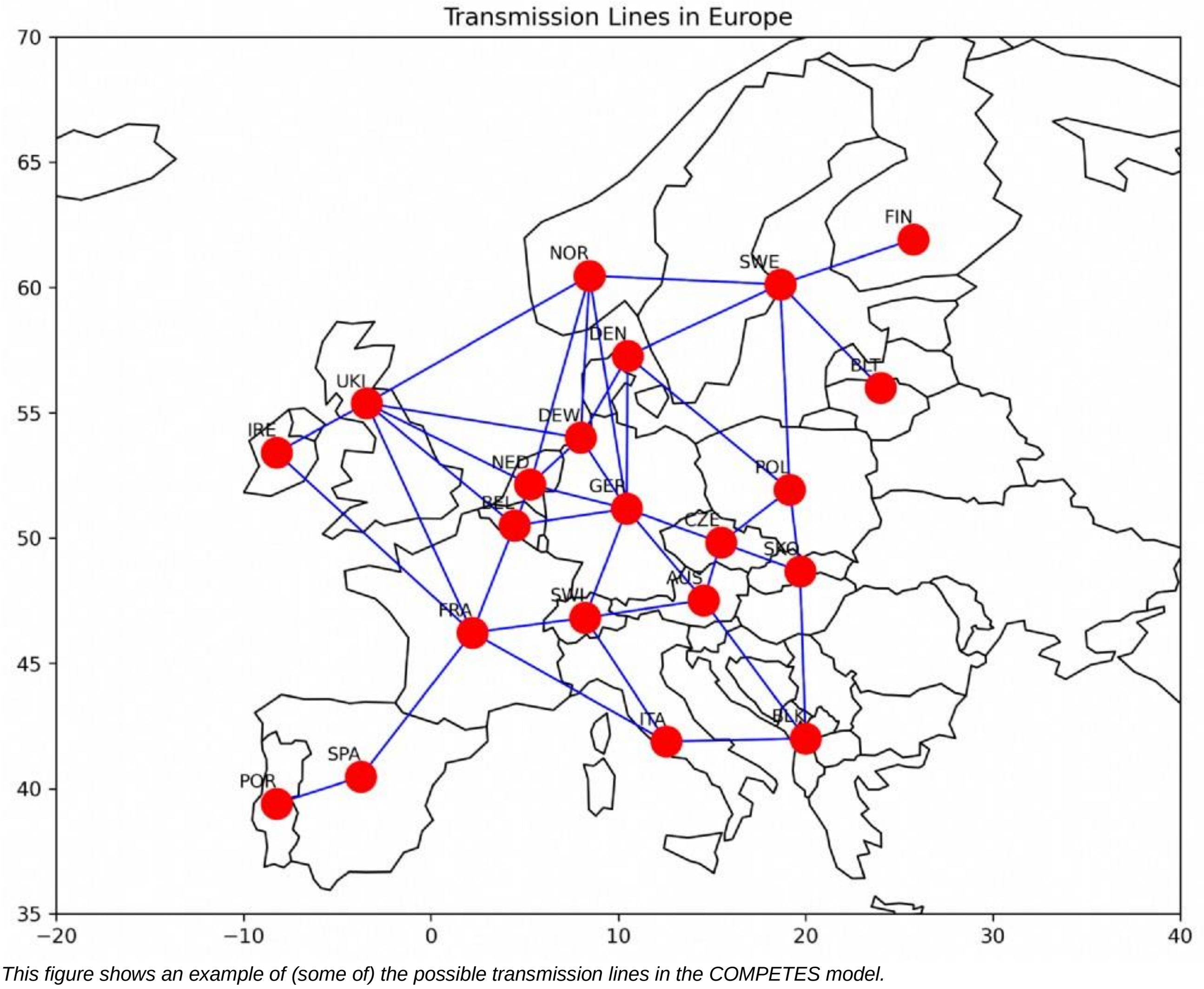
In this paper we will repeat this analysis for each of the lines and show what drives these results. In this case it was the low marginal cost of production at one node, but this is not the only mechanism possible.

Conclusions:At this stage of the submission of the abstract we do not draw any conclusions.

References:Ö. Özdemir, B.F. Hobbs, M. van Hout, P. Koutstaal (2018), Capacity vs Energy Subsidies for Renewables: Benefits and Costs for the 2030 EU Power Market, University of Cambridge, UK (2019) Cambridge Working paper in Economics 1927, Energy Policy Group, https://www.eprg.group.cam.ac.uk/wp-content/uploads/2019/03/1911-Text.pdf

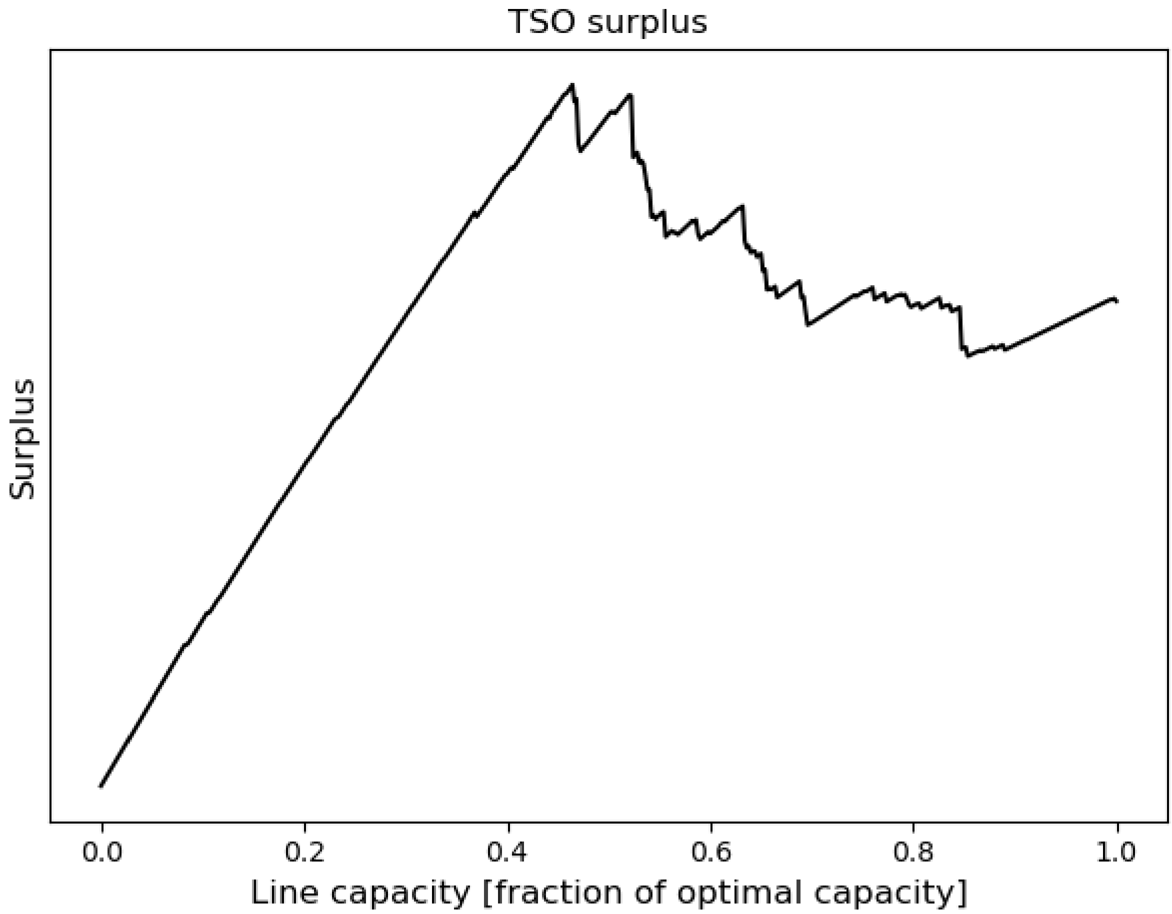
Keywords: Electricity, transmission, capacity expansion, market model, energy transition

Figure 1



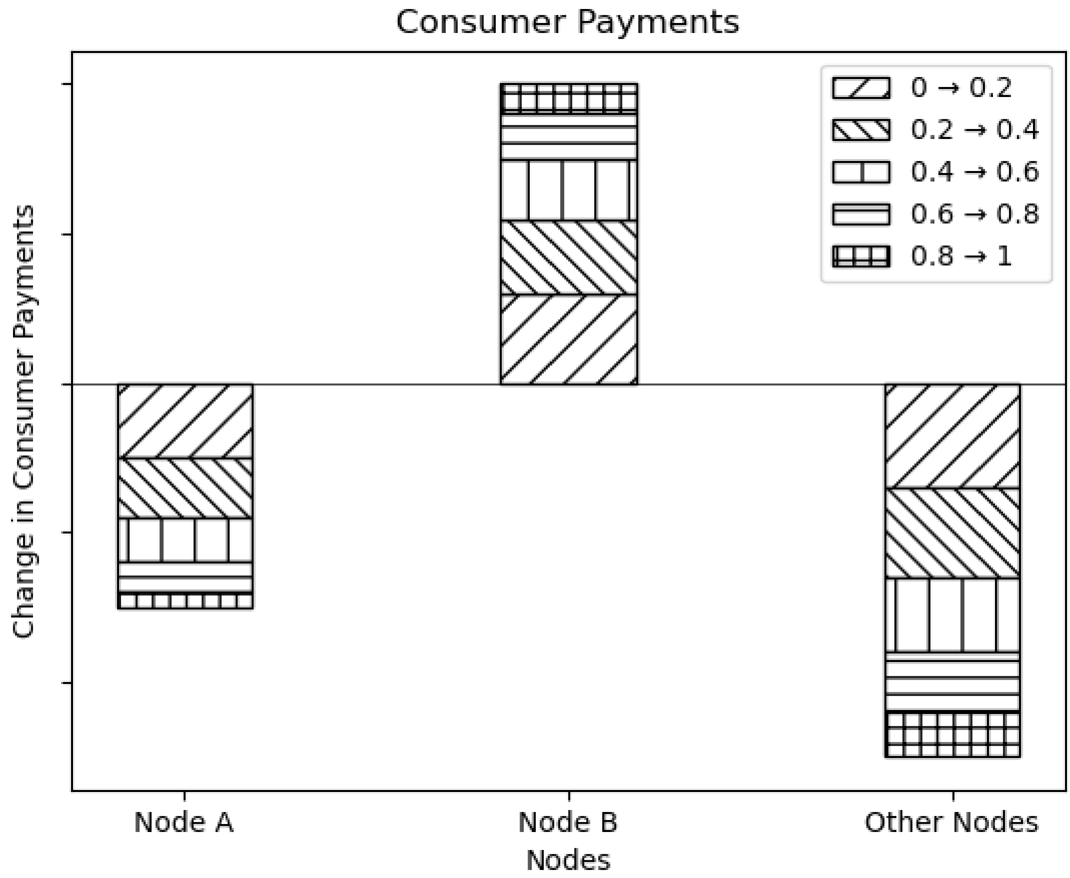
This figure shows an example of (some of) the possible transmission lines in the COMPETES model.

Figure 2



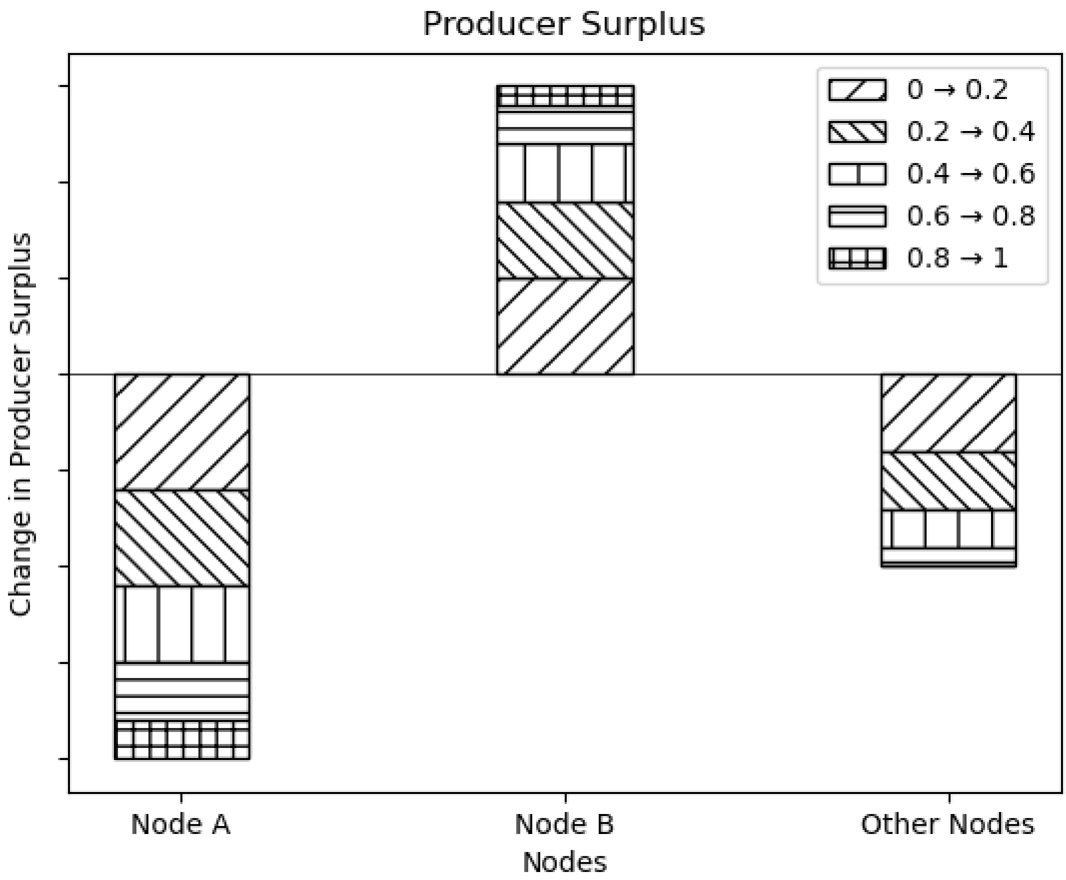
This figure shows the congestion rent or surplus earned by the TSO on line AB and illustrates how we will analyse our results.

Figure 3



This figure shows the change in consumer payments in node A, node B, and all the other nodes together and is an example how we will analyse our results.

Figure 4



This figure shows the change in producer surplus in node A, node B, and all the other nodes together and is an example how we will analyse our results.

AuthorToEditor: We have used a hypothetical example as an illustration of our results, because we felt the results were a bit too preliminary to publicize, even in extended abstract. For the conference we will have vetted the results.

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[Abstract:0402] OP-208 [Accepted:Oral Presentation] [Energy System Transition » Electricity]

Wiring the Future: Uncertainties in European Grid Expansion

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Overview:Investments in the electrical transmission system are crucial to meet European decarbonization goals by 2050. National organisations such as governments, regulators, and transmission system operators, and European organisations such as ENTSO-e, therefore, formulate or evaluate plans that call for investments in the European grid to meet these goals. These plans, however, are based on scenarios about the future. These scenarios are premised on assumptions about the fixed and variable cost of generating electricity, storing electricity and transmitting electricity in addition to assumptions regarding the demand for electricity in 2050 and the policies implemented by national governments. But what if these assumptions turn out to be false? What if the future is different, even if only slightly, from these scenarios?

This question is particularly important because investments in transmission, generation, and storage have different planning horizons. Transmission, generation, and storage assets differ considerably in their economic lifetime and their time to build. Transmission assets, for example, take longer to build than some generation assets and have a longer economic lifetime. Transmission capacity expansion plans therefore have to anticipate which generation assets are profitable to build and where these assets will be built in the next ten but also the next fifty years. Scenarios with assumptions regarding the fixed and variable cost of generation, storage, and transmission can provide some guidance. But it is unclear how sensitive these optimal investments are to (small) changes in these assumptions.

To answer some of these questions, this paper varies the demand for electricity, and the fixed and variable cost of generation, storage, and transmission that can be used to meet future demand. For this analysis, we use a transmission-constrained European power market model, COMPETES. COMPETES is a large-scale optimization model that computes the optimal investment and operational decisions for power generation, transmission, and storage minimising the total power system costs whilst accounting for the generation and cross-border transmission constraints. COMPETES includes 33 European countries represented by 21 nodes (see Figure 1 below).

[INSERT FIGURE 1 HERE]

Our contribution to the literature complements insights by ENTSO-E and other national organisations that make plans and/or evaluate plans that call for investments in the transmission grid. While they provide insights on what investments might be needed to meet European decarbonization goals under sets of consistent assumptions about the future, we provide insight on which of these assumptions might be critical to (optimal) investments in generation, storage, and transmission capacity, and the locations where these investments are realised.
Methods:To answer our question we make use of model-based-experiment. We make use of COMPETES. COMPETES endogenously calculates the least cost transmission, generation, and storage capacity investments. COMPETES uses a two-period optimization approach as described in [Ozdemir et. al. 2018]. Investors of transmission and conventional generation give their investment decisions in the first stage (i.e., 2030) and their generation is dispatched in future electricity markets in the second stage (i.e., 2050). The model minimises total operation and investment costs in the electricity system subject to:

1. Power balance constraints: These constraints ensure demand and supply is balanced at each node at any time;

2. Generation capacity constraints: These constraints limit the maximum available capacity of a generating unit. These also include derating factors to mainly capture the effect of planned and forced outages to the utilisation of this plant;

3. Cross-border transmission constraints: These limit the power flows between the countries for given NTC values;

4. Storage constraints: These constraints represent the operation of storage during the day by charging and discharging;

5. Demand shifting: These constraints represent the shifting of demand within a day from higher to lower price hours.

We first establish a baseline that is based on the input assumptions from ENTSO-E’s Global Ambition scenario. For the baseline, we solve the model for optimal investments in generation, transmission, and storage capacities. We then perform a sensitivity analysis by systematically varying generation cost parameters from the Danish Energy Agency’s Technology catalogue and the electricity demand assumptions from ENTSO-E scenarios. By comparing the changes in generation, storage, and transmission investments compared to the baseline, we can gain insight into which assumptions, if any, are critical to investments in the transmission grid and why these assumptions are critical. Results:Figure 2 and Figure 3 offer an illustration of what kind of results to expect in this paper. Figure 2 shows the European transmission network in 2050 under a baseline greenfield scenario; Figure 3 shows the European transmission network in 2050 but now with very low overnight costs for nuclear generation.

[INSERT FIGURE 2 HERE] [INSERT FIGURE 3 HERE]

The thickness of the transmission lines are scaled and comparable between the two figures: a thicker line indicates more transmission capacity. A comparison between the two scenario's reveals that some lines do not exist under one scenario and do exist under another scenario, the line between Belgium and France is such an example. Other lines are much more important in terms of capacity, such as the line between Norway and Germany.

In this particular example the quantitative differences between the scenario's are also quite large when we look at the change in total transmission capacity and the change in sum of the absolute values of the transmission line capacities when compared to the baseline.

For a more systematic comparison a regression analysis will be used to tease out the effect of changes in individual parameters and their combination.
Conclusions:We have no conclusions to report yet.
References:Ö. Özdemir, B.F. Hobbs, M. van Hout, P. Koutstaal (2018), Capacity vs Energy Subsidies for Renewables: Benefits and Costs for the 2030 EU Power Market, University of Cambridge, UK (2019) Cambridge Working paper in Economics 1927, Energy Policy Group, https://www.eprg.group.cam.ac.uk/wp-content/uploads/2019/03/1911-Text.pdf

Keywords: Electricity, transmission, uncertainty, capacity expansion, energy transition

Figure 1

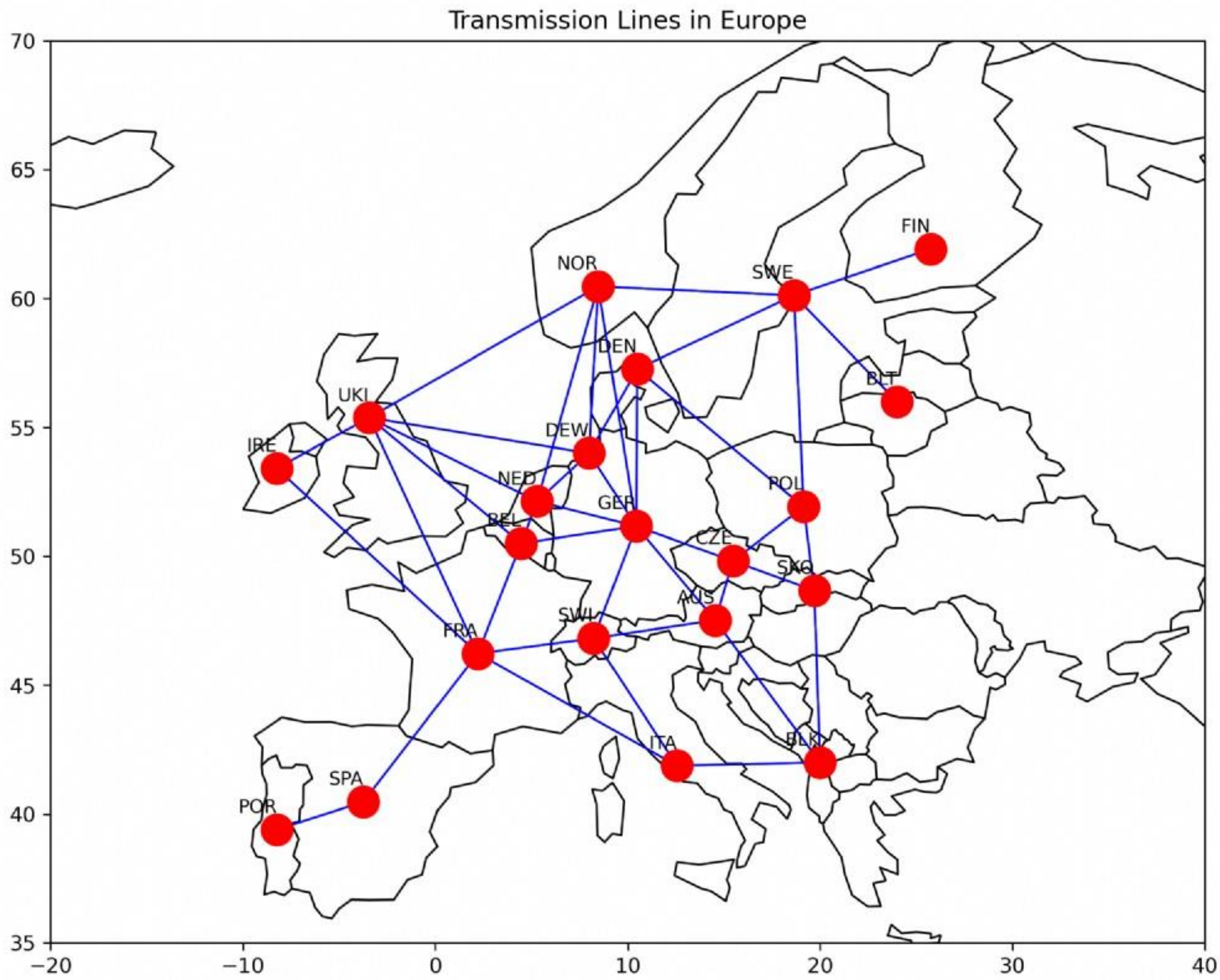

Figure 1 shows an example of the possible links in the COMPETES model.

Figure 2

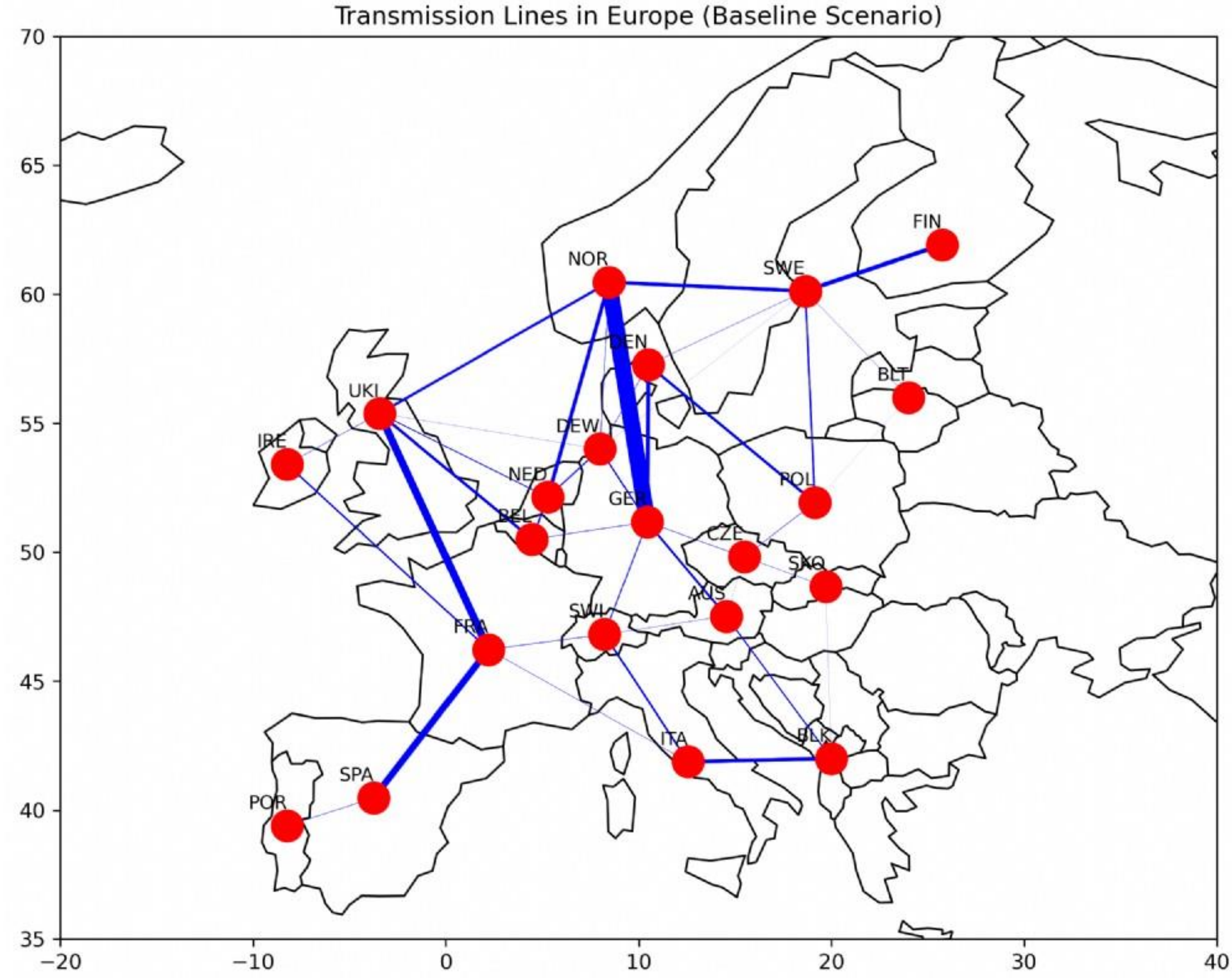

Figure 2 shows the European transmission network under the baseline greenfield scenario.

Figure 3

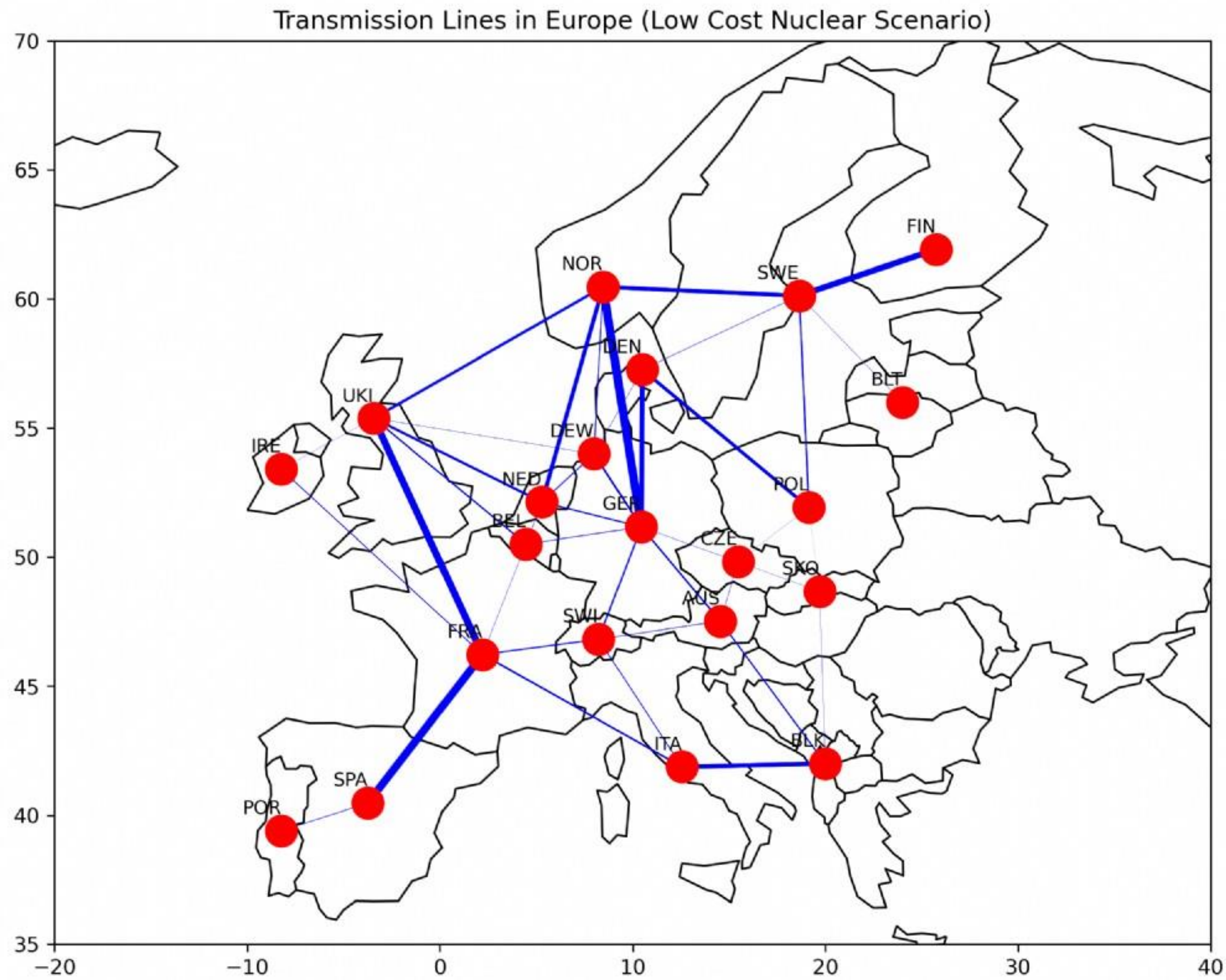

Figure 3 shows the European transmission network under the low cost nuclear greenfield scenario

AuthorToEditor: We do not have many preliminary results to share. For the conference we will have a regression analysis and similar figures to illustrate as those shared here.

[Page: 209]

[Abstract:0628] OP-209 [Accepted:Oral Presentation] [Energy System Transition » Electricity]

Assessing the benefits of flexible load in future power systems

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Overview:Power systems around the world are undergoing massive change. This is happening for a variety of reasons – due to policy, technological change, and as a result of basic economics. Conventional fossil fuel fired technologies are being retired and replaced with a variety of renewable

and carbon-free generation technologies. This tumultuous change is generally referred to as the "energy transition". The ultimate objective for policymakers is to deliver on three basic objectives during this energy transition: provide reliable electricity service that is carbon free (or increasingly lower carbon) while maintaining the relative affordability of electricity for the masses. Achieving all three objectives in a period of disruptive change – and the energy transition is seen as extremely disruptive for many incumbent generation owners and market operators - may be difficult if we continue to focus on just the supply-side factors. In this paper, we will outline the nascent presence of "flexible loads" and how the evolution of demand-side participation in the electricity sector can support system reliability and affordability objectives. We will use real world case studies of system operations and simulation techniques to show the benefits of flexible load integration. We will study a variety of electricity market structure in order to extract lessons learned that can be extrapolated to a variety of economies around the world.
Methods:This paper will used a mix of methodologies. The paper will deploy case study based research to document the universal patterns that are emerging around the world in the energy transition, and identify the challenges that are being raised by stakeholders. Descriptive statistical analysis will be done to identify and categorize the pace of the energy transition and hardships across the major economies around the world. This analysis will also include measurement of the level of demand-side engagement in the electricity sector, in order to provide context around the primary thesis that we are just starting to see new forms of demand participation emerging.
As a second stage of analysis, LEI will select 3-4 jurisdictions with deregulated wholesale electricity markets to study on a detailed system operations basis. LEI will use simulation techniques. Production cost-based and other transmission system simulations models have been used in the power sector for many decades – so the tools that LEI proposes to leverage are well established in the industry. In addition, simulation techniques allow for a dynamic representation of outcomes in the future. We no longer have to necessarily accept that the future will be similar to the past. In other words, simulation techniques allow for analysis of novel technologies and business models in combination with known facts and constraints. The purpose of the simulation-based examination will be to study the impact of flexible loads on system operations (for example, on resilience and reliability of the system), market outcomes (costs to consumers) and policy compliance (for example, achievement of clean energy and/or decarbonization mandates).
Results:LEI's study is ongoing and therefore there are no findings that can be reported at the moment. However, we have identified a number of preliminary observations that we are in the process of studying.

Are there pre-requisites or other conditions that may improve the adoption of flexible loads?

• Flexible loads seek out markets and jurisdictions with low overall tariffs (prices) for electricity. These may not necessarily be the jurisdictions where flexible loads can provide the biggest benefit to the electric system.
• Flexible load may be better suited to power systems that have higher levels of renewables or other forms of intermittent generation - this could be extremely valuable from a social benefit perspective, as power system high levels of renewable penetration generally have increased reliability risks
• Benefit of flexible loads and other forms of demand-side participation will be situationally-specific and impacted given size (demand) and starting supply mix/ natural endowments of a market
• Certain policies and specific market design features may accelerate or inhibit the development and deployment of flexible load

What are the benefits of flexible loads?
• Flexible loads help diversify operational risks associated with weather factors
• Flexible loads may improve system resilience
• Flexible loads responsive to market prices can impact the clearing price of energy and defer certain investment decisions

Are there any negative consequences with flexible loads?

• Depending on scale of load ramping and correlation with other factors, flexible loads may increase costs of system operation under certain conditions
• Flexible loads may not necessarily reduce system-wide carbon emissions
• Depending on rate design, flexible loads may create significant cost shifts to other customers (load) with respect to transmission and distribution costs, as well as fixed costs of generation (depending on how those costs are recovered)
Conclusions:There is a common belief in the electricity sector right now that the cheapest source of power is generated by renewable power plants. However, that perspective ignores consumers' willingness to pay for power when Mother Nature shuts down those resources – when the wind stops

blowing, when the sun sets or clouds roll in, and when drought takes hold of our river systems and drains our dams. Flexible loads can be a valuable complement to renewables for exactly those situations when renewables are not able to generate but many residential and commercial and industrial consumers are still willing to pay handsomely for electricity. This paper will explore the pros and cons of flexible resources, by projecting and analyzing of how this form of demand response would work within future power systems.
References:Julia Frayer is the Managing Director of London Economics International LLC ("LEI"), which is a global economic, financial, and strategic advisory professional services firm specializing in energy and infrastructure. Julia has more than 25 years of experience providing expert insights and consulting services in the power and infrastructure industries. She has worked extensively in the US, Canada, Europe, and Asia on a range of issues in the electricity sector, including market analysis, policy assessment, advisory services around investment and commercial strategy, resource planning, M&A due diligence, and wholesale market design. Julia also has experience with regulatory matters in the electricity sector, including rate design, development of innovative regulations, implementation plans for new policies, performance-based ratemaking, and competition policy reviews.

Keywords: flexible load, future power systems, Energy

[Page: 210]

[Abstract:0594] OP-210 [Accepted:Oral Presentation] [Renewables » Hydroelectricity]

How can tidal range schemes ensure long-term economic sustainability and social benefits considering future energy market uncertainty?

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Overview:The UK government is legally and politically fully committed to achieving net zero emissions by 2050, with a focus on securing, greening and making more affordable the energy supply through a substantial increase in electrification. However, this goal comes with an unprecedented challenge. To meet increasing electricity demand while minimizing greenhouse gas emissions, there has been a strong emphasis on renewable energy sources such as wind and solar power (National Grid ESO, 2021). However, the intermittency of the generation of these renewables implies that there is significant need for flexibility to maintain continuous service in the face of rapid and large swings in supply and/or demand. Various forms of energy storage solutions are amongst possible options to provide flexibility, while each has their own pros and cons in terms of cost, life cycle environmental impacts, and scalability. Tidal Range Schemes (TRSs), such as tidal lagoons and barrages, are renewable generation technologies that can also be operated as grid-scale energy storage facilities.

Operating TRSs as energy generation and storage facilities could increase their revenue through price arbitrage (e.g., control the number of working turbines of TRSs to respond more to peak demand times with higher electricity price, and hence generate more revenue) and providing ancillary and reserve services (i.e., balancing services that ensure the security and quality of electricity supply across UK transmission system, e.g., Fast Reserve, Short-term Operating Reserve, etc.). Delivering such services could provide TRSs with additional revenue streams compared to simply generation and could potentially enhance the economic feasibility of the schemes. However, these schemes normally involve very significant initial capital costs, affecting their economic viability. An assessment of the long-term viability of TRSs will need to accommodate such additional ancillary service revenue

streams. Previous work has considered the viability of TRS within the energy market and arbitrage (Loisel et al., 2018), but none have considered TRS's ability to participate in the ever-growing ancillary services market to provide ancillary and reserve services.

This research aims to explore the research question that whether potential tidal range schemes could get over long-term economic viability thresholds if a fuller range of socio-economic values, including some measure of value of flexibility realised by ancillary services provision and potential societal benefits, were set against the various substantial development costs in the context of future market uncertainties. For this purpose, we use cost-benefit analysis method to explore the answer. In addition to this, we will explore the policy and market instruments (e.g., contracts for difference, feed-in tariffs, etc.) that may be required to support the economic viability of TRS.
Methods:In this paper, a number of generation scenarios regarding modes of electricity generation and whether or not social benefits are considered are analysed using the cost-benefit analysis. A cost-benefit analysis is a systematic process used to measure the benefits and costs of an action, or typically an investment project. It involves evaluating both financial and non-financial metrics, such as revenue, costs, and intangible benefits given some assumed value of parameters, such as discount rate, economic lifespan considered, etc. This analysis helps in determining whether such a project is feasible from a pure economic or a comprehensive social-economic perspective.

To develop the scenarios for the cost-benefit analysis, there are a number of characteristics to consider regarding their various ways of combination. Based on the data information from the stakeholder developers of proposed TRSs in the UK, we summarise them into 3 scale levels in terms of installed capacity (0.2GW, 2.5GW, and 6.5GW), with each level as a representative TRS. All scenarios are applied and analysed to these 3 representative TRSs, and under 3 electricity price profiles (low, medium, and high) as to measure future energy market uncertainty. Different scenarios are mainly distinguished by different electricity generation mode and whether or not social benefits are included.

Specifically, the first scenario considers TRSs operating with maximising electricity generation only, under the 3 price profiles respectively. The second scenario considers operating by maximising revenue through price arbitrage, and the third scenario considers more streams of revenue resulted from ancillary services provided under the 3 price profiles. Based on these, scenario 4 to 6 incorporate the social benefits against the economic costs to each of the first 3 scenarios respectively.

The scenario setting is reflected in these characteristics summarised below:
• 3 TRS schemes (0.2GW, 2.5GW, and 6.5GW)
• 3 price profiles (low, medium, high)
• Maximising generation V.S. maximising revenue V.S. inclusion of ancillary services provision
• Economic benefits V.S. inclusion of intangible social benefits
Results:Table 1 summarises the preliminary results of the first scenario which only considers schemes operating only to maximise electricity generation. It shows that the Net Present Value (NPV) for the three representative schemes with varying installed power capacities (0.2GW, 2.5GW, and 6.5GW) over a 40-year economic lifetime, utilizing a discount rate of 3.5%. The NPV calculations were compared across three electricity price profiles labelled as Low, Central, and High, with respective values of £75.58/MWh, £87.68/MWh, and £105.19/MWh. The results distinctly show negative NPVs across all schemes and price profiles, indicating economic losses for each case. The increase in the electricity price profile from Low to High consistently reduced the magnitude of the losses for each scheme, with the larger installed capacities showing a more significant decrease in negative NPV.

However, it is important to note that this evaluation does not extend to alternative generation modes proposed in further scenarios aimed at maximizing generation revenue through mechanisms such as electricity price arbitrage, nor does it consider the potential provision of ancillary services to the energy market. Moreover, the scenario omits any potential social benefits such as flood defence which could significantly affect the economic assessment. Data collection efforts are underway to integrate these additional values into the analysis. In addition to this, we will explore policy mechanism that could further support the economic outcomes for TRS, as we could see here even with a high price profile the NPVs are still far from the turning point, implying the guaranteed price level and what policy mechanisms could support this is significant in affecting the results. The incorporation of these factors is anticipated to improve the NPV figures substantially, potentially leading to positive valuations that would support the long-term feasibility of varying capacity power generation schemes.
Conclusions:The findings clearly demonstrate that under current price and cost conditions, all three schemes, A, B, and C, are economically infeasible as indicated by their negative NPVs, which represent a loss over the 40-year economic lifetime at a 3.5% discount rate. The least negative NPV

was observed in Scheme A under the High price profile, suggesting that lower capacity installations may incur less financial loss at higher electricity price points.

Furthermore, the trend across the results points to the fact that an increase in electricity prices may mitigate losses but is insufficient to transition the schemes' economic performance into profitability. These outcomes underscore the need for careful consideration of project scale and market conditions when assessing the economic returns for investments in power capacity installations.

Acknowledging the limitations of the current scenario, it is imperative to recognize that the NPVs could be significantly enhanced by considering diversified operation modes maximizing generation revenue and providing additional ancillary services, and potential social benefits such as those associated with flood defence. As this data is being collected and the analysis is yet to be further developed, the incorporation of these revenue streams in addition to any potential policy support is expected to have a notable positive impact on the calculated NPVs, potentially validating the long-term viability of these schemes. The inclusion of such benefits into the overall valuation may further shift the economic narrative, underscoring the multifaceted value of TRSs beyond mere electricity generation.

References:Loisel et al. 2018. Integration of tidal range energy with undersea pumped storage. Renewable Energy 126 (2018) p.38-48. http://doi.org/10.1016/j.renene.2018.03.037. National Grid ESO. 2021. Future Energy Scenarios.

Keywords: tidal range, cost benefit analysis, price arbitrage, ancillary service, social benefits

Table 1. Calculated NPVs of schemes of carrying install power capacities

NPV (discount rate 3.5%; 40 years' economic lifetime)	Electricity price profile (Industrial, £/MWh)		
	75.58	87.68	105.19
	Low	Central	High
Scheme A - Installed power capacity 0.2GW	-1187.14	-1089.59	-948.49
Scheme B - Installed power capacity 2.5GW	-3871.10	-2745.31	-1117.06
Scheme C - Installed power capacity 6.5GW	-9181.58	-6932.63	-3679.91

[Abstract:0202] OP-211 [Accepted:Oral Presentation] [Renewables » Hydroelectricity]

Turbine Selection of Tidal Power Plant using AHP and SMART Methodes

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Overview:The design of a Tidal Power Plant (TPP) generally consists of turbines. The se-lection of this TPP design refers to the conditions present in the coal fired power plant (CFPP) 4 x 315 MW. Optimal selection of the TPP design in-volves choosing the best types of turbines using the Analytical Hierarchy Pro-cess (AHP) and Simple Multi Attribute Rating Technique (SMART) methods. The AHP method is one of the decision-making methods using a hierarchy. The first step is to determine the criteria for comparison for both turbines. The selection criteria for turbines include installability, affordability, operatibility, environability. The subsequent step involves gathering data regarding the choices for turbines. The turbine options considered are Savonius turbine and arrieus turbine. The final step is distributing a questionnaire to experts in marine energy and utilize SMART method. The calculation results yield the sequence of turbine choices as follows: savonius turbine, darrieus turbine. Consequently, the TPP design to be constructed in CFPP will utilize the savonius turbine.
Methods:Based on condition tidal current speeds approximately around 0.5 - 2.5 m/s in the waters of canal outfall cooling water CFPP, technology selected in VAHT is darrieus and savonius.
The Analytical Hierarchy Process (AHP) is one of the decision-making methods that prioritizes various options based on specific criteria. AHP method is grounded in structured organization.
The Simple Multi Attribute Rating Technique (SMART) is utilized to support turbine selection, wherein the determination of weights for each criterion is achieved using the AHP method. Additionally, the best-ranking tidal turbine are identified through the SMART. AHP and SMART is part of multi criteria decision making as qualitative methode.
This study is based on data obtained from the tidal currents in the waters of the canal outfall CFPP 4 x 315 MW with tidal turbine selected using AHP and SMART methods. This area has inadequate electricity supply, and its surrounding waters have high tidal current speeds, making it suitable for harnessing TPP.
Results:The analysis of turbine selection criteria involves evaluating and examining the criteria used to select turbines. This process includes assessing factors such as power generation installability, affordability, operatibility, and environmentability. The consistency ratio from processing the questionnaire is 2.7%, indicating con-sistent questionnaire results. The questionnaire processing resulted in the order of criteria and their values as follows: installability (0.35), affordability (0.22), Operability (0.28), environmentability (0.15).

Determining utility values by SMART methode. At this stage, we need to consider the nature of each criterion, including whether it follows the 'bigger is better' or 'smaller is better' type. Savonius turbine has 0.87 as final value which is bigger than darius turbine 0.73
Conclusions:1. Based on studied, there is potential of energy from the tidal currents in the waters of the canal outfall CFPP 4 x 315 MW.
2. Criteria values as follows: installability (0.35), affordability (0.22), Operability (0.28), environmentability (0.15).
3. Savonius turbine is the selected alternative tidal turbine that applicable in the canal outfall CFPP 4 x 315 MW.
4. Several challanging of tidal turbine from operation maintenance scheme to determine in the next reliability scenario for tidal power plant in the life cycle asset.
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Keywords: Renewable Energy Resources, Tidal Power Plant, Multi Criteria Decision Making

[Abstract:0024] OP-212 [Accepted:Oral Presentation] [Energy and the Environment » Non-Greenhouse Gas Emissions]

Decomposition analysis of household air pollutant emissions in West Africa: Cases of Ghana and Nigeria

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Overview:Recently, issues about the environment have been pivotal to research and policy due to the global goals to achieve sustainability. The school of thought that economic growth and the pursuit of other economic goals should not come at the expense of the environment and the natural resources needed for achieving economic and welfare goals has become popular; thus, prompting actions in favor of environmental sustainability. The Paris Agreement, for instance, set the goal to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels and aims for net zero emissions by 2050. To this end, there is a focus on reducing greenhouse gas emissions, and increasingly, researchers and policymakers are paying attention to global and territorial air quality. Several studies have focused on carbon dioxide (CO2) emissions and their association with economic growth, other macro-level economic variables, and household welfare indicators. Besides CO2, however, there are other pollutant emissions, particularly at the household level, but have received little attention in the literature compared to the attention received by CO2. One of the common emissions at the household level, especially in developing economies, is fine particulate matter (PM2.5). Recently, air pollution, mainly by PM2.5, is recognized as the second most significant risk factor for death in Africa after malnutrition and more than 63% of premature deaths were estimated to be linked to exposure to household air pollution. Even though observations of PM2.5 are still very limited, the West African region experienced one of the highest ambient and indoor PM2.5 pollution in Africa. The considerably large proportion of residential energy in Ghana and Nigeria sourced from biomass opens these two countries up for high pollutant emission levels from the residential sector. While knowledge on the effects of these pollutant emissions on household welfare or macroeconomic variables is increasing due to previous research, there is a dearth of knowledge and literature on the constituting sources of these pollutant emissions, particularly the household or residential sector emissions in developing countries. Furthermore, more could be done concerning empirical literature on pollutant emissions from the residential sector with regard to pollutants other than PM2.5. This study aims to decompose energy-related air pollutant emissions from the residential sector in Ghana and Nigeria, focusing on PM2.5, nitrogen oxide (NOx), and non-methane volatile organic compounds (NMVOC). The main contribution of this study is to clarify the driving factors of multiple air pollutant emissions in the residential sector and in West Africa, where residential air pollution is a severe environmental and health issue. We focus on Ghana and Nigeria for our analysis because they are among the largest economies in West Africa, from which other countries in the sub-region could draw lessons to reduce energy-related air pollutant emissions at the national scale. Methods:This study applied the logarithm mean Divisia index (LMDI) approach of index decomposition analysis (IDA) to decompose several types of energy-related air pollutant emissions

from the residential sector in Ghana and Nigeria (Shigetomi, 2018). This study focuses on PM2.5, NOx, and NMVOC as air pollutants. The study period is from 1990 to 2018 and is informed by data availability. To understand the factors that affect energy-related air pollutant emissions from the residential sector in Ghana and Nigeria, we first decomposed the emissions by four variables (final energy demand by energy source, total final energy demand, population, and the number of households) as shown in Eq. (1). Based on Eq. (1), we decomposed changes in air pollutants from the residential sector into five different factors: emission intensity (emission intensity effect), the share of each energy source (energy type effect), energy intensity (energy intensity effect), household size (household size effect), and the number of households (household effect). We identified each effect by Eqs. (2)–(7), which are the multiplicative form of the LMDI approach. Eq. (2) shows the total effect, Eq. (3) shows the emission intensity effect, Eq. (4) shows the energy type effect, Eq. (5) shows the energy intensity effect, Eq. (6) shows the household size effect, and Eq. (7) shows the household effect.
We collected data for the above variables from the Emissions Database for Global Atmospheric Research (European Comission), the World Energy Balances (International Energy Agency), the World Development Indicators (the World Bank), and the database of the Helgi Library.
Results:Figure 1 shows the results of decomposition analysis for PM2.5 in Ghana and Nigeria (similar trends were found for the other pollutants). In Ghana, pollutant emissions increased until 1999 compared to the 1990 level, but the emissions decreased since then. In 2018, the emissions had fallen to 44–72% of the 1990 levels. By contrast, in Nigeria, pollutant emissions continuously increased since 1990 and reached 180–199% of the 1990 levels in 2018. In both countries, the household effect is the main effect of increasing pollutant emissions: 236% in Ghana and 261% in Nigeria in 2018 compared to the 1990 levels. These results suggest that PM2.5 emissions have increased with increases in the number of households. The household size effect, which showed a constant reduction, is a factor in decreasing emissions: 85% in Ghana and 79% in Nigeria in 2018 from the 1990 levels. The emission intensity, energy type, and energy intensity effects showed different trends in these two countries. In Ghana, these three factors, especially the emission intensity and energy intensity effects, are essential decreasing factors. In contrast, they are stable (a slight decrease or increase was observed) in Nigeria. In Ghana, the emission intensity and energy intensity effects were fairly constant until 1999 but started to decrease since then and reached 54% and 61% of the 1990 level in 2018, respectively. Similarly, the energy type effect was constant until around 2000 but decreased since then, reaching 74% in 2018. These results suggest that Ghana experienced a shift in energy sources from more air-polluting (i.e., biomass energy) to less air-polluting (i.e., fossil fuels and electricity) and successfully reduced the emission intensity, whereas such a shift did not happen in Nigeria. In Ghana, although the household effect worked to increase PM2.5 emissions, other factors contributed to emission reduction and successfully realized the reduction. By contrast, in Nigeria, compared to Ghana, the emission intensity, energy type, and energy intensity effects were not enough to realize a decrease in PM2.5 emissions.
Conclusions:This study examined five socioeconomic drivers for three energy-related air pollutants from the residential sector in Ghana and Nigeria from 1990 to 2018 using IDA. In addition, we compared the similarities and differences in the driving factors of the two countries that showed different emission trends. Our findings suggest that energy-related policy has a considerable impact on the trends of air pollutant emissions. To further reduce emissions or change the trends of emissions to decline, it is recommended that both countries, especially Nigeria, improve emission intensity, energy intensity, and the sources of energy used. These can be achieved mainly by substituting low-polluting fuels for high-polluting ones. The Nigerian government's recent attempt to scrap kerosene subsidies is a good policy to dissuade the patronage of kerosene. However, for the benefits to be better realized, it is recommended that the subsidies be re-directed at liquified petroleum gas (LPG) consumption instead, which is a lower-polluting energy source, particularly for rural and deprived areas. Beyond direct price subsidies for LPG, other interventions for consideration are improving the LPG supply infrastructure in these underserved areas to promote high uptake by rural communities. Further, more action is needed to extend electrification to the large population in Nigeria without access to electricity to discourage the use of dirtier alternatives in the absence of electricity. This would reverse the upward trend of pollutant emissions in Nigeria. Meanwhile, it is recommended that Ghana sustained its current electrification policies to achieve a 100% electrification or universal access within the shortest possible time while exploring other means of increasing LPG penetration since it currently lags behind its target of a 50% penetration rate by the end of 2020. This would be crucial to maintaining the decreasing trends in pollutant emissions observed in the country. For both countries, it is recommended to increase investments in renewable electricity, make it affordable for households, and push through energy transition from biomass and fossil fuels, especially as renewable resources exist in abundance in Ghana and Nigeria. This will go a long way to reducing air pollutants from the residential sector.
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Keywords: Index decomposition analysis, air pollutants, residential sector, sub-Saharan Africa

Equations

$$TPE = \sum_i PE_i = \sum_i \frac{PE_i}{E_i} \times \frac{E_i}{TE} \times \frac{TE}{P} \times \frac{P}{H} \times H = \sum_i PEI_i \times ET_i \times EI \times HS \times H, \quad (1)$$

$$D_{(t)}^{Total} = \frac{TPE_{(t)}}{TPE_{(0)}} = D_{(t)}^{PEI} \times D_{(t)}^{ET} \times D_{(t)}^{EI} \times D_{(t)}^{HS} \times D_{(t)}^{H}, \quad (2)$$

$$D_{(t)}^{PEI} = \exp\left(\sum_i \frac{(PE_{i,(t)} - PE_{i,(0)})/(\ln PE_{i,(t)} - \ln PE_{i,(0)})}{(TPE_{(t)} - TPE_{(0)})/(\ln TPE_{(t)} - \ln TPE_{(0)})} \ln\left(\frac{PEI_{i,(t)}}{PEI_{i,(0)}}\right)\right), \quad (3)$$

$$D_{(t)}^{ET} = \exp\left(\sum_i \frac{(PE_{i,(t)} - PE_{i,(0)})/(\ln PE_{i,(t)} - \ln PE_{i,(0)})}{(TPE_{(t)} - TPE_{(0)})/(\ln TPE_{(t)} - \ln TPE_{(0)})} \ln\left(\frac{ET_{i,(t)}}{ET_{i,(0)}}\right)\right), \quad (4)$$

$$D_{(t)}^{EI} = \exp\left(\sum_i \frac{(PE_{i,(t)} - PE_{i,(0)})/(\ln PE_{i,(t)} - \ln PE_{i,(0)})}{(TPE_{(t)} - TPE_{(0)})/(\ln TPE_{(t)} - \ln TPE_{(0)})} \ln\left(\frac{EI_{(t)}}{EI_{(0)}}\right)\right), \quad (5)$$

$$D_{(t)}^{HS} = \exp\left(\sum_i \frac{(PE_{i,(t)} - PE_{i,(0)})/(\ln PE_{i,(t)} - \ln PE_{i,(0)})}{(TPE_{(t)} - TPE_{(0)})/(\ln TPE_{(t)} - \ln TPE_{(0)})} \ln\left(\frac{HS_{(t)}}{HS_{(0)}}\right)\right), \quad (6)$$

$$D_{(t)}^{H} = \exp\left(\sum_i \frac{(PE_{i,(t)} - PE_{i,(0)})/(\ln PE_{i,(t)} - \ln PE_{i,(0)})}{(TPE_{(t)} - TPE_{(0)})/(\ln TPE_{(t)} - \ln TPE_{(0)})} \ln\left(\frac{H_{(t)}}{H_{(0)}}\right)\right), \quad (7)$$

where TPE is total pollutant emissions ($PM_{2.5}$, NO_X, or NMVOC) from the residential sector of each country (kt), PE_i is pollutant emissions by energy source i (biomass, fossil fuels, and electricity: kt), E_i is household final energy demand of energy source i (TJ), TE is total final energy demand of the residential sector (TJ), P is the number of population, H is the number of households, PEI_i (= PE_i / E_i) is the emission intensity, ET_i (= E_i / TE) is the share of energy source i in total energy demand, EI (= TE / P) is energy intensity, HS (= P / H) is the household size (or the number of people in each household), subscripts (t) and (0) indicate the target year (from 1990 to 2018) and base year (1990), respectively.

Eqs. (1)-(7)

Figure 1

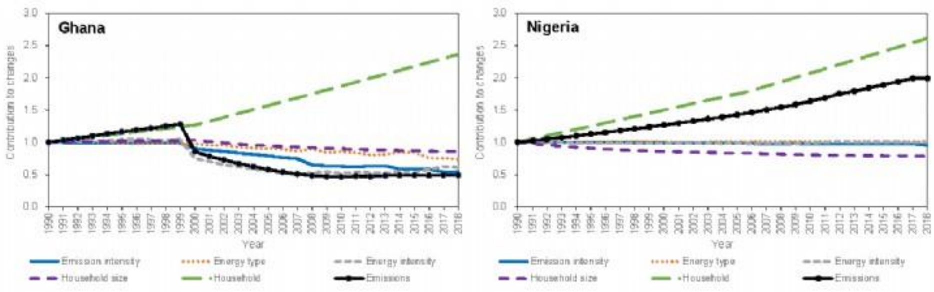

Fig. 1. $PM_{2.5}$ emissions and the driving factors of the emissions.

PM2.5 emissions and the driving factors of the emissions.

[Abstract:0266] OP-213 [Accepted:Oral Presentation] [Energy and the Environment » Circular Economy]

Social and Economic Impacts of E-Waste Recycling: The Case of Mobile Phones with the Cost of Carbon

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Overview:The importance of e-waste, including discarded electronic devices, is immense due to its economic and environmental value as an urban mine. Of particular note are discarded cell phones, of which there are approximately five billion in use worldwide and which have a shorter replacement cycle than other electronic products. Metals, which retain their inherent quality even after deformation, are driving intense research into extraction and recycling technologies. As evidenced by South Korea's 2021 K-Circular Economy Implementation Plan to achieve carbon neutrality through the Ministry of Trade, Industry and Energy, e-waste recycling plays a critical role in shaping environmental policy, with a focus on promoting metal resource recycling. Measures such as tariff exemptions on waste materials (e.g. printed circuit boards) aim to promote metal resource recycling for carbon reduction. However, research on the carbon reduction effect of metal resource recycling through e-waste recycling is limited.
The purpose of this study is to compare the carbon dioxide emissions generated by the recycling process of printed circuit boards (PCBs) from end-of-life mobile phones with the emissions generated by traditional mining and refining processes. Through this comparison, the study investigates the reduction of carbon dioxide emissions during the recycling process and conducts a cost-benefit analysis to assess the economic feasibility of the recycling process. The PCB recycling process was taken from the paper by Pokhrel et al. (2020). The traditional gold mining and refining process was referenced from the paper by Chen et al. (2018), and the process by Hong et al. (2018) was also referenced.
The results of the LCA study showed that the PCB recycling process emits more carbon dioxide when recovering metals than conventional processes. Based on South Korea's 2018 energy mix, it was found that recycling one ton of PCBs emits an additional 3.83 kg of carbon dioxide. The cost-benefit analysis showed a B/C value of 1.95. However, considering the problem of securing high quality PCBs, the fact that most PCBs are exported to China, and the cost of environmental issues such as lead and mercury generated in the recycling process, the B/C value is suggested to be lower.
Methods:This study used the environmental assessment method known as Life Cycle Assessment (LCA). LCA allows for the evaluation of environmental impacts at all stages of a product's life, including impacts on air, water, and soil. The basic structure of LCA includes setting objectives and scope, conducting inventory analysis, assessing impacts, and interpreting results. In the Scope and Objectives phase, the subject and scope of the study are determined, and criteria for substances to be included in the LCA are established. The inventory analysis phase collects data on the processes, resources, energy, chemical inputs and outputs, and by-products within the scope of the study. In the impact assessment phase, the Life Cycle Inventory (LCI) based on inputs and outputs is used to perform the environmental impact assessment. In the final results interpretation phase, the results of the inventory analysis and impact assessment are interpreted to allow for a step-by-step analysis. In addition, this study compares, under the same conditions, the internally generated LCI data for the energy mix and the increased share of renewable energy in the 2030 energy mix in South Korea, where the mix has a higher share of renewable energy compared to the 2018 power generation mix. In this study, a cost-benefit analysis of the recycling process of printed circuit boards (PCBs) from discarded mobile phones is conducted. PCBs are assumed to be recovered from mobile phones and laptops containing high precious metals, with a yield of 0.04 wt% based on Park et al. (2018). The PCB recycling plant is based on a facility in Taiwan, which processes 700 kg of PCBs per hour with a work schedule of 8 hours per day for 5 employees. In addition, the study includes the cost of purchasing carbon emission rights for the additional carbon dioxide generated in the PCB recycling process. Imports are limited to gold and copper, which are the focus of the LCA evaluation and are considered to be the main sources of income for the recycling of 1,400 tons of PCBs per year at the plant. The prices of gold and copper were set as the 5-year average prices in the KITCO Jintuo precious metals market, which were analyzed as fixed values. A social discount rate of 4.5% was applied, and the analysis period was set at 20 years. In addition, sensitivity and scenario analyses were conducted, considering changes in gold prices and PCB supply as variables affecting the plant's operating rate.
Results:In summary, this study conducted a comparative analysis of carbon dioxide emissions from the printed circuit board (PCB) recycling process and traditional metal mining and refining processes

by uniformly applying Korea's Life Cycle Inventory (LCI) data. According to the study results, even with an increased share of renewable energy in the 2030 energy mix, carbon dioxide emissions from the PCB recycling process were higher than those from traditional mining and refining methods. Based on 2018 data, recycling one ton of PCBs resulted in an additional 4.21 $x10^3$ kg of carbon dioxide emissions, and in the 2030 scenario, an additional 2.13 $x10^3$kg of carbon dioxide emissions were observed. However, applying the 2030 energy mix to the primary energy source, electricity, used in the recycling process resulted in a 44.48% reduction in carbon dioxide emissions compared to 2018. This indicates that the recycling process of discarded mobile phones and e-waste does not contribute to carbon reduction and could even lead to additional carbon emissions.
The economic evaluation of the PCB recycling process showed a favorable B/C ratio of 1.95 through a cost-benefit analysis. However, contrary to the results of the study, it was pointed out that private investment in the domestic e-waste industry is limited and the industry is largely dependent on the form of government investment. A sensitivity analysis was conducted using the change in the price of gold, which accounts for the majority of imports during the PCB recycling process, and the supply of PCBs as variables. When the price of gold decreased by half, the B/C value decreased significantly to 1.12. It was also found that if the annual PCB recycling scale is less than 273 tons, the B/C value falls below 1. The results of the cost-benefit analysis showed that the price of gold greatly influences PCB recycling, and a stable supply of high-quality PCBs is necessary for economic feasibility.
Conclusions:The recycling process of waste mobile phones was found to contribute to additional carbon emissions rather than carbon reductions. This highlights the need for environmental impact assessment studies of recycling as part of global low-carbon policies, extending beyond WEEE to processes such as plastics and fuel recycling. However, this study assumed full recycling of collected waste mobile phones and conducted a comparative analysis of carbon dioxide emissions with traditional metal mining and refining methods, excluding consideration of disposal methods such as landfilling and incineration for discarded mobile phones and other electrical and electronic products. Subsequent research should examine landfill and incineration volumes and conduct additional environmental impact assessments to compare with recycling processes.
The economic evaluation of the PCB recycling process showed a favorable cost-benefit ratio of 1.95. However, this study assumed a stable annual supply of 1,400 tons of recyclable waste mobile phone PCBs. According to a previous study conducted by Roland and Blass (2010), recycling of e-waste mobile phones was found to have low economic viability due to high recovery costs. According to the Korea Electronics Recycling Cooperative's 2021 annual report, the amount of collected waste mobile phones is estimated to be 53 tons, and the amount of PCBs is estimated to be about 6 tons, indicating a shortage of supply compared to the assumed amount. It is expected that it will be difficult to meet the annual amount of 1,400 tons, even if PCBs from other electrical and electronic products are recycled in addition to waste mobile phones. In addition, this study did not assume changes in electricity costs due to the transition to renewable energy, the cost of carbon emission rights, and the cost of refining additives. Even including high-value PCBs from laptops and computers, it seems challenging to secure an annual supply of more than 273 tons of PCBs in South Korea.
Currently, most PCB recycling is done with mixed PCBs. This results in lower recoveries of valuable metals such as gold and copper than assumed in this study, which has a significant impact on revenues. As with separate waste collection, PCBs should be separated and disposed of based on their valuable metal content to gain advantages in the recycling process.
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Keywords: Recycling, Waste Mobile Phone, Life Cycle Assessment, Cost-benefit analysis, Cost of Carbon

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[Abstract:0359] OP-214 [Accepted:Oral Presentation] [Energy and the Environment » Energy-Water Nexus]

How is climate change going to impact our energy supply? Empirical evidence from Poland

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Overview:The effect of climate change in the form of higher volatility in weather patterns is increasingly observable. Extreme weather events such as heatwaves in Europe or freezing temperatures in the US have become now a common occurrence. The extremity of these weather patterns often has a negative impact on the power supply. Recently, in Texas, the extreme low temperatures froze the natural gas pipes, which lead to widespread disruptions in the supply of natural gas to power plants resulting in state-wide outages. Similarly, western US experience power disruptions due to wildfires. In Poland and much of Europe, climate change has manifested itself in the form of unprecedented heatwaves in the last few decades.

This paper aims to answer two main research questions in the context of Poland 1) How does extreme weather in the form of heatwaves affect power generation and distort electricity supply? 2) What is the welfare cost of these supply side distortions? Thus, we demonstrate a previously unstudied channel through which climate change induced weather volatility may impact the energy supply. To that aim we use novel high-frequency data on Poland's electricity sector, weather, and climate patterns from 2015 to 2023 and apply a difference-in-difference estimation strategy, to demonstrate that heatwaves induce unplanned shutdowns at power generation plants, and cause loss in welfare.

In Poland - a country with 19 C average summer temperature - maximum daily summer temperature in 2015 exceeded 35 C over 14 consecutive days (Sobik, Polish Report, 2018). The hotter days were accompanied by lack of wind and an increase in demand for electricity (through the use of air conditioning) put yet additional pressure on the electricity grid. Polish government asked the energy consumers to reduce the use, over 8000 companies were asked to temporarily cease production. Consequently, Poland faced a threat of countrywide power outage as the unplanned outages reached the 20% of electricity demand. The heatwave that occurred in Europe in 2015 is not an isolated incident, in fact, maximum temperature reports have been exceeded multiple times in the last decade.

The structure of Polish electricity production has traditionally been dependent on hard coal and lignite and continues to be (25% lignite and 54% of hard coal in 2021). The rest of the supply consists of gas (9%), wind (10%) and imported power from the EU if needed. As extreme weather events become more frequent, it is important to understand how they will affect the electricity supply, especially in the coal dependent countries such as Poland, India, China and others.

This paper will contribute to two literatures: i) welfare effects of climate change induced extreme weather events, and ii) effect of supply side distortions in energy supply. There is profound interest in understanding the many pathways through which climate change can cause loss in welfare but the empirical evidence is lacking in the context of energy systems (Cronin et al, (2018)). Majority of the existing papers focus on the effects of hurricanes or floods in the context of real estate and infrastructure, while the few papers on weather volatility induced outages such as Alemazkoor et al. (2020) are not economic in nature. Thus, to our knowledge this is the first paper to calculate welfare

losses accruing from energy system inefficiencies due to climate change induced extreme weather. The paper will also contribute to the literature on the factors affecting the supply side (Davis and Wolfram (2012), Cicala (2015)) and provide evidence for a climate change induced channel that affects power generation.

Methods:This paper uses comprehensive high frequency data from several sources. Firstly, we use data on power plant power outages, hourly electricity generation and capacity at the plant level. The data categorizes outages as planned or unplanned with corresponding reason for each outage. This data is obtained from the European Network of Transmission System Operators for Electricity (ENTSOE). Secondly, we merge our hourly electricity generation data with rich weather data from public meteorological monitors (air temperature, wind speed, wind direction) and hydrological monitors (water temperature, water height) from the State Institute of Meteorology and Water Management. The latter consists of the 200 public weather monitors spread across Poland. Data on air temperature and meteorological variables is reported three times a day (6am, noon, 6pm), in case of water related data such as water temperature – at the daily level. We merge the two datasets based on the nearest neighbour index. We complement our analysis with pollution data observed by the public pollution monitors from Chief Inspectorate of Environmental Protection, which report particulate matter (PM 1.0) at the daily level.

The empirical strategy consists of two parts. In part one we use a difference-in-difference strategy using geographical variation in intensity of the heatwaves experienced by the coal power plants in Poland and summer vs. winter season variation as used by Deschenes, Greenstone and Shapiro (2017, AER). In part 2, we use novel variables "water temperature" and "water height" to investigate as a cause for unplanned power outages. We employ latest advances in DID literature such as ‘Honest DID’ (Rambachan & Roth (2020)) to put bounds on the impact estimates.

Results:Our results show that heatwaves significantly reduce the efficiency of coal power generation and increase probability of generation outage by 21% in the summer season. The mechanism is through increase in water temperature but not decrease in water supply that lends the water supply unsuitable for use in power generation. More specifically the coefficients on water height remain statistically insignificant in all the model specifications. In contrast, we also find that if water temperature (instrumented by air temperature) increases by 1 Celsius degree, then the probability of an outage increases by 1-4%. Heteorgeneous analysis shows that for some parts of the country that this water temperature power outage probability increases by 17%, while the electricity generation can reduce by 14%.

Conclusions:Climate change is altering the way we are planning for our future and this includes energy supply. Fossil fuel powered generation is a significant contributor to climate change, and yet, we show in this paper, it itself faces high risks from climate change induced weather patterns. The empirical evidence from this paper will further underline the threats posed by climate change.In the next step, we will estimate welfare costs by conducting alternative policy scenarios and will rely on comparing cost of generation within Poland to prices of imported power from outside Poland.

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Keywords: power outage, water temperature, water height, difference-in-difference

[Abstract:0193] OP-215 [Accepted:Oral Presentation] [Energy and the Environment » Carbon Capture, Utilization and Storage]

Emerging Energy Economics and Policy Research Priorities for Enabling Carbon Capture and Storage

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Overview:-

We highlight key emerging research priorities for enabling the carbon capture and storage (CCS) sector using a three-pronged approach. It includes examining journalistic reports from a research perspective, corroborating the determined research priorities with recent literature, and consulting a diverse group of experts in policy, energy, economics, and industrial applications fields. We delineate ten overarching themes that correspond to distinct research challenges and prospects. Specific emerging research issues related to – (i) a comprehensive analysis of global CCS policies and their consequential impacts; (ii) an assessment of the economic and financial aspects pertinent to the establishment and operation of DAC facilities; and (iii) a critical examination of the challenges leading to, and the implications of, the closures in CCS projects – received particularly high scores, computed by integrating expert ratings on importance in enabling the CCS sector, novelty and feasibility using a multi-criteria decision-making framework. Pursuing this new research agenda should help inform policymakers, and industry decision makers to ensure a smooth ride towards CCS enablement.

Methods:-

We first derive overarching themes by summarizing and categorizing the wide-ranging scope of recent media investigations pertaining to the CCS sector reported in Bloomberg New Energy Finance (BNEF) news between June 2022 and June 2023. We start off with media reports as they frequently shed light on nascent industry, energy economics, policy, and sustainability issues before they are thoroughly examined in scholarly literature. This can be attributed to the delays inherent in securing research funding and the time-consuming peer-review process that characterizes academic publishing. Furthermore, media reports frequently incorporate perspectives from non-academic stakeholders, often underrepresented in scholarly articles. Finally, we delineate specific research challenges and priorities that require more thorough consideration by applying an energy economics and policy research lens (including academic and industrial) on the formulated emerging themes.

We solicit expert opinions to prioritize the identified research challenges surveying a diverse group of international experts in policy, energy, economics, and industrial applications fields. The participants were asked to evaluate the identified research challenges and opportunities using a Likert-type (one to five) scale, assessing their importance, novelty, and feasibility. The respondents were also asked to rate the significance of each criterion, i.e., importance, novelty, and feasibility, relative to one another. Furthermore, data was gathered pertaining to the professionals' affiliations with either non-profit or for-profit entities, their educational credentials, years of experience in the CCS sector, and their level of familiarity with the research subjects under examination in this survey.

The expert survey results were analyzed using a multi-criteria decision making (MCDM) framework. AHP (Analytic Hierarchy Process) (Saaty 1988) was used to calculate the weight scores for the three criteria – importance, novelty and feasibility – by having respondents make a series of pairwise comparisons. TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) (Hwang et al. 1981) was used to rank the different alternatives based on their normalized scores – a measure of the extent of similarity between alternatives and the hypothetical ideal solution (with importance, novelty and feasibility ratings of five each) - considering AHP-based criteria weights. Given the subjective nature of the expert survey, it would have been better to use AHP for both deriving weights for criteria and ranking alternatives. From a time perspective, however, requiring respondents to make pairwise comparisons between twelve alternatives appeared impractical. A sensitivity analysis was performed using three different schemes to calculate the weighted average of the ratings given by the experts for use in the TOPSIS framework, including: (i) equal weighting, (ii) experience-based weighting, and (iii) familiarity-based weighting.

Results:-

Table 1 displays the identified set of contemporary research challenges, their respective rankings based on the normalized AHP-TOPSIS scores, and the sensitivity of these rankings to the selected weighting scheme. Bold ranks indicate issues that scored the highest. Overall, the results are fairly robust as 4 out of 10 alternatives encounter a maximum change of two ranks only across three weighting schemes.

Conclusions:-

This work systematically explores the multifaceted challenges and emerging research priorities pivotal for enabling the CCS sector. By delving into diverse themes, it provides a comprehensive analysis of the current state and future directions of research.

By employing three distinct respondent weighting schemes within the AHP-TOPSIS framework, we identify key emerging issues in enabling the CCS sector that are critical in terms of importance, novelty, and feasibility. Among the high-ranking research challenges that merit in-depth exploration include – (i) analyzing global CCS policies and their impacts; (ii) assessing cost and financial considerations for direct air capture (DAC) plants; (iii) examining challenges and closures in CCS projects.

While this study offers a broad overview of the issues at hand, it acknowledges certain limitations. The rapidly evolving nature of emerging issues in CCS sector implies that findings might require continual updates. Moreover, the reliance on expert inputs, although valuable, may not fully capture the diversity of perspectives in this global industry.

This work contributes to the field by offering a structured framework to analyze and prioritize research areas in the CCS sector. It bridges the gap between academic discourse and practical application. In particular, the delineated priorities could serve as a potential roadmap for guiding forthcoming research endeavors within both the industrial and academic domains. Research findings from such initiatives may yield practical recommendations for policymakers and industry stakeholders, consequently fostering the formulation of strategies aimed at expediting the emergence of a resilient CCS sector. In conclusion, the emerging issues identified through journalistic reports, a review of published literature, and expert consultations provide a solid foundation for identifying the imperative research priorities required to facilitate a robust CCS sector.

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Keywords: Carbon capture and storage, Direct air capture, Carbon removal

Expert ratings-based ranking of potential research challenges, considering 3 cases: (a) equal weights, (b) respondent experience-based weights, and (c) respondent familiarity-based weights. The rankings were obtained using the combined AHP-TOPSIS approach

Alternatives	Equal weights	Experience based weights	Familiarity based weights
Government Financial and Policy Support for CCS • Comparing incentives and permitting regulations across countries and impacts on competitiveness and investment attractiveness, considering countries’ spending and debt constraints • Impact of government incentives on CCS-related projects’ feasibility, economic viability and capital spending by companies, particularly oil & gas • Policy design and effectiveness where government pays private companies for CO2 DAC as a public benefit, evaluating trade-offs and unintended consequences • Research on the synergies and trade-offs between carbon removal policies and other climate change mitigation and adaptation measures • Policy frameworks and regulatory mechanisms' role in advancing carbon transport and storage infrastructure	1	3	1
Major Companies’ CCS Efforts Across Industries • Potential synergies and challenges of utilizing CCS in hard-to-decarbonize sectors, and integrating with other low-carbon technologies • Comparing different CCS projects, including timing, scale, investment, financing, technology, government involvement, capital expenditure, operating expenses, revenue streams, financial implications and risk management for companies involved • Techno-economic analysis of compact carbon capture systems for small polluters, including performance, cost-effectiveness, and scalability	4	5	4
Challenges for CCS Projects • Implementation challenges, including increasing capture and storage rates; particularly technological, economical and skilled workforce issues, and efforts to address them • Examining CCS project closures due to high costs, low revenue, or unfavorable market conditions and examining strategies and policies that could have prevented them	2	1	3
The Potential and Challenges of Direct Air Capture Technology • Comparing engineered and nature-based DAC of CO2 solutions considering economics, scalability, permanence, life cycle environmental impacts and energy requirements • Societal attitudes, beliefs, and concerns influencing DAC acceptance or resistance, with a focus on potential usage by fossil fuel industry	6	4	5
Scaling Up Direct Air Capture: Cost Considerations and Revenue Streams • Examining DAC cost drivers including capital investment,	3	2	2

operational costs, financing, and economies of scale and learning-by-doing • Budgeting risks for DAC plants considering cost uncertainties and overruns • Breakeven point analysis for DAC plants considering revenue streams from tax credits, enhanced oil recovery and selling carbon offsets			
Advancing Carbon Removal Start-ups: Investments and Challenges • Synergies, conflicts, and comparative analysis of banks' and other financial institutions' support for DAC start-ups, especially given their sustainability goals like net-zero goals and fossil fuel financing • Examining carbon removal prices in offtake agreements and their role in supporting and scaling carbon removal startups	8	9	7
Experts' Views on CCS Role in Addressing Climate Change • Stakeholder responses to adopting CCS to phase out fossil fuel emissions, including drivers, barriers, and strategies to increase acceptance and support	9	8	10
CCS in Oil & Gas Industry: Enhancing Recovery and Addressing Emissions • Social, economic, climate, and political factors that influence acceptance or opposition to using captured CO2 for enhanced oil recovery (EOR) projects, and addressing concerns to increase stakeholder buy-in • Evaluating net CO2 emissions reduction by DAC of CO2, where captured CO2 is used for EOR, taking into account carbon emissions associated with EOR oil	5	6	6
Carbon Capture for Building Emissions: Compliance and Climate Mandates • Effectiveness of policy, such as New York City Local Law 97, in driving landlords to adopt carbon capture technology for large buildings' emissions reduction • Cost-effectiveness of carbon capture for addressing buildings' emissions, considering diverse building types and budgets, compared to other emission reduction or regulatory compliance strategies	10	10	9
Societal acceptance of CCS • Factors influencing societal acceptance of CCS, including the role of climate activist groups in shaping public opinion and policy debates • Techno-economic viability of carbon capture technologies, including comparison with emission reduction strategies	7	7	8

[Page: 216]

[Abstract:0269] OP-216 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Sustainability Reporting Policies and Stock Price Crash Risk: Evidence from Energy Industries in China

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Overview:This paper explores how different types of sustainability reporting policies affect stock price crash risk. We study two milestone sustainability reporting policies in China, the 2006 Voluntary Reporting Guideline and the 2008 Mandatory Reporting Notice. By investigating Chinese firms including those in energy industries, we find that the adoption of the voluntary reporting policy is the determinant for crash risk control, while the mandatory reporting policy gives limit contribution to lower crash risk. Further tests confirm these findings. This paper contributes to the literature on crash risk, sustainability reporting policy and information disclosure.
Methods:We use two dependent variables (NCSKEW_(i,t) and DUVOL_(i,t)) to denote the crash risk by firm i in Year t following previous studies (Chen et al. 2001; Hutton et al. 2009; He et al. 2022; Li, 2023). A higher value for NCSKEW_(i,t) or DUVOL_(i,t) means a higher likelihood for a company to have information opacity and thus incur the stock price crash risk.

We construct independent variables to examine the policy effects. We create POST2006 to examine the effect of the voluntary reporting policy. POST2006 is a binary variable that equals 1 for post-adoption period of the 2006 CSR Reporting Guideline (2006 and afterwards) and 0 for periods before 2006. To examine the effect of the mandatory reporting policy, we create two binary variables. POST2008 is a binary variable that equals 1 for post-adoption period of the 2008 Mandatory CSR Reporting Notice (2009 and afterwards) and 0 for periods before 2009. MANDATORY is an indicator to distinguish observations with mandatory reporting requirements (equal 1), and the voluntary reporting observations (equal 0). We use an interaction term (POST2008×MANDATORY) as the independent variable to measure the effects of 2008 mandatory reporting policy. This interaction term can detect the qualified observations whose corresponding firms belong to the mandatory classes after the mandatory regulation operated in 2008.
Results:Using a sample of Chinese firms during 2003-12, we choose two milestone policies on sustainability reporting, the 2006 Voluntary Reporting Policy and the 2008 Mandatory Reporting Regulation, and assess their effects on the stock price crash risk. We find that the voluntary reporting policy significantly lowers the crash risk, while the mandatory reporting policy has no significant effect on crash risk. Our findings are confirmed by robustness tests. Our finding adds to the limited empirical evidence and helps better understand how the different types of policies influence the quality of information disclosure.
Conclusions:Our findings suggest practical implications on policy selection between mandatory reporting and voluntary reporting. In China, the number of mandatory reporting listed firms is much smaller than that of voluntary reporting firms.The applicable scope of mandatory reporting policy is still limited in the markets. Therefore, the regulators should extend the number of mandatory reporting firms if they intend to strengthen the impact of mandatory reporting policies. Furthermore, our findings show the contribution of voluntary reporting policies. CSR activities are voluntary in nature and go beyond legal, regulatory, and contractual requirements. The voluntary reporting policy motivates firms to dedicate in the responsible behavior, which not only fills in the sustainability report but lower the risk to firms.
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Keywords: Stock price crash risk, Corporate social responsibility, Sustainability Reporting

[Abstract:0409] OP-217 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Uncertainties, Renewable Energy, and Merger and Acquisition in the Energy Sector

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Overview:The impact of distributed energy resources (DER) on large-scale power generators and utilities depends on the scale of DER generation, policy frameworks, and the specific characteristics of the utility’s infrastructure that enables grid integration and two-way power flow (e.g., AMI, digitalization, etc.). Empirical evidence suggests that electric utilities consider mergers and acquisitions as a strategic response to the challenges and opportunities presented by integrating a growing number of DER sources. In this study, we characterize common and firm-specific shocks related to integrating DERs into the electric grid to examine the impact of cost uncertainties, DER size, and carbon tax, on the profitability of a merger between two or more power generators. Our results suggest that electric utilities are able to offset cost uncertainties with more precise information about the extent to which DERs affect integration costs. As a result, total industry electricity production increases with more DER electricity production as long as electric utilities are able to offset integration costs sufficiently. A merger between different power generators is profitable if the merged entity is in a better position to offset the shocks coming from DER generation.
Methods:The modelling framework adopted in this paper aims to place our results in relation to the respective literature. There is a fixed number of energy producers which use two types of assets or technologies to produce energy: fossil-fuel sources to generate and sell a given amount of electricity. Each firm produce energy using cleaner production like renewable. So, each firm is a multi-product firm having the capability to produce both clean and grey energy. Following the literature, we use a Cournot oligopoly with product differentiation to represent the output competition among these firms. In addition, we consider costs uncertainties under pre and post merging situation. Our modeling strategy is to consider affine information structure with common and private shocks (signaling games). We determine the Bayesian Nash equilibrium of the game in which the regulatory instrument is made under informational constraint, i.e., before the realization of the state of the world. Finally, we examine the consequences of varying the informativeness of signals and its impact on profits (pre and post merger).
Results:- We show that, facing common and private signals, firms may have incentives to merge in the energy sector.
- Merging may be profitable to players in the market place under some conditions and can offset costs uncertainties with more precise information (quality of the information).
- Comparative statics are performed meaningfully in order to analyze merging issues in response to changes in the parameters of the model which sometimes are inherently difficult to estimate.

Conclusions:Efforts to enhance informational access may offer important lessons for environmental regulation moving forward. Facing industry wide and firm-specific shocks, there are enormous opportunities to make the best use of available set of data to enhance the quality of the environment. Such information may be used to overcome a serious lack of information on polluted activities, and could have impact on firms' behavior and levels of pollution.

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Keywords: Energy Sector, Merging, Cost Uncertainties, Signaling Games.

[Abstract:0032] OP-218 [Accepted:Oral Presentation] [Renewables » Solar]

Developers' perspective on barriers affecting distributed solar PV generations in Chile

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Overview:Over the last few years, the role of Non-Conventional Renewable Energies (NCRE) in the Chilean matrix has increased significanttly. The participation of NCRE in the total installed energy capacity grew from only 5% in 2014 to 30% in August 2021 (Energía Abierta, 2021). Solar PV technology is the most developed technology, corresponding to 16% of the energy matrix. However, most of this capacity comes from large-scale projects (utility scale). Despite the large resource potential of distributed solar PV generation in the country and all their benefits -emission reductions, cost reductions in electricity supply, decrease in electrical losses, improvement in service quality,

and lessening transmission congestions- to date, the progress of these technologies in the country has been low. On reason for this is that distributed solar PV is currently in a development stage and facing several important obstacles.

In this context, we examine the key barriers that influence the implementation of distributed photovoltaic projects in Chile from the perspective of project developers, which is relevant as they are directly involved in the implementation of distributed generation projects. Identifying the main barriers allows to then propose policy recommendations to policy makers and other market players to encourage the deployment of distributed photovoltaic solar generation in Chile
Methods:The methodology utilized in the paper consists of three complementary methods. First, we designed and implemented a questionnaire survey (comprising quantitative and qualitative data collection). Second, we conducted a series of semi-structured interviews (qualitative data collection only) with the project developers in Chile. Third, we analyzed the data to obtain robuts conclusions. These methods allow us not only to gather detailed and systematic information about the different barriers preventing a higher penetration of distributed solar PV generation in Chile, but also understanding better the exising limitations and analyzing them in a systematic a consistent way. The questionnaire was designed and developed for conducting an online survey of project developers and obtain their opinions concerning the barriers affecting the distributed solar PV generation in Chile. For this purpose, a selection of potential barriers and relevant market actors were selected first. Then, a preliminary list of barriers was tested in a small pilot study to establish the extent to which the barriers found in the literature were also relevant and applicable in Chile. This was followed by the implementation of a questionnaire survey. Finally, the data collection from the online survey was complemented afterwards by face-to-face interviews from a random sample of selected developers from the survey respondents. The purpose of these interviews was to provide important insights and better understading of the investors' opinions and experiences over the barriers they have faced in the marketplace. In the last phase, the study uses a well-known methodology, based on the Technique of Order of Preference for Similarity with the Ideal Solution (TOPSIS) to identify and prioritize in a systematic and robust way the main critical barriers for the implementation of distributed photovoltaic projects.
Results:The results show that the most important barriers affecting and limiting the implementation of distribuated solar PV projects in Chile are "the structure of the network, its capacity and regulation for expansion", "the long administrative process and the costs of connection to the network", "uncertainty due to stabilized price policy and other regulatory requirements" and "financial structuring and financing costs". Several of these barriers can be overcome with public policies that are not difficult to designed and implement as they mainly depend on directly government intervention, while others required a change in regulations that need Congress approval and then required a longer time.
Conclusions:The greater expansion of photovoltaic distributed generation in Chile can play a key role in the achievement of main energy objectives of the country established by the National Energy Policy plan, which contemplates fully decarbonizing its energy matrix and reaching 80% of electricity generation from renewable energy sources by 2050. In addition, This is why identifying the barriers that this segment currently faces is key to encouraging its further development.
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Keywords: Distributed solar PV, Barriers, Project developers, Chile

[Abstract:0489] OP-219 [Accepted:Oral Presentation] [Renewables » Other]

The internationalization of global renewable energy finance

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Overview:To limit global warming to well below 2°C above pre-industrial levels, significant investments in low-carbon infrastructure are crucial, especially in the energy sector, responsible for over 70% of greenhouse gas emissions [1]. Although annual global investments in renewable, low-carbon energy alternatives are increasing, they still need to more than quadruple from an estimated USD 1.3 trillion in 2022 to USD 5 trillion by 2050 [2]. To attract the necessary funds, renewable energy (RE) investments must become an internationally adopted, mainstream asset class.

With the global growth of RE deployment, both technological knowledge and financial market expertise have increased [3]. Accordingly, it would be expected that these technologies are moving from niche opportunities to a more mainstream asset class. While there is not a concluding, universal definition for "mainstream asset class", it typically includes well-known, internationally traded assets such as stocks and bonds [4]. RE investments however significantly differ from such traditional mainstream assets. They for example involve large upfront capital investments [5] and are typically financed through project finance [6] setups, thus seldom traded in secondary markets. Moreover, clean energy investment markets often rely on policy support [7], affecting risk considerations, especially for risk-averse institutional investors crucial for large-scale RE financing [8]. Thus, a direct comparison with typically known mainstream assets prove difficult. Accordingly, the assessment, when RE technologies become a mainstream investment opportunity lacks a simple measure. To address this, we suggest contrasting key investment flow dynamics of RE investments with those of the general economy. Since international financing flows tend to reflect broader dynamics of a global economy and financial system [9], this study specifically proposes to focus on the dynamics of international cross-border flows as an indicator for the mainstreaming tendency of RE investments.

While substantial research exists on who finances RE projects [8] and the international diffusion of RE technologies [10], understanding the international diffusion of RE financing is lacking. Specifically, data on cross-border RE investment flows over time is missing. To address this gap, this paper compiles detailed data on RE investment flows to unveil dynamics of cross-border RE investment in- and outflows for OECD countries. These RE investment dynamics are then compared to foreign direct investment (FDI) as a proxy for mainstreamed international investment flows, exposing technology differences in the progress towards mainstreaming and investor types driving it.
Methods:The study leverages Bloomberg New Energy Finance (BNEF) data to build a novel dataset on cross-border utility-scale RE investments in the OECD. It focuses on the four largest RE technologies by total deals/investments: Wind onshore, solar PV, wind offshore, and biomass & waste, covering 89% of the deals available in the BNEF asset finance dataset. Deals with a date of close between 2004 (BNEF was established) to 2022 (last full year available) are considered. Despite BNEF being one of the most exhaustive datasets available on RE real asset investments, there are several instances of missing data, even within known and reported deals. In this paper, we therefore use a random forest model [11] to impute missing investment amounts and conduct several robustness checks to validate the integrity of the developed dataset.

Based on the devised dataset, flows from "source countries" (where equity and debt providers are based) are mapped to the respective "destination countries" (where the asset is located) and the resulting net outflows are analysed. In a second step, these investment flows are contrasted to net FDIs of each observed country as a proxy for the mainstream financial flows of the general economy. This comparison is both conducted on the entire time period of available data (2004-2022) as well as sub-periods based on major global climate policy milestones. In a third step the observed international investment flow dynamics are further split into the four key RE technologies. Finally, the paper identifies investor-specific differences of internationalization, by distinguishing between four investor types: Utilities, project developers, financial investors, and other investors from the

"real economy".
Results:The paper offers a first glimpse at developments and patterns of international RE financing flows and a series of key insights. Firstly, the trajectory of RE investments has been found to increasingly converge with the patterns of general economy investment flows over time (see Figure 1). As such, contrasting renewable energy investments and FDIs could serve as a potential indicator of a technology's financial mainstreaming.

When applied to technology-specific observations, the findings show that wind onshore and solar PV investments have experienced a convergence to FDI flows, while offshore wind as well as biomass & waste investments did not. This observation would imply that the former two technologies are already more advanced at attracting mainstream financing than the latter.
The paper further shows that an increasing level of internationalization is evident across all technologies over time. Even though some technologies, such as offshore wind, are inherently more international, the overall trend indicates a broadening scope of international investments. This surge in internationalization may be partially attributed to the expanding role of financial investors in the RE sector. Generally, these investors demonstrated a propensity for larger shares of investment outflows compared to other investor types.
Conclusions:Our findings provide an initial perspective on international RE financing flow dynamics, serving as a measure for detecting mainstreaming patterns and informing potential policy initiatives aimed at further mainstreaming RE finance. They provide a basis for future research to better understand energy transition financing dynamics within a globally connected economy. Such research could for example focus on countries that showed significant outliers in the observed correlation matrices between FDIs and RE investments and explore if country-specific policies contribute to diverging patterns. Further, the analysis could be extended to non-OECD countries. In such a case, specifically inflow patterns and their driving factors could provide interesting policy insights when aiming to increase local deployment of RE with the help of foreign investments.
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Keywords: Renewable Energy Investments, Internationalization, Financing Flows, Investment Mainstreaming, Cross-border Investments

Figure 1

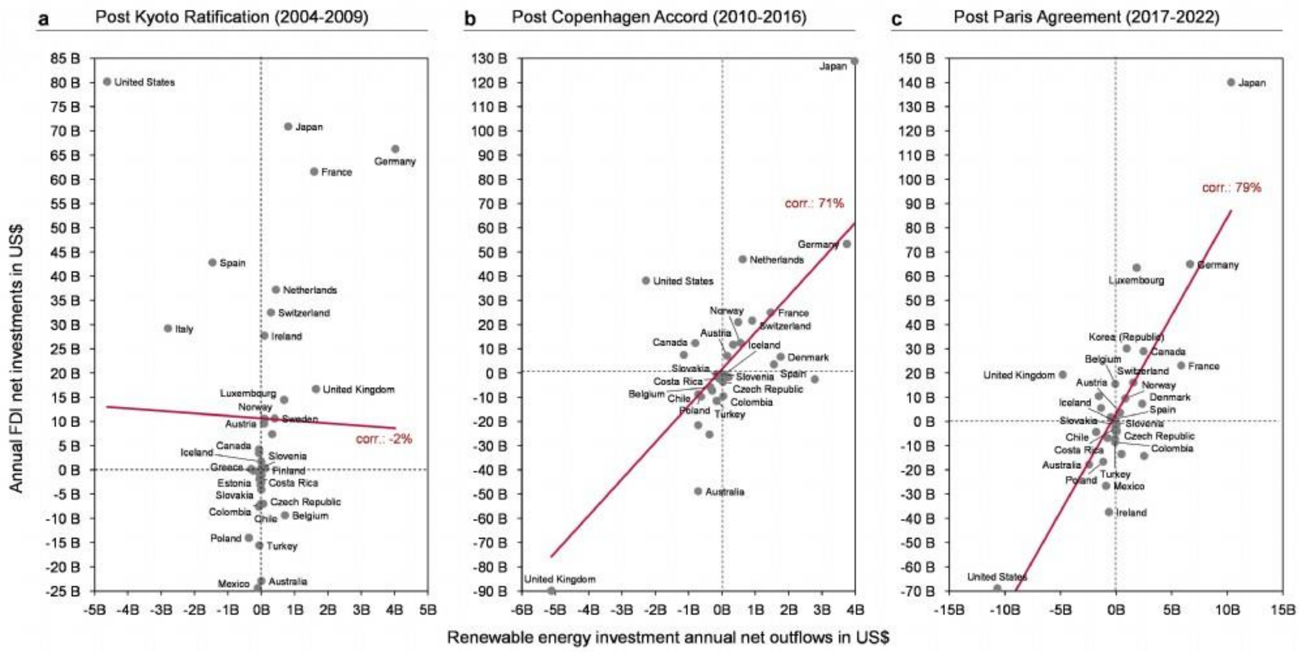

Figure 1: Absolute net investment flows into RE contrasted with foreign direct investments per country. a. Aggregated for the period post the Kyoto Protocol Ratification (2004-2009). b. Aggregated for the period post the Copenhagen Accord (2010-2016). c. Aggregated for the period post the Paris Agreement (2017-2022). Data is aggregated across all RE technologies and in 2020 US$.

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[Abstract:0282] OP-220 [Accepted:Oral Presentation] [Renewables » Solar]

Peer influence and pv panel adoption dynamics: unravelling the impact on different adopter types

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Overview:EU policymakers encourage consumers to actively participate in energy markets as “prosumers”, by installing photovoltaic (PV) panels on their rooftops (ACER & CEER, 2019). However, many consumers remain reluctant to install PV panels due to barriers and uncertainties, including informational barriers and uncertain returns on investment (Rai et al., 2016; Sahu, 2015). Local peer effects can help to (partly) overcome these barriers (Graziano & Gillingham, 2015; Rai et al., 2016). Local peer effects can be observed through the spatial diffusion of PV panels, as a wave-like centrifugal diffusion pattern signifies social dependence, while a random pattern signifies independent behaviour. Policymakers require better understanding of these local peer effects to design effective instruments to accelerate PV panel adoption.

Consumers are not all equally subjected to barriers and uncertainties in the adoption of PV panels. Rogers (2003) identifies five adopter types, based on their innovativeness: innovators, early adopters, early majority, late majority, and laggards, representing a continuum from early to late adoption. These adopter types have different attitudes and motivations, and perceive different levels

of barriers and uncertainties towards innovations. The literature on the adoption of PV panels indicates heterogeneity of peer effects, influenced by factors such as income and market maturity (Dokshin et al., 2024; Stewart, 2022). This paper expands on the existing literature by analysing how consumer heterogeneity affects the spatial diffusion of PV panel adoption. Our unique dataset contains information on PV panel adoption in the Netherlands on an individual level, enabling to better capture local effects in a mature PV panel market.

The diffusion of PV panels diminishes with time and space (Graziano & Gillingham, 2015; Robinson & Rai, 2015). The literature identifies access to information through visibility and social interactions (Barnes et al., 2022), increased trust in technology and information (Rai & Robinson, 2013), and adherence to social norms (Curtius et al., 2018) as important mechanisms underlying these spatial peer effects.

Consumers perceive different barriers to PV adoptions, as early adopters are less dependent on local peers for access to information, are willing to take more risks due to higher financial resources, and are less adherent to local social norms than later adopters (Rogers, 2003). Because of this heterogeneity in adopter characteristics, local peer effects are likely to vary between the adopter types. Early adopters perceive less barriers in the adoption of PV panels than later adopters. Therefore, later adopters are expected to exhibit a stronger, positive correlation between the adoption of PV panels and that of their neighbours than early adopters.

This research uses spatial regression models to analyse two key aspects: 1. The strength of local peer effects and 2. How these effects are influenced by consumer characteristics.
Methods:We use secondary data provided by the Dutch data consultancy Geomarktprofiel, which includes information from 8,287,730 Dutch households spanning 6 years. Home addresses are linked to geographical coordinates through the BAG (basic registration of addresses and buildings). Moreover, the dataset includes information on the household’s consumer segment including income levels, education levels, age category, household composition and employment status. Furthermore, the data contains information on the characteristics of the residence and whether and when PV panels were detected on the roof of the residence. The data on PV panel adoption is derived from satellite images.

First, we estimate the level of spatial clustering using the Global Moran’s I for different neighbourhoods and years. The Global Moran’s I estimates the degree of spatial autocorrelation of an entity with its neighbouring entities. However, the Global Moran’s I cannot be compared across neighbourhoods and does not provide information on the source of the spatial correlation. Therefore, we estimate spatial autoregressive models to determine whether the dispersion stems from endogenous interactions, contextual interaction or correlated effects (Manski, 1993). Endogenous effects describe the tendency of a household to behave in a way which varies with the behaviour of the neighbourhood. Contextual interactions describe the spatial dependence of explanatory factors causing similarity in behaviour. Finally, correlated effects describe how similar unobserved correlated effects might influence similar decisions of regions. Following Elhorst (2010), we take a general-to-specific approach, progressing from OLS to the complete Manski model, to analyse the nature of the spatial correlations in the data. The sign and size of the endogenous effects provide understanding in the importance of local peer effects. The inclusion of household-level characteristics helps us to identify whether these peer effects are heterogenous among consumers.
Results:We will run these analyses in the next months and present the result at the conference in June. The outcomes will provide insights into the local peer effects of PV panels adoption for different adopter types. We expect that the results will indicate variations in diffusion patterns among different consumer segments due to the differences in access to information, need for trust, and compliance to local social norms. Specifically, we expect that less access to information, higher risk and uncertainty aversion, and higher compliance to social norms will all contribute to the positive spatial autocorrelation of the adoption of PV panels. This applies particularly to early majority adopters and late majority adopters, who perceive higher barriers and uncertainties compared to innovators and early adopters, and therefore benefit more from local peer effects.
Conclusions:There are four possible conclusions from our research. The first conclusion would be that there is no difference in local peer effects of PV panel adoption between the different adopter types. The second conclusion would be that early adopters exhibit a stronger local peer effect of PV panel adoption than late adopters, and the third conclusion would be the opposite — that late adopters have stronger local peer effect of PV panel adoption than early adopters, and a fourth that there is one or more adopter types who stand out from the other adopter types, unrelated to the innovation stage. These conclusions offer valuable insights for policymakers to design effective instruments and for campaigns promoting PV adoption and fostering the energy transition. The insights from this research can be extrapolated to other regions and countries.

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Keywords: Solar panel, prosumers, peer effects, spatial diffusion

[Page: 221]

[Abstract:0515] OP-221 [Accepted:Oral Presentation] [Renewables » Solar]

The welfare effects of reindustrialization: the case of the European solar PV industry

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Overview:REPowerEU is the European answer to the 2022 gas crisis. This plan aims to ensure a stable and decarbonized energy supply for the continent in the coming years [1]. It proposes three main lines of action: energy efficiency, fuel diversification, and renewable development. More

specifically, REPowerEU sets an objective of 600 GW of newly installed solar photovoltaic (PV) capacity by 2030. Yet, more than 80% of manufacturing capacities along the solar PV supply chain are concentrated in China [2]. Chinese products are necessary for decarbonizing the European economy, but such high levels of concentration can be a risk to Europe's growing demand for affordable solar energy. In line with the stated goals of the Net Zero Industry Act currently discussed at the European Parliament, developing a resilient solar manufacturing sector is one of the means to reduce such a risk. However, domestic manufacturers are dealing with historically low prices today due to an oversupply of Chinese products, jeopardizing their profitability and long-term market presence [3], [4], [5].
Different policies have been proposed (trade tariffs on Chinese PV products, resiliency as a non-price criteria in public auctions, eco design, ecolabeling, gigafactory, etc.) to increase European production along the solar PV supply chain. However, imposing restricted access to foreign products can reduce the pace and raise the cost of the energy transition. In this context, analyzing the conditions for a reindustrialization policy to be welfare-improving is necessary for its long-term relevance and sustainability. This study proposes a partial-equilibrium model of the European solar PV market. Under budget and renewable development constraints, consumers maximize their utility while producers are profit-driven. The novelty of this framework lies in the representation of consumer preferences for domestic and foreign products and how those can impact market outcomes. Especially, this will allow us to study different policies proposed to develop the European solar industry and find the most suitable one given the market conditions. We believe the relevance of the proposed framework is not limited to the solar industry as it can be extended and applied to other strategic sectors for the energy transitions (batteries, electric vehicles, etc.).
Methods:In our study, we introduce a framework of a partial equilibrium model of the European market for solar PV panels. We consider that domestic solar panels are preferable goods than imported ones. Everything else equal, if given the budget, consumers will choose the former over the latter. Such preferences capture the non-priced social (job creation, strategic energy independence, etc.) and environmental (CO_2 emissions, waste management, etc.) externalities associated with the consumption of a domestic product over an imported one. Also, solar panels are essential goods for the energy transition. Therefore, a minimal consumption is required every year to decarbonize the economy. Following Fleurbaey's framework [6], the consumption of Chinese solar panels can be labeled as "forced". Indeed, everything else equal, if consumers had higher budgets for solar panels, they would have chosen domestic ones. Therefore, a policy that reduces forced consumption under a given budget constraint allows welfare improvements. The graph attached illustrates the concept of forced consumption in a partial equilibrium context.
In the proposed partial-equilibrium model, European producers choose their production levels to maximize their profits subject to their capacity constraints. The price of extra European panels is exogenous. Consumers look to maximize their utility under budget and renewable development constraints. In descending order of their preferences, consumers can choose to consume domestic panels, European panels, or imported panels. With a fixed budget, consumers will look to fulfill their renewable development target with the highest possible share of domestic and European products.
Results:This research project is still in the early stages of development. We expect results to show that restricting access to foreign products can induce welfare loss and slow down the pace of the energy transition. However, if the introduction of non-price criteria in public auctions aligns with society's preferences, such a policy can induce welfare gains at the European level. Those gains are not necessarily fairly distributed among European countries depending on market conditions. An adequate redistribution scheme might be needed to accommodate market mechanisms and harness the benefits of reindustrialization.
Conclusions:The solar industry is a key sector for the European energy transition. Facing historically low prices, domestic manufacturers' market presence is compromised, and several policies have been proposed to help maintain manufacturing capacity on the continent. If certain propositions can have positive welfare effects at the European levels, their benefits are not necessarily evenly distributed among country members, and additional levers might be needed to reap the full potential of reindustrialization.
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Keywords: Photovoltaic, Solar, Reindustrialization, International trade

Forced consumption in a free market

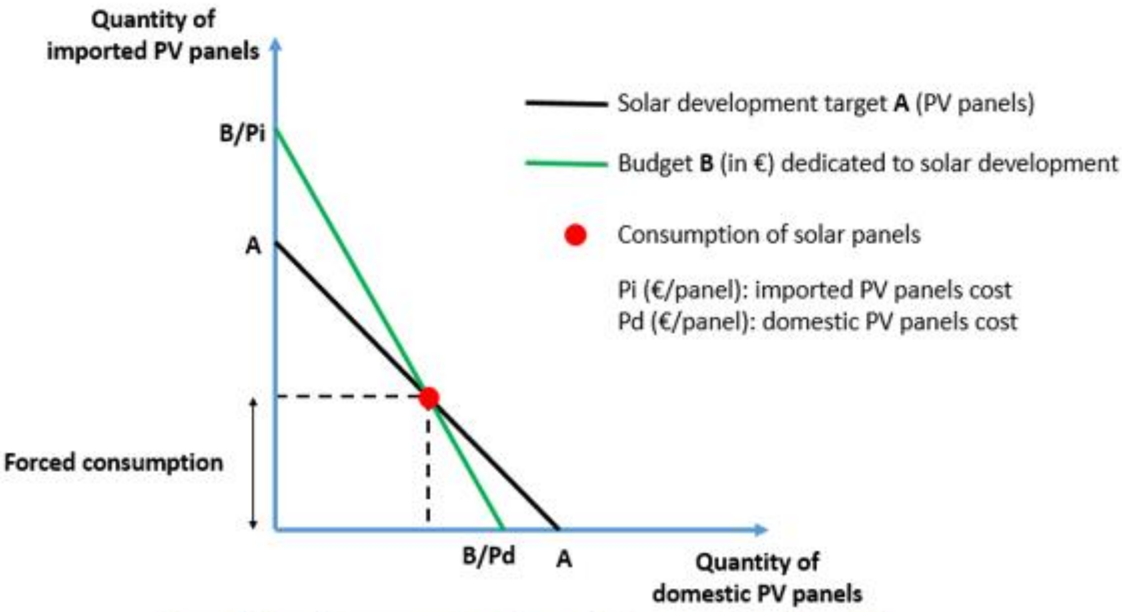

Figure 1: Forced consumption in a free market (source: adapted from [4])

Simplified representation of the equilibrium problem

Table 1: Simplified representation of the equilibrium problem (source: author proposition)

Consumer at the country level	Producer at the country level
max Utility **Constraints** *Renewable development objective* *Budget constraint*	*max Profits* **Constraints** *Capacity constraint*

[Abstract:0536] OP-222 [Accepted:Oral Presentation] [Renewables » Solar]

Solar photovoltaic energy scenarios generation: a novel methodology for multi-area electricity markets

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Overview:Solar photovoltaic energy has experienced rapid global expansion, primarily driven by the urgent need for countries to shift towards decarbonized economies and the simultaneous reduction in associated technology costs, thereby elevating this energy source to a position of significant competitiveness. Despite its growth, solar photovoltaic systems have inherent limitations, notably their lack of manageability. These systems' power generation is inextricably linked to the amount of solar radiation received by the panels, resulting in significant day-to-day variability based on meteorological conditions. As the dependency on solar energy grows, the uncertainty in power supply increases, and more accurate solar power scenarios are needed to inform decision-making processes in power systems [1].

In this paper, a novel methodology is introduced for the generation of solar photovoltaic energy scenarios within multi-area electricity markets. Diverging from the existing short-term focus in the literature, the proposed approach tackles the challenge of creating realistic long-term scenarios for solar energy, taking into account the inherent variability of solar availability. Traditional representations of individual solar units are transcended, with hourly scenarios being developed to collectively reflect the solar energy production of entire markets [2]. This method significantly improves the decision-making process in electricity markets by more accurately capturing the dependency relationships of solar power behavior across diverse regions. A distinctive feature of this methodology is the segmentation of historical data on a monthly basis and the application of unique Seasonal Auto Regressive Integrated Moving Average (SARIMA) models for each month and area. The accuracy of scenario generation is further enhanced by the production of hourly multivariate residuals. These residuals, being correlated and conforming to normal distribution functions, integrate spatial correlations derived from covariance matrices of monthly historical data series. Then, Monte Carlo simulations are employed, effectively merging the temporal dependencies captured by the SARIMA models with the spatial dependencies gleaned from historical data covariances. This integrated process results in more comprehensive and reliable solar energy scenarios.

A significant improvement over the traditional method, which involves fitting a single SARIMA model to the complete time series data of each area, is obtained. The focus of the study, encompassing Spain, Portugal, and France, involves an evaluation of the scenario quality over a two-year period. Main results indicate that the inclusion of a monthly-level dependencies modeling significantly enhances the quality of solar power scenarios, thereby improving their applicability across various temporal scales.

Methods:In this paper, a five-stage methodology is proposed to generate solar energy scenarios, which incorporates the spatio-temporal dependencies of interconnected multi-area electricity markets. The methodology can be outlined as follows:

1) Data Pre-processing: The initial stage involves a stage of data curation and cleaning, encompassing error correction, outlier management, and adaptation to temporal variations during winter and summer periods. Furthermore, dependencies between solar energy and the installed capacity for each area are subsequently removed. This step diverges from short-term methodologies by constructing time series based on the utilization of solar power, rather than actual power generation. In the next step, a focus is placed on handling nighttime hours. Considering the varying lengths of night across seasons, particularly the extended winter nights compared to summer, accurately capturing daily seasonality and conducting time series decomposition becomes challenging. To manage seasonal time shifts and variations in day length, data processing techniques are employed to ensure the optimal utilization of available data while effectively preserving the seasonality patterns. This step is relevant for maintaining the integrity of the time series despite the removal of specific records, thereby enhancing the accuracy of long-term scenario generation. The last step includes the transformation to a Gaussian- normalized time series. This transformation is implemented to mitigate asymmetries and spurious interactions within the time series.

2) Time Series Decomposition: Once the pre-processing stage is completed, the time series is decomposed into three key components: annual seasonality, daily seasonality, and residuals. In the historical data analyzed for this paper, the trend was found to be negligible. The annual seasonality is modeled using a Fourier series [3], capturing variations in solar radiation relative to the changing length of daylight hours throughout the year. Lastly, daily seasonality is delineated by solar radiation patterns within a single day, typically peaking at midday. Lastly, the residuals represent the variability not explained by these two seasonal components.
3) Detection of Spatial-Temporal Dependencies: A nuanced approach to model temporal dependencies in solar energy generation is adopted across different time scales. Instead of using a single SARIMA model for each area's time series, the historical data is segmented on a monthly basis. This segmentation allows to construct twelve distinct SARIMA models per area, each finely tuned to capture the unique dynamics of individual months. Model construction follows the Box-Jenkins methodology [4], which involves a cyclical process of model identification (using Autocorrelation Function (ACF) and Partial Autocorrelation Functions (PACF) analyses), parameter estimation (via maximum likelihood estimation method), and diagnostic checks to validate model adequacy.
4) Scenario Generation: Traditional methods generate solar power scenarios from uncorrelated and univariate normal distributions. However, in multi-area electricity markets, time series may exhibit strong correlations, mainly due to shared weather conditions in nearby areas. This challenge is addressed by generating hourly multivariate residuals that are correlated and follow normal distribution functions, incorporating spatial correlations derived from covariance matrices of monthly historical data series. Monte Carlo simulations are then leveraged to generate solar scenarios, integrating both temporal dependencies identified with the SARIMA models and spatial dependencies from historical data covariances.
5) Performance Evaluation: The quality of the generated scenarios is assessed by comparing key statistical properties of the historical time series with the proposed scenarios across various time scales. The Pinball Loss Function (PLF) and the Winkler Score (WS) are used to evaluate the similarity between the distributions of historical data and the generated scenarios, assessing the accuracy and reliability of the scenarios in capturing the essential statistical characteristics of the historical time series.
Results:In this study, focused on solar photovoltaic energy scenarios in Spain, Portugal, and France, the proposed pre-processing methodology was used to overcome challenges posed by null data during night hours and variability in solar generation.The study accomplished a detailed characterization of the unique idiosyncrasies within each market, emphasizing the pronounced annual seasonality across the different countries. Through normalization methods like Box-Cox and Logit, and the fitting of monthly individual SARIMA models using the Box-Jenkins methodology, this research successfully generated 300 distinct solar energy scenarios using Monte Carlo simulations. These scenarios, which considered multivariate residuals and covariances between the areas, revealed that this approach outperformed traditional methodologies, with distributions and descriptive statistics closely resembling historical values, which reflects a high degree of accuracy and reliability. In addition, performance evaluation indicated the spline interpolation method's effectiveness in capturing annual seasonality.
Conclusions:In conclusion, the research conducted on solar photovoltaic energy scenarios in Spain, Portugal, and France has been instrumental in significantly enhancing the understanding of solar power variability and addressing the challenges associated with capturing the dynamics of solar time series. This study revealed distinct seasonal patterns across the studied countries, highlighting the complexity and dynamism inherent in solar energy and the correlations among the areas. Utilizing an innovative methodology, 300 diverse solar energy scenarios were successfully simulated, demonstrating their effectiveness in reproducing the key statistical properties of the historical data in the scenarios generated compared to traditional scenario generation methods. Future work is suggested to be focused on refining these models for better accuracy in extreme weather conditions and integrating advanced technologies such as deep learning-based strategies. These advancements are expected to significantly improve the precision of solar energy predictions, contributing to the development of more robust and resilient renewable energy systems in a world increasingly dependent on renewable sources.
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Keywords: Solar Energy Forecasting, Spatio-Temporal Energy Modeling, Long-Term Power Scenarios, Multi-Area Electricity Markets Analysis

[Abstract:0039] OP-223 [Accepted:Oral Presentation] [Energy Finance and Trading » Project Finance]

Techno-economic feasibility study of solar photovoltaic power plant using RETScreen to achieve Indonesia energy transition

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Overview:Energy is a critical component of Indonesia's economy, and the sustainable and equitable development of the energy sector is vital for the country's growth [1]. Indonesia electricity consumption has grown by 75% from 2010-2020, averaging about 7.5% annually [2]. To overcome the energy demand with sustainable development, Indonesia has set a target of achieving a 23% renewable energy mix by the end of 2025 [3]–[5], and attain net-zero emission in 2060 [6]. However, the current realization of Indonesia's renewable energy mix stands at only 11.5% by the end of 2021 [7]. To accelerate the energy transition into renewable energy, Indonesian government release a new regulation about renewable energy tariffs in Indonesia [8]. The new tariffs include various considerations in the calculation, including capacity, location, and type of technology used. Unfortunately, according to author's knowledge, no prior academic research has been conducted regarding the feasibility study of photovoltaic power plant using the newly implemented renewable energy tariffs. Perusahaan Listrik Negara (PLN), as the state-owned company responsible for electricity supply in Indonesia, has made a commitment to lead the country's transition to renewable energy sources [9]. One of the strategies being pursued by PLN is the de-dieselization program, which involves converting diesel-based power plants to renewable energy sources including solar power plant [10].
Methods:This research aimed to determine the feasibility of utility-scale project to assess its feasibility based on the new renewable energy tariffs from various perspectives. In a way to address the research objective, this study utilized RETScreen Expert software to conduct a feasibility study that includes energy and emission analysis, financial analysis, sensitivity analysis, and risk analysis. The feasibility study was performed on a 26 MW PV power plant project in Nias, Indonesia. Five scenarios were developed in order to assess the feasibility of the project based on various perspectives. Base case, RUPTL, and proposed case scenario will be reflecting IPPs perspectives. Cost-savings scenario will be reflecting PLN's perspectives, PLN's cost savings from de-dieselization is included in the calculation. Finally, the clean-energy scenario was developed in order to assess the feasibility of the project based on the IPPs perspective, considering the introduction of emission reduction incentives in Indonesia. This research aims to determine the feasibility of solar photovoltaic power plant based on the newly implemented renewable energy tariffs. This study uses cost-savings from de-dieselization of 0.0572 for cost-savings scenario which represents PLN perspective, and 10 USD/tCO2 incentives for clean-energy scenario. The experiment is performed with five types of different scenarios (Please see Appendix)

The feasibility study is divided into 5 models. The first model or energy model calculates the energy production of the facility according to the project configuration. The second model or cost model calculates the cost incurred by the project, including operation and maintenance cost, initial cost, and cost of debt. The third model or emission model calculates the emission reduction incurred from

the project. Fourth model or financial model calculates the financial outcomes of the project, including cumulative cash flow, net present value, payback period, internal rate of return, energy production cost, and benefit-cost ratio. Fifth model or risk model calculates the risk entailed by the project using Monte Carlo simulation.

Results:In base case scenario, average tariff of 0.0570 USD/kWh was assumed, and any credit for emission reduction was not considered. PV systems technical conditions of 49,576 MWh of electricity exported to grid annually was considered for the project. The equity payback period of the base scenario is 17.8 years meaning that the base case scenario would bring positive cash flows after 17.8 years, with total cumulative cash flows of 12,155,922 USD. Based on the base case scenario achieved results, the pre-tax internal rate of return-equity equals to 5.6%, pre-tax internal rate of return-assets equals to -1.4% simple payback of 10.4 years, NPV of -1,459,834 USD, 0.81 cost-benefit ratio and energy production cost or LCOE of 0.0595 USD/kWh.

In RUPTL scenario, average tariff of 0.0573 USD/kWh was assumed, and any credit for emission reduction was not considered. PV systems technical conditions of 49,576 MWh of electricity exported to grid annually was considered for the project. The equity payback period of the RUPTL scenario is 17.6 years meaning that the base case scenario would bring positive cash flows after 17.6 years, with total cumulative cash flows of 12,579,922 USD. Based on the RUPTL scenario achieved results, the pre-tax internal rate of return-equity equals to 5.8%, pre-tax internal rate of return-assets equals to -1.3%, simple payback of 10.4 years, NPV of -1,262,249 USD, 0.84 cost-benefit ratio and energy production cost or LCOE of 0.0595 USD/kWh.

In proposed case scenario, average tariff of 0.0594 USD/kWh was assumed, and any credit for emission reduction was not considered. PV systems technical conditions of 49,576 MWh of electricity exported to grid annually was considered for the project. Based on proposed case calculation, the equity payback period of 16.7 years meaning that the proposed case scenario would bring positive cash flows after 16.7 years, with total cumulative cash flows of 15,155,257 USD. Based on the proposed case scenario achieved results, the pre-tax internal rate of return-equity equals to 6.9%, pre-tax internal rate of return-assets equals to -0.69%, simple payback of 10 years, NPV of -61,714 USD, 0.99 cost-benefit ratio and energy production cost or LCOE of 0.0595 USD/kWh.

In cost-savings scenario, which represents PLN perspective, average tariff of 0.0594 USD/kWh and cost-savings of 0.0572 USD/kWh from de-dieselization were assumed, and any credit for emission reduction was not considered. PV systems technical conditions of 49,576 MWh of electricity exported to grid annually was also considered for the project. Based on the calculation, the equity payback period of the cost savings scenario is 2.4 years meaning that cost savings scenario would bring positive cash flows after 2.4 years, with total cumulative cash flows of 86,086,119 USD. Based on the cost savings scenario achieved results, the pre-tax internal rate of return-equity equals to 41.8%, pre-tax internal rate of return-assets equals to 12.3%, simple payback of 4.8 years, NPV of 33,002,234 USD, 5.2 cost-benefit ratio, and energy production cost or LCOE of 0.0595 USD/kWh.

In the Clean Energy Incentives scenario, the average rates for PV based electricity of 0.0594 USD/kWh and PV systems technical conditions of 49,576 MWh electricity exported to grid annually was considered for the project. Emission incentives of 10 USD/tCO2 for the reduction of greenhouse emissions were considered with 38,230.6 tCO2 emission reduction annually. Based on the calculation, the equity payback period of the Clean Energy Incentives scenario is 10.7 years meaning that the Clean Energy Incentives scenario would bring positive cash flows after 10.7 years, with total cumulative cash flows of 24,712,897 USD. Based on the Clean Energy Incentives scenario achieved results, the pre-tax internal rate of return-equity equals to 11.3%, pre-tax internal rate of return-assets equals to 1.4%, simple payback of 8.7 years, NPV of 4,393,516 USD, 1.6 cost-benefit ratio, emission reduction revenue of 377,010 USD/annum and energy production cost or LCOE of 0.0595 USD/kWh.

Conclusions:This study has conducted a feasibility study of a 26 MW PV power plant project located in Nias, Indonesia. The analysis carried out in this study considers various possibilities that can occur in the field.

- For various possible scenarios conducted in this study, the application of PV power plant is more economical compared to diesel power plant.
- Based on Indonesia’s existing renewable energy tariffs [8], the project is considered not financially feasible for IPPs due to tariff limitation and the lack of other incentives such as emission reduction incentives.
- When viewed from PLN’s perspective, the project is highly feasible due to the significant cost savings by reducing the diesel power plant usage due to the presence of the PV power plant
- The project would lead to an annual reduction of 38,230.6 tCO2 emissions, which is equivalent to avoiding the consumption of 16,511,760.9 liters of gasoline per year.
- The projected LCOE of the power plant is 0.0595 USD/kWh, indicating a significant potential reduction in PLN's electricity production costs in Nias.
- The clean-energy scenario results showed that $20/tCO2 emission reduction incentive was sufficient to make the PV power plant project financially viable based on the IPPs perspective. Based

on those results, this study recommends emission-reduction incentives as a mean of attracting more investors.

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Keywords: PV Plant, Feasibility study, RET Screen

Type of Scenario

Scenario	Initial capacity (MW)	Expansion capacity (MW)	Average tariffs (USD/kWh)	Cost savings (USD/kWh)	GHG reduction incentives (USD/tCO2)
Base Case	26	0	0.0570	n/a	n/a
RUPTL	6	20	0.0573	n/a	n/a
Proposed case	10	16	0.0594	n/a	n/a
Cost-savings	10	16	0.0594	0.0572	n/a
Clean energy incentives	10	16	0.0594	n/a	10

The experiment is performed with five types of different scenarios

[Abstract:0133] OP-224 [Accepted:Oral Presentation] [Energy Finance and Trading » Project Finance]

How financial de-risking can channel private capital toward the energy transition?

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Overview: Limiting global warming to 1.5°C requires net-zero greenhouse-gas (GHG) emissions by no later than 2050 [1]. Climate neutrality in energy sector, which accounts for 75% of global GHG emissions [2], is the key milestone in respecting climate goals. This will require investing in clean electricity production (notably renewables), electrification of end-uses, efficiency improvements, electrolyzers for renewable hydrogen production, storage options, bioenergy, and carbon capture and storage [3–6]. This in an unprecedented challenge, with massive investment needs that can reach as high as US$200 trillion [7]. Moreover, these solutions are associated with lower risk-return profiles than their fossil counterparts because they generally require higher upfront costs, are more disruptive and less mature, or their respective markets are nascent. Therefore, the investments remain well-below the required levels, especially in developing economies [8]. Higher risks are translated into higher cost of capital, entailing extra financing costs. Therefore, assessment of the costs of capital of clean energy projects and the quantitative impact of different de-risking instruments on them is of utmost importance.

While some studies look at the cost of capital of a single country or a small set of countries [9], they do not offer holistic comparison between geographies and technologies [10, 11]. Moreover, these studies identify the risks associated with renewable investments [12] but fail to both internalize them in the economic assessments and quantify the effect of different de-risking tools with a technology- and geography-focused perspective. This paper addresses this question by exploring the key drivers of the cost of capital and the effect of different de-risking instruments on the cost of the energy transition and investment facilitation.

Methods: In this paper, we assess the risk elements of renewable energy investments, and we quantify the cost of capital for solar PV, onshore and offshore wind power projects through an algebraic cost of capital calculation model. Cost of capital is equal to the weighted average of cost of equity and cost of debt, proportional to the share of equity and debt in the overall capital needed. For the cost of equity, an adapted capital asset pricing model is used to account for systemic risks and project risks [13] across all countries. Project-specific risks are modelled through Monte Carlo Simulations [14]. This method relies on cash-flow modelling that incorporates the risks with volatility of each input data. Then, regulatory and information instruments, economic and market instruments and financial instruments are modelled to quantify their impact on risk reduction, the cost of capital and the levelized cost of electricity and hydrogen (LCOE and LCOH).

We evaluate the instruments' effectiveness levels based on their cost of capital reduction potentials. It allows to highlight which instruments are the most useful in each geography and for each technology. The assessment is done by adding operational subsidies, investment subsidies, guarantees and insurances, mezzanine instruments and climate strategies in the financial cashflow model. The synergies between these instruments are also studied based on four case studies in different regions (Northwestern Europe, South America, Sub-Saharan Africa and Southeast Asia) for different technologies (onshore and offshore wind power, solar PV and solar PV-based renewable hydrogen). We also complement the effectiveness assessment with a cost-benefit analysis based on the cost of the instrument to the society (public cost) and the cost reduction it entails to the project (increase in net present value and change in the cost of capital). The difference between the net present value of the project for two counterfactual cases of with and without de-risking mechanism is divided by its cost to the society.

Finally, we model the effect of refinancing on the reduction of the investment needs using three case studies: an offshore wind farm in Brazil, and onshore wind farm in Vietnam and a solar PV power plant in Chile. Refinancing means that the cost of equity and debt of projects that are already under construction or operational are reduced. From a modelling perspective, this means a dynamic cost of capital for not only the new investments but also for operational projects.

Results: The risks associated with green investments are categorized as macro, technical, market and financial risks. Macro risks encompass political and regulatory risks which stem from lack of political visibility, incomplete or inadequate regulatory frameworks, or poor administrative procedures, as well as currency risks. Our modelling sows that they account for 45% to 90% of the cost of capital of current renewable projects. Market risks consist of all the commercial and market-related risks such as revenue, liquidity, missing market and commercial track record and economic competitivity risks. While most of the new projects in developing economies sign offtake agreements to reduce these risks, the cost of capital modelling reveals that market risk premia still represent a required of 13 percentage points additional return for private lenders (percentage point addition to the cost of equity). Underperformance, missing infrastructure, construction delay and cost overrun risks form up technical risks. The modelling results show that under current financing conditions and without de-risking instruments, the cost of capital for solar power plant projects vary from 7% in Western Europe to 17.7% in Sub-Saharan Africa (Figure 1). For onshore wind power, this increases to 8% in Western Europe and 19.3% in Sub-Saharan Africa.

We show that in countries with high political risks, political risk guarantees can prove the most effective de-risking instrument, with up to 14 percentage points (pp) reduction in cost of capital (Figure 2). Though in case of a stable political environment, their impact becomes negligible. Revenue guarantees and grants can reduce the cost of capital by up to 3 pp. These instruments are followed by performance guarantees (0.2 to 2.5 pp reduction), concessional loans (0.7 to 2.4 pp), and network planning and streamlined permitting processes (0.4 to 2.4 pp). Transparent regulatory environment through climate and energy strategies and taxonomies can reduce the cost of capital by 1 to 1.8 pp, while tax incentives by 0.3 to 1.6 pp. Finally, subordinated equity can bring up to 1 pp of reduction in renewable power projects' cost of capital. Figures 3, 4, 5 and 6 show the combined impact of de-risking instruments on the LCOE and the LCOH of the case studies defined in Uruguay, Indonesia, Denmark and Namibia. Combined deployment of different de-risking instruments can reduce the LCOE of wind and solar power and the LCOH by up to 35%.

Each of these de-risking instruments comes at a cost to society, implying the need for a comparative assessment of their economic efficiency, beyond their effectiveness. This is particularly important for developing economies, where states run on tighter budgets which must therefore be used efficiently to maximize private capital leverage. As the most or the least effective de-risking instruments, political risk guarantees can be the most or least cost-efficient ones, depending on local macro risks (Figure 7). Tax incentives and grants are among the most cost-efficient financial de-risking instruments with up to 2.3 US$/US$ efficiency but they also require higher public spendings per project. Depending on the project type and its location, other tools (notably performance guarantees, concessional loans, and junior equity) can prove efficient complementary de-risking instruments.

Financial learning can lower the cost of capital of green projects by 2 percentage points in advanced economies and 5.5 percentage in developing economies by 2050. As a result, it can save between 14% and 15% of the total project costs for renewable power generation technologies (Figure 8) and reduce the cost of the overall transition by 5% (US$10 trillion cumulatively through 2050, figure 9) in a net-zero scenario aligned with International Energy Agency's Net-Zero Emission scenario [15].

Conclusions:In our assessment of the underlying components of renewable energy projects, we grouped different risks renewable projects face and matched them with different de-risking instruments, and through an algebraic cost of capital modelling and Monte Carlo simulations, we calculated the weight of each of these risks in cost of capital and the risk premia reduction impact of de-risking tools. A case-by-case optimal combination of de-risking instruments plays a pivotal role in reducing the cost of capital in an effective manner with a minimal cost to society. Therefore, tailoring the mix of de-risking strategies to specific market conditions, geographies and technology maturity levels will bring the most substantial reductions in the cost of the energy transition.

To enhance risk return profiles and "bankability" of renewables in developing economies, our findings suggest that policymakers need to create low-risk project environment through clear energy strategies and regulations and market-specific economic (subsidies, grants and tax incentives) and project-specific financial instruments (blended finance instruments and insurances and guarantees).

From pilot through the beginning of an established market, de-risking instruments are crucial to pave the way to kickstart projects and build track record to enhance the risk perception associated with them, especially in developing economies. Finally, making the most of refinancing requires a flexible project finance environment to facilitate transfer of ownership, enable the time-evolving debt and equity cost reduction and attract low-risk appetite capital providers throughout the projects' lifetimes.

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Keywords: Clean energy investments, sustainable finance, risk assessment, cost of capital, financial modelling, financial de-risking

Figure 1. The cost of capital of solar power plants without de-risking measures over the globe

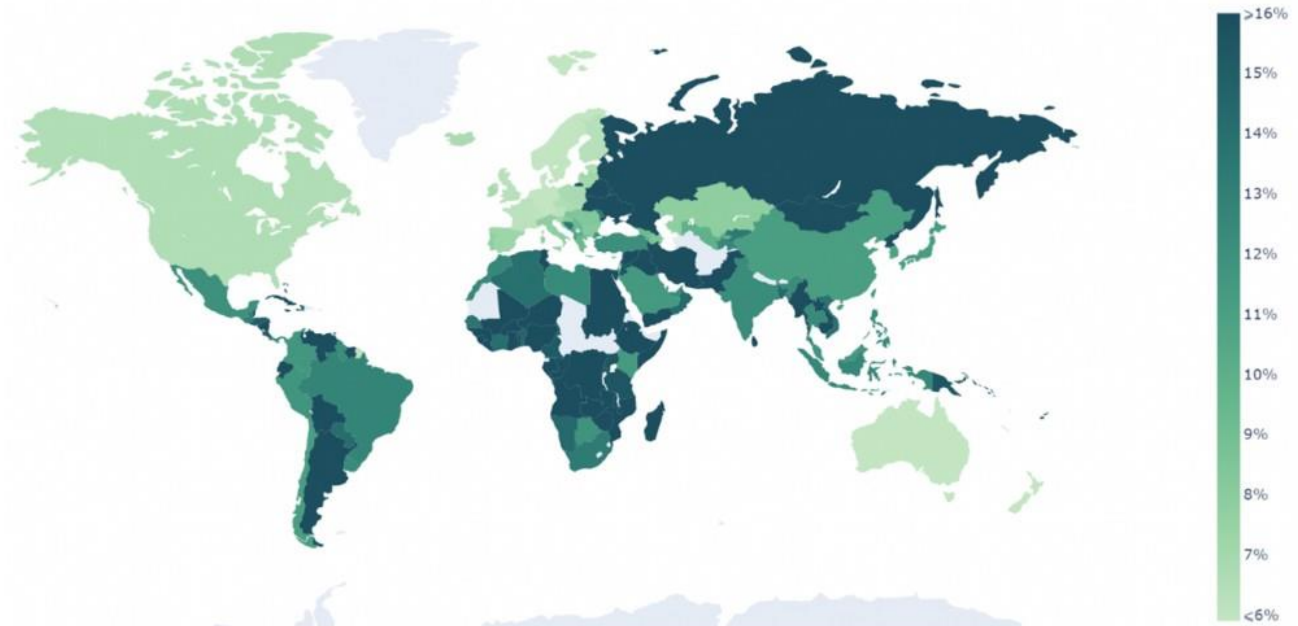


Figure 2. Effectiveness range of key de-risking tools on the cost of capital

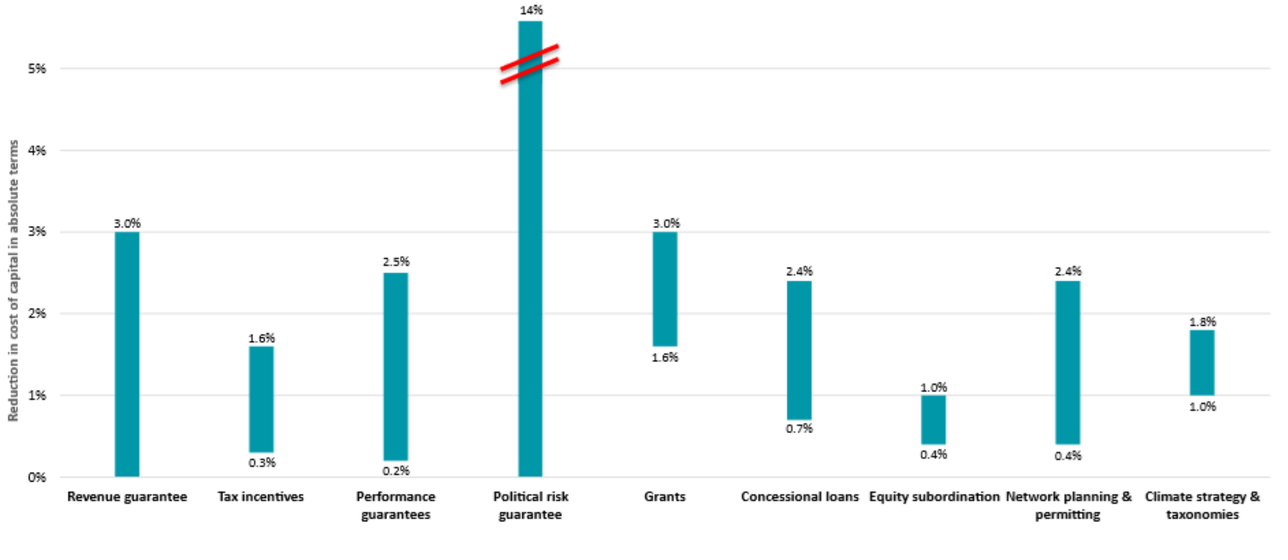


Figure 3. The impact of de-risking instruments on the levelized cost of onshore wind power production in South America

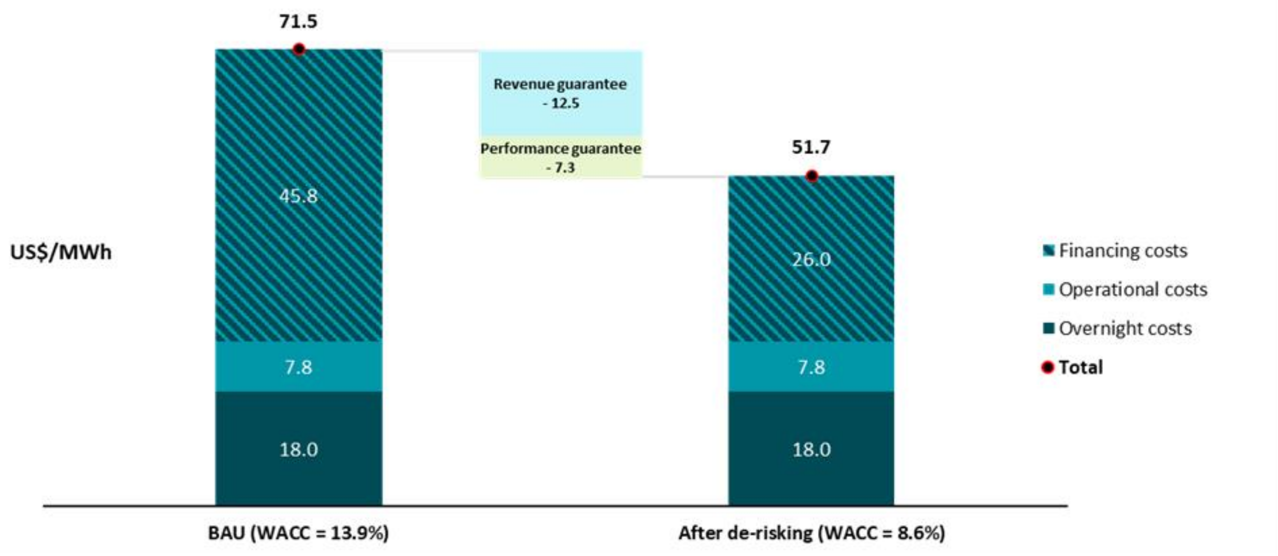


Figure 4. The impact of de-risking instruments on the levelized cost of solar power production in southeast Asia

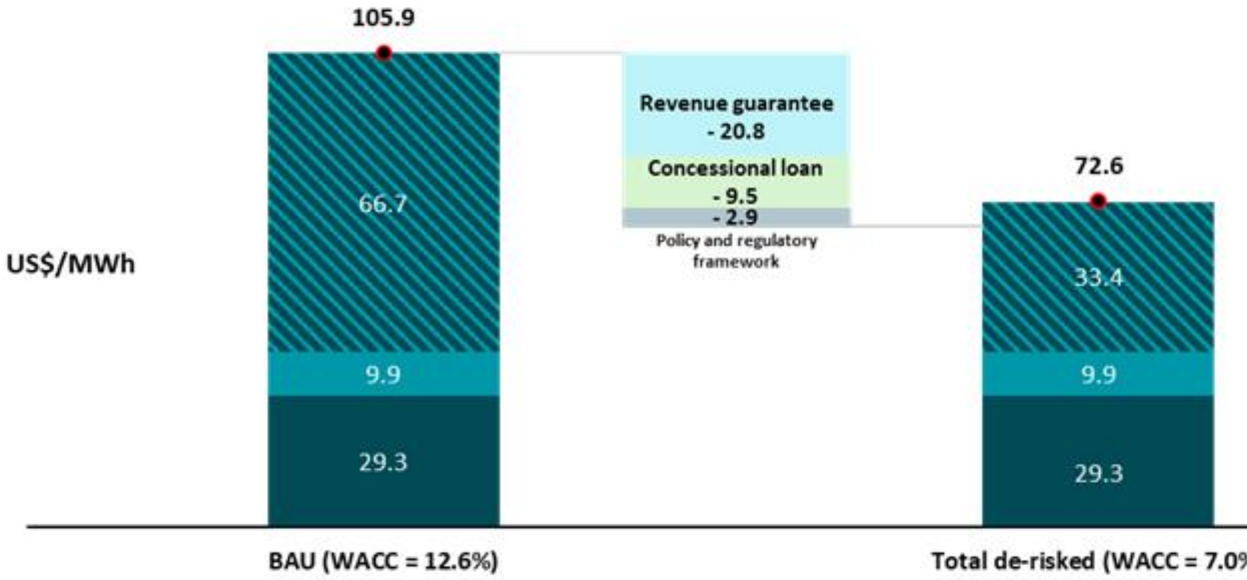


Figure 5. The impact of de-risking instruments on the levelized cost of offshore wind power production in northwest Europe

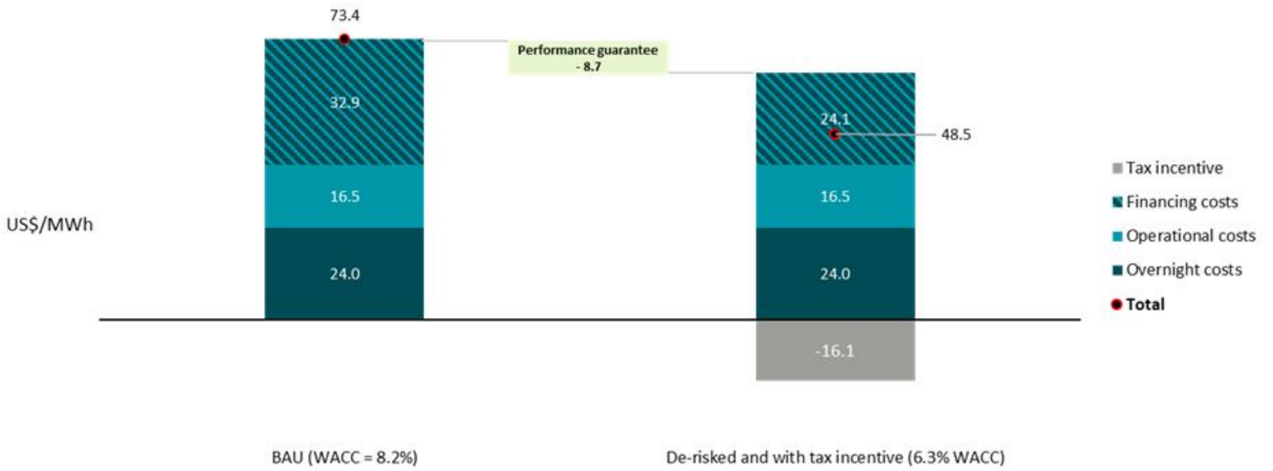


Figure 6. The impact of de-risking instruments on the levelized cost of solar PV-based green hydrogen production in Namibia

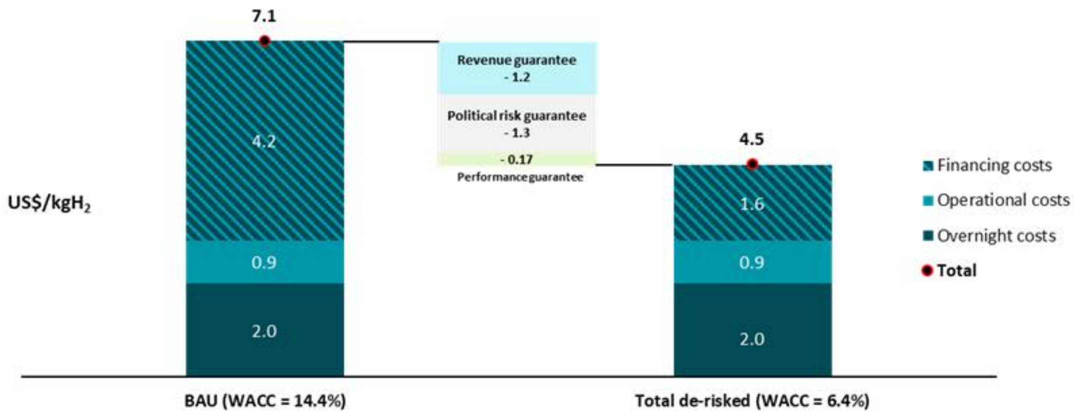


Figure 7. Range of efficiency of instruments as function of their public cost

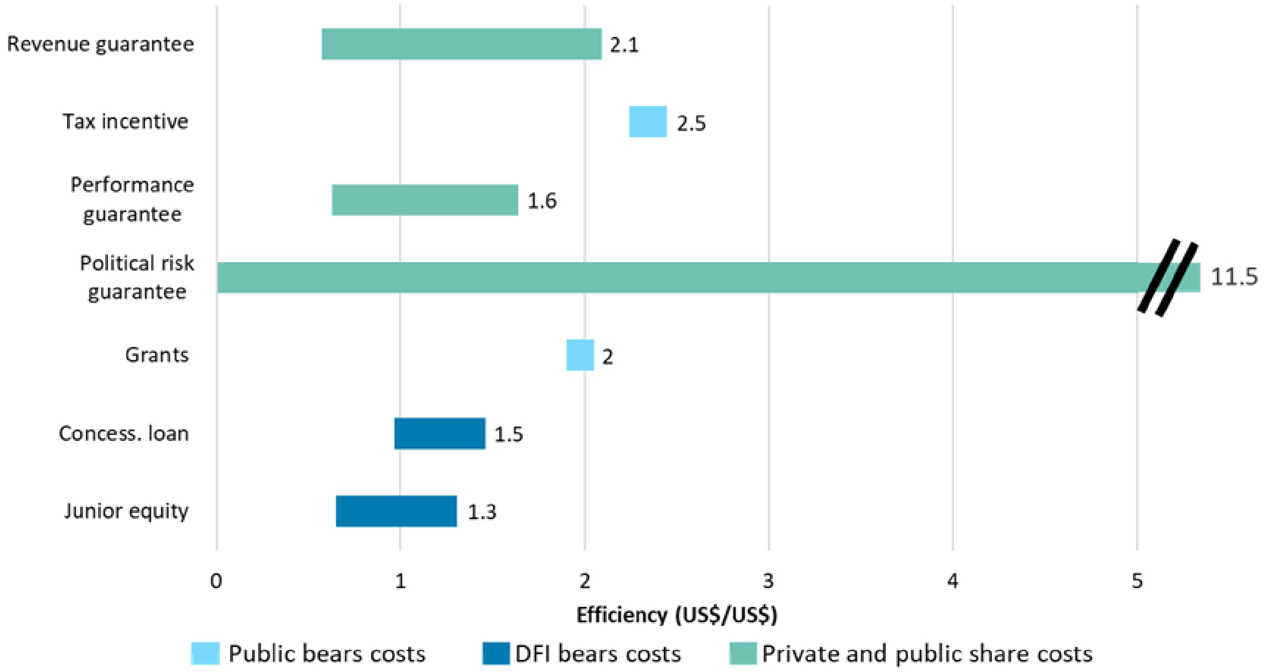
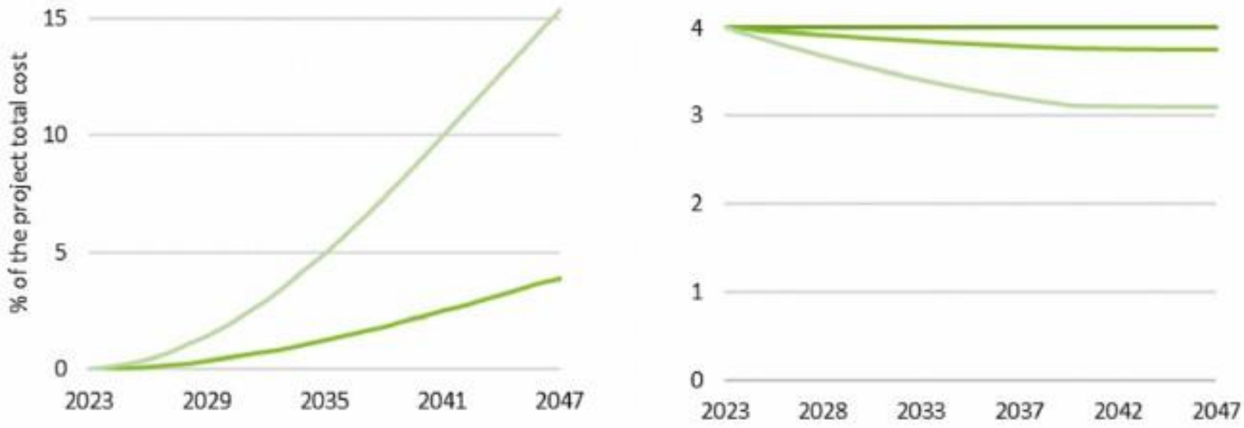
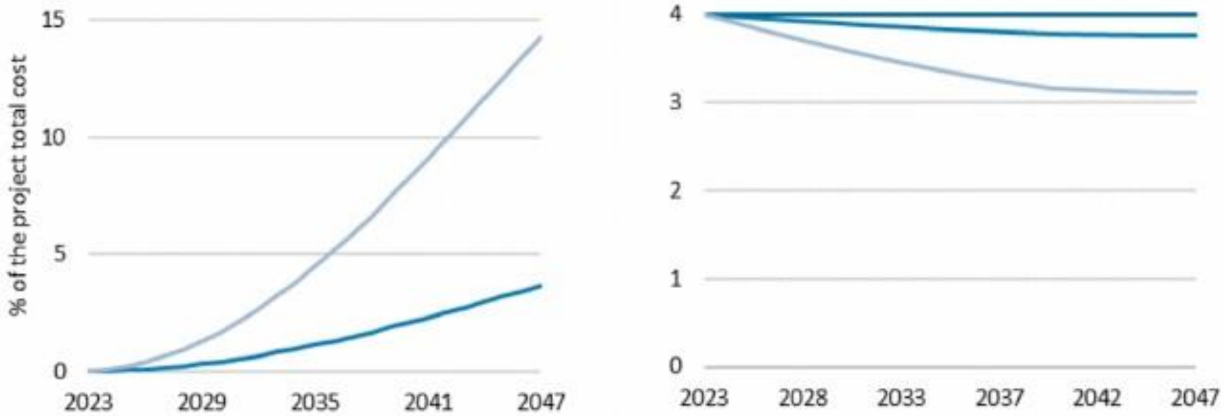


Figure 8. Project-level view of the effect of refinancing on expenditures

a. 100 MW solar PV farm in Chile



b. 100 MW onshore wind farm in Vietnam



c. 1 GW offshore wind farm in Brazil

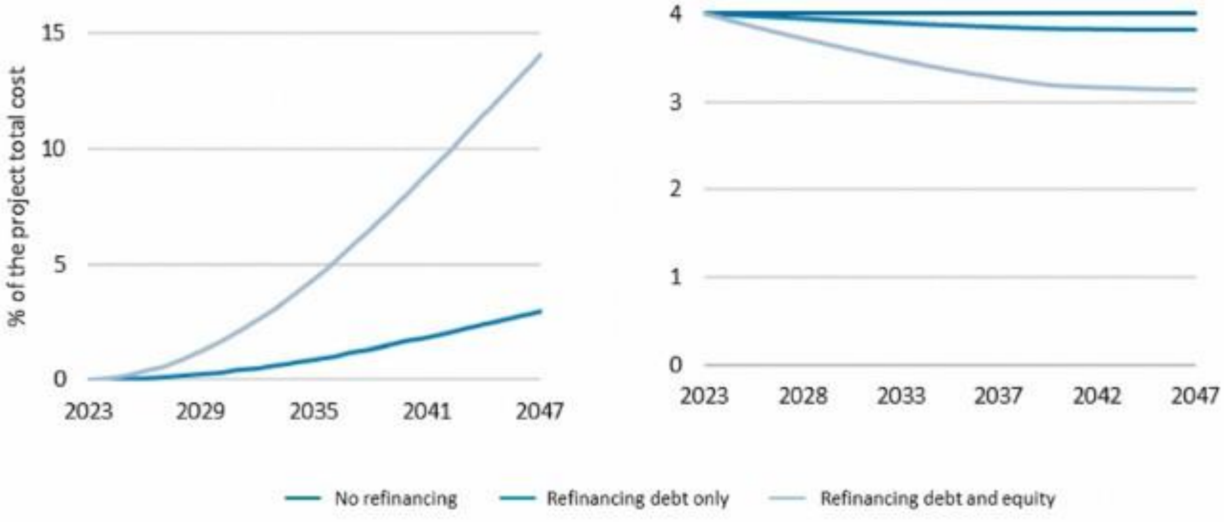
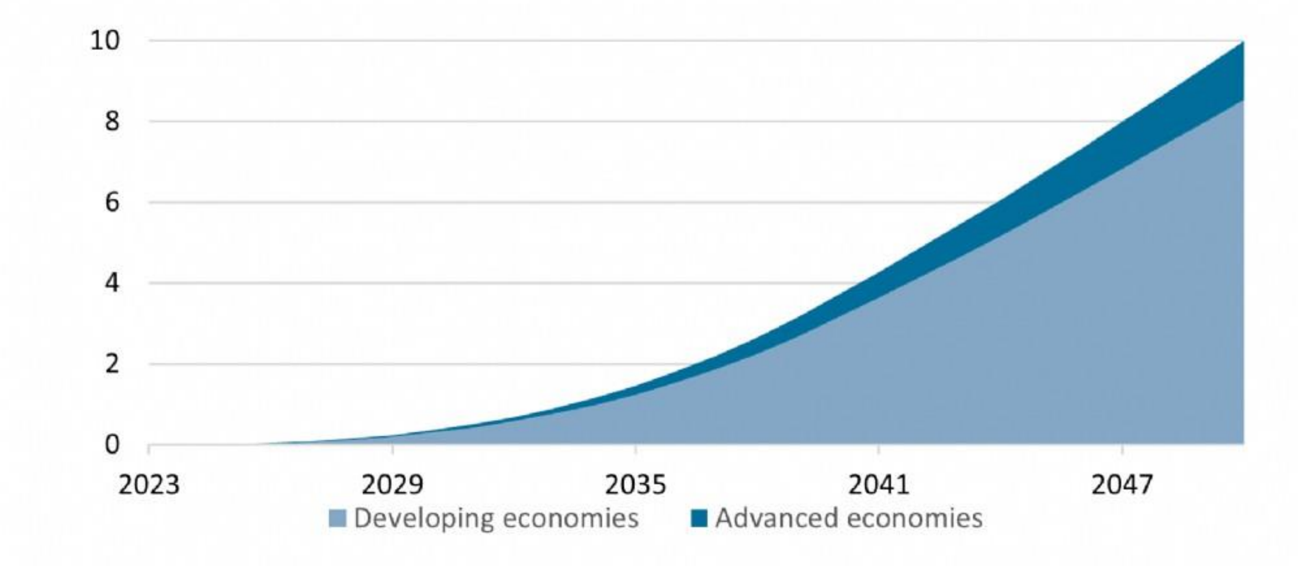


Figure 9. Cumulative cost saving potential of refinancing.



[Page: 225]

[Abstract:0417] OP-225 [Accepted:Oral Presentation] [Energy Finance and Trading » Project Finance]

Investigating drivers of risk premium in cost of capital for financing renewable energy projects in emerging economies vis-a-vis OECD countries

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London Economics International LLC ("LEI")

Overview:The cost of capital or the weighted average cost of capital ("WACC") for a project is one of the key aspects of project finance which determines whether an infrastructure project will proceed beyond planning stages to the implementation stage. A negative Net Present Value ("NPV") of expected cash flows over the lifetime of a project implies that expected financial costs outweigh the expected financial benefits. WACC is broadly composed of cost of debt (loans, bonds etc.) and cost of equity. Both components are highly sensitive to perceived risk in debt and equity financing i.e., higher risk is correlated with higher WACC.

Due to multitude of risk factors, financing an infrastructure project in a developed economy is cheaper than financing a similar project in an emerging economy. For a large energy project such as utility scale solar and wind generation projects, the key risk factors include currency volatility, regulatory risk, inadequate transmission network, off-taker risk, political risk, and sovereign risk. While not all the above risk factors are salient for all emerging economies, most are affected by some combination of the above risks. However, the magnitude of risk premium can vary widely among these countries. For instance, a 2023 report published by Climate Policy Initiative estimated a cost of equity of 8.3% for renewable energy projects in Germany and 59.7% for similar projects in Argentina.

There is a rich availability of literature quantifying WACC for developed and emerging economies. However, in authors' experience, there is insufficient country-specific focus on quantifying the magnitude of key risk factors affecting the risk premium. Such an exercise would make it easier for policy makers to hone in on mitigating the key risk factors. The International Energy Agency ("IEA") has taken some steps towards identifying country specific risk factors. The IEA performs annual surveys of key energy industry stakeholders in emerging and developing economies (Brazil, India, Indonesia, Mexico, South Africa, Senegal, and Vietnam) to help policy makers to better understand the risks. Among other outputs, the IEA identifies top 3 risk factors for each of the surveyed countries and recommends some mitigation options. While this is an extremely valuable resource, the authors believe that a deeper dive into each of the key risk factors is important.

Rapid scaling up of renewable energy in emerging economies is extremely important in meeting ambitious global targets for greenhouse gas emissions reductions. Even a marginal reduction in WACC for financing the required projects may prove to be a crucial factor in contributing towards achieving these goals.
Methods:In this paper, the authors shall take the following approach:

• The annual IEA surveys referenced above will be the starting point. The authors will choose 2-3 emerging economies from the list of surveyed countries and compare them with 2-3 countries from the Organisation for Economic Co-operation and Development ("OECD") countries to investigate further.

• The authors will estimate the WACC for renewable energy projects in chosen countries based on the latest available WACC estimates for key renewable energy technologies such as solar photovoltaic, onshore wind and offshore wind. The sources may include World Bank, IEA, and S&P global intelligence.

• The authors will then focus on the individual risk factors. For example, the IEA survey identifies regulatory risk, currency risk and off-taker risk as the top 3 risk factors for renewable energy projects in India.

• In the Indian example, currency risk can be quantified by comparing the yields for sovereign government bonds issued by India and a developed economy. After isolating the sovereign risk by comparing the sovereign credit rating between two countries, the rest can be attributed to currency risk as India only issues rupee denominated bonds.

• In the Indian example, off-taker risk may be ascertained by looking at the data published by the Central Electricity Authority of India ("CEA"). The CEA publishes monthly 'Outstanding Dues Reports' (payments from utilities to generators which have been delayed by more than 45 days) for all Central Public Sector Undertaking ("CPSU") generators. The authors will use a representative sample from the data to derive the magnitude of off-taker risk by comparing delayed payments over time with the return on equity allowed to these generators.

• In the Indian example, after accounting for sovereign risk, the balance risk premium will be assumed to be primarily occurring from regulatory risk.

• After quantifying the magnitude of key risk factors, the authors will provide policy recommendations to mitigate the risks, with the focus on most important risk factors driving the risk premium.
Results:The authors will attempt to quantify the magnitude of each of the key risk factor responsible for driving the risk premium for financing renewable energy projects in the chosen emerging economies.
Conclusions:The results from this study will assist in isolating key risk factors driving the risk premium in chosen emerging economies and provide mitigation recommendations accordingly.
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- Several additional references are expected to be used in the paper/presentation.

Keywords: cost of capital, risk premium, project finance, renewable energy

[Abstract:0476] OP-226 [Accepted:Oral Presentation] [Energy Finance and Trading » Project Finance]

Public energy finance via export credit agencies: Trends and implications amidst the energy transition

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Overview:The increasing urgency of interconnected climate and ecological crises requires rapidly re-directing financial flows away from fossil fuels and toward renewable energy technologies.[1 2 3] To reach the required scale and speed, public finance must play a critical role[4], and therefore, institutions such as multilateral development banks[5] or state investment banks[6 7] have received growing attention in the literature. By contrast, there has been little empirical research in the academic literature on public export credit agencies (ECAs), which support national exporters in overseas markets via guarantees and direct lending, thus de-risking projects and crowding in private capital.[8] Recent years have seen substantial policy shifts regarding ECAs, with an overhaul of the OECD Arrangement (the only supranational rulebook for ECAs) to allow for more generous financing terms for renewables and the creation of several climate club-like initiatives like Export Finance for Future (E3F).[9] However, a systematic empirical assessment of ECAs' role in the global transition to low-carbon energy is missing.

Methods:To fill this gap, we use transaction data from the TXF database on 718 ECA-backed energy deals between 2013–2023 to analyze the evolution of ECAs' energy finance portfolios amidst the energy transition. By reclassifying the financed projects according to the Joint Transparency Reporting guidelines of the E3F initiative, we disaggregate inflation-adjusted financing volumes by energy technology and steps of the value chain and conduct technology-specific analyses of financing volumes, deal structures, and recipients. Furthermore, we triangulate results with two publicly available datasets on public export finance, the Public Finance for Energy database by Oil Change International and the Joint Transparency Reporting, and find consistently better coverage by the commercial TXF data, particularly for ECA guarantees.

Results:Our findings highlight the critical role of ECAs in public energy finance, with their annual commitments to electricity projects exceeding the corresponding estimates for multilateral development banks.[5] Over the past decade, the share of renewable energy projects in ECAs' energy finance commitments has increased from less than 15% in 2013 to over 50% in 2023, primarily due to increased ECA support for offshore wind projects. Following COP26 in Glasgow in 2021, ECAs worldwide have abandoned their international coal power financing, in line with the OECD's ban on export finance for coal-fired electricity. However, several ECAs remain heavily involved in oil and gas deals, with a steady increase in financing volumes for upstream gas projects in particular. Therefore, the gradual greening of ECAs' energy finance portfolios is primarily driven by increasing energy finance market shares of the E3F climate club, including Denmark and Germany. The observed brown-to-green shift in ECAs' energy finance portfolios has significant implications for borrowers, shifting loans and guarantees from middle- to high-income countries and from public utilities to project companies.

Conclusions:Our results have several important policy implications for revisiting ECAs' mandates and multilateral rulebooks, such as the OECD Arrangement, and for international climate-related

cooperation in official export finance. First, our findings suggest that the OECD's ban on export finance for coal-fired electricity and a general uptick in the climate ambition of ECAs has spilled over to non-OECD parties, resulting in a global phase-out of international ECA finance for coal-fired electricity. This has important implications for climate club-like initiatives of ECA countries, such as the European E3F or the Clean Energy Transition Partnership of over 40 countries, including the United States. Second, oil and gas deals remain a key part of ECAs' energy finance portfolios, highlighting the need for clear mandates and rulebooks to ensure that public export finance remains compatible with the goals of the Paris Agreement. Lastly, our findings highlight clear differences in deal structures and characteristics between renewable energy and fossil fuel projects, meaning that ECAs should keep revising their terms and products to match the financing needs of the energy transition.

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Keywords: Energy finance, derisking, export credit, energy policy, loan guarantees

[Abstract:0437] OP-227 [Accepted:Oral Presentation] [Nuclear Power » R&D and Emerging Technologies]

Questioning nuclear scale-up propositions in low-carbon scenarios – Availability and economic prospects of light water, small modular and advanced reactor technologies

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Overview:The necessity for rapid decarbonization of energy systems is consensus (IPCC 2022). However, energy scenarios draw different technology pathways, with some future energy scenarios exploring fully renewable energy systems (e.g., (Bogdanov et al. 2021)), while others include other low-carbon technologies such as nuclear power or carbon capture technologies (e.g. (Knapp and Pevec 2018)). Energy scenarios play a major role as they can influence real-world decision-makers (Krey et al. 2019). Consequently, the feasibility analysis of energy scenario is necessary in order to support decision-makers in creating policies for (cost-)efficient and doable energy system decarbonization. In this context, the discipline of feasibility studies for energy scenarios has emerged (Brutschin et al. 2021; Vinichenko et al. 2023). However, such studies focus mostly on technology scale-up from an aggregated perspective and have little information about different sub-technology options. This is especially prevalent for feasibility assessments of nuclear power, all while the industry and other proponents envision the development of other reactor types than high-capacity light water reactors that dominate today's reactor fleets (Nuttall 2022). Just recently several countries have pledged a tripling in installed nuclear capacity (U.S. DOE 2023), while actual developments are characterized by ageing reactor fleets, limited actor bases and high capital costs (Wilson et al. 2020; Markard et al. 2020; Schneider et al. 2023). Thus, this analysis provides insight into feasibility studies on nuclear power and their applicability to current energy scenarios, and provides a framework for the assessment of technology feasibility on a sub-technology level that is exemplary conducted for nuclear power.

Methods:The analysis follows a two-step approach. First, a literature analysis of the current role of nuclear power in future energy system scenarios is conducted, which is then matched with current feasibility studies on nuclear power scale-up (e.g. (Brutschin et al. 2021)). Although some of the scenarios model a steep increase in nuclear electricity generation, the proposed thresholds are rarely crossed, which has led to a critical revisit of the proposed thresholds. Consequently, we introduce our framework that allows for the assessment of a given energy generation technology's feasibility from a sub-technology perspective, see Figure 1: From a first assessment of general necessity of further scrutiny, one must first determine possibly relevant sub-technologies that could be applied for proposed expansion plans. For each of the identified sub-technologies, the technological availability and economic competitiveness (compared to other low-carbon energy generation technologies) are assessed to determine whether a given sub-technology could contribute to rapid decarbonization. Following a final assessment for each sub-technology, it is assessed whether potential thresholds defined in feasibility studies should be adapted to more accurately reflect the current state of an energy generation technology.

Results:The following sub-technologies are included: 1) high-capacity light-water reactors (LWR), 2) low-capacity light-water reactors or so-called "small modular reactors" (SMR), and 3) non-light water reactors, in particular sodium-cooled fast reactors (SFR). For each of these, we conduct the assessment of availability and economic competitiveness. For LWRs, the long-standing history and its diffusion as the dominant reactor design was illustrated. However, such reactor technology is characterized by a small number of reactors that are actually under construction, of which most are located in China or are built by Russia. Other new-builds are limited to individual projects that experience serious cost and construction duration escalations. In terms of economic competitiveness, it is highlighted that reactor new build of high-capacity LWRs is far more expensive than other low-carbon technologies. SMR availability is even more limited as only a few are in operation, and many concepts remain either in licensing processes or are in early design stages. The economic competitiveness is linked to economies of multiples that are hoped to overcome the inherent scale deficiencies. However, such potential cost reductions for SMRs are historically unproven and thus remain a theoretical concept. Given that many hundreds of SMRs would have to be built in factory-like conditions, which in turn would require a substantial amount of down payments and pre-orders to finance, substantial cost reduction seem highly unlikely in the near future. Non-light water reactors such as SFRs have a history of project cancellations, where just very few are in operation namely in Russia.. Theoretical cost competitiveness depending on uranium prices. However, their commercial deployment is uncertain until at least the 2050s. The current status, marked by limited availability and/or economic viability across sub-technologies, raises doubts about a rapid nuclear scale-up, prompting the need to reevaluate thresholds and revisit scenarios.

Conclusions:From our sub-technology specific assessment, we find that no nuclear sub-technology is currently available for large-scale expansion for rapid energy system decarbonization in the next two decades. Further, economic challenges show that other low-carbon technologies are more cost-efficient. The assessment further shows that current thresholds as defined by (Brutschin et al. 2021) should be reassessed to absolute rather than relative values, and that the potential role of nuclear power seems to be overestimated in some of today's energy scenarios. Our framework could also be applied to other energy generation technologies, such as wind, to ensure that energy scenarios remain in the realm of "feasibility".

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Keywords: nuclear power, advanced reactor technology, feasbility, energy scenarios

[Abstract:0456] OP-228 [Accepted:Oral Presentation] [Nuclear Power » Policy and Regulation]

Innovative Nuclear Power for Latin America? Breakthrough?, or Just More of the Same Stagnation?

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Overview:For several decades, several countries in Latin America have attempted to establish an industry regime for a sustainable, i.e. self-sustaining, development of nuclear power, until now without success. Argentina, Brazil, and Mexico have attempted to import nuclear technology to kickstart a domestic national innovation system since the 1970s and 1980s, but this has not succeeded, and the contribution of (imported) nuclear power technology to electricity supply has remained small in all three countries. Other countries, such as Colombia, Peru, and Chile, have developed domestic nuclear research laboratories, without going to the next step of producing commercial nuclear energy. However, in the wake of global attempts to develop nuclear innovation for larger-scale development (sometimes (mistakenly) called "nuclear re-naissance")), Argentina, Brazil and Mexico have chimed into the euphoria, and announced bold development plans, too. In this paper, we analyze whether the current hype about nuclear power in these Latin American countries has the potential of an industry regime change, or whether it is just more of the same "wishful thinking", observed already during the last decades. We deploy a triple embeddedness analysis of the initial period (called t-1), the present (t0), and the announced "nuclear future", called t+1, and we ask whether they point towards a "regime shift".

Methods:The conceptual TEF framework developed by Frank Geels (2014) aims to understand bidirectional interactions between "firms in industries" and their embedded external environments. Such industries are characterized as large, political powerful, scale intensive and have many sunk investments, thus are rather interested in incremental change (Geels 2014). Furthermore following Geels (2014), they are embedded into two external environments (socio-political and economic), which put selection pressure on the current industry systems, see Fehler: Verweis nicht gefunden. Whereas the economic environment includes the relation between supplier and customers, factors such as competitiveness, efficiency and financial performance among others are relevant. The socio-political environment inhibits policy makers and the public such as activists, civil society and public discourse and thus legitimacy and social fitness are relevant criteria (Geels 2014). The paper applies such framework for three time periods; the initial period (called t-1), the present (t0), and the announced "nuclear future", called t+1, and evaluate whether they point towards a "regime shift".

Results:We find little evidence to support a "breakthrough", in either country. The three countries already relying on imported technology and knowledge project nuclear dreams of a plutonium future that lack industrial and economic substance, whereas the potential newcomer countries ("newbies") seem to lack the capacity to establish the required absorptive capacity for large-scale imports and/or domestic development. Thus, Latin America seems to reflect trends in other countries world-wide (outside the very few nuclear superpowers) that are stuck in failed attempts to benefit from nuclear energy for their respective energy transformations.

Conclusions:The paper discusses the historical attempts of several Latin American countries, including Argentina, Brazil, and Mexico, to establish a nuclear power industry. Despite decades of efforts, the importation of nuclear technology has not led to significant development in domestic nuclear power. The analysis extends to countries like Colombia, Peru, and Chile, which have research laboratories but no commercial nuclear energy production. The paper used the TEF framework to address the interactions between industries and their external environments. The framework considers economic and socio-political factors influencing industry systems. The analysis spans three time periods: the initial period (t-1), the present (t0), and the announced "nuclear future" (t+1), aiming to assess whether there is potential for a "regime shift." The findings indicate little evidence of a breakthrough in either group of countries. Established countries relying on imported technology lack substantial industrial and economic foundations for their nuclear aspirations. Newcomer countries, referred to as "newbies," appear to lack the capacity to absorb large-scale imports or develop domestic capabilities. The conclusion suggests that Latin America mirrors global trends, with many countries struggling to derive significant benefits from nuclear energy for their energy transformations.

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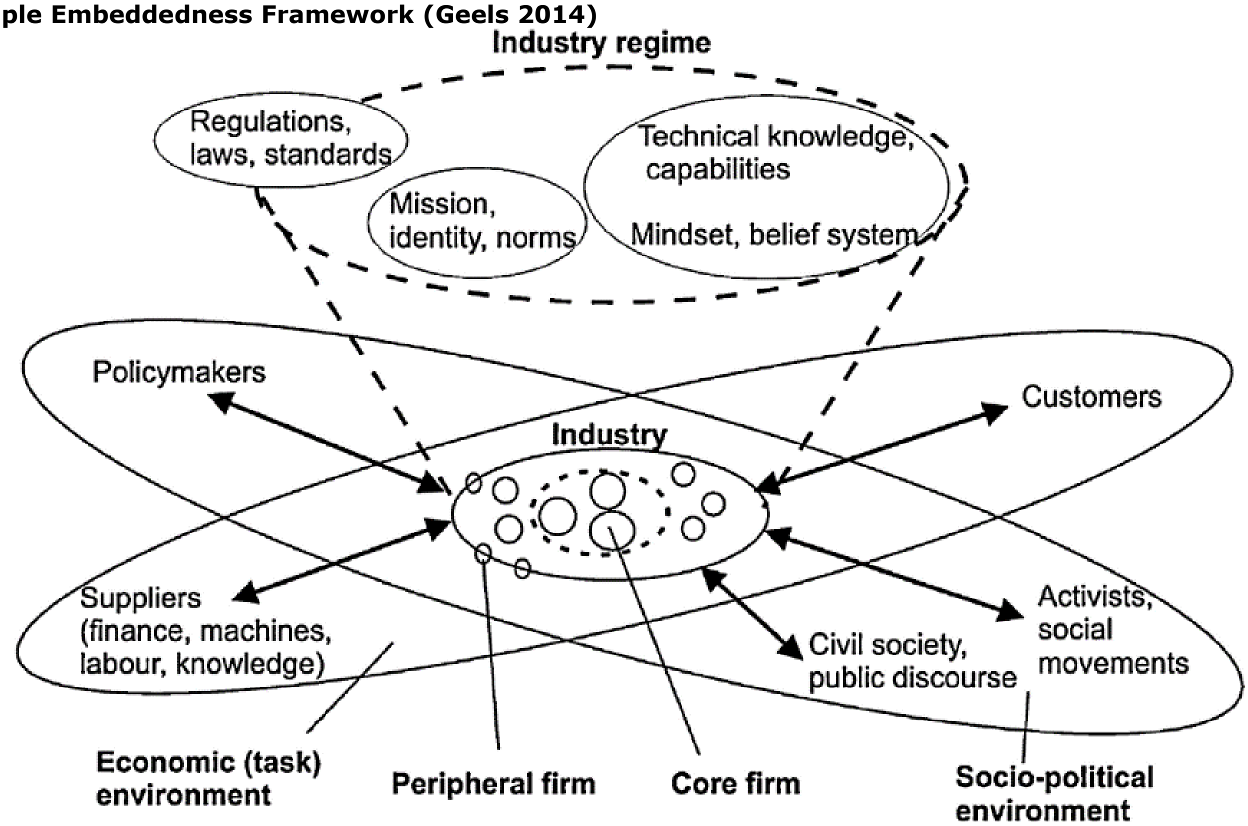
Keywords: Triple Embeddedness Framework, TEF, Nuclear Energy, Latin America

Triple Embeddedness Framework (Geels 2014)



Visual explication of the framework used for the analysis.

[Abstract:0493] OP-229 [Accepted:Oral Presentation] [Nuclear Power » Policy and Regulation]

Rationale and trade-offs of state involvement in nuclear decommissioning and waste management – case Studies from the United Kingdom and the United States

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Overview:Decommissioning of nuclear power plants and nuclear waste management are complex processes, both technical and organizational (Brunnengräber et al. 2015; Laraia 2018). The safe decommissioning of nuclear facilities, such as nuclear power plants, demands the coordinated efforts of various organizations. This complex long-term process is shaped by the challenges posed by the facilities' particularities and size, uncertainties, and radiation-related risks. This underscores the interdependence of organizational and technological considerations (Wealer and von Hirschhausen 2020). The complex supply network poses the risk of false incentives, limited or lack of liability, and insufficient oversight, subsequently risking the project success, potentially leading to cost and time overruns and in the worst case to adverse effects on the environment and human health. This calls for research on well suited governance structures. Large variations exist among different governance structures within and between different countries (Lordan-Perret, Sloan, and Rosner 2021; Wimmers et al. 2023). Together with the question of vertical integration of the process (Wimmers et al. 2023), one apparent observation is the prominent role of the state within these supply networks and governance structures. This submission takes stock of the different roles that public bodies can fulfil in the context of nuclear decommissioning and theoretically rationalizes the patterns. Subsequently, main trade-offs are derived regarding the role of the state within nuclear decommissioning and waste governance.

Methods:The paper presents a two-country case study of the United States (US) and the United Kingdom (UK). The basis for rationalizing are transaction costs theory, the resource-based view and property rights reasoning which altogether represent an interwoven and complementary theoretical framework for understanding governance structures (Albuquerque Augusto and De Souza 2015; Barzel 2005; Foss and Foss 2005; Williamson 1985). Within this framework, the literature is analysed regarding general reasonings for the involvement of public actors. Identified materials are used to 1) lay down the decommissioning and waste governance for each case and 2) rationalize the governance choices regarding the position of the state and point out advantages and disadvantages.

Results:The UK scheme can be described as a centralised system dominated by the state. The Nuclear Decommissioning Authority (NDA), a public entity, is the responsible actor (or respectively its subsidiaries for different sites and tasks). The publicly controlled and owned NDA makes strategic and operational decisions and builds capacities. Executive tasks are contracted to private firms but with limited decisions scope and autonomy of these firms, see Figure 1 (Wimmers and Von Hirschhausen 2023).

The US decommissioning landscape can be divided into two broad spheres: Decommissioning of and waste management at military or research facilities as well as waste management of all high-level waste is conducted by the Department of Energy and in so far works like the central-state model of the UK. However, public-private partnerships can be observed with varying levels of private involvement, especially for decommissioning tasks. The other sphere is dominated by privately conducted decommissioning and low-level waste management efforts, with the state acting mainly as regulator, see Figure 1 (Wimmers and Von Hirschhausen 2023).

The promise of privatized decommissioning and waste management are twofold: First, market competition promises to increase governance efficiency due to the disciplining effect of competition, and secondly, involving private actors (or the complete provision by them) allows for leveraging of existing capabilities and resources. In contrast, four basic rationales for increasing state involvement within decommissioning and waste management are identified, departing from the theory mentioned above.

1) Regulation may pose high transaction costs especially if processes and not outcomes are regulated. Being directly involved in the operations can lower information costs and hence increase governance efficiency. Furthermore, the need for a failsafe transaction(Williamson 1999) when

handling radioactive material, can be a reason for state involvement.
2) Nuclear decommissioning and waste management require a highly specific set of scarce resources, capabilities and investments (Invernizzi, Locatelli, and Brookes 2020). Private firms have low incentives to engage in the necessary capacity building to participate in the market with increasing numbers of participants. This is due to the limited size of the regionalized markets and the necessity to learn on site, providing incumbents with resource advantages. When facing a monopoly-like situation, it might be reasonable to enable the state to execute decommissioning and waste management.
3) Connected to the last point, decommissioning and waste management might pose a prohibitive high risk for private actors, depending on the facility, such that they would not engage in that activity under sole responsibility. Here, state participation or ownership, as last resort, could absorb risk and foster innovation. The decisive factor here is the risk of abandonment the contaminated sites, whereas in other high-risk cases, services and goods would simply not be provided.
4) Especially radioactive waste disposal siting poses a social challenge and is repeatedly the subject of NIMBY debates. Direct involvement of the state can increase the legitimacy of the siting process, potentially leading to public acceptance. Furthermore, state participation ensures continuity, responsibility and accountability, which is especially important regarding long term storage.
Conclusions:Every country that uses or has used nuclear technology inevitably faces the task of nuclear decommissioning and waste management. The analysis shows that there are reasons for state involvement in nuclear decommissioning and waste management, but the reasonable degree of state involvement varies depending on the technology of the facilities, market conditions and existing and required capabilities and resources. Policy makers should take the trade-offs of increasing public involvement into account when revising policy frameworks to implement safe and efficient nuclear decommissioning and waste management. Future research should analyse other country cases. Also, the development of quantitative performance indicators for decommissioning and waste management could be of great use. Furthermore, the paper might also inform policy makers concerned with other sectors with similar issues. One example could be the governance of carbon capture and storage regarding the social challenge or the initial risk during development (IEA 2023).
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Keywords: nuclear decommissioning, transaction costs, case study, united kingdom, united states, property rights

[Page: 230]

[Abstract:0495] OP-230 [Accepted:Oral Presentation] [Nuclear Power » R&D and Emerging Technologies]

The economic efficiency of non-light water reactors and their non-electrical applications in decarbonized energy systems

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Overview:This paper provides a methodology to assess the competitiveness of non-light water reactors, and first estimates. Previous research showed that, first, cost projections for high-capacity light-water reactors ("Generation III(+)", that constitute the majority of currently operational reactors, are overly optistimic and underly a high degree of variance, and secondly, overnight construction costs would have to significantly lower than already optimistic projections or even current Western projects to be considered by a cost-optimizing energy system model for a decarboinzed European energy system (Göke, Wimmers, and von Hirschhausen 2023). However, so-called "advanced" non-light water reactors, such as sodium-cooled fast reactors (SFR) and so-called small modular reactors (SMR) are envisioned in future energy systems dominated by fluctuating renewable energy sources by providing non-electrical use cases such as heat, either district or for industrial purposes (IAEA 2017; Brown 2022), hydrogen production (Nuttall and Bakenne 2020), seawater desalination (Ingersoll et al. 2014) or load following (Jenkins et al. 2018). In order to succeed in a decarbonized energy system, such reactor concepts must be 1) affordable, 2) economically competitive, 3) socially acceptable, and 4) commercially available (Committee on Laying the Foundation for New and Advanced Nuclear Reactors in the United States et al. 2023). While none of the proposed reactor concepts are currently commercial available, ongoing development efforts might well lead to availability of some non-light water concepts in the coming decades. The paper thus provides insight into ongoing reactor concept development efforts, potential non-electrical applications and related cost data, and assesses whether such reactor concepts can, from today's point of view, compete with renewable energies in a future decarbonized energy system.
Methods:This submission consists of three methodological steps. The first step comprises an in-depth literature analysis into potential non-electrical applications and potentially suited reactor concepts. This includes descriptions of historic applications and a qualitative assessment of future applicability.

The second step is an analysis of currently available data on costs for non-light water reactor concepts. The basis for this analysis is a wide array of studies, papers, industry projections and technical reports. Data is divided into "first-of-a-kind" (FOAK) and "n-th-of-a-kind" (NOAK) data. Cost data is normalized following (Abou-Jaoude et al. 2023). The third step is the integration of these cost projections into a comprehensive techno-economic model to assess the applicability of reactor concepts in a future decarbonized energy system (Göke 2021a; 2021b). The model application includes a total of four stylized reactor concepts that are each able to provide a certain type of heat in combination with standard electricity production. "Generation III(+)" reactors produce district heat, SMRs produce low process heat (≤ 150°C), SFRs produce medium process heat (300-500°C) while HTRs produce medium and high process heat (>750°C).
Results:Results of the first part of the analysis indicate that while there have been several use cases for non-electrical applications from nuclear reactors, they are limited to certain geographical regions and individual reactors mainly due to technological constraints regarding the transportation of heat and the non-availability of non-light water reactors. The cost analysis yields a wide range of cost projections for overnight construction costs (OCC). Cost projections range back to 1978 and differ strongly depending on the type of reactor. A discrepancy of FOAK and NOAK costs is not directly visible and subject to further analysis. However, cost data shows that expectations of such currently unavailable reactor concepts are low or sometimes even on the level of already unrealistic projections for high-capacity light-water reactors (Göke, Wimmers, and von Hirschhausen 2023). Figure 1 shows the normalized OCC in USD/kW for different reactor types and readiness levels (NOAK & FOAK, the x-axis indicates the year of the respective publication). First results of the model application show that at mean NOAK OCC and seven years construction time for all four available reactor concepts, only HTRs are built in a future decarbonized energy system. These reactors provide a total of 2338.3 TWh of energy, divided equally between high temperature process heat and electricity. Only when OCC are further reduced, are other nuclear reactor technologies chosen by the model. At FOAK costs, no nuclear reactor is built. Further scenarios and in-depth analyses are currently under development.
Conclusions:Our current results indicate that first, many so-called "advanced" reactor technology cost projections are similarly over-optimistic as projections for current "Generation III(+)" reactors, and that even if reactor technologies became available at such proposed cost levels in the coming decades, they would compete with cheaper renewable energy and storage technologies that are already available today. Consequently, discussions on the future role of nuclear power should acknowledge the current unavailability and inexperience regarding the operation of non-light water reactor concepts, discrepancies in cost assumptions, and the actual potential cost-efficient role of nuclear in a future decarbonized energy system.
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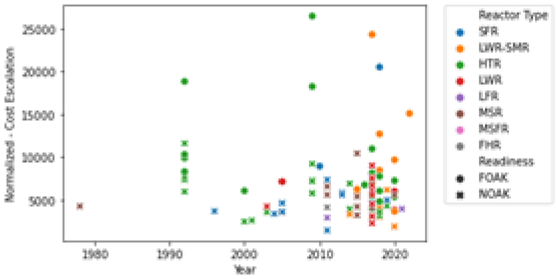
Keywords: nuclear power, small modular reactors, low-carbon energy system, advanced reactors, cost analysis

Figure 1: OCC projections in USD/kW for reactor types and readiness levels



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[Abstract:0568] OP-231 [Accepted:Oral Presentation] [Nuclear Power » Markets and Prices]

From Concept to Commercialization: Assessing Market Entry Scenarios for Fusion Energy

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Overview:The development of fusion energy has gained momentum in recent years with scientific breakthroughs, technological advances and growing financial and regulatory support from public and private sectors. This has led to a growing number of private start-ups aiming at commercializing fusion energy in the 2030s. However, academic scholars point out that early customer involvement is crucial in the development of such disruptive innovations. The aim of this research is to explore the process of engaging potential customers in a project that may still be 10-15 years away and to provide a detailed overview of the current hypothesis of early fusion markets. This broad approach allows the relatively new topic to be approached from different angles. It provides a comprehensive perspective on the research question of which industries are best suited for fusion power plant market entry and how to identify them.
Methods:This study uses an exploratory case study of a German fusion energy startup and a total of eight potential target customers. The individual steps of the analysis are inspired by the multiple case study methodology as originally introduced by Eisenhardt (1989). Such a qualitative research design is particularly suitable for the analysis of new phenomena where theoretical observations have yet to be formalized. To identify potential target markets, we first elaborate on the benefits of fusion power plants by analyzing the existing literature on fusion commercialization and energy markets and aligning it with the fusion industry practitioners involved. We then used this information to identify suitable sectors following the principles of theoretical sampling, including the electricity market, energy-intensive sectors such as metals and chemicals, hydrogen production and its derivatives, desalination and direct air capture. The assessment of potential target industries is triangulated from different perspectives, including market modeling, interviews with market experts as well as field visits and workshops. In this research project phase, we primarily focused on the German market. The German market poses unique challenges for the energy transition due to

ambitious decarbonization targets, the phase-out of coal and nuclear power, and limited availability of renewable resources. These factors create a significant tension in energy supply for companies.

To gain a comprehensive understanding of each potential target group, we conducted site visits, workshops, expert interviews, and literature reviews for each industry sector. The companies studied included two players from the steel industry, two copper manufacturers, two chemical companies, one energy suppliers and one company from the sustainable aviation fuel sector, which is a derivative of hydrogen production. Workshops and field visits were held together with both the fusion startup and the respective industrial player. Multiple representatives each participated to minimize bias and include different perspectives and expertise. The insights gained were supplemented with 30–60-minute semi-structured expert interviews with two experts per sector.
Results:Our analysis indicates that fusion energy is a suitable solution for off-grid energy supply on-site, particularly for energy-intensive industries with high electricity demand and the ability to utilize thermal energy. These industries face significant challenges in meeting their high, baseload demand with intermittent renewable energy sources that have low energy density. They urgently need solutions to their energy problems, especially as they strive to remain economically competitive while decarbonizing. In Germany, industrial companies are particularly concerned about the risk of de-industrialization if suitable energy sources are not found. Our hypothesis that fusion energy can be a promising solution to their challenges is confirmed by their willingness to pay up to 50 EUR/MWh, but there are significant concerns about the feasibility of achieving this cost level, especially in the initial phase of commercialization. The importance of the timescale is also highlighted, as decarbonization is expected to be well advanced by the mid-30s. Therefore, the contribution of fusion energy to this transition would be most valuable if it were already available in the late 20s or early 30s.

In addition to providing insights into early markets, the innovative aspect of our research project lies in the application of fundamental principles from case study research to strategic go-to-market development. Our chosen process yielded a variety of insights on how to approach deep tech commercialization processes and achieve high customer engagement. Strategies that proved particularly fruitful included combining data from different sources to generate high-confidence forecasts under high uncertainty, engaging in discussions with a large number of industrial players to improve awareness of the issue and signal to investors, and developing white papers in collaboration with potential customers to analyze the possible integration of fusion energy into their processes. Of the eight companies we approached, three have confirmed their interest in developing such a white paper, and another three are expected to agree.
Conclusions:This analysis provides two main contributions: In terms of commercializing disruptive innovations, this work provides a framework for developing a go-to-market strategy with high customer engagement while still being far (10+ years) away from actual product commercialization. It provides an appropriate process for identifying and developing markets in uncertain environments by utilizing experts and practitioners in each field and triangulating data from multiple sources. Evidence found in employing a case study on fusion energy enriches the emerging body of research on its commercialization. These findings pave the way for the targeted development of fusion energy. They point to risks and gaps that need to be bridged between fusion start-ups and industrial customers through appropriate legal frameworks.
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Keywords: Fusion energy, early markets, commercialization, disruptive innovation, energy transition, case study

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[Abstract:0405] OP-232 [Accepted:Oral Presentation] [Hydrogen » Markets and Prices]

Perspectives on future domestic hydrogen production from electrolysis and effects on electricity systems: The case of Central Europe

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Overview:The reduction of greenhouse gas emissions demands an increasing share of renewable energy sources (RES) in the European electricity system. The fluctuating nature of their electricity generation induces a growing number of hours with low electricity prices towards zero, while residual loads are still supplied by conventional generation in the remaining hours. Hydrogen, as demanded by industry [1] and hydrogen-based power plants, is an emission-free fuel, which can be produced by electrolysis. In the context of a growing number of hours with low electricity prices, electrolysis is planned to be a core technology to be used in the European electricity system besides valid global importing options [2] in order to obtain hydrogen for domestic demand. National governments are therefore aiming at expanding electrolysis capacity in the future years. Germany, acting as the largest electricity generating and consuming country in Europe, plans on installing 10 GW electrolysis until 2030 with further expansions afterwards [3]. Also France with a high share of nuclear electricity generation plans on expanding electrolysis capacities to 6.5 GW until 2030 [4]. The question remains, whether hydrogen production in Central Europe is competitively viable until 2030 in comparison to the future global importing options. If electricity prices remain at a high level in the future years, the operation of electrolysers needs potentially to be subsidized and has additional involuntary price effects [5], since it is acting as electricity demand in hours of low prices. In this research, an analysis on the price effects and market operation of electrolysis in the years 2030 and 2040 is conducted for the countries in Central Europe with a special focus on Germany. Our results cover demand and price effects as well as the potentially needed subsidies of electrolysis capacity or produced hydrogen in an electricity market environment.
Methods:We conduct our analysis on the market-based operation of electrolysis in Central Europe by using an electricity market model, which is based on [6], [7] and [8]. The model is a representation of the European electricity market, which consists of (mostly) national bidding zones and uniform electricity prices. In this model, the central participating agents' behaviour and investment strategies can be depicted under the current market design. Thus, price and demand effects can be analysed among other results. Electricity generation capacity decisions, such as investment and decommission, are modelled endogenously, while the expansion of RES as well as installed

electrolysis capacity for the two target years are exogenously given due to their political character. The operation of electrolysers is characterized by demanding electricity from the spot market and producing hydrogen with an exogenously given equivalent value. We use two different data sets as input for the model: One for the year 2030 and one for 2040. Data includes both a centralised European perspective on the two target years as well as individual national strategies. Germany and its neighboring countries as well as the Nordics and Italy are covered regarding their generation, flexibility and demand structure. The resulting electricity market model is implemented as a welfare maximization problem in General Algebraic Modeling System (GAMS).
Results:Results cover core electricity market results for the two analysed target years: 2030 and 2040. Additionally, the operation of electrolysis under the year- and country-specific circumstances is considered. The transformation by expanding RES follows an ambitious path, but is not fully realized until 2030. Hence, lower electricity prices can be expected than in the current status of the market. In this process, the rising prices for emission certificates lead to a decommission of coal-fired power plants and a market-driven expansion of gas power plants in affected countries. The levelized cost of hydrogen (LCOH) depends on both electricity prices and the full load hours of the electrolysers. Therefore, optimal results are also characterized by a high utilization of the electrolysers, whereby the electrolysis systems often have a price-setting effect. Price effects are significant, as additional electricity demand is added to the market. In 2040, the overall prices for electricity are expected to be lower than in 2030 due to the higher share of RES. Within this setting, electrolysis is a more significant production option for hydrogen. Full-load hours are significantly larger than in 2030 and levelized cost for the domestic production decreases. Price effects are larger than in 2030 due to the bigger capacities and increasing full-load hours. Specific countries with a low residual load, such as Norway or Denmark, turn out to be a viable production site for hydrogen within Europe considering their country-specific LCOH. For other countries with a large residual load, such as Germany, the domestic production of hydrogen by electrolysis is only suitable in a relatively small dimension and needs to be complemented by imports to cover future demands.
Conclusions:Our analysis shows, that domestic hydrogen production in Central Europe can be a viable option to complement import from more suitable locations around the world. However, electricity demand and resulting price effects would be too large for a domestic production with full supply. Thus, importing hydrogen remains a economically viable solution in the future. Especially in the short-term future until 2030, substantial subsidies for the operation of the politically targeted electrolysis capacity have to be provided, since electricity prices remain high. In the long-term future until 2040, the needed subsidy decreases, but remains significant. The European countries are in need of a conclusive hydrogen strategy in order to supply growing demand in industry and electricity generation.
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Keywords: Hydrogen, electrolysis, price effects, electricity demand, subsidy

[Abstract:0504] OP-233 [Accepted:Oral Presentation] [Hydrogen » Markets and Prices]

Levelized Cost of Green Hydrogen Production in the Antofagasta Region

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Overview:As part of its nationally determined contribution (NDC) to reduce emission levels under the Paris Agreement, Chile is committed to fully decarbonizing its energy matrix by 2050. Even though the plan for the retirement of all coal-fired power plants was a voluntary agreement between the private sector and the government, it is an ambitious goal not easy to achieve. One difficulty to accelerate this process is that new renewable technologies, mostly solar PV and wind, have intermittence and variability, so as the deployment increases, the system ends up with several periods with low and high costs of electricity. In this context, with a higher variance in prices, investors owning or developing renewable energy projects see with concern the evolution of the market as their projects face major curtailments and become riskier. One alternative to reduce the risk and uncertainty of the projects is to provide a use to all energy generated by renewable plants increasing, for this purpose, the demand at the hours when that energy is available and low cost with the production of fuels such as hydrogen.
Hydrogen is the most abundant chemical element in the universe and has the great power of being a very powerful fuel to be used in an ever-increasing number of processes, including transportation and industrial uses. Because it is not available to be taken and used directly from nature, hydrogen must be produced. The production of hydrogen from renewable energies is called green hydrogen and is considered an opportunity for improving the global economic growth and simultaneously help to combat climate change. In this study, we estimate and analyze the levelized cost of green hydrogen production in northern Chile, since it has a great solar potential and ideal conditions to produce it.
The specific area of analysis is the Antofagasta Region, which is a mining region in northern Chile, with plenty of demand for green hydrogen and the port infrastructure to export to other countries. An additional and relevant advantage is that he region has very high irradiation levels and significant wind resource. However, one drawback of the area is that it has no freshwater, so any hydrogen production has to start by water desalination (World Bank, 2019).
In the paper we present a methodology to calculate the Levelized Cost of Hydrogen (LCOH) according to different parameters such as distance to the power grid, distance to ports, and height from sea level.
Methods:The first step in methodology of this study consists of analyzing in detail all of the most cost-effective technologies for the region, including the electrolyzer, the corresponding stack, the desalination plant, transmission lines, pumping and piping equipment and the balance of plant (International Energy Agency, 2020; Huehmer, R., et al, 2011). In the second step, considering all the main technical characteristics of each technology and the specific conditions in the Antofagasta Region, a PEM-type electrolysis unit (Peterson, D., et al, 2020) and a reverse osmosis desalination unit (SWRO) capable of producing 447,500 tons per year were chosen as the best option to evaluate. The methodology then calculates the capital and operation costs, CAPEX and OPEX, respectively, for various locations within the region. These cost obviously vary due to considerations such as distance to ports and transmission grids and also reflect the height of the plant reflecting the need to pump water to it. Once all the components -technical and geographical- are explicitly taken into account the LCOH is calculated per location.
Results:The result of the evaluation shows costs of around 2.33 US$/kg H2 as LCOH in the area near Antofagasta City. This area was selected over other zones that were analyzed in the region, as at this site hydrogen production is more convenient bases on all parameters, including the distance to the coast and the electrical system.
Conclusions:The research shows that it is feasible to calculate the LCOH in different geographical areas to allow developers to find the optimal location for their investment. In the case of the Antofagasta Region, LCOH change slightly depending on the specific location: the farther from the coast and the higher the plant is located above sea level, the higher the capital and operating costs

are. In particular, the most suitable place in the Antofagasta Region is by the ocean and near Antofagasta city.

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Keywords: Hydrogen, Renewable Energy, Solar Energy

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[Abstract:0584] OP-234 [Accepted:Oral Presentation] [Hydrogen » Markets and Prices]

A Multi-Commodity Partial Equilibrium Model of Imperfect Competition in Future Global Hydrogen Markets

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Overview:Several countries have dedicated specific strategies to hydrogen and respective derivatives (IEA 2021a; 2021b). Some foresee a large proportion of imports from currently non-existing global markets (cf. e.g. German Federal Ministry for Economic Affairs and Energy 2020). Therefore, many recent techno-economic studies have investigated procurement costs of hydrogen on various international trade routes (cf. e.g. Heuser et al. 2019; Armijo and Philibert 2020; Collis and Schomäcker 2022 and many more). However, strategically behaving exporters have not been considered adequately in this context, despite similar behavior frequently observed and modeled in the fossil fuel world, e.g. by the OPEC, or in the natural gas sector (Egging, Holz, and Gabriel 2010; Hecking and Panke 2012; Egging-Bratseth, Holz, and Czempinski 2021; Ansari 2017). In addition, a suspected inelastic demand for hydrogen, high capital intensity and risks involved with market entry, as well as illiquid markets and subsidized long-term contracting indicate some potential for strategic behavior.
Methods:This work introduces a novel techno-economic model of oligopolistic trade tailored around the value chain of future global hydrogen trade. Model features include procurement of inputs, production of commodities, conversion and storage, as well as multiple transport options. Repurposing of legacy transport, storage and conversion facilities is possible, as well as varying temporal and spatial resolution. The model is formulated as a mixed complementarity problem, with a reformulation as a convex optimization problem. This allows to solve for both competitive and oligopolistic equilibria much beyond the capabilities of traditional complementarity problems, while still featuring dedicated considerations about strategic behavior. The model code is written as a standalone Julia package, with detailed validation of functionality and model mechanics.
Results:In an illustrative case study, some insights from the newly introduced model are given. The case study includes 26 aggregated regions and investigates global trade of hydrogen and ammonia

in both a competitive setting, as well as one where exporters can behave strategically by withholding quantities to increase profits. Strategic behavior of exporters can have a significant effect on prices in both importing and exporting regions. For importers, seasonal prices may increase by 30-50 €/MWh by 2050 and 2030, respectively. Withholding quantities in export makes cheaper resources available for domestic use and thereby may reduce local hydrogen prices by over 25 €/MWh in some exporting regions. Imperfect competition hence increases the price spreads observed under competitive conditions. This creates a twofold narrative for potential exporting regions to incentivize strategic behavior: Since profits of exporters increase and may hence contribute larger tax volumes, prices paid by domestic consumers decrease. While few preferred trade routes emerge under perfect competition, markets characterized by oligopolistic competition show smaller trade along individual arcs, however with many more active arcs in general. Here, quantities withheld by exporters are partially offset by additional market entrants.
Conclusions:Results indicate that assuming perfectly competitive price formation in early phases of future global hydrogen markets may lead to overly optimistic cost projections, especially within Europe, and Japan or South Korea. Policymakers and practitioners from the energy sector should explicitly consider the possibility of strategically behaving exporters and that hydrogen prices in international markets may not necessarily be cost reflective. The newly introduced model specifically enables dedicated large scale analysis of oligopolistic or perfectly competitive hydrogen and derivative markets under varying spatial and temporal scopes, a topic that may deserve much attention in the following years.
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Keywords: Equilibrium Modeling, Mixed Complementarity Model, Hydrogen, Convex Reformulation

[Abstract:0653] OP-235 [Accepted:Oral Presentation] [Hydrogen » Markets and Prices]

The economics of global green ammonia trade – Shipping Australian wind and sunshine to Germany

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Overview:To mitigate climate change effectively and timely, rapid decarbonization of the global economies is required. The transformation is already well advanced in the electricity sector of various industrialized countries, where competitive renewable energy technologies increasingly replace coal- and gas-fired power plants. Climate-neutral electricity will now be used directly or indirectly – via hydrogen and its derivatives – to decarbonize all remaining sectors of the economy. In this context, the production and transport of hydrogen and energy carriers is getting increasing attention, as they have the potential to replace fossil coal, oil, and gas as a global energy commodity.
Methods:There are several options being considered for the transportation of hydrogen from overseas, including the transportation of cryogenic hydrogen and the use of liquid organic hydrogen carriers. In the short term, the transport of ammonia is particularly attractive, since ammonia and its derivates are already traded worldwide and therefore existing infrastructure can be used. Furthermore, all links in the process chain of large-scale renewable ammonia production are already established and have a very high technology readiness level. This paper contributes to understanding the transformation of global energy trade to green energy carriers, focusing on green ammonia as the foreseeable first green hydrogen carrier. We provide a comprehensive overview of today's ammonia trade and assess scaling options for the trade of green ammonia. To that aim, we develop an optimization model for the integrated assessment of the green ammonia value chain that covers all steps from green ammonia production in an exporting country, up to delivery to a harbor in an importing country. The model endogenously chooses among different technology options and determines cost minimal operation. In a case study, we apply the model to the large-scale import of ammonia from Australia to Germany in a scenario for 2030.
Results:The Australian-German case study yields average levelized cost of green ammonia of 109.39 €/MWh (566.64 €/t) at the harbor in Germany and 159.18 €/MWh (5.3 €/kg) for green hydrogen from cracked ammonia for the year 2030. The results show that green ammonia can reach cost parity with gray ammonia even for moderate gas prices (but not necessarily with blue ammonia) if CO2 prices are high enough. We also provide a sensitivity analysis with respect to the interest rate and other key technical and economic parameters, such as electrolysis efficiency and capex of various relevant technologies.
In addition, our results show that cracking ammonia to provide pure hydrogen comes at a 45 % cost markup per MWh at the destination. Thus, it is advisable not to convert ammonia that has been imported. Instead, it is better to meet the demand for ammonia in the country of destination through ammonia imports, either for feedstock or for direct energy applications.
Conclusions:For meeting the demand for hydrogen, it might be better to rely on regional production or pipeline imports, which enable the transportation of compressed hydrogen. Gaseous hydrogen imported by pipeline will likely be the most cost-effective option. However, it is unlikely that the amount of hydrogen available through this method will be sufficient to meet the long-term needs of Europe alone. Therefore, the importation of hydrogen from overseas, which will be initiated by importing green ammonia, will play an important role on the way to a hydrogen economy.
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Keywords: Green hydrogen. Green Ammonia, Techno-economic assessment, Cost optimization models, renewables, Ammonia cracking

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[Abstract:0407] OP-236 [Accepted:Oral Presentation] [Hydrogen » Policy and Regulation]

Incentives for pipeline decommissioning and repurposing in regulated grids

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Overview:This paper analyses a gas network operator's incentives to decommission or repurpose. The paper is motivated by the expectation of decreasing demand for natural gas due to decarbonization efforts. Interestingly, gas pipelines can potentially be repurposed for the emerging supply of hydrogen, which in turn might accelerate the demand reduction due to substitution effects. In Europe, a consortium of key actors is anticipating that almost 17,000 km of natural gas pipelines could be repurposed until 2030 and another 17,000 km until 2040 (European Hydrogen Backbone 2023). These estimates have been growing and represent up to 60% of the overall envisioned hydrogen grid, as well as around 17% of the current natural gas grid.
In this paper, the problem is formalized as a decision to scrap part of the existing assets to maximize regulated profits in the expectation of decreasing demand. The analysis expands the existing literature for the case of negative scrapping cost, i.e. revenue from repurposing. Additionally, the paper covers the effect of accelerated demand substitution linked to the repurposing of assets. I compare the firm's incentives under rate-of-return and incentive regulation and for integrated natural gas and hydrogen operators as well as separate entities with different regulatory regimes.
Methods:The paper is rooted in the literature on investment in regulated networks as surveyed by Guthrie (2006) and its recent applications to the energy transformation for example in Costa et al. (2017), Marques et al. (2014) and Mauritzen (2014). The analysis is based on a theoretical model representing the changes in a network operator's profit function when deciding to scrap part of its existing capacity in response to an expected demand shock. As a starting point, I establish the framework for an investment decision in a regulated environment based on the change in present value. Next, I successively extend this model. First for a real options representation of delayed investments due to uncertainty. And eventually, to represent an endogenous additional demand surge if the repurposed asset drives the demand decline by increasing the attractiveness of a substitution option.
Results:The analysis shows that network operators are more likely to let their assets strand with rate-of-return regulation and if the course of demand decrease (or its translation into the regulatory framework) is uncertain. If repurposing propels an additional demand reduction this adds to the effect. The paper explores options for tuning regulatory parameters to the requirements of repurposing and decommissioning. Tuning parameters include, (1) the sharing factors between shareholders and network users for operational and (2) capital expenditure, (3) a mark-down for the expected demand decline, (4) the timing of the regulatory review and (5) the depreciation model. Decisive characteristics of the scrapping options are (1) cost of decommissioning resp. revenue from repurposing, (2) residual life time, (3) substitutability between natural gas and hydrogen.
Conclusions:Firstly, the paper contributes a theoretical analysis of investments in regulated grids. The existing literature does not cover situations of declining demand or the ramp-up of new regulated networks sufficiently to inform imminent policy choices.
The regulation of both new hydrogen and existing natural gas grids needs to carefully reflect the new reversibility of investments in gas grids in order to ensure that grid operators decommission and repurpose the right kind of and amount of assets at the right time. Measures such as advances of

depreciation might serve to support struggling incumbent operators and support emerging hydrogen operators at the expense of network users and overall system efficiency. Instead, adjustments in network regulation that reflect the expectation of declining demand for network operators may be more suitable. Both options, however, suffer from the significant uncertainty regarding key aspects of the gas transition.
Thus, the paper guides the regulation of existing natural gas and new hydrogen infrastructure. The analysis is topical for example regarding the emerging hydrogen transmission grids. It can also be potentially transferred to other aspects such as the switch from gas distribution to district heating.
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Keywords: network regulation, decommissioning, repurposing, scrapping, assets, declining demand

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[Abstract:0006] OP-237 [Accepted:Oral Presentation] [Natural Gas » Shale Gas]

The Effects of a Shock to Critical Mineral Prices on the World Oil Price and Inflation

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Overview:Critical minerals (CMs) such as lithium, cobalt, nickel, and rare earth metals, are essential to the development of clean energy technologies, electronics, and defense and space industries, among others. Demand for these minerals is expected to grow quickly as energy transitions accelerate. In this study, we develop a model that is capable of examining the consequences of market disturbances from CM price shocks across a wide variety of locations, diverse economic and political systems, and market conditions. The results suggest that CMs, as a rising industry, are starting to have an impact on the macro level. The industry and its impacts are not fully developed yet but appear to have diverse implications across countries similar in some respects to the current major commodity – oil.
Methods:We expand Mohaddes and Pesaran's (2016) canonical quarterly Global Vector Autoregression (GVAR) model by (1) including a new variable: the Critical Minerals price index; (2) increasing the geographical coverage and extending the estimation: we estimate the GVAR for 36 countries including Russia, Venezuela, and Iran; (3) expanding the coverage period from 1979Q2 to 2022Q1. Our updated model also represents a policy tool that will have the capacity to perform scenario and counterfactual analysis of market disturbances to the CM price and oil markets, with potential policy prescriptions. Our study runs a number of counterfactual simulations of a CM price

shock.
Results:1. Shocks to world oil prices tend to have more of an effect on CM prices than CM prices do on world oil prices. This is an expected result as the CM market still constitutes a very small portion of the global economy.
2. For most of the countries under observation, the deflationary effects of the negative shock to Brent are less pronounced than the inflationary effects of a positive price shock. This is true in the first year following the shock for all countries under observation except the U.S., where the deflationary implications of a negative shock to oil prices are higher than the inflationary implications of a positive shock to Brent.
3. The cross-price elasticity of oil with respect to CM prices is positive in the United States, where CM's and oil are substitutes, and negative for Saudi Arabia where CMs and oil are compliments.
4. The macroeconomic impacts of oil price shocks tend to be stronger, more uniform, and statistically significant than those of CM price shocks.
Conclusions:Our scenarios indicate the unsuitability of a one size fits all energy policy and a need for closer examination of the national and country specific relationships between the oil and CM sectors. In addition, we may see an increasing role of CMs in shaping various global and country-specific macroeconomic indicators over time.
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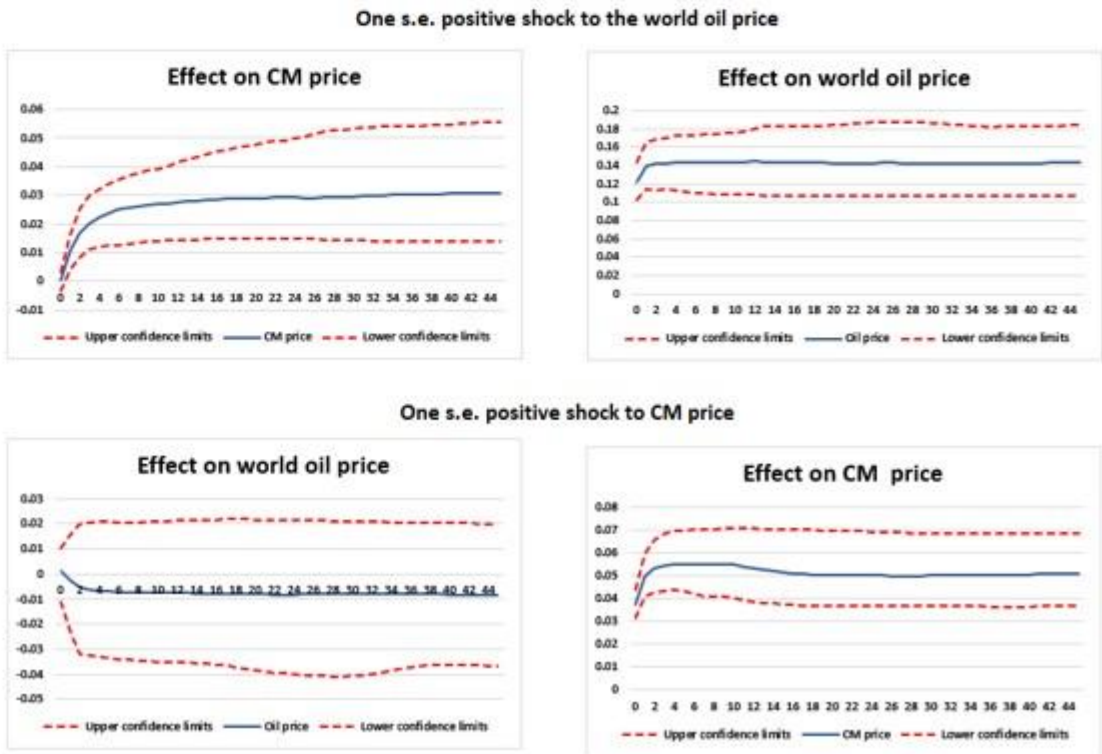
Keywords: critical minerals, rare earth metals, GVAR, oil price, inflation

The effects of a positive shock to CM and world oil prices

Figure 1.a. The effects of a positive shock to CM and world oil prices



Note: Bootstrap median estimates with 90% bootstrap error bounds.

[Abstract:0128] OP-238 [Accepted:Oral Presentation] [Natural Gas » Markets and Prices]

The dynamics of interregional natural gas prices and their association with the oil price: Assessing market integration through cointegration and causality analysis

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Overview:Natural gas fills an important gap in the energy mix. Compared to oil and coal, its cleaner environmental profile aligns with the global sustainability goals and is cost-effective compared to some existing renewable energy options. This study explores the evolving gas price formation in North American, European, and Asian markets. It assesses the current relationship between gas and oil prices, focusing on market changes and LNG supply developments over the past two decades.
Methods:To assess the level of market integration, the long-run relationship between six natural gas benchmark prices and Brent crude oil price is investigated using a bivariate ARDL approach and the Bounds Cointegration Test proposed by Pesaran et al. (2001). The monthly data from 2001 to 2020 is represented in two distinct datasets based on a structural break and data availability. Furthermore, a price discovery framework identifies leading and lagging markets within cointegrated pairs. Additionally, an all-variable VAR assessment from 2010 to 2020 is presented as a robustness test.
Results:The models from 2001 to 2020 show evidence of integration between European and Asian gas markets, with crude oil influencing all gas prices except North American Henry Hub (HH), which operates independently with its internal gas-on-gas price formation. In bivariate models considering a 2010-onward dataset with the Dutch TTF and Asian LNG prices, a large number of error-correction models are found, with generally faster speeds of adjustment. This is interpreted as evidence of increased economic integration of gas markets. The VAR assessment confirms a strong European-Asian gas market correlation considering recently established spot gas prices. These results strengthen previous findings on market integration.
Conclusions:There is a significant shift in the causality relationships in the sample period 2010-2020, which has been divided by structural dynamic change. Gas markets have increased integration in the shorter and more recent sample period, while oil-gas integration has weakened. Notably, three European gas prices and the spot Asian gas price exhibit a strong causal relationship. The Russian gas export price emerges as the leading market, driven by Europe's dependence on Russia's gas exports until 2020. While the VAR assessment has eliminated certain causal relationships, it supports the most important findings. Overall, the emergence of spot gas price benchmarks in Europe and Asia enhanced the integration between gas prices, decoupling them from the oil price. This study enhances understanding of global gas market dynamics and suggests future research on the asymmetric causality relationships between natural gas prices while acknowledging methodological limitations.

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Keywords: Natural gas prices, Cointegration, Causality, North America, Europe, Asia-Pacific

AuthorToEditor: Please don't hesitate to contact me if you have any questions about the abstract. I appreciate your time and consideration. Thank you.

[Abstract:0130] OP-239 [Accepted:Oral Presentation] [Natural Gas » LNG]

LNG in 2040: the role of Europe

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Overview:This conference contribution aims to provide valuable insights into the ongoing discourse surrounding the extent to which liquefied natural gas (LNG) can be pivotal in steering Europe's energy system towards carbon neutrality. Our research delves into the intricacies of cost-optimized LNG trades, focusing specifically on the delivered ex-ship cost among the foremost global importers and exporters projected for 2040. The emphasis is placed on regions vigorously supplying LNG to Europe, elucidating the associated (average and marginal) supply costs. In exploring various scenarios pertaining to global and European LNG demand, our study additionally underscores the impact of geopolitical tensions on the global LNG flows, particularly those directed towards Europe. The analytical framework further exposes the complexities inherent in Europe's dual strategy, aiming to concurrently achieve decarbonization objectives while addressing pressing concerns related to energy security within the context of LNG (see the reference).
Methods:A simple linear optimization model is proposed. The objective function is to meet the global LNG demand with minimum supply cost and consists of two distinct terms. The first considers the product of the delivered ex-ship cost and the quantity of LNG exchanged between an exporter and an importer. The second term considers an alternative supply option for the European importers. This term considers using European domestic production equipped with carbon capture and storage (CCS) to substitute LNG imports. It is used when delivered ex-ship costs for European importers are higher than the domestic natural gas production costs equipped with CCS. We consider two scenarios (so-called *Net Zero* and *Persisting Fossil Demand*) that provide a wide range of future developments in the global and, particularly, the European LNG market. Essentially, the scenarios define the LNG demand of the different importers. Thus, as common in this literature, demands are defined as exogenous parameters. The other key-determining parameters of the model are assumed to be independent of the scenario.
Results:Upon analyzing the volumes of LNG directed towards Europe, we expect that the results highlight the significant role played by certain exporters in the supply chain. As global demand for LNG varies between the scenarios, we expect that our results reveal the challenges associated with discerning enduringly stable trends or patterns in global LNG trade.
Conclusions:We envisage that our research will offer a constructive contribution to fellow modeling teams involved in the decarbonization of European energy systems. In particular, we perceive our quantitative and qualitative findings as valuable inputs for large-scale energy system models endeavoring to optimize the sustainable transition of Europe's energy infrastructure. We advocate for incorporating the average and marginal supply costs derived from our analysis into these models to augment the precision of exogenously formulated assumptions, thereby enhancing the robustness of their analytical frameworks.
References:Nikas, Alexandros, et al. "Three different directions in which the European Union could replace Russian natural gas." Energy (2024): 130254.

Keywords: LNG, 2040, Europe, decarbonization, political tension, supply cost

[Abstract:0363] OP-240 [Accepted:Oral Presentation] [Natural Gas » Markets and Prices]

Pricing curves in European natural gas: A tale of liquidity, storage, and efficiency

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Overview:In this paper, we compare how natural gas storage capacity relates to the forward curve price formation at Northern Europe's two principal natural gas hubs, the Title Transfer Facility (TTF) in The Netherlands and Trading Hub Europe (THE), located in Germany. Applying the theory of storage, introduced by Fama and French (1987), we calculate the convenience yield of the natural gas markets using natural gas forward prices and corresponding day ahead prices. In addition, we test market performance with regard to efficiency with seasonal variables, oil product prices, and electricity prices in our model to factor in their possible influence on the value of natural gas storage. We also include storage data, aggregated at the country level, in our model. This analysis gains urgency in light of Europe's escalating reliance on liquefied natural gas (LNG), a shift predominantly driven by the significant reduction in Russian natural gas supplies via pipelines. This growing dependency on LNG introduces complex challenges pertaining to the security of supply. In contrast to natural gas delivered through pipelines, LNG operates within a highly competitive global market, where suppliers have greater delivery flexibility than pipeline suppliers of natural gas. In this new scenario in the natural gas markets, natural gas storage will play an increasingly important role in smoothing out supply disruptions, adding flexibility, and balancing the natural gas system.
Methods:The first part of our paper focuses on calculating the convenience yield for TTF and THE. We utilize interest rates from the European Central Bank, combined with forward contracts of varying maturities from these natural gas markets. Our model is grounded in the present value model of rational asset pricing, equating the price of an asset to its current and discounted future payoffs. We explore the no-arbitrage condition for natural gas futures pricing, examining the interplay of spot prices, foregone interest, and the convenience yield. Our model translates the no-arbitrage condition into an effective framework for analyzing market efficiency and the relationship between convenience yield and storage levels. We further extend our analysis by regressing the convenience yield against variables like quarterly seasonality, oil product prices, and real storage levels. This approach, inspired by the work of Fama and French (1988) and Stronzik et al. (2009), aims to scrutinize market efficiency in the natural gas sector.
Results:We anticipate that our findings will highlight the complexities inherent in natural gas storage, especially in the context of Northern Europe's increasing reliance on LNG. This paper expects to reveal insights into the efficiency and competitiveness of the natural gas market, potentially echoing Stronzik et al. (2009)'s observations of market inefficiency in 2008. Despite the TTF's enhanced liquidity in recent years, we hypothesize that similar challenges persist in the market, emphasizing the critical role of storage management and infrastructure in the stability and functionality of the natural gas supply chain. Our results aim to provide a comprehensive understanding of the intricate relationship between natural gas storage, price formation, and market efficiency, offering valuable insights for stakeholders in the evolving energy landscape.
Conclusions:Our preliminary analysis on natural gas storage capacity and its influence on price formation at TTF and THE hubs suggests a complex interplay between storage dynamics and market efficiency. While detailed insights will emerge from the full paper, early indications highlight the crucial role of storage in price stability. The anticipated findings, although not yet definitive, are expected to contribute to a better understanding of market mechanisms in a rapidly evolving energy landscape. This study sets the stage for further investigation into how storage strategies and infrastructure development can adapt to the changing dynamics of natural gas supply and demand.
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Keywords: natural gas, energy futures, security of supply, LNG, energy crisis

[Abstract:0675] OP-241 [Accepted:Oral Presentation] [Natural Gas » Shale Gas]

Unconventional Reservoir Production Optimization and Economic Consequences: Reservoir Surveillance and Data Analytics

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Overview:Increased horizontal drilling with associated efficiency and improvement in hydraulic fracturing stimulation design has led to significant oil and natural gas production from the Eagle Ford region in south Texas (EIA, 2014). Hydraulic fracturing is the process of injecting pressurized fluids into a rock formation to create open fracture systems and is used extensively in the development of low-permeability hydrocarbon reservoirs (Eaton, 2018; Eyre et al., 2019). Fine-grained reservoir rocks, often referred to as "shales," are typically characterized by exceedingly low matrix permeability in addition to considerable clay and total organic carbon (TOC) (Moghadam & Chalaturnyk, 2016; Kozlowska et al., 2018). A key factor in the economic development of unconventional resources is determining optimal well spacing. As a result, production from these reservoirs is dependent on several parameters that are functions of other variables. For instance, production may be a function of proppant, but the latter is a function of rock type, clean fluid volume, slurry volume, injection rate, fluid type, and type of proppant. To ascertain tangible patterns regarding components of stimulation, there is a need to define their unique relationship. In an attempt to fulfil this quest, appraisal and pilot tests, involving the drilling, stimulating, and flow testing of a large number of wells, are required to determine what influences performance or guarantees acceptable repeatability for field development decisions. In cases where these field tests have not been conclusive, value realization has been compromised because of the adopted suboptimal recovery strategies (Fredd et al., 2015). As abilities to acquire and store big data have improved, data-driven modeling is one of the approaches that has been considered. It is based on analyzing data about a system, in particular, finding connections between the system state variables without full explicit knowledge of the physical behavior (Solomatine et al., 2008). Historically, the notion of finding useful patterns in data has been given a variety of names, including data analytics, knowledge extraction, information discovery, information harvesting, data archaeology, neural networks, artificial intelligence, and data pattern processing (Fayyad et al., 1996). In simple terms, data analytics refers to the overall process of obtaining useful knowledge from large quantities of data based on understandable patterns and trends, oftentimes previously unknown (Wood, 2018; Wood & Choubineh, 2018; Wood & Choubineh, 2019). Success in extracting hydrocarbons from unconventional resources has been accompanied by significant collection of data. This study shows the contribution of diverse surveillance data acquisition in reducing uncertainty in unconventional reservoir fracture modeling for realistic reservoir simulation and development solutions. In addition, effort was put into the use of data analytics approaches to interrogate existing repositories to unlock the parameterized production and stimulation matrix for well productivity drivers and associated statistical variance. Initially, production, in the form of determined proxies for long-term production potential, was selected and correlated with associated stimulation parameters, which included perforated lateral length, total vertical depth, number of fracturing stages and perforation clusters, volume and types of fracturing fluid, and amount and type of proppant placed. This was based on the hypothesis that well productivity is related to certain hydraulic fracturing stimulation parameters. Figure 1 shows that the average proppant concentration yielded a poor

correlation with cumulative gas and condensate production (Kurison, et al, 2019b). Where, average proppant concentration (lb./gal) was defined as Total Fracturing Proppant (lb.)/Total Fracturing Fluid (gal). Even at the same proppant concentration, well productivity varies with an increasing trend when a larger volume of fractured fluid is used. Based on the subsequent trends and patterns, starting models/hypotheses were envisaged. Appropriate prior knowledge was incorporated, and further analysis decoupling of parameters on a play-by-play basis was undertaken to provide probable explanations supporting the results.
North America's Eagle Ford and Utica have been selected for this quest because they possess significant amounts of accessible data and are analogs of a couple of plays, among which are formations in Saudi Arabia and Vaca Muerta in Argentina (Durham, 2019; Walzel, 2018); thus, results from this study have potential applications elsewhere.
Methods:Production data for an early Eagle Ford horizontal well, classical reservoir flow regimes, and planar fracture models were used for validating a proposed mechanism for reserves stranding and associated quantification. Evidence of severe interference in the early well indicated the phenomenon was an early occurrence in spite of recent concern.
Results:Success in extracting hydrocarbons from unconventional resources has been accompanied by significant collection of data
Conclusions:To counteract the negative impact of interference resulting from too close spacing, industry has adopted cube or co- development where wells are drilled and stimulated in the same phase before any is subjected to long term flow. However, slight reductions in stress in the first well to be stimulated might still induce asymmetric fracture propagation and reduce the intensity of intended hydraulic fracturing. Thus, lower recovery with more wells when compared to widely spaced laterals with intense hydraulic fracturing.
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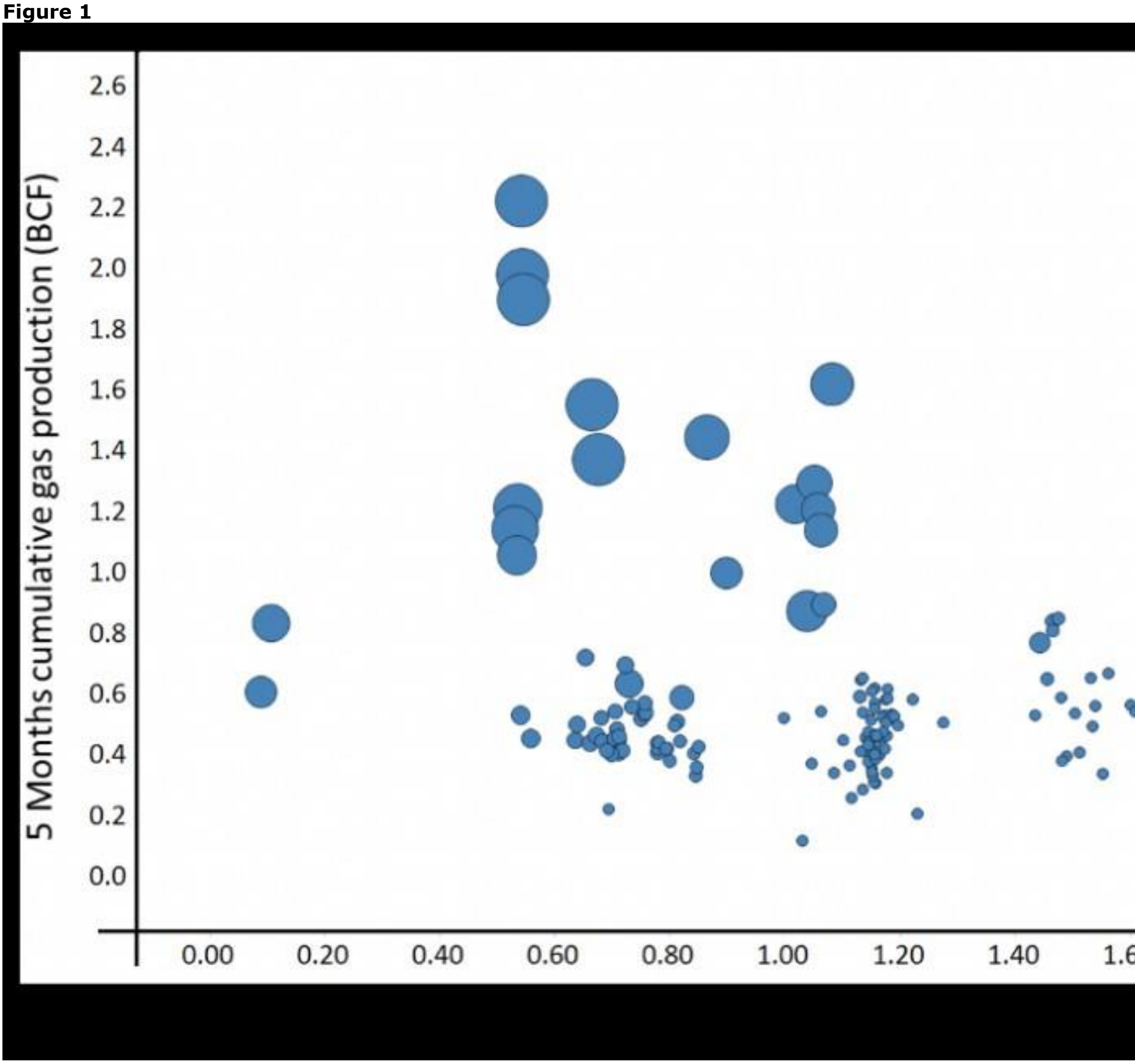
Keywords: shale reservoirs, productivity loss, reservoir surveillance, data analytics

Figure 1



Decoupling Amount of Proppant and Fluid Using Average Proppant Concentration. The individual wells on both plots are sized per a scale proportional to fracturing fluid volume per well for further interpretation. Courtesy of Kurison, Kuleli, and Mubarak, 2019b.

[Abstract:0505] OP-242 [Accepted:Oral Presentation] [Energy Modeling » Panel Data Analysis]

Understanding the Dynamics of the Renewable Energy Transition: A Determinant Index Approach

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Overview:Achieving net-zero targets is an urgent policy agenda item in many countries. As part of their nationally determined contributions (NDCs), many countries engage in various mitigation and carbon management activities, in which, renewable energy (RE) has undoubtedly captured the most attention globally. According to recent data, the global share of RE in power generation has increased from less than 1% in 1990 to 7.5% in 2018. Despite this global trend, it remains unclear how much countries utilize their RE opportunities. To better identify its dynamics, this study constructs a composite index to measure countries' RE transition potentials. Based on two decades of academic research, we identify 45 main determining factors of the RE transition. We classify these factors into seven subindices: economic factors, financial development, human capital, energy access, energy security, environmental sustainability, and institutional infrastructure. We then aggregate the subindices into a composite index, the renewable energy transition potential index (RETPI). The composite and subindices are available for 149 countries for the period from 1990 to 2018. The RETPI is a valuable benchmarking tool for policymakers. Using the RETPI, they can undertake peer comparisons and scenario analyses to identify the bottlenecks that are essential for better positioning of their countries in the RE transition.
Methods:The RETPI specifically focuses on the determining factors of the RE transition to primarily provide a forward-looking picture of countries' RE opportunities. With this focus, it differs from the common indices in the literature, including the World Economic Forum's Energy Transition Index (Singh et al., 2019), and the World Energy Council's (2020) Trilemma Index. Whereas these two indices focus on countries' broad energy transition performances, the RETPI focuses on RE. Additionally, these other two indices consider both the determinants and the outcomes of the energy transition (e.g., the share of RE in power generation). In contrast, the RETPI concentrates solely on the determining factors of this process and, thus, measures country potentials rather than their current performances. The RETPI's weighting methodology also significantly differs from the two indices. Whereas those indices rely on equal or pre-assessed weights to aggregate factors, the RETPI employs principal component analysis (PCA) to determine the weights for aggregation. These distinct approaches may have different strengths and weaknesses. However, the RETPI uses more objective criteria in its aggregation, as the weights are based on the correlations across the variables and are therefore data-driven. Moreover, the RETPI provides more comprehensive coverage, where it expands country coverage to all countries with populations over one million and time coverage to the last three decades.

More specifically, following the recent literature on the driving factors of the RE transition (e.g., Bourcet, 2020; Darmani et al., 2014; Sener et al., 2018), we categorize the most common factors identified by the literature into seven sub-groups: economic factors, financial development, human capital, energy access, energy security, environmental sustainability, and institutional infrastructure. We then construct the relevant dataset, where the missing observations are imputed based on a standard three-step procedure, over-time averages and growth rates, and regression analysis. Finally, using this comprehensive data, we create indicator scores, which are aggregated from bottom to top using PCA.
Results:The RETPI 2018 scores are displayed in Figure 1, which indicates country-level RE opportunities based on their current stance on various determining factors. However, this potential

may not always map into actual performance in a country. To establish the link between these two variables, we undertake an empirical analysis. In the analysis, we employ the non-hydroelectric RE share in power generation to proxy countries' RE transition performance. The analysis provides results from both descriptive plots (Figure 2 and Figure 3), as well as a robust regression setup. The results show that after controlling for various factors (e.g., country fixed effects, regional and income group time-variant effects), the RETPI continues to be a positive and statistically significant determinant of RE power generation. These results are robust to different specifications.

Through its subindices, the RETPI also identifies the factors that must be improved to ensure a healthy RE transition experience. For instance, the RETPI scores for 2018 show which countries have strong RE transition potentials. They include the U.S. and Canada in North America; Germany, Ireland, Austria and the Nordic countries in Europe; Hong Kong, Singapore, Japan and South Korea in Asia; and Australia. In contrast, most African countries have low RE transition potentials. Among the subindices, economic factors, financial development, human capital and energy access contribute the most to the RETPI's acceleration. These factors appear to be lacking in most lagging countries.
Conclusions:The RETPI is a useful benchmarking tool for policymakers and researchers. It explains the dynamics of RE transitions using three decades of historical data and, thus, indicates a country's transition potential relative to its peers. A higher RETPI is strongly and positively correlated with higher RE usage, a widely used proxy for the RE transition. Through its subindices, the RETPI also identifies the factors that must be improved to ensure a healthy RE transition experience. For instance, the RETPI scores for 2018 show which countries have strong RE transition potentials. They include the U.S. and Canada in North America; Germany, Ireland, Austria, and the Nordic countries in Europe; Hong Kong, Singapore, Japan and South Korea in Asia; and Australia. In contrast, most African countries appear to have low RE transition potentials. Among the subindices, economic factors, financial development, human capital, and energy access contribute the most to the RETPI's acceleration. These factors appear to be lacking in most lagging countries.
Using the index, policymakers can assess their respective countries' transition potentials relative to their current performances and the performances of their peers. With the RETPI, policymakers can carry out scenario analyses to explore the possible impacts of different policies on their countries' RE opportunities.
Moreover, the paper also promises an extensive literature review and a comprehensive data source for researchers, which includes a massive data collection and a comprehensive literature review spanning the last two decades.

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Keywords: Energy transitions, Renewable energy, Composite indices

[Abstract:0260] OP-243 [Accepted:Oral Presentation] [Energy Modeling » Integrated Assessment Modeling]

Climate Policy Modelling Scenarios for Efficient Space Cooling in India using Appliances Inventory Approach

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Overview:As per IPCC AR6 (2021), global warming will continue to rise by 1.5°C in the near term and carries the best estimates of reaching 2.7°C by the end of this century under the intermediate scenario (fig.1). Due to the lack of policy coverage and their implementation gap across the several countries under the NDC scenario, the increase in temperature is very likely to exceed 1.5°C-2.0°C during the century. India, among the most vulnerable to climate change impacts, has already been exposed to more than 700 heat wave episodes over the last five decades, accounting for approximately 17,000 fatalities (Ray et al., 2021). The ownership of air conditioners in India is rising and has tripled to reach 24 units per 100 households in 2022 since 2010, pertaining to its geographic and meteorological conditions, growing per capita income and building spaces, and urbanisation. Due to emerging space cooling requirements, electricity consumption has witnessed a 21% rise between 2019 and 2022, accounting for about 10% of the total electricity demand. According to WEO (IEA, 2023), increased use of air conditioners in India is one of the significant contributors to four times surge in peak electricity demand by 2050 under both the Announced Pledges Scenario (APS) and Stated Policies Scenario (STEPS). According to ISHRAE (2021), India's room air conditioners (RAC) stock reached more than 7 million units in 2020 from a few thousand units in the past twenty years. Apart from RACs, air conditioning systems that are used in commercial space cooling in India include chillers, packaged direct expansion (DX) and variable refrigerant flow (VRFs) types that hold19% of refrigerant-based equipment stock in India in 2017-18 (ICAP, 2019). Space cooling needs in the residential sector in India are predominantly met by fans and air coolers with less portion of RACs. As per the demand analysis performed by AEEE (2018), fans and air coolers are projected to reach 40% share of the total cooling sector energy consumption in 2027. The reported share is even higher than energy consumption by chillers, VRF and DX in the commercial sector in that year and hence, fans and air coolers are also crucial among space cooling appliances in terms of improvements in energy efficiency and energy saving standards.

India's need for space cooling will increase substantially in the upcoming decades, owing to significant growth in infrastructure development in both the residential and commercial sectors due to the country's rapid economic growth and expanding urbanisation, leading to significant electricity consumption. The study aims to evaluate the policy scenarios concerning efficiency and star rating standards of these energy-intensive appliances. The appliance inventory has been built over the modelling horizon 2020-2050 for the cooling appliances used in India's residential and commercial sectors subjected to account efficiency improvements over the years. The bottom-up modelling has been performed to frame the scenarios based on energy demand and appliances' efficiency trajectories to analyse the final energy requirement for cooling needs in India with the upcoming stocks of appliances and advancement in technology, and possible GHGs emissions reductions. Adaptation measures and several energy-efficient solutions to decrease the energy demand in the buildings have been considered in the scenarios to significantly reduce the energy demand in the building sector, which is largely due to air conditioning appliances.
Methods:CER-EAL, IIT Kanpur has carried out the study on developing energy-climate modelling for India using the MESSAGEix framework to study long-term energy transition for India, including decarbonization pathways scenario analysis. However, the model needs an accounting for appliance inventory in the residential and commercial sectors. Therefore, a new model has been developed to address this gap in two sectors, currently considering appliances used for space cooling. The data for appliance stock or sales has been collected by considerable exploration of past reports and surveys of National Sample Survey Office (NSSO), BEE, CEEW, AEEE, JRAIA, IBEF, RAMA, IEA, EESL and Motilal Oswal consumer durables. Despite the thorough data search, a dedicated effort was made to compile an extensive data inventory, ensuring a comprehensive and tailored dataset for the analysis due to the unavailability of certain information. Besides this, costs, technical, economic and environmental data has also been collected from different manufacturers' specifications reports, UNFCCC and government reports.

The study has developed a new appliance inventory-based database to integrate with the bottom-up energy system model accounting for possible efficiency improvement in the appliances over the years. A bottom-up integrated assessment modelling framework, MESSAGEix, developed by IIASA, has been used for detailed energy modelling in BAU and other alternative policy scenarios developed based on efficiency trajectories of appliances and energy demand for space cooling. The scenarios consist of several adaptation techniques to reduce the cooling loads of the buildings, such as energy-efficient building design and construction measures, energy-efficient appliances and policy interventions that can robustly reduce the energy consumption in the buildings. Results:The study's outcomes would assist in evaluating the impact of policy scenarios with reference to efficiency and star rating standards of energy-guzzling appliances in India and could be significantly relevant for the Bureau of Energy Efficiency, Government of India. The outcomes could also serve to achieve one of India's revised NDC targets of reducing GDP emission intensity by 45% (from 2005 levels) by 2030. The potential GHG emissions reductions by adopting energy-efficient technologies and related policy interventions could be considered towards framing the policy instruments for India's long-term net-zero carbon emissions target by 2070. Conclusions:The study reveals critical insights into India's evolving energy landscape, driven by escalating space cooling demands. The surge in air conditioner ownership and associated electricity consumption underscores the urgency for effective policies. Anticipating a significant surge in demand for space cooling driven by ongoing infrastructure development, income growth and urbanisation, the study assesses various policy scenarios with a specific emphasis on efficiency and star rating standards. Despite data challenges, the dedicated efforts in constructing a comprehensive appliance inventory have enabled nuanced modelling. Outcomes hold crucial implications for policy formulation, contributing to India's NDC targets and net-zero carbon emissions goal, emphasising the pivotal role of energy-efficient technologies in navigating India's dynamic energy scenario and mitigating environmental impact effectively.

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Keywords: Space Cooling, Energy Demand, Appliances stock, Integrated Assessment Modelling, Energy Efficiency, India Climate Policy

Change in Global Mean Temperature under SSP1-2.5

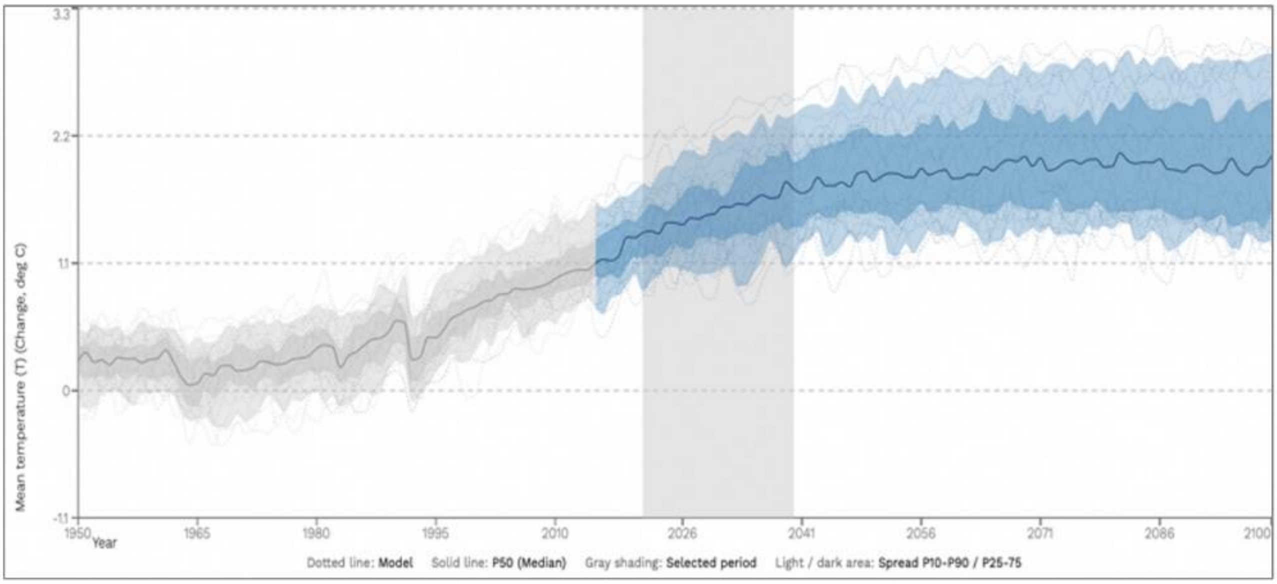

Fig.2 Change in Global Mean Temperature under SSP1-2.5

Source: *https://interactive-atlas.ipcc.ch*

Change in Global Mean Temperature under SSP2-4.5

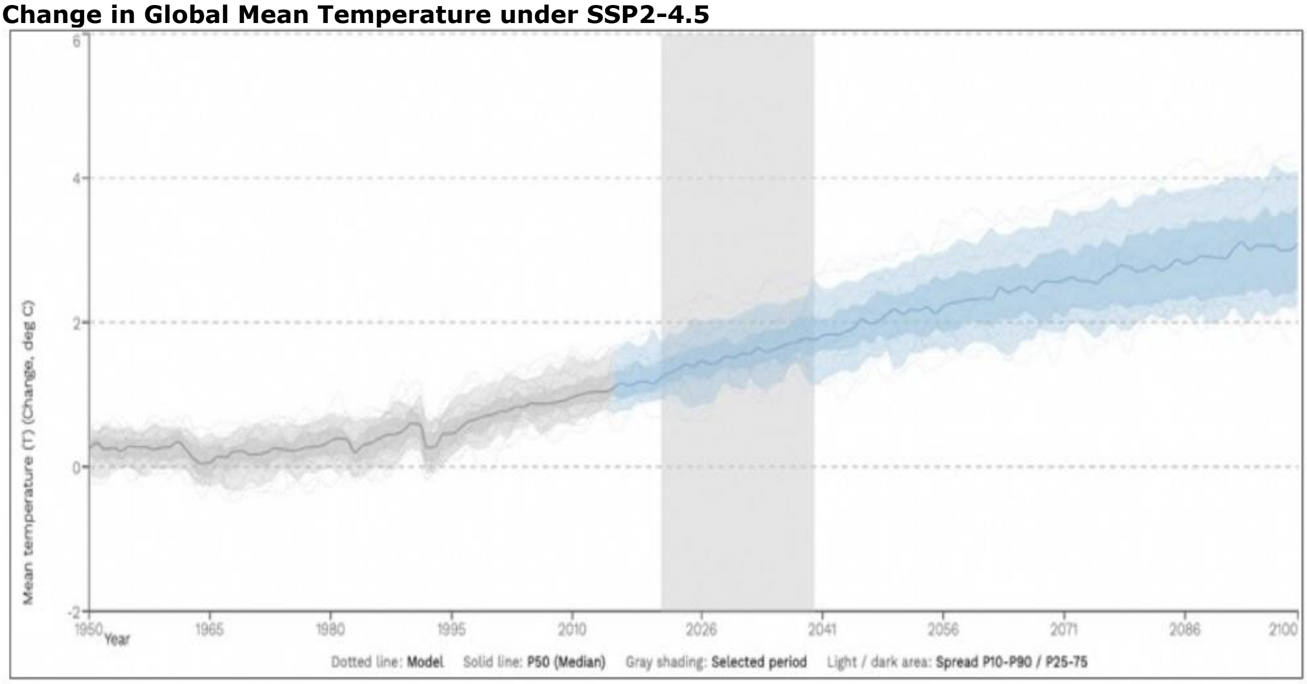

Fig.1 Change in Global Mean Temperature under SSP2-4.5

Source: *https://interactive-atlas.ipcc.ch*

Technology shift in RACs

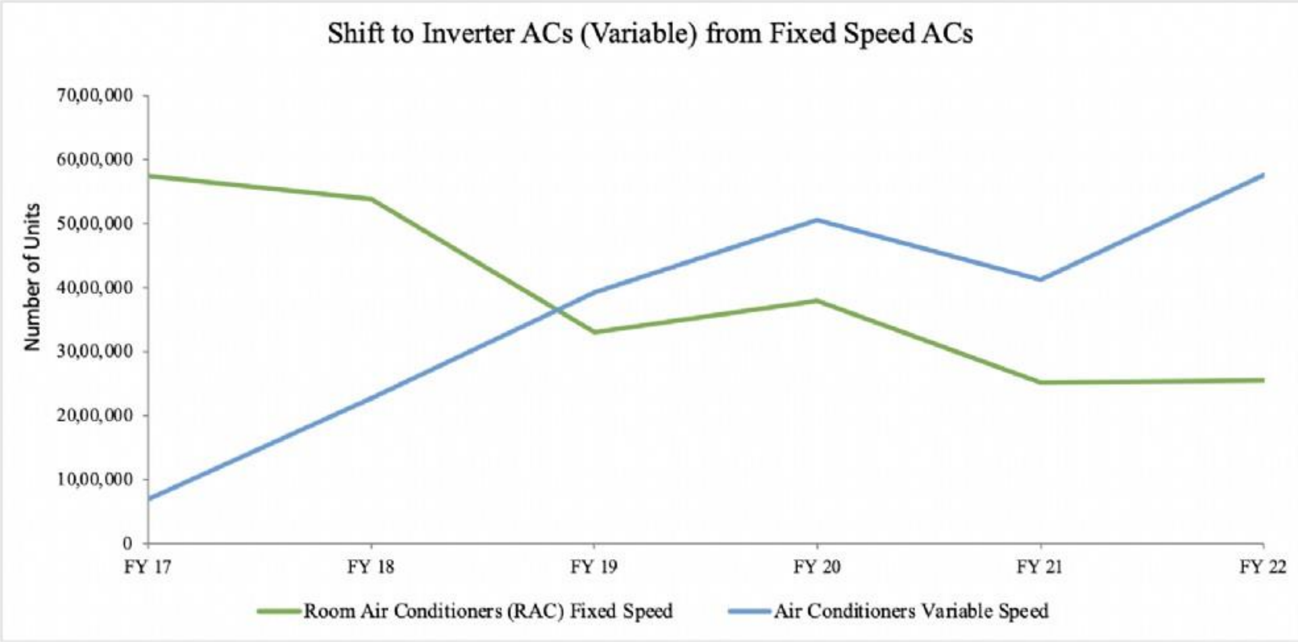

Fig.3 RAC Demand

Source: Bureau of Energy Efficiency.

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[Abstract:0391] OP-244 [Accepted:Oral Presentation] [Energy Modeling » Time Series Analysis]

Weather effects in energy seasonal adjustment: an application to france energy consumption

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Overview:In the context of climate change, the Paris Agreement aims to reduce global emissions, and thus one of France's objectives is to limit energy consumption. To this purpose, the French government has been engaged in several policies with both efficiency and sufficiency goals. Assessing changes in energy consumption, to studying the impact of climate-related policies are complex as many factors contribute to them, such as socio-economic and meteorological factors (see e.g Dell et al., 2014). To make reliable comparisons over time and assess the impact of socio-economic factors alone, it is necessary to correct observed consumption for seasonal and weather variations. This paper introduces a robust statistical methodology for determining the base temperature of Heating Degree Days (HDD) at an aggregated level.
The approach extends to selecting the most reliable meteorological indicator for aggregated analysis. Applied to France, the methodology yields a country-specific base temperature and explores

alternative meteorological indicators. It also confirms that the base temperature is not static over time or space, emphasizing the need for adaptive parameter adjustments.
The proposed methodology employs regSARIMA modelling and incorporates a two-stage process, based on self-extracted threshold (SETAR) and penalized regression methods (LASSO), for selecting meteorological vectors among high-frequency meteorological data1. This adaptive approach ensures a more precise determination of the aggregate HDD base temperature (De Azevedo et al. (2015)), enhancing the robustness of energy consumption adjustments.
Finally, in a structural VAR framework a la Kilian (2009), we evaluate the impact of the French sufficiency plan, controlling for socio-economic factors using seasonally adjusted energy consumption data

Methods:We consider the period covering 2000 to 2022 at a monthly level and use the energy consumption data, electricity and gas, produced by the statistics department of the French Ministry for Ecological Transition and publicly available. For weather, we use data made available at high frequency by the French meteorological and climatological service. Weather data is available from around 600 stations across the country. To obtain an accurate national representation, each station is weighted by the population of the nearest cities, using the population recorded in the latest French census (Taylor (1981)). The methodology is situated in the context of producing seasonally adjusted statistics, accounting for working days and climate variations. The initial model specification follows Eurostat recommendations and employs a regressive Seasonal Autoregressive Integrated Moving Average (regSARIMA) model. The SARIMA component defines the seasonal variation pattern, while the regressive part includes regressors explaining non-seasonal variations, such as working days and meteorological indicators. In this study, the seasonal variation pattern and working days regressor are fixed, allowing the testing of various meteorological vectors. Multiple specifications are compared using the Akaike Information Criterion (AIC) and the Root Mean Square Error (RMSE) to select the most precise specification with the least overfitting. We propose a preliminary methodology for selecting potential meteorological vectors.
Initially, it draws on the work of Bessec and Fouquau (2008), demonstrating the non-linearity between temperature data and energy consumption. Our study suggests using a non-smooth method based on Lo and Zivot (2001) using a SETAR modelling. The output provides a base threshold for constructing an HDD indicator and potentially other weather-related indicators. In the subsequent stage, a time-rolling process for selection through penalization is employed. Building on Liu et al. (2020) work, this approach introduces a penalty term to minimize the error, effectively penalizing variables with low explanatory power. The output of this stage identifies variables with significant explanatory power at each time step. This two-stage methodology contributes to a more robust and adaptive determination of the base threshold for weather indicators, addressing the dynamic nature of climatic conditions over time.

Results:The application of this methodology to France is presented, offering a robust base temperature and exploring alternative meteorological indicators. By implementing the methodology, a specific base temperature tailored to the French context is proposed: 15°C. Via robustness exercise, we prove that this base temperature is not constant over time. Additionally, the study enriches our understanding of factors influencing energy consumption by exploring other potential meteorological indicators. The newly developed methodology allows to extract a robust weather indicator to explain energy consumption, as the weather indicator produced by our method leads to the best regSARIMA specification. Once the energy consumption is adjusted from seasonal and weather variations, we then proceed to implement a VAR process a la Kilian (2009) and use the historical decomposition, to give an initial interpretation of the sharp fall in final energy consumption in France for the years 2022 and 2023. Thus, while the fall in 2022 is due solely to a price shock linked to inflation, the fall in 2023 is due to a price shock as well as a strong consumption shock, which can be attributed to the French sufficiency policy implemented since November 2022

Conclusions:The preliminary results from this work confirm the non-constance in time of the base temperature, meaning people do adapt to their environment. To go further, first applying the methodology at the region level could confirm or refute the other main assumption that the base temperature is not constant over space. Second, on the statistical side, the use of a MIDAS modelisation to use different data frequencies could improve the specification and allow to capture other weather indicator variations such as the wind speed.

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Keywords: time-series, seasonnal adjustment, public policy, energy consumption, weather

[Page: 245]

[Abstract:0229] OP-245 [Accepted:Oral Presentation] [Energy Modeling » Forecasting and Market Analysis]

Research on the low-carbon transformation path of China's steel industry - based on CGE model

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Overview:China is the world's largest producer of steel, with its steel production accounting for 53.9% of the global total in 2022. The massive steel production has resulted in significant carbon emissions, with the carbon emissions from China's steel industry representing approximately 15% of the national total. This is primarily due to the unclean production structure of the Chinese steel industry. The production process in China is dominated by the traditional blast furnace-basic oxygen furnace (BOF) route (90%) and supplemented by the electric arc furnace (EAF) route (10%). In the context of China's carbon neutrality goals, the steel industry faces significant challenges in transformation.

EAF technology is a key technology for carbon reduction in the Chinese steel industry. China's electric arc furnace steel technology has considerable development potential, although the overall proportion of EAF steel has fluctuated and remained around 10% in recent years. The high production cost is a major factor restricting the widespread adoption of EAF in China. On one hand, the development level of EAF in China is relatively low. The higher energy consumption makes electricity costs a significant factor in the cost of EAF steel. Against the backdrop of the low-carbon transformation in the electricity industry, gradually increasing electricity prices have also contributed to the rising cost

trend of EAF steelmaking. On the other hand, the cost of iron-containing raw materials for EAF steel is persistently high. In 2021, molten iron accounted for 74.8% of the iron-containing raw materials for electric arc furnace steel in China, and scrap steel accounted for 15.2%. China started scrap steel recycling late, lacking relevant supporting systems, and the scrap steel recycling system is still in the exploration stage. The current stock of scrap steel in China cannot meet the demand for steel production. The low input of scrap steel is an issue that cannot be ignored in the transformation process of China's steel industry.

The green transformation of the steel industry's production structure will be significantly influenced by direct and indirect factors from other industries. It is imperative to model the input-output structure of different technologies in China's steel industry and long-term plan the green transformation path of the steel production system within a general equilibrium modeling framework.

Methods:We have dissected the steel industry production in China for the year 2017 based on the energy input, steel material input, and other data related to BOF and EAF steelmaking processes. This led to the creation of a Social Accounting Matrix (SAM) that includes both BOF and EAF steelmaking. Utilizing this SAM, we constructed a Computable General Equilibrium (CGE) model for China, which incorporates both BOF and EAF steelmaking processes.

In this model, several innovations have been introduced. Firstly, the model characterizes the substitution relationship between molten iron and scrap steel in EAF steelmaking. Secondly, it captures the interdependencies between energy input and steel material input, illustrating a positive correlation between molten iron input and coke input, as well as between scrap steel input and electricity input. Thirdly, the model depicts the mutual substitution relationship between EAF and BOF steelmaking. Lastly, the model places a special emphasis on characterizing the "learning by doing" effect of EAF steelmaking technology and incorporates it as a dynamic constraint in the intertemporal optimization of the CGE model.

Through the constructed CGE model, we conducted a study on the impact of implementing energy taxation policies, carbon pricing policies, low-carbon technology subsidies, and policies guiding investments in low-carbon technologies on the development of the steel industry.

Results:Based on the results of policy scenario simulations, we have identified the following FINDINGS:

Firstly, the implementation of energy tax policies does not effectively promote the clean transformation of the steel industry and may exacerbate the decline in steel industry capacity. Carbon pricing policies can, to some extent, promote the clean transformation of the steel industry but may further intensify the decline in steel industry capacity.

Secondly, policies guiding investments in low-carbon technologies and providing subsidies for low-carbon technologies can increase the capacity of the steel industry and promote its clean transformation.

Thirdly, as the proportion of EAF steelmaking increases, the share of molten iron in the steel material input for EAF gradually rises. This leads to a decrease in the overall carbon intensity of EAF steel.

The last, simultaneous low-carbon transformation in the electricity and steel industries, can significantly reduce the entire life cycle carbon emissions of steel.

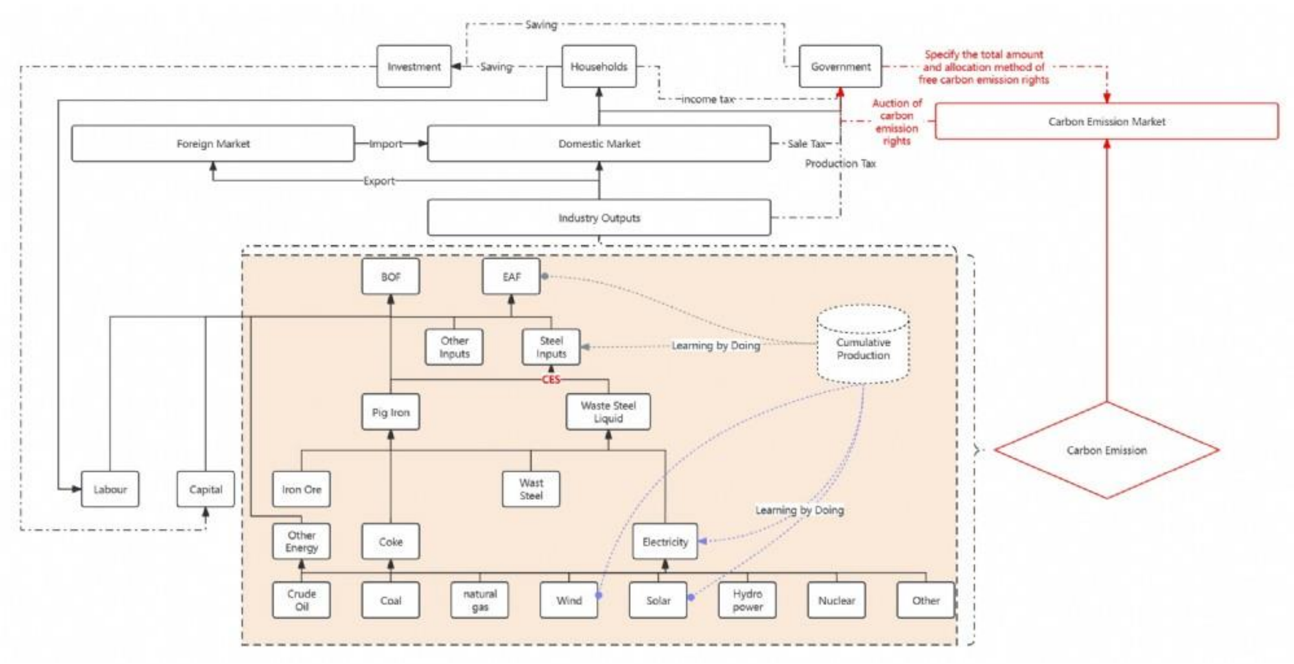
These findings highlight the complex interplay between different policy measures and industry dynamics in shaping the trajectory of the steel industry toward cleaner production and reduced carbon emissions.

Conclusions:We suggest that incorporating the iron and steel industry as well as the power industry into the carbon market would aid China in achieving its carbon peak and carbon neutrality goals. Since electric arc furnace steelmaking technology is not entirely carbon-neutral, it is recommended to complement carbon pricing with policies such as low-carbon technology investment guidance and subsidies to mitigate the impact of carbon pricing on the steel industry.

References:

Keywords: CGE model, steel, low-carbon transition, EAF, BOF

The structure of Steel-CGE model



[Page: 246]

[Abstract:0301] OP-246 [Accepted:Oral Presentation] [Energy Modeling » Forecasting and Market Analysis]

Hydrogen development in Europe: Estimating metals and water consumption in Net Zero Emissions scenarios

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Overview:Low-carbon hydrogen has already been announced by many governments as one of their priorities for achieving carbon neutrality by 2050. In Europe, particularly, a political momentum for hydrogen use has strengthened in recent years. This potential for massive development of low-carbon hydrogen in the coming decades raises questions about the global impact of the different production technologies. The main risk of such technological change is that it shifts the environmental impacts from greenhouse gas emissions to other environmental burdens, such as mineral resource dependence and water use and scarcity. The aim of this article is to assess the consumption of water and raw materials with hydrogen development in Europe through to 2050. It also provides insights on possible risks related to the supply of these materials. The article also conducts a more in-depth analysis of Iridium (used in PEM electrolyzers) and more generally of platinum group metals (PGMs). It thus presents a broad picture of the current market situation and explore potential geo-economic tensions to be anticipated.
Methods:The methodology adopted for this study is an ex-post evaluation of the material and water requirements for a hydrogen development scenario in Europe. To do so, we rely on the hydrogen evolution pathway obtained in the framework of the Hydrogen for Europe (H24EU) project, led by IFP Energies nouvelles, Deloitte and SINTEF. This project was based on an energy system model that integrates a wide range of existing and future hydrogen technologies, competing with a variety of other technologies to meet the energy demand of all sectors. More precisely, the model used was designed to optimize the evolution of the energy system by following a least cost paradigm, while

respecting several constraints including the achievement of carbon neutrality in 2050. This article focuses on the reference scenario of H24EU project, namely the “Technology Diversification pathway”. The new installed capacities per decade for each hydrogen production technology, as well as the annual production of H2 by technology, are derived from this baseline scenario. The material and water consumption for each H2 production technology are then estimated through an extensive literature review to build up the necessary data set. At this stage, the material consumption of the hydrogen sector by decade, between 2015 and 2055, can be calculated, as well as the annual water consumption. A sensitivity analysis is also performed on these results, considering a potential technical progress that could reduce the material contents of hydrogen production technologies. Finally, the projected water requirements of the hydrogen sector are compared to the water consumption of the energy sector in Europe, and the projected material requirements to the current annual production. This enables the identification of potential supply tensions to be anticipated. The results are also compared to the existing literature, quantitatively where possible, but also qualitatively on the identification of critical materials. A particular focus is made on Iridium, whose criticality was identified to be the highest in the hydrogen development scenario studied.
Results:Hydrogen production could represent 5 to 7% of water consumption for energy purposes in Europe in 2050. However, it should be kept in mind that the water market is highly regionalized: a more local analysis would be necessary, especially for regions with a high potential for hydrogen production, but with high water stress. Iridium is by far the most critical material, with a projected consumption in Europe alone of about 130-140 tons per year in the decade 2045-2054, while current global consumption is barely 8 tons per year. This high demand could seriously threaten the development of PEM electrolysis. Despite the low development of biomass gasification compared to other technologies, the demand for olivine that it generates is substantial. However, no supply tension is to be expected. The demand for nickel generated by hydrogen production is not negligible. This demand comes mainly from the electrodes of alkaline electrolyzers. It could be even higher if the PEM electrolyzers were hampered by their excessive demand for iridium and replaced by alkaline electrolyzers.

Conclusions:The deployment of low-carbon hydrogen in Europe will certainly put pressure on several resources identified and quantified in this study. The results show that the iridium demand for PEM electrolyzers could cause major supply tensions. These tensions would be exacerbated by the fact that iridium is exclusively a by-product of other platinum-group metals, so an increase in iridium demand would not systematically trigger an increase in mine production. Yet iridium contents for PEM electrolyzers are likely to be greatly reduced in the coming decades, which could alleviate the identified tensions. This study also shows that the nickel demand for alkaline electrolysis could represent a significant proportion of total consumption, which, in the context of a drastic increase in demand for nickel due to the development of electric vehicles, could also hinder the implementation of this type of electrolysis. Finally, this study highlights that the water requirement of the future hydrogen production system is far from negligible. It also underlines the need to investigate more thoroughly the water requirements from the hydrogen sector on a local level, considering the sunniest regions where PV technology coupled with H2 production would be the most profitable to develop are also the driest region.

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Keywords: Hydrogen, metals criticality, TIMES Markal model, water

[Abstract:0511] OP-247 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Capacity Remuneration Mechanisms for a Future Decarbonized Power System

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Overview:A decarbonized power system that will be primarily powered by variable renewable sources (vRES) will present a significant challenge for recovering investment costs. In this work, we compare a strategic reserve (SR), a capacity market (CM), and a capacity subscription (Doorman, 2005) with an energy-only market (EOM) in a decarbonized power system.
Methods:We apply a co-simulation between an investment agent-based model (ABM), EMLabpy, and a short-term market ABM, AMIRIS (Reeg, 2019). EMLabpy is based on EMLab (Chappin et al., 2017) . Both models are co-simulated in Spinetoolbox, an application that enables the execution of complex simulation tasks in sequence and parallel (Kiviluoma et al., 2022). We test the mechanisms in a future decarbonized power system with 40 different weather years.
Results:We observed that a capacity market incentivized more hydrogen turbines. More installed capacity reduced the fluctuation in electricity prices for all technologies as well as the volatility in cost recovery. Implementing a price cap of 40 Eur/kW·Y effectively brought down the annual loss of load (LOLE) to the current standard of 4 hours. Implementing technology-neutral auctions led to an increase in capacity prices and overall costs.
We modeled a strategic reserve where the activation price is fixed at 1600 Eur/MWh, and the strategic reserve margin ranged from 10 to 20% of the inflexible demand. This mechanism was less effective in incentivizing more investments. The volatility of electricity prices increased, and the lifespan of hydrogen turbines was prolonged, leading to a slight reduction in shortages. Although prices were more frequent at higher levels, limited additional capacity was built.
Next, we will implement a capacity subscription.
Conclusions:We conclude that a strategic reserve could be suitable for incentivizing flexible resources in a transition phase, but in the long run a capacity market brings more certainty to investors. Finally, we tested an EOM with less electrolyzers' flexibility (EOM_S1) and observed higher and more volatile prices.
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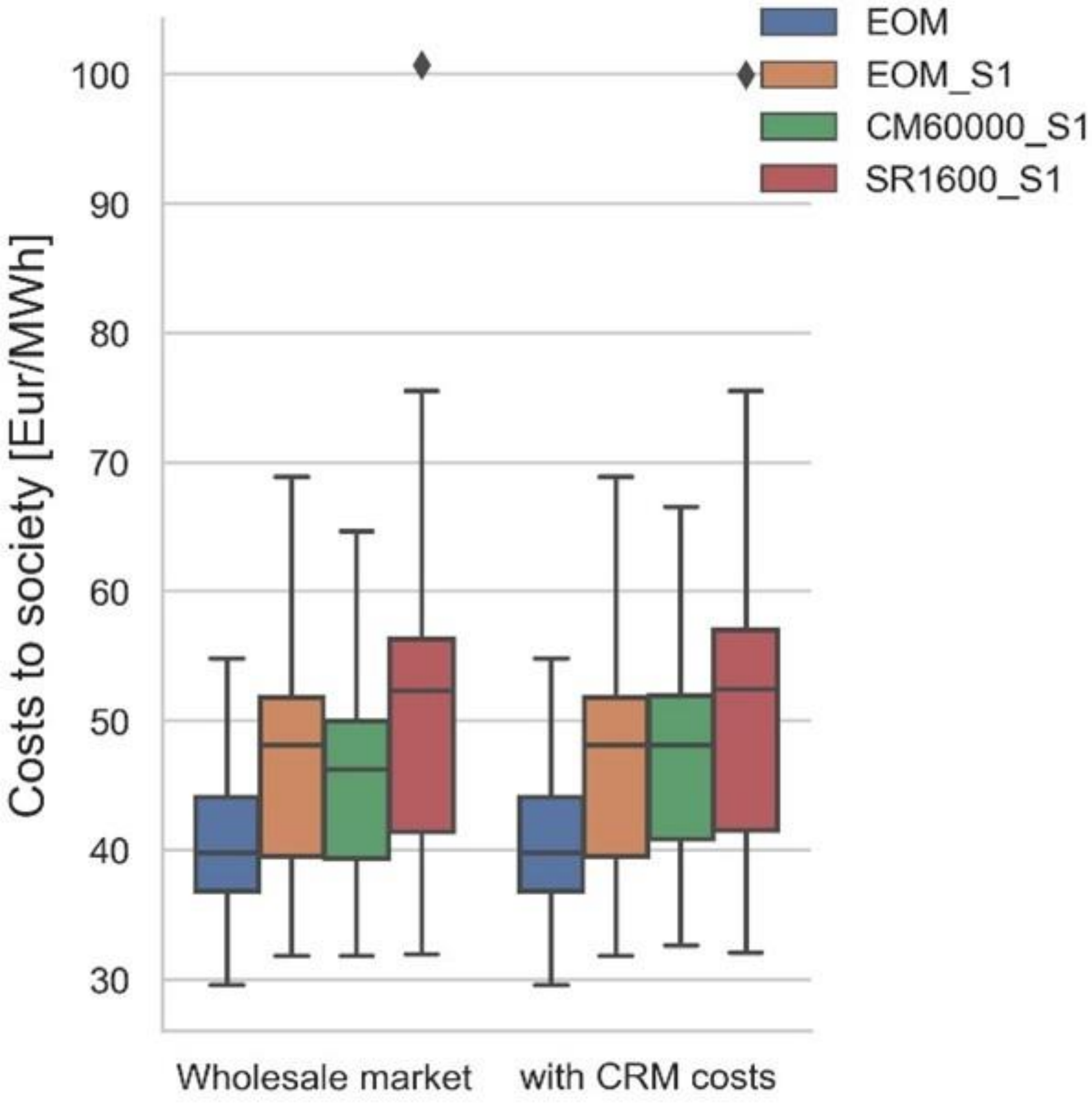
techno-ökonomischer und soziotechnischer Effekte bei der Strommarktintegration und Refinanzierung erneuerbarer Energien.

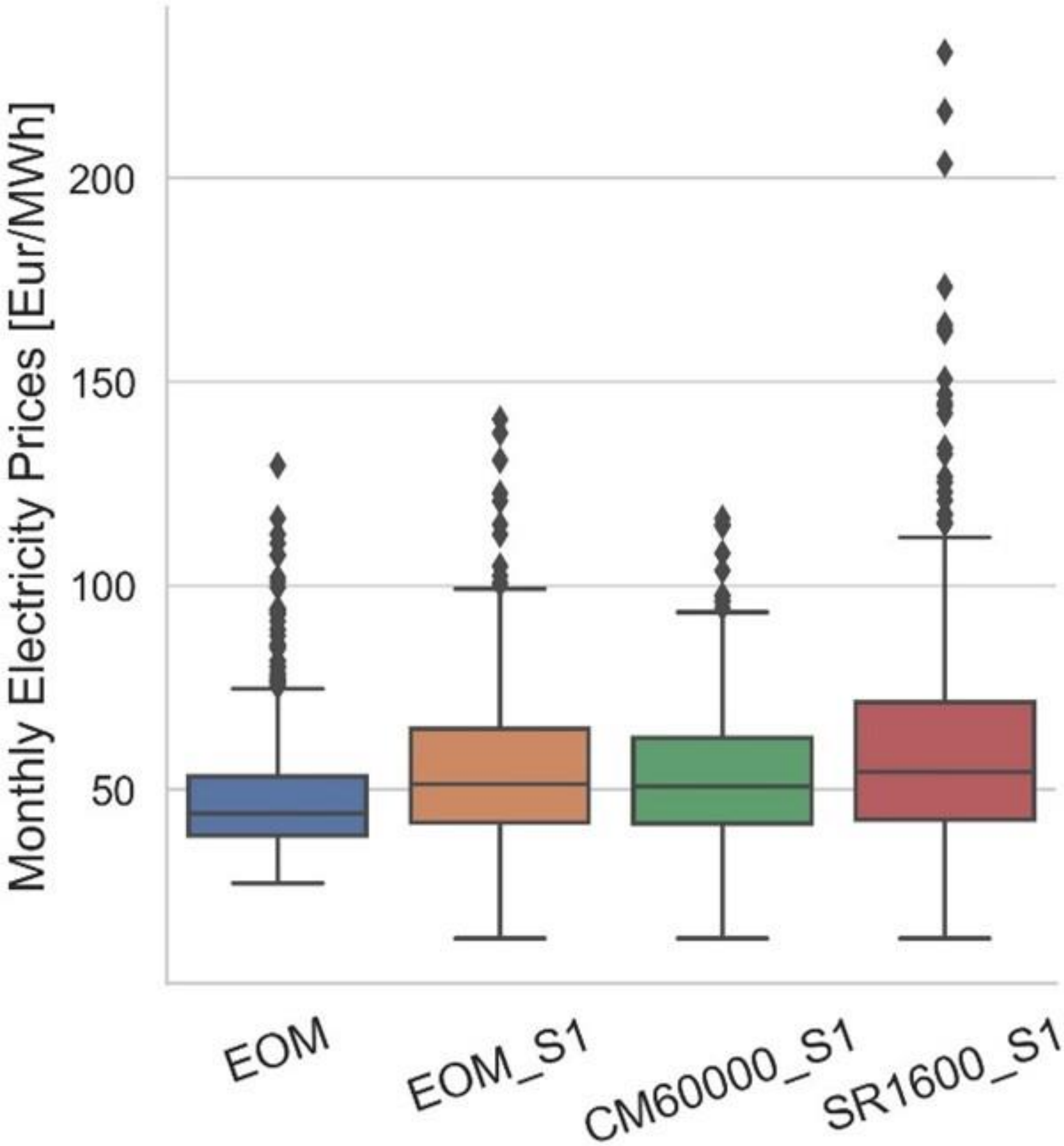
Keywords: Capacity remuneration mechanisms (CRM), Strategic Reserve, Capacity Market, Agent-Based Models, Co-simulation

Costs to Society



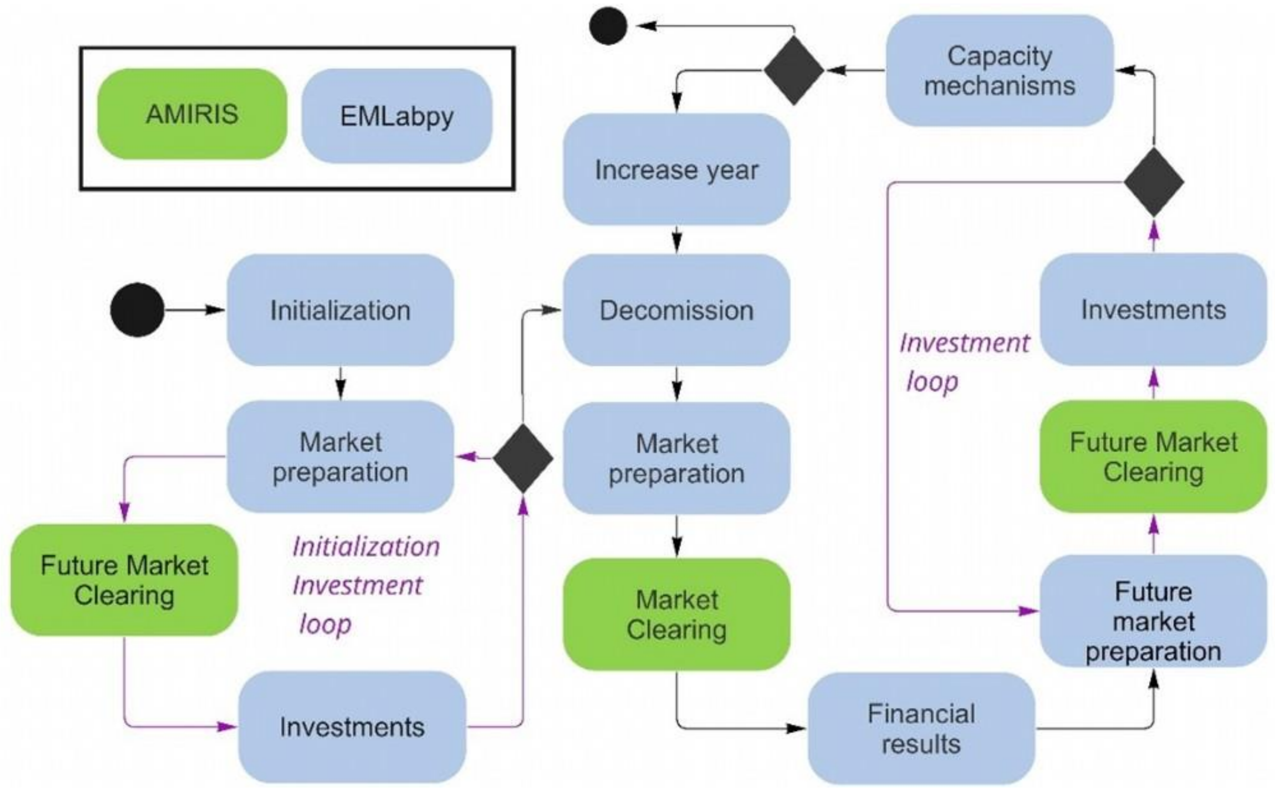
Comparison of scenarios considering the revenues of the wholesale market and additional revenues from CRMs

Monthly electricity prices



Monthly electricity prices with a more flexible EOM, a less flexible EOM (S1), a capacity market, a strategic reserve

Workflow



Conceptual workflow of the co-simulation EMLabpy-AMIRIS

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[Abstract:0529] OP-248 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Dealing with renewables integration in the European balancing phase: A comparative study of the French and Belgian imbalance markets

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Overview:Since the back end of the twentieth century, significant progress have been realized to integrate the sequence of power markets, especially the day-ahead segment, into the European internal energy market. Last part of the sequence corresponding to the balancing phase that encompasses reserve markets and imbalance market, remains poorly integrate [1]. At the moment those markets can take very heterogeneous forms across member states, sometimes reflecting the legacy of pre-liberalization context. However there is an harmonization push at the European level through publications of guidelines and network codes [2]. In parallel European countries are

experiencing the rapid deployment of wind and solar technologies into power system, and such trend will accelerate in the next decades [3]. It creates new challenges for the short-term balancing of grids. Due to their intrinsic characteristics, in particular the uncertainty they hold on their own [4], renewables affect the needs for short-term flexibility.
This paper investigates the relevance of the promoted imbalance market design at European level, which favors reactive balancing philosophy. It analyzes the potential superiority of single imbalance pricing based on marginal pricing, that is commonly associated with reactive balancing activation of reserves, over dual-pricing traditionally relying on weighted average pricing. Assessing the suitability of imbalance pricing methods is of particular interest, given the fact that short-term market designs can facilitate the integration of renewables into power system by mitigating their potential negative effects in terms of reserves needs [5], [6]. To the authors' knowledge, we are the first to conduct a systematic comparative study assessing respective performance of proactive and reactive balancing approaches, through real-world observations data.
Methods:Our empirical work is based on the comparison of imbalance markets in Belgium and France trough an econometric study. The former relies on reactive philosophy and can be considered as the standard design that will be set-up at European level. The latter based on dual pricing, at the contrary represents the opposite imbalance market design that might disappear in coming years. This comparative work aims at assessing the relevancy of incentives send to Balancing Responsible Parties (BRPs) under both imbalance settlement schemes. We use 2021 data describing power mix plus Day-Ahead and Imbalance prices for France and Belgium at half-hour and quarter-hour granularity respectively. Analogous to models used in a similar context by Deman and Boucher [7] and by the literature on short-term electricity prices forecasting [8] an ARMAX-GARCH model is set-up. A particular attention is given to the way that both market designs handle the integration of renewables. Therefore, regressions try to evaluate and compare the effects of renewables integration on 1) system imbalance (by examining energy reserve activation by direction) and 2) on financial incentives send to BRPs (according to the direction of their own imbalance).
Results:Results suggest the superiority of reactive approach based on marginal pricing compared to weighted-average pricing, in line with theoretical prediction. We find a larger financial incentives in Belgium. BRPs penalties and rewards are between two and three times larger in the imbalance price settlement based on marginal pricing. Those larger financial incentives find their translation in terms of physical imbalances. In fact, imbalances are lower in the reactive system. However, some similar patterns relative to renewables penetration remain in both system. We observe increasing (resp. decreasing) volumes of downward (resp. upward) energy activation with higher level of renewables in the system. The magnitude of those effects tend to be lower in Belgium even though the country experiments higher level of renewables penetration compared to France.
Conclusions:Our findings support the harmonization towards reactive approach promoted at European level. Relative to renewables effects on balancing activity, we find similar results than previous observations from Deman and Boucher [7] but with a generalization to the Belgian context. Those persistent results about renewables effects, whatever the imbalance market design considered, support the needs for further research. It leaves room to discussion and potential additional studies linking imbalance markets with other short-term markets like Intraday and Reserves. Therefore, the last part of this work discusses open issues arising from our results and gives some insights about potential explanations that remain open to debate.
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Keywords: imbalance market, renewables, market design, reserve energy

[Abstract:0532] OP-249 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

Barriers to flexibility in Dutch day-ahead wholesale power market

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Overview:Increasing penetration of variable renewable energy, electrification of end-uses and proliferation of decentralised assets have collectively created an energy market with increasing variability and reducing predictability of both supply and demand. The system, thus, requires resources that are capable of adapting their behaviour to techno-economic signals provided by the system, commonly termed as flexible resources or just flexibility. Grid balancing and ancillary services have traditionally been provided by conventional generators, predominantly natural gas power plants in the case of The Netherlands. However, with the evolving electricity network, these resources are rapidly becoming inadequate on account of two key factors: i) phase out of fossil based generation required to meet climate goals, ii) requirement for higher levels of flexibility and lower response time that current assets are unable to provide[1]. Newer components of electricity system such as distributed generation, battery energy storage systems, electric vehicles, electrolysers and other consumer-sited assets are capable of providing this flexibility in a decentralised manner while also serving their primary purpose. Additionally, use of existing resources can defer or eliminate the need for large-scale system upgrades. Thus, it stands to reason that the impact of participation of such resources in the electricity system must be evaluated, facilitated and optimally integrated in the market.

While the study of technical feasibility of flexible resources is important, it is equally, if not more, crucial to study their economic feasibility and the ability of the market design to support their utilisation. Optimal utilisation of flexible resources should ideally lead to reduced system operating cost. In fact, when considered in the larger context of the entire electricity system, it will also reduce cost of network upgrades in the long run [2]. However, determining what this optimal use is and how it must be supported is a complex task. Due to the diversity of both sources of flexibility, ranging from large industrial consumers to electrolysers, heating grids and residential heat pumps and batteries, as well as the actors that own and control them, the applicable rules and market forces vary widely. Thus, the need arises for formulating market design and regulatory framework that are able to maximize the value drawn from these resources and accommodate the interests of all the actors. Under this overarching objective, I intend to improve the representation of flexible resources and incorporate market and regulatory factors in the Dutch electricity market model with the aim to identify financial incentives and policy provisions that will encourage the use of flexible resources in future energy markets.

The main research question addressed in this paper is: What are the market barriers that prevent optimal utilisation of flexible resources in the system?

Methods:To answer this question, I am building a security constrained economic dispatch model of the Dutch energy market that represents demand elasticity of consumers. In order to do this, I will create demand functions for different types of consumers and incorporate them in an optimisation model to study the change in demand elasticity in the presence of financial distortions such as taxes and subsidies. Further the impact of information insufficiency due to lack of market clearing beyond day-ahead horizon will be evaluated by running the model with a rolling time horizon over a multi-day period and comparing with existing market design.

Results:The results of the modelling exercise are expected to show the impact of financial distortions on different consumer groups and reveal their ability to change their behaviour in response to external factors. To begin with, the impact of varying network charges on demand flexibility different consumers will be studied.
Conclusions:Conclusions will derived upon the analysis of results. As the model is currently under development, conclusions can be provided at the time of presentation.
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Keywords: flexibility, demand response, energy markets, day-ahead market

[Page: 250]

[Abstract:0545] OP-250 [Accepted:Oral Presentation] [Electricity » Policy and Regulation]

A Strategy for Flexibilization of Thermal Generation under Increasing RE Integration

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Overview:In its Intended Nationally Determined Contributions (INDCs), India committed to reduce the emission intensity of its GDP by 45% by 2030 from the 2005 level. India has also set the ambitious target of 50% cumulative electric power installed capacity from Renewable Energy Sources (RES) by 2030 [1]. Furthermore, India aims to achieve net zero carbon emissions by 2070 [2]. The growing share of Variable Renewable Energy (VRE) will be predominant in attaining the INDCs. However, large-scale integration of non-dispatchable RES alongside the advent of novel technologies engenders uncertainties pertaining to both demand and supply facets, thereby presenting apprehensions, notably for system operators. To address these issues, there is a requirement for enhanced power system flexibility [3] [11].
The flexibility of a system can be enhanced by demand-side management, improving supply-side flexibility of thermal generation, strengthening interconnection capabilities, and the deployment of storage devices [3]. Achieving an affordable, sustainable, and reliable electricity supply necessitates proactive government intervention in policy, market design, and system operation codes to incentivize investments in flexibility and storage solutions. The development of policies and regulatory frameworks, along with various initiatives, is aimed at encouraging the adoption of more expensive storage technologies such as Battery Energy Storage Systems (BESS) or Pumped Hydro Storage (PHS) through Production Linked Incentive (PLI) schemes and Viability Gap Funding (VGF) [4].
Thermal plants' flexible operation holds significant weight in the quest for enhanced system flexibility, with its capacity accounting for 49.1% of the overall capacity mix [5]. In terms of generation in the year 2023, 70% of the electricity generation is through thermal plants and merely 13% from RES, (installed capacity share of RES: 30.12% excluding large hydro) [5]. The thermal plants play an important role in absorbing variability due to RES by fulfillment of net demand, which is the total demand excluding demand met by RE generation. However, these are plants are associated with

Minimum Thermal Loading (MTL) constraints as well as ramping rate limitations. The flexibility of existing thermal plants can be enhanced by changing their operations and retrofitting to increase the ramp rate and reduction of startup and shutdown time and MTL [6]. Policies and regulatory are being formulated to encourage investment in thermal plant flexibility [9],[10]. The existing framework for tariff determination for the generation of electricity (under section 62 of the Electricity Act, 2003) is now supplemented with the incentive for greater ramping for coal-based thermal power plants [7]. Subsequent to this, Grid Controller of India Limited (Grid-India) laid out a framework for providing incentives for flexibility and better ramping delivery [8][9]. The technical standards are mandated for minimum ramp rate and thermal capabilities [9]. Table.1. summarises a few important regulatory schemes to mandate and incentivize the flexible operation of thermal plants.

Methods:Analysis conducted by EAL IIT Kanpur suggests that not all thermal plants require flexibilization [12]. Instead, priority should be given to power plants with high variable costs (VC) that need to operate below their full capacity, i.e., at minimum power levels, or system marginal plants. The plants with lower VC are observed to be operating at their maximum capacity maximum percent of the time as in Table 1. This paper focuses on identifying those plants IN need OF investment for flexibilization at the current share of RE and identifying the phase of investments needed for flexibilization of these plants and others with increasing VRE. The analysis is done for the Northern region's coal-based generating stations and discusses their implications. This paper conducts an analysis of inter-state coal-based thermal power plants in the Northern region of India, focusing on their operational profiles and Reserved Shutdown (RSD) frequency. Operational data spanning one year for each plant is utilized to ascertain their operational characteristics. The plants are categorized into High VC, mid-VC, and lower VC. The load curve for each plant is derived from its one-year operation data, depicting the percentage of time spent at its MTL.

Results:Fig.1. provides details on the Northern region's inter-state thermal plants, including their operational ranges in terms of the maximum percentage of time and the percentage of time they operate at MTL. Additionally, Fig. 2 present the load curves for two thermal plants, each representing the higher and lower VC plant categories, respectively. It can be seen that Dadri thermal plant can be ramped up (or down), being operated at lower PLF (given lower schedule due to higher VC) to incorporate VRE. Thus, the investment, if required, for increased flexible operation can be justified for Dadri thermal plant than the Jhajjar plant, operating at approx. 100% PLF for more than 90% of the time of the year.

Conclusions:The paper analyses plant operating parameters and characteristics of the inter-state thermal generating station. The marginal or infra-marginal plants require investment for flexible operation as a priority to enhance flexibility. The analysis will identify the sequence of thermal plants according to priority for flexibilization opportunity based on their operational behaviour. The study provides the phase-wise investment strategy for optimal RE integration through enhanced thermal plant flexibility.

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Keywords: RE integration, flexible thermal plants, flexibility, flexible resources, ramping rate, Minimum thermal load (MTL)

Fig.1. Key Regulations for the flexible operations of thermal plants and their key provisions

Plant Name	PLF	% of time operation below/at MTL
ANTA_CRF	98% - 100%	22%
ANTA LF	98% - 100%	17%
ANTA RF	98% - 100%	2%
AURY RF	98% - 100%	4%
AURY LF	98% - 100%	8%
BHAKRA	98% - 100%	0%
BSIUL	98% - 100%	0%
CHAMERA1	98% - 100%	0%
CHAMERA2	98% - 100%	0%
CHAMERA3	98% - 100%	0%
DADRI CRF	98% - 100%	15%
DADRI LF	98% - 100%	13%
DADRI RF	98% - 100%	4%
DEHAR	98% - 100%	0%
DHAULIGNGA	98% - 100%	0%
DULHASTI	98% - 100%	0%
JHAJJAR	54% - 56%	2%
KISHANGANGA	98% - 100%	0%
KOLDAM	98% - 100%	0%
KOTESHWR	98% - 100%	0%
NAPP	98% - 100%	0%
NJPC	98% - 100%	0%
PARBATI3	98% - 100%	0%
PONG	98% - 100%	0%
RAMPUR	98% - 100%	0%
RAPPB	98% - 100%	0%
RAPPC	98% - 100%	0%
RIHAND1	98% - 100%	0%
RIHAND2	98% - 100%	0%
RIHAND3	98% - 100%	0%
SALAL	98% - 100%	0%
SEWA2	98% - 100%	0%
SINGRAULI	98% - 100%	0%
SINGRAULI HYDRO	98% - 100%	0%
TANAKPUR	98% - 100%	0%
TANDA2	98% - 100%	6%
TEHRI	98% - 100%	0%
UNCHAHAR1	54% - 56%	0%
UNCHAHAR2	54% - 56%	0%
UNCHAHAR3	54% - 56%	0%
UNCHAHAR4	98% - 100%	44%
URI	98% - 100%	0%

Fig.2. Load duration curve for higher VC plant Dadri and lower VC plant Jajjar

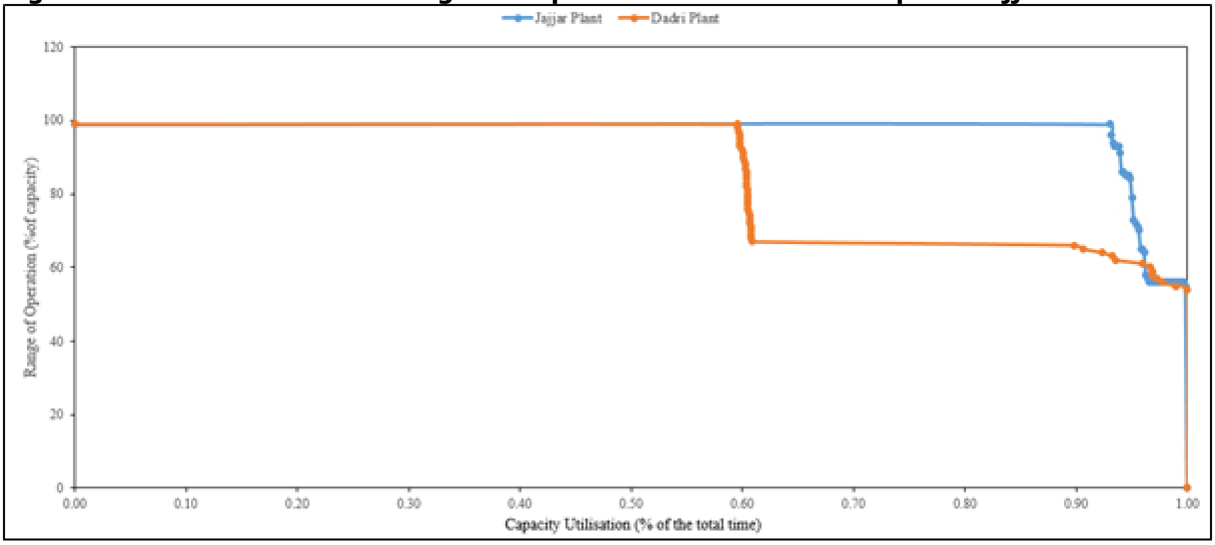

Table 1. Key Regulations for the flexible operations of thermal plants and their key provisions

Name of Regulation	Key Provisions
Terms and Conditions of Tariff Regulations, 2019 [9]	Incentive and penalty structure for flexible operation of thermal plants. Applicability: Thermal generating stations (with effect from 1.4.2020) Mandated to achieve the ramp rate of 1% per minute. Failure: Reduce the Return on Equity (RoE) rate by 0.25 percentage points. Over and above: Additional RoE rate of 0.25% for every incremental ramp rate of 1% per with ceiling of additional rate of return on equity of 1.00%
CEA (Flexible Operation of Coal based Thermal Power Generating Units) Regulations, 2023 [10]	Applicability: Central Government, State Governments, or private all coal-based thermal power generating units Minimum power level capabilities: 40% to be achieved within one year (In-phase achievement for those that are not able to achieve) Ramp rate requirement: 3% per minute for operation between 70% - 100% 2% per minute for operation between 55% - 70% 1% per minute for operation between 40% - 55% of maximum continuous power rating.

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[Abstract:0644] OP-251 [Accepted:Oral Presentation] [Electricity » Generation Technologies]

Nuclear and hydrogen future role in POLES NZE scenarios

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Overview:Nuclear and hydrogen both play significant roles in the potential decarbonization of energy systems, offering low-carbon alternatives to traditional fossil fuels. Each technology has its strengths and challenges, and their roles can complement each other in achieving a sustainable and low-carbon energy future.
Methods:Synergies and Integration:
1. Hydrogen as an Energy Carrier: Nuclear power can be used to produce hydrogen through processes like electrolysis, providing a clean source for hydrogen production.
2. Load Following: Nuclear power can provide stable baseload power, while hydrogen can be used to store excess energy during periods of low demand and release it during high demand, helping to balance the grid.
3. Decentralized Power Generation: Hydrogen can enable decentralized power generation, allowing for the production of energy where it's needed most.
POLES model permits to study interactions between new developments of nuclear and clean hydrogen diffusion in the framework of NZE scenarios to 2050 and 2100.
Results:NZE for France: Nuclear is expected to remain an important component of the French electricity mix
Due to electrification of uses and needs linked to a reindustrialization, electricity generation will reach 558-591 TWh by 2030.
By 2030, the goal is to add more than 100 TWh of renewable heat, thanks to expected ramp-up of heat pumps, geothermal, biomass and biogas.
In our last NZE scenario, nuclear power should provide about 73% of electricity generation, which corresponds to more than 400 TWh by 2030.
Nuclear loose its primacy after 2040, providing 44% of total generation by 2050; renewables representing 58%.
The arbitrage must better take into account all the costs, direct and indirect, of all solutions in competition.
Conclusions:Due to their capacity to broaden the field of analysis of energy-economy-environment interactions, energy models are important instruments of reflection and useful decision-making tools:
They ensure the internal coherence of the analysis while exceeding the limits of linear reasoning and can evaluate the outcome of various contradictory effects.
But they must be used with caution because, no model can take into account all the dimensions of the energy transition.
A cross-examination between several modelling exercises remains necessary to study uncertainties and better understand the various issues involved and build the most effective climate change policies possible.
There are many possible paths to decarbonization… but none is an easy one.
Scenarios which incorporates a set of uncertainties that cross climate goals, energy policies and new behaviors to study the impacts of different nuclear trajectories are key elements for the development of flexible strategies and resilient policy configurations.
The place of nuclear in the NZE sc is all about trade offs, tied to the consideration of climate – nuclear risks:
Climate risks - critical needs for curbing greenhouse gases:
Nuclear energy as a low carbon technology, contributor to security of supply and diversification (with a high energy density) to meet increasing electricity demand,
Nuclear can provide also flexibility to the grid in high share of VRE sc: load following, co-generation, pink or orange H2, grid services,
In this framework Nuclear seems a necessary component of the energy mix
Nuclear risks - the challenges are great:
High cost of new nuclear capacity, long construction time, management of wastes, safety, public acceptability….
new or improved technologies or systems are needed (as SMRs….)
Governments should play an important role through clear-designed energy & environmental policies, and appropriate assistance to address the challenges.
Regulation, organization, estimation of the costs of a decommissioning, private sector involvement and financing of nuclear decommissioning are also fields of future research.
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Enerdata Power Plant Tracker.

Keywords: Nuclear, Hydrogen, NZE, POLES model

[Abstract:0138] OP-252 [Accepted:Oral Presentation] [Energy Access » Energy Poverty and Equity]

Bringing the heat: Does climate change exacerbate energy poverty in South Africa?

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Overview:A close connection exists between energy and climate change, wherein the latter can significantly impact energy demand and supply. Understanding how rising temperatures affect energy poverty is crucial for achieving the Sustainable Developmental Goals. The objective of this study is to examine whether climate change exacerbates energy poverty in South Africa for the period 1996 to 2021. In this study, climate change is proxied by the average surface temperature recorded over South Africa. Energy poverty is a multiplex issue residing at the nexus of household earnings, energy expenses, and the efficiency of housing infrastructure (Faiella & Lavecchia, 2019). Despite the growing body of research on the topic, a lack of consensus remains in defining and measuring energy poverty within the existing literature. As a result, this study will narrow its focus to two key aspects: access to electricity and the affordability of electricity services. The ARDL approach is employed to capture both short-term and long-term dynamics, allowing for a comprehensive understanding of how average surface temperature changes affect the South Africa's energy poverty. The results show that increased average surface temperature positively (negatively) influences access to electricity in the long run (short run). The study also finds that higher average surface temperature is negatively associated with household expenditure on electricity services in both the short- and long-run – implying that warmer temperatures lead to a modest reduction in the household electricity cost burden. This study challenges conventional assumptions by suggesting that rising temperatures resulting from climate change might present certain advantages in mitigating energy poverty in South Africa. These insights hold broader implications for nations grappling with similar climate conditions and formulating policies to address energy poverty within the context of climate change.
Methods:This work identifies two measures of energy poverty: (i) using access to electricity as the dependent variable and (ii) using electricity affordability as the dependent variable. In both models, this study uses the Autoregressive Distributed Lag (ARDL) approach to estimate the relationship between energy poverty and climate change due to the mixture of I(0) and I(1) variables and the small sample size.

The first model estimates the relationship between the proportion of the population with access to electricity (EP1) and the average temperature recorded in degrees Celsius (Temp) while controlling

for CO_2 emissions measured in kt (CO_2). The baseline model can be written as follows:

$$EP1=f(Temp,CO_2)$$

The lag order selected as the best model based on AIC is ARDL(4,5,0).

The second model estimates the relationship between the affordability/cost burden of electricity services (EP2) and the average temperature recorded in degrees Celsius (Temp), while controlling for the annual percentage change in the urban population (Urban). The electricity cost burden is calculated as follows:

$$EP2=(Price \times Electricity\ Consumption)/(Household\ Consumption\ Expenditure)\times 100$$

Where Price is the annual average electricity price charged by the state-owned electricity provider, Eskom, across various categories expressed in cents per kilowatt-hour. Electricity Consumption is total electricity consumption measured in Terawatt-hours. Household Consumption Expenditure is the final consumption expenditure in millions by households on housing, water, electricity, gas, and other fuels, without adjusting for inflation or fluctuations in the cost of living.

The baseline model can be written as follows:

$$EP2=f(Temp,Urban)$$

The lag order selected as the best model based on AIC is ARDL(1,1,1,0). Results:The long-run estimations suggest a positive relationship between average surface temperature and access to electricity, with this effect only becoming significant in period 5 at a 1% significance level. Holding all else constant, a 1°C increase in temperature is expected to lead to an increase in access to electricity by 4.14% after five years. This implies that higher temperatures are linked to greater access to electricity over time, possibly due to increased energy demand (Yao, 2021).

In the short run, a negative relationship exists between access to electricity and average surface temperature, but this effect only becomes significant after a lag. An increase of 1°C in temperature is expected to decrease access to electricity by 6.39% at lag 1, 6.57% at lag 2, 6.38% at lag 3, and 4.14% at lag 4, ceteris paribus.

The lagged effects observed in both the long- and short-run relationships indicate that changes in access to electricity are not immediate. Access in previous periods determines access in the current period, emphasising the importance of historical trends and past investments in shaping the current energy landscape. The positive relationship in the long run and the negative relationship in the short run imply that while there may be a positive overall trend of increased electricity access with higher temperatures, increased temperatures will not alleviate energy poverty in the short run.

In the long-run analysis for the affordability model, the cost burden was negatively affected by temperature in the current period and the previous period, at a 10% and 5% significance level, respectively. A 1°C increase in temperature in the current period is expected to decrease the proportion of household spending on electricity services compared to expenditure for all utilities by 5.18%, ceteris paribus. Similarly, a 1°C increase in temperature in the previous period is expected to decrease the cost burden in the current period by 5.96%, ceteris paribus.

Similar to the long-run analysis, a negative relationship exists between the electricity cost burden and average surface temperature at a 5% significance level in the short-run. A 1°C increase in temperature is associated with a decrease of 5.18% in the electricity cost burden, ceteris paribus. However, urbanisation has a statistically negative effect on the cost burden in the short run. A 1% increase in urbanisation is expected to lead to a 0.11% decrease in the proportion of household spending on electricity services compared to expenditure for all utilities.

In both the long- and short-run analysis, a statistically significant negative relationship exists between temperature and the cost burden in the current period. This finding suggests that this relationship is not just a temporary fluctuation but that temperature in a given year appears to be a significant driver of changes in household expenditure on electricity services in that year.

This aligns with results from Awaworyi Churchill et al. (2022), who find that global warming is expected to have a modest effect on decreasing the prevalence of energy poverty in Australia. This may be because a warming planet lessens the need for heating during cold periods, reducing the energy demands associated with staying warm. It should be noted that this result is highly dependent on the country in consideration's climate. For example, energy poverty studies considering the effects of temperature changes in countries closer to the equator, where the need for cooling is greater due to warmer temperatures, have opposing results to this study (Feeny et al., 2021; Li et al., 2023). Conclusions:This study concludes that increasing temperatures due to climate change may offer particular advantages in alleviating energy poverty in South Africa. However, it is important to emphasise that this study does not advocate for inaction on climate change, especially concerning the country's current energy landscape. Other indicators of climate change not considered in this study could offer different conclusions. For example, extreme rainfall events are associated with expensive infrastructure repairs and road closures, limiting electricity access and contributing to a higher prevalence of energy poverty (Dove et al., 2021).

While increasing temperatures may offer some benefits in alleviating energy poverty in South Africa, the South African government must continue its efforts to mitigate and adapt to climate change. These strategies should focus on reducing greenhouse gas emissions, developing climate-resilient infrastructure, and promoting sustainable energy sources. Other factors could influence energy poverty, such as the frequency of heatwaves, flooding and droughts, to name a few. Future research should consider these when studying the energy poverty-climate nexus. Beyond just access to electricity and affordability, future research should aim to consider a more comprehensive definition of this issue. South Africa has been reckoning with an increasingly unreliable electricity supply since 2007. Assessing the reliability of electricity services in South Africa in energy poverty studies could also help policymakers design more effective interventions to address this issue.
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Keywords: Energy Poverty, Temperature, Climate Change, South Africa

Figure 2: Observed Annual Mean-Temperature, 1901-2021 Source: (Climate Research Unit, 2023)

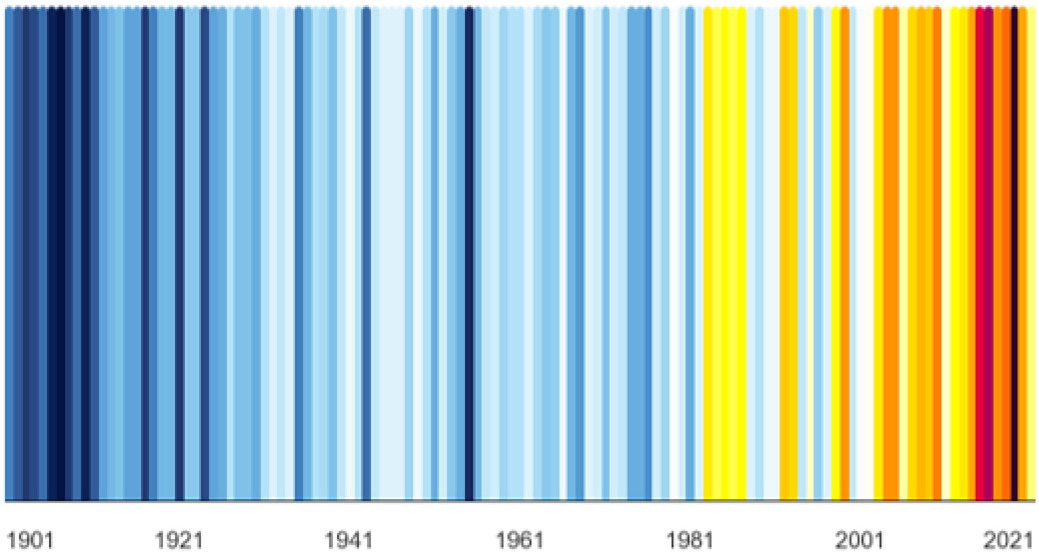

Figure 2: Observed Annual Mean-Temperature, 1901-2021

Source: (Climate Research Unit, 2023)

Over the years, South Africa has experienced significant temperature increases (see Figure 2). Since 1990, the national average temperature has risen twice as fast compared to that of global temperatures (USAID, 2022). This warming trend is projected to continue, with mean monthly temperatures expected to surge by 2.0°C by the 2050s and 4.2°C by the 2090s (Dove et al., 2021). Such rising temperatures pose serious threats, including substantial economic losses, damage to land used for agriculture, infrastructure damage, and potential loss of life (Dove et al., 2021).

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[Abstract:0240] OP-253 [Accepted:Oral Presentation] [Energy Access » Energy Poverty and Equity]

The effects of energy accessibility on income inequality in Latin America and Caribbean countries

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Overview:Transitioning to clean energy offers multiple benefits: curb Carbon Dioxide emissions, foster job creation, and provide affordable electricity. However, such a transition can also intensify inequalities. Indeed, addressing income inequality is vital to avert political and economic instability, which can obstruct poverty alleviation efforts.
Access to electricity brings several advantages to households and communities. It enables income generation, for instance, through the creation of small businesses, creates job opportunities, and improves education by allowing nighttime studying and internet access. Moreover, school electricity can improve student performance, attract talented educators to rural areas, enhance local institutions' operational efficiency, and improve street lighting safety. In addition, electricity can reduce a nation's reliance on environmentally harmful and polluting fuels, reducing greenhouse gas emissions.

Income inequality and energy accessibility are intertwined, with the latter significantly reducing disparities. Enhancing energy access can lead to more equitable income distribution through income generation, improving health and education, and promoting economic development, particularly in underserved communities. This concept leads to the fact that addressing income inequality involves addressing energy poverty and ensuring that energy policies and investments prioritise the needs of low-income populations.

This article explores the intricate relationship between energy access and income inequality. The focus is on Latin America and the Caribbean (LAC) nations that experience disparities in energy access and income inequality, more specifically, Bolivia, Brazil, Colombia, Costa Rica, El Salvador, and Honduras. While some urban areas in the region enjoy reliable and modern energy services, many rural and marginalized communities still lack access to electricity and clean cooking fuels. This disparity in energy access within a single region provides a clear context for studying its impact on income inequality. Furthermore, many countries in the LAC region struggle with income inequality and are characterized by various energy access and income distribution policy approaches. Lack of access to modern energy services, often prevalent in marginalised communities, hampers well-being, health, and economic prospects.

Methods:Econometric models, correlation analysis, and Granger causality tests are employed using data from the six LAC countries, analyzing the period between 2000 and 2019, aiming to respond to the following research hypothesis:

H1. Does access to electricity have an impact on the Gini Coefficient?

H2. Does access to clean cooking fuels have an impact on the Gini Coefficient?

H3. Does access to electricity impact the access to clean cooking fuels?

Thus, regression models were tested to gauge the advantages of energy access and modern energy services. This method typically investigates whether the advancement of modern energy services is a driving force behind or a result of developmental outcomes. The main variables tested include the total population with access to electricity, the percentage of people with access to clean cooking fuels, the Gini Index, but also other economic variables, such as GDP per capita, the share of urban population, and energy prices, among others. In addition, correlation analysis and Granger causality tests were applied to each of the six countries to establish causation when assessing the impact of energy accessibility and access to clean cooking fuels on income inequality.

Results:Results reveal that the link between per capita GDP and income inequality varies across countries, being responsible for increasing energy disparities in some and reducing energy disparities in others. Granger causality tests revealed that the impact of energy access on income inequality also varies by country, with Bolivia experiencing a causal relationship where increased access to electricity led to reduced income inequality. At the same time, Costa Rica and Honduras exhibited a mutual causation, suggesting a feedback loop between energy accessibility and income inequality. Income inequality is responsible for Granger causing access to clean cooking fuels in Brazil, Costa Rica, and Honduras. In Costa Rica and El Salvador, electricity access Granger caused the access to clean cooking fuels, while in Honduras, they mutually Granger caused each other. In other words, variations in income inequality are associated with changes in the availability and use of clean cooking fuels over time, possibly due to income levels influencing affordability and access to modern energy sources.

Conclusions:The availability of modern energy plays a crucial role in facilitating the achievement of various Sustainable Development Goals (SDGs). For instance, addressing poverty (SDG 1) by enabling economic opportunities and reducing inequalities is essential (SDG 10). Energy is also a prerequisite for enhancing food security, nutrition, and sustainable agriculture (SDG 2). Moreover, it contributes to economic growth and employment (SDG 8), mainly through job creation in general industry, food processing and preservation, and the operation of agricultural systems and conservation of perishable products. Furthermore, modern energy supports water pumping systems, which, in turn, improves water and sanitation (SDG 6). In the context of health services and promoting well-being (SDG 3), energy is indispensable for preserving medicines through refrigeration, sterilizing medical equipment, and providing lighting for nighttime surgeries and deliveries. In education (SDG 4), electricity is essential for quality learning, including modern communication services and school computers, which enhance educational outcomes. Energy services also contribute to better working conditions for women and their participation in community activities, aligning with the goal of gender equality and empowering women and girls (SDG 5).

To understand the potential impact of energy access on income inequality, this article utilized econometric models. The analysis was conducted on a panel of six middle-income countries from the LAC region—specifically, Bolivia, Brazil, Colombia, Costa Rica, El Salvador, and Honduras—along with individual time series data for each country.

Our findings confirm the three hypotheses related to the relationship between the variables — however, the impact direction changes from one country to another. It underscores the need for tailored strategies and policies to improve access to electricity and address income disparities in the LAC region, as energy access can both impact and be influenced by income inequality, ultimately

contributing to a more equitable and sustainable impact.
This article emphasizes the potential of clean energy access in income inequality reduction and offers recommendations to policymakers. Despite focusing on LAC countries, these findings have broader implications for other middle-income countries. It also underscores that strategies to diminish income inequality through enhanced energy access must be tailored to each country's unique context. It is important to note that reducing income inequality by fairly distributing economic income is a multifaceted task that requires a comprehensive approach involving law enforcement and economic, social, and political policies, where policies could play a role by promoting safety and stability. However, broader systemic changes might be necessary to address the root causes of income distribution in the LAC region.
References:There are no references.

Keywords: Energy access, Inequality, Latin America and Caribbean, Econometrics

[Abstract:0328] OP-254 [Accepted:Oral Presentation] [Energy Access » Energy Poverty and Equity]

Transcending Energy Poverty: Contributions and Characteristics of China's Overseas Development Finance

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Overview:Energy poverty is one of the major challenges to global sustainable development, severely constraining economic and social development and human health and well-being. As of 2021, 675 million people globally, mainly in the least developed countries (LDCs) and sub-Saharan Africa, still do not have access to electricity, and 2.3 billion people depend on fuels that are harmful to health and the environment for cooking (World Bank, 2023). In particular, energy poverty, which is the engine of economic development, is a serious constraint to their economic development. Some developing countries can hardly afford the high cost of building and upgrading energy infrastructure, and their more outdated financial systems can hardly support energy financing needs. Developing countries still face a huge energy financing gap of US$2.2 trillion per year, accounting for more than half of the overall SDG investment gap (US$4 trillion) (UNCTAD, 2023).

As an emerging donor, China has begun to play an increasingly important role in international development finance development in recent years. 2008-2021, China's two global development finance institutions, the China Development Bank (CDB) and the Export-Import Bank of China (Exim Bank), have committed $498 billion in development finance, amounting to 83 percent of the World Bank's sovereign lending. Unlike traditional development finance's focus on the public sector, such as health and wellness, China's development finance is committed to the energy and infrastructure sectors, and has already provided the world with more energy finance than the major multilateral development banks combined (Gallagher et al., 2018). This has aroused concerns among some scholars, with the controversy centering on the fact that energy projects promoted by China may be detrimental to the energy transition, affecting the coal exit process and leading to carbon lock-in (Chen et al., 2021). In fact, the socio-economic development of host countries in South-South cooperation is its primary need. Chinese development finance can finance the reliable and affordable energy supply that developing countries desperately need for their economic takeoff. However, few studies have systematically and empirically assessed it.

This paper use data from China's overseas development finance energy projects to assess its effect

on energy poverty in host countries, its mechanisms, and its characteristics that distinguish it from projects from developed countries.

The contributions of this paper lie in the following. First, under the perspective of South-South cooperation, this paper empirically evaluates the role and contribution of China's overseas development finance in alleviating global energy poverty and bridging the North-South gap in energy investment, which is seldom dealt with in the existing literature. Second, it compares the different impacts of China's development finance and the model of traditional donors, and verifies that the two are more complementary than competitive.
Methods: Data on China's development finance projects are obtained from the China's Global Energy Finance (CGEF) database on China's overseas energy finance at Boston University, covering data on energy projects committed by CDB and Exim Bank from 2003-2020, and are merged with the national panel data accordingly. The host country energy poverty index is constructed with reference to Kahanna et al. (2019) and Xia et al. (2022), which considers the three dimensions of Accessibility, Availability and Affordability.

In the benchmarking regression model, the dependent variable is energy poverty in the host country, and the core independent variable is the cumulative number of Chinese overseas development finance projects accepted in country i in year t. In addition, the cumulative number of World Bank, OECD, and PPI energy projects is also controlled. Control variables include the stock of FDI absorbed by the host country, GDP per capita, natural resource endowment, urbanization rate, and government governance index. We also control for country fixed effects and year fixed effects.

To deal with the endogeneity problem, we use the interaction term between one-period-ahead Chinese industrial production inputs and the host country's frequency of accepting Chinese financing during the sample period as an instrumental variable, and estimates it using two-stage least squares.
Results: Benchmark regression results find that Chinese overseas energy-based development finance significantly alleviates energy poverty in host countries.

We explore three mechanisms. First, what types of projects help alleviate energy poverty? We find that power generation projects and grid projects, especially non-renewable power generation projects, can alleviate energy poverty. Second, which dimension of energy poverty can China's development finance programs alleviate? On the dimension of energy poverty alleviation, power generation projects can improve access to clean fuels, while transmission and distribution projects can improve access to electricity. Third, how can China's development finance programs alleviate energy poverty? In terms of promoting energy accessibility and availability, they can help increase energy infrastructure and energy production at the macro level and promote the development of power enterprises in host countries at the micro level; and in terms of raising incomes and promoting development, they can help increase the GDP per capita and power consumption in host countries at the macro level and promote the development of manufacturing enterprises in host countries at the micro level.

We further explore the characteristics of China's overseas development finance in order to answer why it helps alleviate energy poverty in host countries. Comparing Chinese energy-based overseas development finance projects with World Bank, OECD and PPP infrastructure projects received by host countries, we find that Chinese development finance projects are more inclined to go to countries and regions with lower levels of democratization, weaker governmental governance, and lower levels of financial development, and that these prerequisites do not affect the effectiveness of Chinese projects in alleviating energy poverty.
Conclusions: This study finds that China's overseas development finance and its features help alleviate energy poverty in host countries. The relationship between Chinese projects and traditional donors is complementary rather than competitive. This helps to fill the financing gap needed to alleviate energy poverty.
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Keywords: Energy Poverty, Development Finance, Energy Finance

[Abstract:0425] OP-255 [Accepted:Oral Presentation] [Energy Access » Energy Poverty and Equity]

Toward Equitable Energy Access in Tanzania: Challenges and Opportunities in Refugee Camps and Host Communities

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Overview:The pursuit of equitable energy access in Tanzania has gained paramount importance, particularly within the unique context of refugee camps and their adjacent host communities. The challenges and opportunities in this field present a complex landscape that necessitates thorough examination. The geographical and social dynamics of the region underscore the importance of addressing energy disparities not only to meet the basic needs of refugees but also to enhance the resilience and well-being of the host communities in Tanzania.

With the increasing demand for energy, comprehending the challenges and opportunities in achieving equitable access becomes pivotal for developing effective strategies that bridge gaps and foster sustainable solutions on-site. This exploration aims to contribute valuable insights into the distinctive context of Tanzania, offering a nuanced understanding of the complexities surrounding energy access in the specific setting of refugee camps and host communities. Through the analysis of these dynamics, the study seeks to inform policies and initiatives that strive towards creating a more equitable and sustainable energy landscape for all stakeholders involved on-site.

The survey specifically targeted two refugee camps, Nyarugusu in Kasulu district and Nduta in Kibondo district, both situated in the Kigoma region. Beyond the refugee camps, data collection extended to host communities within a 5km radius from the refugee settlement boundaries, covering six host communities: Nyamidaho, Nangwa, and Mvungwe surrounding Nyarugusu refugee camps, and Rusohoko, Kumhasha, and Kumbanga surrounding Nduta refugee camps.

Nyarugusu refugee camp, established in 1996, played a crucial role in sheltering approximately 150,000 Congolese refugees fleeing civil wars in the Sud-Kivu region of the Democratic Republic of Congo (DRC). Conversely, Nduta refugee camp, opened in 2015 as an emergency measure, aimed to relocate 40,000 Burundian refugees from Nyarugusu refugee camp to alleviate congestion. Nyarugusu settlement comprises 30,749 households distributed across 14 zones, while Nduta settlement includes 15,947 households distributed across 18 zones. Following the closure of Mtendeli refugee camp in 2021, refugees were redistributed to Nyarugusu and Nduta camps. It's noteworthy that over 60% of refugees in Nyarugusu are of Congolese origin, while 99% of refugees in Nduta are Burundians.
Methods:The study employed a participatory and consultative approach, utilizing mixed methods involving both qualitative and quantitative techniques. Quantitative data were gathered through household surveys utilizing a pre-designed online questionnaire, while qualitative methods included

key informant interviews and literature reviews. This mixed-method approach aimed to enhance the validity and reliability of the data, uncover unexpected results, and provide a deeper understanding of cooking systems and energy options in refugee camps and host communities.

The sample design involved purposive selection of Nyarugusu and Nduta refugee camps, the only camps operating in the region, while host communities were selected through systematic random sampling. Six host communities, three surrounding each camp, were chosen for the study. The selection of households involved purposive random sampling, with respondents chosen based on zones and villages in refugee camps and sub-village levels (hamlets) in host communities. Gender representation was considered to ensure engagement with women, youth, and marginalized community groups.

Key informants for the market survey were purposively selected based on their involvement and experience in the cooking energy value chain. The sample size comprised 880 households, including 376 from refugee camps, 476 from host communities, and 28 key informants for market categories.

Data collection techniques included desk reviews of relevant documents, household interviews using structured and semi-structured online questionnaires, and key informants' interviews to validate and complement initial data. The study utilized statistical tools such as SPSS, STATA, and advanced Excel for data analysis, ensuring precision and reliability. Descriptive statistics techniques were applied, and the findings were compiled cohesively to present a comprehensive representation of the study's outcomes.
Results:In total, 852 respondents were interviewed, with 376 from refugee camps and 476 from host communities. Burundians comprised the majority in refugee camps (72.8%), with the rest being Congolese. The average household size was 7 in Nyarugusu Camp, 6 in Nduta refugee camp, and 5 in host communities.

The average age of respondents was 37 years, reflecting a diverse age range from 15 to 90 years. Adult females, adult males, and female children constituted higher numbers in households, indicating a significant youth presence in the study areas. The heads of households in refugee camps were predominantly females, aligning with UNHCR requirements, while in host communities, males took on this role, reflecting local cultural norms.

Livelihood activities varied, with refugees in camps engaging in limited activities like small-scale agriculture and small businesses. Host communities, on the other hand, predominantly relied on farming, with over 84.7% engaged in agricultural practices.

Regarding fuel consumption, firewood was the primary cooking fuel in both refugee camps and host communities, constituting 70% of usage. Charcoal and other sources accounted for 26% and 4%, respectively. The average distance to the typical firewood collection point was 3.3km, taking 3 hours and 30 minutes in host communities. Security concerns, including harassment and threats, were significant challenges faced by those collecting firewood.

On average, households consumed 9.8kgs of firewood, 4.4 kgs of charcoal, and 3.38kg of briquettes per day in refugee camps. In host communities, the daily consumption was 9.7kgs of firewood and 3.8 kgs of charcoal. Notably, security challenges persisted during the collection of fuelwood, underscoring the need for safer alternatives.

The study also revealed the prevalent use of traditional cooking stoves, such as mudstone for 1 pot, mudstone for 2 pots, and 3-stone open fires. These stoves were primarily self-produced or distributed by NGOs. The findings collectively emphasize the dominance of traditional cooking practices, the challenges associated with fuelwood collection, and the urgent need for sustainable energy solutions in both refugee camps and host communities.
Conclusions:In conclusion, this study provides a comprehensive insight into the socio-economic dynamics and energy practices in Nyarugusu and Nduta refugee camps and their surrounding host communities in Tanzania. The findings underscore the multifaceted challenges faced by both refugees and host communities in accessing and utilizing energy resources. The dominance of traditional cooking practices, particularly the use of firewood, reveals the urgent need for sustainable and alternative energy solutions. The study highlights the significant impact of energy practices on daily life, with security concerns and the arduous process of fuelwood collection posing formidable challenges. The prevalence of traditional stoves, coupled with the associated issues of smoke and durability, calls for innovative and efficient cooking technologies.

Importantly, the study emphasizes the unique socio-economic dynamics within refugee camps, where restrictions on livelihood activities impact residents' self-sufficiency. In contrast, host communities heavily rely on agriculture, highlighting the need for tailored interventions to address energy challenges in diverse contexts. To foster a more sustainable future, the conclusion advocates for the adoption of cleaner cooking technologies, afforestation initiatives, and the integration of renewable energy sources. Policy frameworks and humanitarian efforts should consider the specific needs of both refugees and host communities, ensuring equitable access to energy resources while promoting economic resilience.

As the findings shed light on the intricate interplay between energy, livelihoods, and security, addressing these challenges becomes crucial not only for the immediate well-being of the communities studied but also for fostering long-term sustainability and resilience. This study serves as a foundation for informed decision-making and the development of targeted interventions to enhance energy access, livelihoods, and overall socio-economic well-being in displacement settings.

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Keywords: Sustainable energy, refugee camps, host communities, traditional cooking practices, alternative energy solutions, livelihoods

AuthorToEditor: "The research contributes significantly to the understanding of energy dynamics in displacement settings, and I look forward to seeing the continued impact of this work in Tanzania and other regions"

[Page: 256]

[Abstract:0018] OP-256 [Accepted:Oral Presentation] [Energy Efficiency » Residential and Commercial Buildings]

Energy efficiency auditing in higher education buildings: case study of the sulaiman al-rajhi university model from an economic and environmental perspective

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Overview:The building sector is responsible for 32% of the total energy consumed worldwide. Additionally, this sector contributes approximately 20% of global greenhouse gas emissions [1]. In the Kingdom of Saudi Arabia, the buildings sector consumes about 29% of the primary energy [2].

Energy auditing, energy efficiency, and sustainability have become critical elements in modern buildings, particularly due to growing concerns about climate change, resource depletion, and rising energy costs. This paper presents a case study of Salman Al Rajhi University campus and investigates the environmental and economic impact of energy auditing in university buildings.
Methods:Conducting an energy audit study on the campus of Sulaiman Al-Rajhi University from an environmental and economic perspective involves utilizing practical tools and scientific methodologies to achieve the desired results.
The energy audit was mainly targeted at identifying practical, sustainable, and economically viable energy-saving opportunities in all sections of the university, resulting from a detailed study and analyses of technical parameters. The energy audit involved using a wide range of sophisticated, portable, diagnostic, and measuring instruments to generate refined data and facilitate complex analyses to give a more reliable basis for evaluation of energy-saving potential and economic viability.
Currently, the annual electricity consumption and cost of the 58,000 square meter university building for the year 2022 is 13 Million kWh and 2.5 Million SAR. The facility has an annual EUI of 240 kWh/Square meter.

The following pie chart shows the energy break down amongst the building's systems. The chart shows that the chillers plant is the largest energy consumer as it constitutes around 52% of the total electricity consumption, the second large consumer is the Air handling units which constitute around 20%. Details of the building electrical consumption are shown in the figure.

Environmental perspective:
The environmental perspective section contains data on environmental carbon dioxide emissions before and after the implementation of energy auditing on buildings. It includes various environmental data that demonstrate the environmental impact of electrical energy consumption before and after energy auditing, as well as a comparison of emissions before and after.

Economic perspective:
The section includes a cost-benefit analysis of electricity consumption based on the value of the load, applying the laws of cost-benefit analysis before and after the implementation of energy auditing on buildings.
Results:The results shown in the table1 are a summary of what was provided economically and environmentally through the tools and equations that were used in each perspective.
Conclusions:After completing the study, it was found that energy auditing is economically and environmentally beneficial, especially with the scientific and urban development witnessed by the Kingdom of Saudi Arabia and its vision for 2030 in improving energy efficiency and reducing environmental emissions. Energy auditing is environmentally beneficial by reducing 5.3 million kWh and saving 3,758 metric tons of carbon dioxide. Energy auditing is economically successful by reducing the total cost by 945,478 Saudi Riyals. Through the study results, it was evident that energy auditing is beneficial and feasible, but it faces a challenge in convincing decision-makers to consider the initial cost savings as a return on investment over a specific period of time. In future work, we will focus on implementing renewable energy systems to achieve sustainable buildings.
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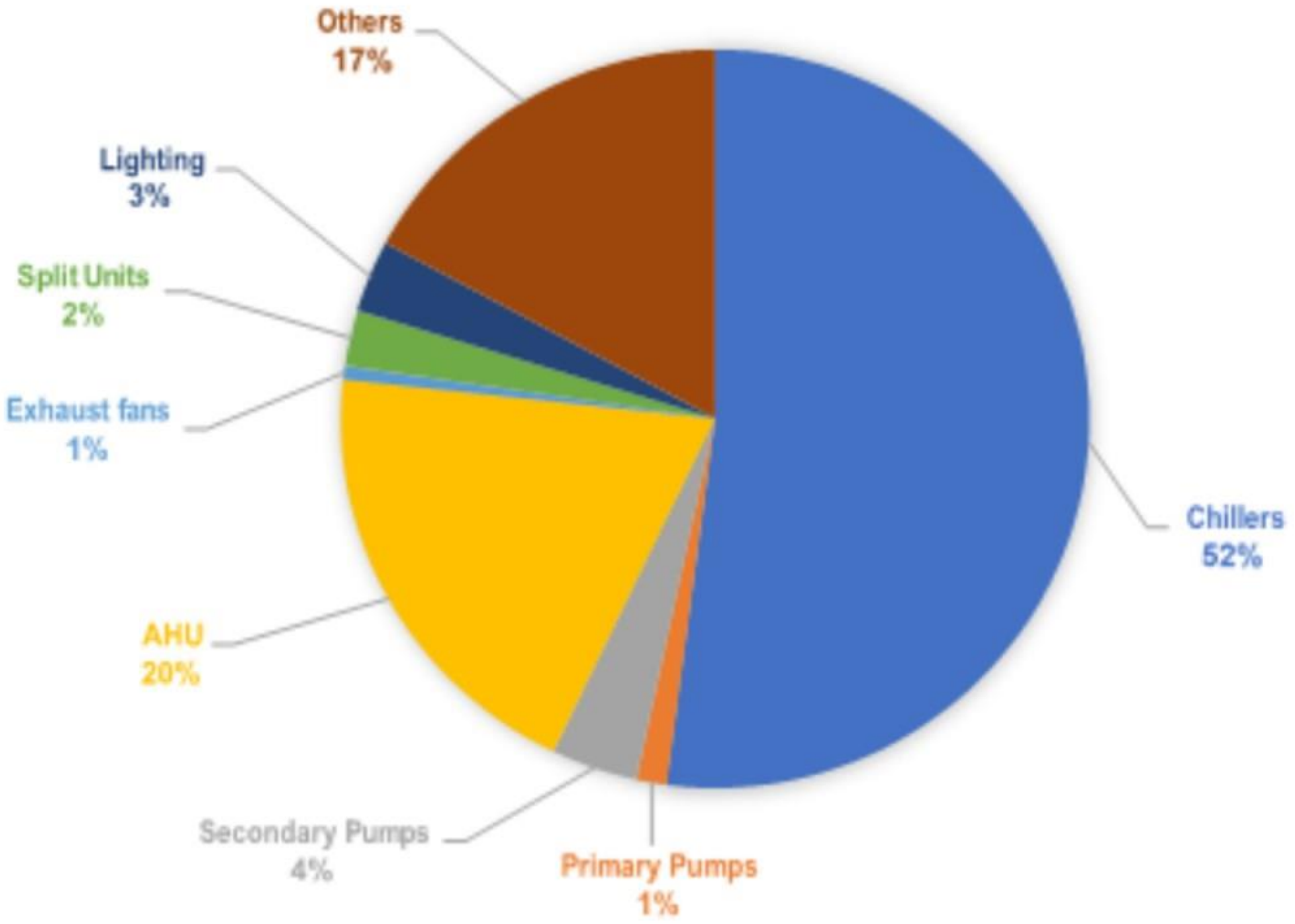
Keywords: saudi arabia vision 2030,Saudi Energy Efficiency Center,Environmental perspective,Economic perspective

Electricity consumption breakdown



The following pie chart shows the energy break down amongst the building's systems. The chart shows that the chillers plant is the largest energy consumer as it constitutes around 52% of the total electricity consumption, the second large consumer is the Air handling units which constitute around 20%. Details of the building electrical consumption are shown in the figure.

Results

parameter	amount
Annual Electricity Savings (KWh)	5.3 Million
kWh Annual Electricity Cost Saving (SAR)	945478
Metric tons CO2 Reduced	3,758
Proposed EUI	150
Simple Payback Period	6.0 Years

AuthorToEditor: We appreciate the opportunity and eagerly anticipate the chance to participate and benefit from your scientific expertise.

[Abstract:0150] OP-257 [Accepted:Oral Presentation] [Energy Efficiency » Residential and Commercial Buildings]

Future residential electricity demand in Saudi Arabia and the role of energy efficiency

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Overview:With the ambitious goal that Saudi Arabia has set to reach net zero by 2060, reducing domestic electricity consumption, and hence curbing greenhouse gas (GHG) emissions is critical. Since the residential sector is the biggest consumer of electricity in the Kingdom, understanding how its electricity consumption would evolve in the long-term horizon can help policymakers to design policies through which the sector can contribute effectively to that target. The aim of this paper is twofold, forecasting the residential electricity consumption to 2060, and assessing the potential impact of energy efficiency on curbing the demand over the forecast period.
Methods:We construct a forecast model using the Autoregressive Integrated Moving Average (ARIMA) technique and historical residential electricity consumption data. We then build on this forecast to assess the potential impact of energy efficiency (EE) in curbing the electricity demand growth over the forecast period using a bottom-up building stock model tailored for Saudi Arabia. The EE assessment is divided into targeting future residential houses and renovating existing houses. The analysis shows that future electricity consumption is expected to pick up a steady upward trend over the next 39 years.
Results:The EE assessment shows that regularly tightening minimum energy performance standards (MEPS) can reduce future consumption by 8% and 2060's consumption by up to 12%. In addition to targeting future stock, renovating existing stock can curb the overall consumption by 18% over the forecast horizon and up to 30% of total consumption in 2060.
Conclusions:Using ARIMA forecasting technique and historical data from 1983 to 2021, we forecast the residential electricity consumption of the next 39-year horizon, 2022 to 2060. The forecast shows that the residential electricity consumption would develop a consistent upward trend again after the disruption it witnessed over the last few years. It is expected to reach 274.3 TWh by 2060 if all influential factors, such as population growth, electricity prices, income, etc., maintain the same growth. This growth is 92% of 2021's consumption. The analysis then utilizes a published model to examine how EE enhancement can reduce that potential growth over time. We find that enhancing the standards of future housing stock can flatten the consumption growth and reduce consumption by 8% over the forecast horizon. The potential reduction in 2060's consumption is expected to decrease by up to 12%. If Saudi Arabia targets existing housing stock, in addition to targeting future housing stock, the residential electricity consumption would witness an overall reduction of 23% over the forecast horizon and up to 46% of 2060.
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Keywords: Energy efficiency, residential energy consumption, building sector

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[Abstract:0185] OP-258 [Accepted:Oral Presentation] [Energy Efficiency » Residential and Commercial Buildings]

Impact Assessment of Cooling Technology and Measures under Different Future Scenarios

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Overview:The increasing demand for space cooling necessitates prompt attention to sustainable and resource-efficient space cooling planning. This involves an analysis of various space cooling technologies and measures, aiming to provide a comprehensive overview of the quantifiable economic, environmental, and social impact of each technology, as well as the potential savings per measure. The broader impact of increasing space cooling demands and the implementation of reduction measures at the country and EU level remains uncertain. Through this study, our objective is to quantify and assess the techno-economic impact of these technologies and measures on the overall decarbonization of the energy sector on the European level.
Methods:We estimate the theoretical-useful energy demand using the Invert/EE-Lab model, which calculates the theoretical-useful energy demand for space cooling in regions or countries based on an underlying building physics model conforming to national and international norms [1]. Our approach involves utilizing bottom-up technology distribution data [2] and statistical space cooling demand data [3] to estimate the technology diffusion/distribution rate per country for the base year. Similarly, we also calculate technology distribution rates for future projected demand, considering the adoption of different space cooling measures by assuming a certain level of alterations in building

envelope properties resulting from the passive measure uptake.
After obtaining the practical-useful energy demand per country for various scenarios, we proceed to estimate the final energy consumption based on SEER of different technologies and then proceed to the estimation of the primary energy demand for space cooling using the standard primary energy factor. Subsequently, we estimate the CO2 emissions associated with cold generation. Additionally, we analyze the economic implications of passive measures and the uptake of certain efficient space cooling technologies and assess the societal co-benefits of these measures. This includes aspects such as improvement in the quality of life, increased employment, health benefits etc.
Results:In the baseline (BAU) scenario, the space cooling demands are primarily met by electricity, with 80% of the supply technology mix coming from vapor compression units. Given the relatively lower share of renewable energy in the supply mix, this results in expectedly high CO2 emissions. However, with the implementation of space cooling measures such as shading and night ventilation, an anticipated energy demand reduction of 60-75% is projected [4]. The uptake of measures will already reduce the environmental impact even under constant BAU energy mix scenarios.
The adoption of more efficient technology options, such as reversible heat pumps with low-temperature heat sinks and central supply systems like district cooling, is expected to further enhance the environmental performance of the space cooling supply system. In various space cooling demand forecast scenarios, we will assess the CO2 emissions per unit of primary space cooling energy supplied. Additionally, we will evaluate the levelized cost of space cooling for different technologies per country and the cost of energy savings associated with various cooling measures. Our analysis will also extend to quantifying societal co-benefits in monetary terms, providing insights into the economic advantages of technology uptake and measure implementation.
Conclusions:With this study, we aim to quantify the impact of various technologies and measures on the rising space cooling demand. We will compare different scenarios of technology and measure uptake to assess their overall impact on demand at both the European and Member State (MS) levels.
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Keywords: Cooling Technologies, Passive Cooling Measures, GHG emissions, Environmental Impact, Economic Impact

[Abstract:0220] OP-259 [Accepted:Oral Presentation] [Energy Efficiency » Residential and Commercial Buildings]

The impact of energy performance certificates and the display of monetary information on energy-efficient decision making

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Overview:According to the Energy Performance of Buildings Directive (2002/91/EC), EU member states were required to adopt laws, and regulations concerning energy performance certification of buildings. The Directive was recast in 2010 (Directive 2010/31/EU), revised in 2018 (Directive 2018/844/EU), and is currently undergoing another revision. Energy performance certificates provide information on the energy performance of buildings in a standardized way. Usually, this is done by rating the building's energy efficiency on a harmonized scale using letters from A (the most energy-efficient) to G (the least energy-efficient). While energy performance certificates in the EU have been studied before in different countries and contexts (Andaloro et al., 2010; Brounen & Kok, 2011; Gonzalez-Caceres et al., 2020; Olaussen et al., 2017), the concepts of energy and financial literacy have scarcely been researched in this area. This paper aims to bridge the identified gap, providing evidence from Slovenia. Data obtained from a stated choice experiment are analysed using discrete choice models. We explore whether financial and energy literacy and other socio-economic factors influence household decisions to rely on energy performance certificates when making real estate purchasing decisions and whether better energy performance of residential buildings leads to respondents accepting a price premium for real estate that is more energy- and/or cost-efficient, with all other elements kept constant. Another important consideration is whether providing monetary information on the energy label facilitates decision-making. Our research goal is to determine whether energy performance certificates are effective as an informative measure in supporting energy-efficient decision-making in residential buildings.
Methods:The final sample consists of 2,484 respondents from Slovenia, economic decision-makers within the household, who are either owners or co-owners of their home. The data was collected from an online household survey in August 2020 as part of the EU-funded Care4Climate project. Characteristics of respondents in the sample closely resemble the population with respect to the region, gender, and age, with a slight over-representation of individuals with higher levels of education, possibly related to the fact that the survey was conducted online. We designed a discrete choice experiment with stated preference to establish whether a better energy performance certificate rating would encourage respondents to accept paying a price premium for a more energy-efficient real estate, with all other elements kept constant. Different discrete choice methods were employed to estimate the specified model (Hoffman & Duncan, 1988; McFadden & Train, 2000; Train, 2009). We were particularly interested in exploring the roles of financial literacy, energy literacy, and the display of monetary information (Blasch et al., 2019) in the process of selecting a more energy-efficient home. We estimated a probit model to explain how different socio-economic factors, energy literacy, financial literacy, energy-efficient behaviour, and attitudes towards or against energy conservation influence the respondents' decision to rely on the energy performance certificate when making real estate purchase decisions. This was followed by a choice experiment, requiring respondents to select between two apartments: their current home and a home with a better energy rating for which they would be required to pay a price premium, ceteris paribus. The treatment group received information on the monthly level of energy savings from switching to a more energy-efficient home expressed in monetary terms (in EUR) and the energy performance certificate, while the control group only had information on the energy performance certificate. We then estimated a probit model observing how different factors impact the selection of real estate with a better energy rating. Finally, we estimated a bivariate probit model and a recursive bivariate probit model. In the recursive bivariate probit model, the dependent variable from the probit model concerning the decision to rely on energy performance certificates when making real estate purchasing decisions was used as an explanatory variable in the probit model concerning the decision to select the real estate with a better energy rating.
Results:We report the results of the bivariate probit model. It was found that higher levels of financial literacy, as well as pronounced energy-efficient behaviour significantly and positively impact the decision to rely on the energy performance certificate and therefore select a more energy-efficient real estate. We also found a significant and positive effect of the correct total life-cycle cost calculation. This may be explained by the fact that the knowledge required to perform a correct investment calculation is translated into both, an awareness of energy performance certificates and energy-efficient decision-making, reflected in the selection of a more energy-efficient home. A larger premium and a 'free-rider' attitude towards energy conservation negatively impact the decision to rely on the energy performance certificate and accept the price premium for a more energy-efficient home. There is also a pronounced positive effect of residing in a home that is not energy-efficient, which can be an additional incentive for the respondents to improve their living conditions. Certain socio-economic characteristics, such as income, appear as a driver, while age has a negative impact. Given that financial concerns are often recognized as a barrier to energy-efficient decision-making in households, these results are expected. Interestingly, we did not find the treatment variable to have a significant influence on the likelihood of energy-efficient real estate selection. This means that in our sample, it did not matter whether the respondents received both monetary information on energy savings and the information on the energy performance certificate, or just the information on the energy performance certificate. One explanation may be found in the low energy literacy scores. In

this setting, the display of information might not have been as relevant to the decision-making as the respondent lacked the knowledge to adequately interpret the information. Another reason may be that the achieved energy savings might have been considered too low compared to the price premium.

Conclusions: When discussing the results of our research, it is worth noting that our sample exhibited low levels of energy literacy, with more than half of homeowners not even knowing the energy rating of the home they live in. This leads us to believe that while energy performance certificates can visually serve as a heuristic device, the respondents still do not possess the knowledge necessary to make an informed choice. Low energy literacy may also be the reason why, contrary to our expectations, monetary savings did not turn out to significantly influence the choice of energy-efficient real estate. In addition, monetary savings might have been perceived too low compared to the price premium at the time. The energy price rise we have been recently experiencing in the EU could imply different behaviour, which remains to be investigated in future research. Based on the results we obtained, we find that continued education and information campaigns that raise awareness of energy efficiency are still required, especially in the area of energy literacy. A potentially useful feature of energy performance certificates for homeowners is the recommendations provided for cost-effective retrofits and other measures to reduce energy consumption. By enhancing and better promoting this feature, the homeowners would be motivated to obtain the energy performance certificate and consequently, to implement the recommended measures. We thus conclude that continued education campaigns concerning energy and financial literacy, and information campaigns that raise awareness of energy performance certificates are required to improve the effectiveness of energy performance certificates and tackle the information barriers to achieving residential energy efficiency.

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Keywords: energy performance certificates, energy labels, residential energy efficiency, energy-efficient household decision making, bivariate probit model

[Abstract:0234] OP-260 [Accepted:Oral Presentation] [Energy Efficiency » Residential and Commercial Buildings]

Cost-optimal design and operation of distributed energy systems: a comprehensive approach supporting corporate investment decisions

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Overview:In contrast to traditional centralized energy systems that rely on large nuclear or fossil-fuel-based power plants, the deployment of solar and wind power has led to an increase in distributed energy systems (DES). These systems generate electricity closer to the point of use. DES can often provide more cost-effective energy solutions by avoiding or reducing transmission and distribution costs, having shorter development times for new projects, and improving energy security [1]. Unlike the power supply infrastructure, heat supply has traditionally been decentralized, with individual heat generation systems for each residential or commercial building (except for district heating networks). Buildings that rely on decentralized heating can benefit from integrating decentralized power generation to form an integrated DES through efficient cogeneration of power and heating, using electricity generated by solar PV to operate heat pumps, and the ability to generate revenues by feeding excess electricity into the grid. Thus, the integration of power and heating in DES can lead to synergies, resulting in higher energy efficiency and autonomy, which in turn reduces energy expenditures. However, companies (also households) are facing tightening regulations, confronted with high initial investment costs for new systems, and difficulties in quantifying the return on investment. Furthermore, decision-makers face a complex decision-making process due to the wide range of available technology alternatives.
This study presents a comprehensive approach for addressing these challenges by quantifying the costs of investing in DES that meet both heating and electricity demands. The objective of this study is to develop a method to assess the techno-economic viability of these alternative solutions from a business perspective and apply it to case study in the healthcare sector. The developed comprehensive techno-economic model determines the optimal configuration, sizing, and operation for integrated DES. It considers a broad range of technologies, such as photovoltaics, heat pumps, combined heat and power (CHP) units, gas boilers, and electric and thermal storage. This is partly analogous to studies such as [2] and [3] with addition of considering key economic and regulatory factors such as fuel costs, electricity tariffs, feed-in tariffs, and investment costs. This study showcases an application to a case study of a medium-sized hospital, using load profiles that reflect the distinct energy consumption patterns typical of the healthcare industry. Local sensitivity analyses are performed on the electricity tariffs, fuel prices, and feed-in tariffs to assess their influence on the optimal configuration and sizing, and to analyze the effects on model behavior.
Methods:This study presents an economic appraisal model for DES that satisfy the power and heat demands of buildings. The model is applied to data of a medium-sized hospital in Germany and consists of an optimization model, as well as a PV dimensioning and profile generation model and a Coefficient of Performance (COP) timeseries generation model. The photovoltaic system size is determined based on the available roof space of the analyzed building, and generation profiles are calculated according to the geographical location. Economic feasibility is determined using the Equivalent Annual Cost (EAC) approach, which represents the annualized cost associated with owning, operating, and maintaining the system. The optimization model addresses a linear

programming problem with the objective of minimizing the equivalent annual cost. The solution determines the optimal selection of power and heat generation and storage technologies, as well as their optimal sizing and operation.
Simple techniques of local sensitivity analysis are used for sensitivity analysis to assess the impact of variations in fuel and electricity prices on the optimal decision and operation. The method enables the incorporation of variable pricing settings, including fixed and variable electricity prices, as well as modifications to specific regulatory support mechanisms, such as feed-in tariffs.
Results:The preliminary results of the case study indicate that, given current price and regulatory conditions, a combined heat and power system with an additional gas boiler outperforms the use of a heat pump system. Most of the generated electricity is self-consumed with additional feed-in, with some hours requiring electricity to be purchased from the grid. The initial findings suggest significant changes in system design and operation in alternative scenarios. Ongoing research is expected to enhance the understanding of the impact of model sensitivities. The analyses are expected to demonstrate the significant impact of changes in the regulatory framework and price setting on the energy balances of electricity and heat, especially regarding the use of grid electricity usage and the role of heat storage.
Conclusions:The decision support procedure presented in this study can guide corporations, policymakers, and energy system planners by providing insights into the economic feasibility of transitioning to low-carbon DES. The importance of economic and regulatory factors in shaping optimal energy system configurations is made transparent, underscoring the need for strategic decision-making and supportive regulatory environments to drive successful, cost-effective transitions towards decarbonized heating systems. Results show the need for simple modelling approaches which open up the possibility of fast and extensive sensitivity analyses.
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Keywords: Energy system planning, Investment analysis, Distributed energy systems, Decision support

[Abstract:0275] OP-261 [Accepted:Oral Presentation] [Energy System Transition » Shipping]

Paths towards shipping decarbonization: A global energy model of the merchant fleet

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Overview:Shipping is responsible of around 3% of the global CO2 emissions and this is expected to grow in the future, due to crucial role of the sector in the global economy (90% of trade; IMO, 2023). Shipping decarbonisation remains challenging due to a lack of economic incentives and global regulation, despite recent attempts (Annex VI Marpol CII, EEX; EU-ETS). Technologically, vessels carbon mitigation faces issues such as the heterogeneity of the fleet, the lack of industrial shipbuilding series to easily integrate innovation, and of the dependence of abatement technologies on the vessel type and its use. So far the literature on shipping decarbonization has focused on the energy consumption with regard to substitution promising solutions (e-fuels, wind-sailing, etc), yet inertia related to the technical life-time of vessels and the momentum of the fleet retrofit and renewal has been subject to less attention. This study builds a technology-rich bottom-up model applied to vessel age-pyramid and to demand type (container, bulk, chemical, oil, LNG, general cargo) such as to realistically draw the sector transition to 2050. Results show that the transition will not be linear as fleet inertia plays a large role. The coming decade is crucial in advancing technologies to ensure a major shift towards a zero-emission fleet during the 2035-2050 period. Our model based on highly detailed vessel data and market segmentation will provide a useful decision-making tool, combining technology and economics along supply-demand trajectories, in support to the regulation of the maritime trade sector.

Methods:The fleet under consideration contains around 55,000 cargo vessels, categorized into six types: container ships, bulk carriers, chemical tankers, oil tankers, LNG carriers, and general cargo. Together they represent 78% of the sector carbon emissions. Our transition model combines an energy model at the fleet-level triggered by technology and trade supply-demand equilibria, with technological, economic and regulatory levers such as fuel availability, new technology costs and IMO regulations. (Fig. 1). The following section describes the steps in building the fleet energy model:

(1) The fleet segmentation consists of grouping similar vessels, for each of the six types, based on their average technical characteristics using two criteria: transport capacity and engine power. Data, documented from the Clakrson Research database, is harmonized, net of extreme values related to the average, by means of two statistical methods, i.e. the interquartile range (IQR) and the z-score. Each segment is represented by a vessel of reference with average characteristics. Several regressions are performed to calculate missing values and to ensure that the model fleet reproduces the actual one, in terms of number of ships and trade capacity.

(2) The fleet evolution to 2050 follows a yearly time-step algorithm based on the age pyramid of the previously determined fleet segmentation. At each time-step, ships that are at the end of their technical lifetime are scrapped and replaced by similar-type but new ships, while additional ships are built, when necessary, to meet annual increased demand. Several traffic scenarios to 2050 are used (12 scenarios), based on the IMO Fourth GHG study for projections of goods transported by ship type, and two more radical scenarios are also tested. Based on constrained linear programming written with Python software, the model integrates economies of scale for the shipowners' strategy to build larger vessels in front of growing demands.

(3) The third step evaluates the fleet energy consumption, that generally depends on too many parameters, such as ship characteristics in terms of size, draught and engine power, the weather conditions (wind speed and waves), and the operational behavior such as the distance sailed, operating speed, and time spent at sea and at berth. Applied to our 55,000-ship fleet, the database would be too large, hence unlikely to be built and further analyzed. We used a simplified approach based on the ship operational profile and the engine specific fuel consumption. The amount of data required is therefore significantly reduced, and all we need is the evolution of the ships' operating speed over the course of a year and the specific fuel consumption curve of the engines. To validate our results and methodological approach, a comparative analysis will be conducted by confronting our results with the reported fuel oil consumption data provided by shipowners participating in the International Maritime Organization's Data Collection System (IMO DCS) and its European counterpart, the EU Monitoring, Reporting, and Verification (EU MRV) program.

Results:Looking at the age pyramid, we calculate the annual replacement rate of the actual fleet by 2050. (Fig. 2). 22% of the fleet will have reached the end of its technical life and will have to be replaced by zero-emission ships over the next ten years, and the remaining 78% over the following sixteen years. The next decade appears to be the critical period, after which 100% of new buildings should be zero-emission ships to meet the IMO target. The 2035-2050 period will witness a profound transition towards a zero-emissions fleet. Our model offers a fine-grained representation of the merchant fleet with more than 40 different segments and allows drawing the fleet evolution per year until 2050 for each of the 12+2 transport scenarios considered. The analysis of a segment-by-segment market determines the annual growth for each segment, the average size of new vessels built, the energy consumption and the annual building and scrapping capacity required. This detailed segmentation offers great potential for sensitivity analysis, which is crucial to accurately develop technological levers based on the profile and constraints of each ship segment.

Conclusions:In front of need of more investigations of complex maritime trade evolution, this study undertakes rich calculations and empirical equations to establish an energy model in support to decision-making tools for the merchant fleet decarbonization to 2050. The model integrates a cross-disciplinary approach with a high-detailed description of vessels and the economics of maritime trade with supply-demand equilibria by market segment. This energy modelling represents the initial phase in developing a transition model for the merchant fleet. Subsequent steps include:

(1) Modelling of technological and economical levers for decarbonization: we consider two categories

of levers, those that reduce consumption (hull design, engine efficiency, slow steaming, route optimization, just-in-time arrival) and those aiming to replace the energy sources of ships (biofuels, electro fuels, wind propulsion, electric propulsion, carbon capture and storage). The challenge lies in quantifying the impact of these technologies' implementation (engine efficiency, carrying capacity, energy autonomy) and each technology's applicability (Technology Readiness Level, production capacity for alternative fuels, costs, safety issues).

(2) Modelling of regulatory levers: The IMO's strategy for reducing greenhouse gas emissions from ships includes a number of regulations that will come into force in the coming years. The model will allow us to analyze the impact of the proposed regulations.

(3) Modelling retrofits: Some studies predict that about 15-20% of ships will remain fossil-fueled in 2050 if no retrofitting measures are taken for them. Our model aims to consider more accurately the impact of retrofitting for each possible technology (loss of transport capacity, idle time, costs, potential revenues).

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Keywords: energy consumption model, shipping decarbonization, fleet inertia, transportation demand scenarios

Figure 1. Methodology flow chart

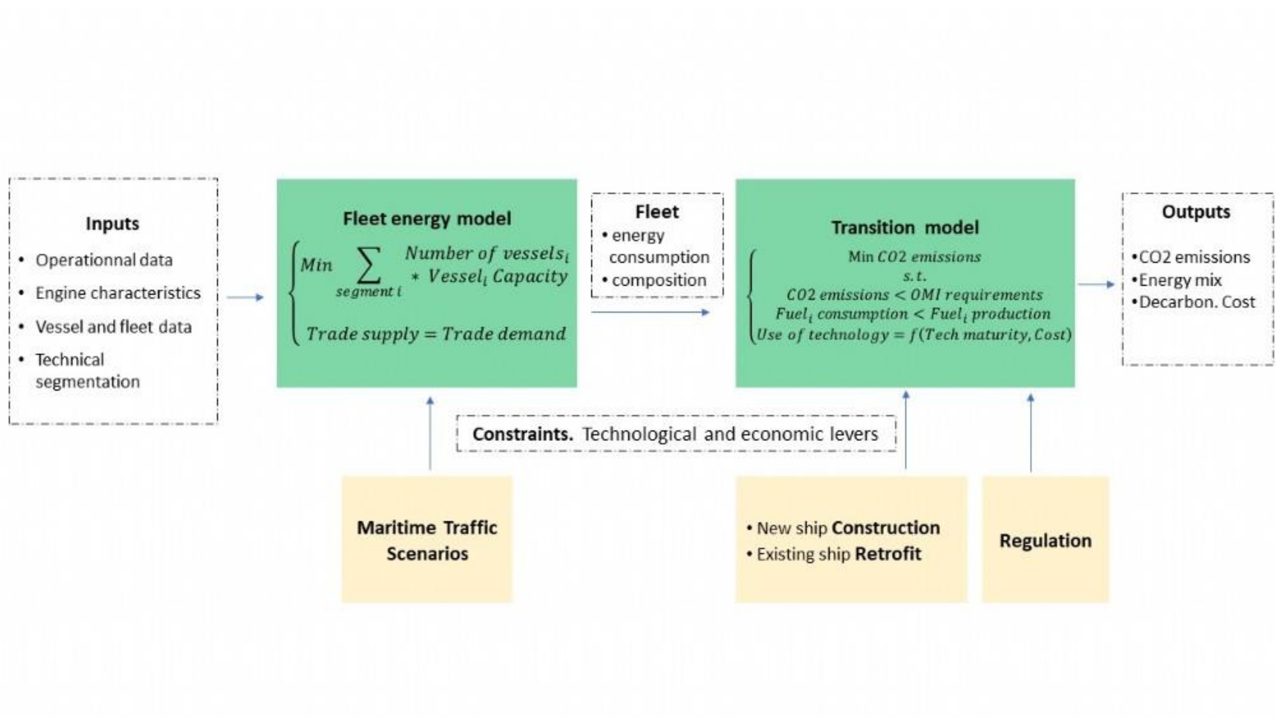
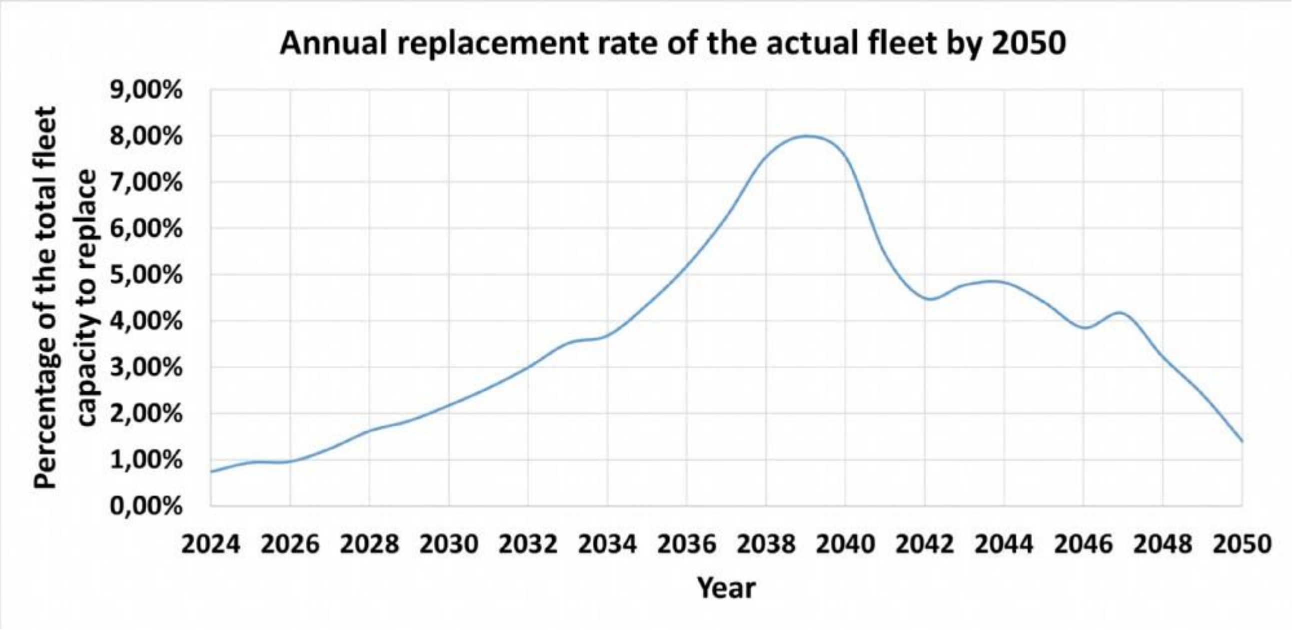


Figure 2. Annual replacement rate of the actual fleet by 2050



[Abstract:0444] OP-262 [Accepted:Oral Presentation] [Energy System Transition » R&D and Emerging Technologies]

How manufacturing firms invest in clean technologies: carbon taxes, investment subsidies and learning

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Overview:To comply with the Paris Agreement commitments to keep warming well below 2◦C, the manufacturing sector, which accounts for 29.2% of global greenhouse gas emissions, needs to replace its existing fossil fuel using capital stock with a new one, based on clean production technologies. These technologies, such as hydrogen based steel-making, electric steam cracking or low carbon cement, are significantly less mature than their tried and tested fossil fuel alternatives. Yet, to commit the massive investments needed to decarbonize manufacturing, firms must expect that these new technologies can be competitive. This may happens once these technologies have matured and become standardized, which may slow down manufacturing decarbonation pathway.

This paper develops a theoretical model where an industrial sector responds to carbon taxes and subsidies to clean investments when choosing between an immature clean technology subject to learning by doing and a mature dirty technology.

The high opportunity costs for switching from incumbent fossil fuel based technologies to bleeding edge clean ones is a case in point for carbon lock-in (Unruh, 2000): fossil fuels benefit from an historical advantage, as a large array of current technologies, infrastructure and institution has been developed around them. Acemoglu et al. (2012) propose a macroeconomic model with directed technical change where support to R&D allow a clean technology to supersede a more mature dirty one. Kalkuhl et al. (2012), in a theoretical model with learning-by-doing, show how a dynamically optimal technology may remain under-used. Our work builds on this literature by considering heterogeneous agents and explicit capital stocks embodying each technology.
Methods:We first take stock of the management literature underpinning technology adoption. This trans-disciplinary approach allow us to identify the key drivers for firms decision to invest in a new technology.
We then build a partial equilibrium model, where a continuum of firms produce an homogeneous good by combining labor with either a clean energy and a clean technology based capital, or with a dirty energy input and a dirty technology capital

The production function is composed of two linear modules, one for each technology (dirty and clean): This refers to a manufacturing firm, where equipment for a given production step are not directly dependent on the previous and the next ones. Each step produce an output to be processed by the next step, using either a clean or a polluting technology and corresponding energy inputs. Each module is specified as Cobb-Douglas, a choice consistent with Golosov et al. (2014). Firms display decreasing returns to scale, consistent with Khan and Thomas (2003) and Winberry (2021) which also features heterogeneous firms producing an homogeneous good.

Firms are price takers in the energy market and the final goods market, an assumption consistent with the exposure of the manufacturing sector to foreign trade. They have heterogeneous productivity with the clean technology. This represents differences in their absorptive capacity, a concept developed in the management literature by Cohen and Levinthal (1990). It defines a company ability to turn an external knowledge into a competitive advantage. Absorptive capacity tends to be path dependent, as previous successes will foster it.

As a piece of knowledge has been integrated and turned by early movers, it will then diffuse in the economy, improve and become standardized. Thus clean technology also benefits from learning-by-doing, with all firms converging to a terminal productivity as experience accumulates, representing how first movers see their competitive edge erode, while competitors are able to adopt it. We build on the sepcification proposed by Kalkuhl et al. (2012).

The public authority may use a lump sum carbon tax τt on the dirty energy input, or a subsidy to investment in the clean technology ιt. It aims at keeping total cumulative CO_2 emissions, generated by the consumption of the dirty energy input below a target carbon budget denoted by S. We parameterize our model and run three policy simulations with differing subsidies to investment: The

first policy, "low subsidy", features a 33% subsidy to clean investment at each period, consistent with recent estimates of industrial policies in the OECD (Criscuolo et al. 2023). The second policy, "high subsidy", features a 50% subsidy. The last one, "frontloading", considers 60% subsidy gradually phased out.

We calibrate our model with a carbon tax consistent with EU current carbon prices, and propose a steady increase until 2050. Clean energy prices are based on Standard & Poors projection for the EU, while dirty energy prices are based on IEA Net Zero Scenario (IEA 2023). The carbon budget is calibrated based on the EU carbon and climate strategy. The carbon. Other parameters are standard in the literature.
Results:1) Analytical results

We evidence that the total capital stock of a firm is increasing over the price of dirty energy when its productivity with the clean technology is sufficiently above the productivity of all firms and derive corresponding condition analytically.

We also evidence which investment subsidy may result in an investment equivalent to a higher experience stock. Finally, we demonstrate that the target maximum cumulative CO2 emissions is feasible if and only in the following condition:

2) Numerical results

As shown on fig. 1, large initial subsidies allow the clean technology to develop and displace the dirty one and are consistent with a carbon budget (fig. 2). The development of the clean technology reshuffles the market positions, as shown on fig. 3: firms that are the most able to leverage the new technology gain market shares, before the accumulated learning allow other firms to adopt it, eroding the edge of first movers. Our model thus reflects the findings of the management literature on absorptive capacity and technology adoption.
Conclusions:This paper shows how carbon tax, clean investment subsidy and the maturation of clean technology drive manufacturing decisions to adopt clean technologies.Building on observations from management sciences, firms are heterogeneous in their ability to make use of a new, untested technology. Thus, diffusing the clean technology past a fringe of first movers innovators requires subsidies to front-load investments and generate learning, which in turns allow other firms to adopt it. Such a policy initially rewards first movers with higher market shares, although their advantage recedes over time as the technology matures.
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Keywords: Investment, industrial policy, clean technologies, firms heterogeneity

Fig 1: Evolution of the capital stocks

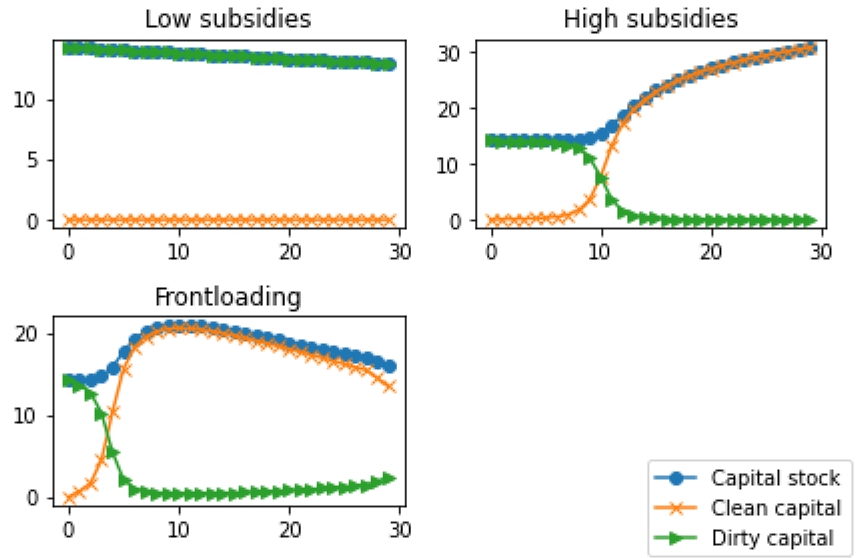


Fig 2: Cumulative emissions compared to the carbon budget

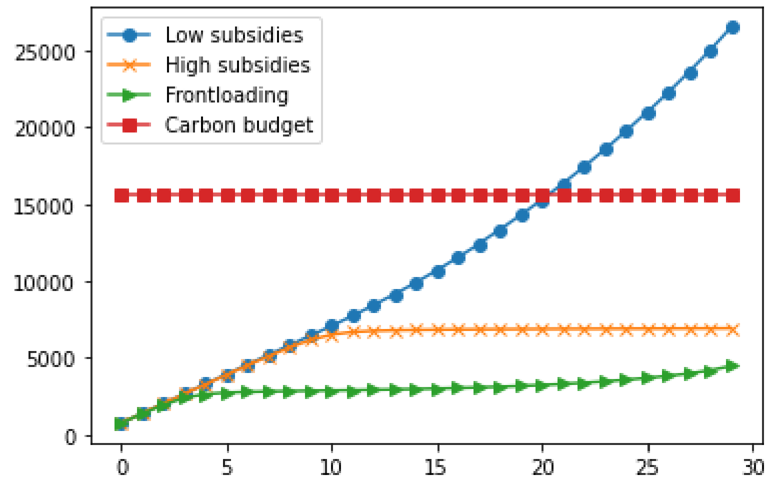
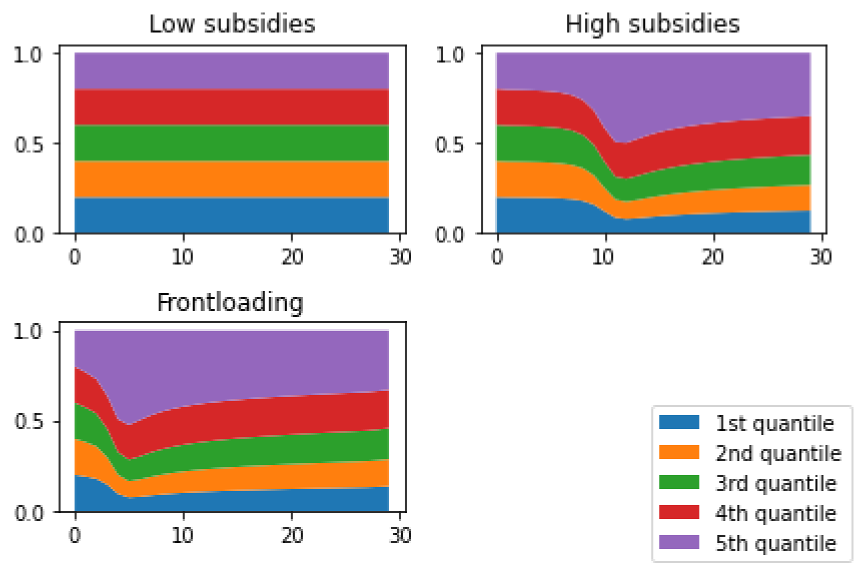


Fig 3: Market shares by quantile of firms



[Page: 263]

[Abstract:0531] OP-263 [Accepted:Oral Presentation] [Energy System Transition » Other]

A heated debate - the long-term cost-efficieny of technologies and grid infrastructures for climate-neutral heating

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Overview:If Germany is to achieve its 2045 net zero emissions target, a transformation of residential heating is necessary. Solutions for climate-neutral heating are: Using a climate-neutral substitute for fossil fuels like synthetic natural gas, using a carbon-free energy carrier like hydrogen, or direct electrification using heat pumps, either as centralized or decentralized heating technologies. A number of uncertainties regarding the costs of fuels and infrastructure determine which technology is cost-efficient in the long term.
Methods:In this paper, we assess the long-term cost-efficiency of climate neutral residential heating technologies under the consideration of relevant heterogeneity in the building sector and technologies. Additionally, we include uncertainties regarding the development of energy prices, technology costs and infrastructure. We compare the levelized costs of heating of ten technologies for central and decentral heating in rural, village, urban and city settlement types in Germany and quantify the maximum additional unknown costs for infrastructure by comparing the cost-efficient technology with the next best option. We conduct a sensitivity analysis, investigating the impact of multiple heterogenous and uncertain parameters on the levelized cost of heating.
Results:The results demonstrate that the economic viability of heating technologies depends on the settlement type and the hydrogen price. Hydrogen boilers, heat pump-powered heating grids and decentral heat pumps seem to be the most economical technologies for radiator-based heating. Air-to-air heat pumps seem economical and can be used for heating and cooling. The more urban a settlement, the lower the hydrogen price until hydrogen boilers are cost-efficient. Except for rural settlements, heat pump powered heating grids are cost-efficient over a wide hydrogen price range due to significant scale effects on heat pump investment cost. Only if hydrogen prices are below 100 EUR/MWh in villages or 70 EUR/MWh in urban and city settlements, heating with hydrogen boilers is

the single cost-efficient technology.

Conclusions: We find that:

1. Out of all considered technologies, either hydrogen boilers, heat pump-powered heating grids, or decentral heat pumps seem the most economical.
2. Keeping existing gas infrastructure and replacing natural gas by synthetic natural gas does not seem economical due to high fuel costs.
3. The economic viability of heating technologies depends on the settlement type and the hydrogen price, which is highly uncertain.
4. Increasing hydrogen prices favor the technologies in the following order: hydrogen boilers (characterized by low investment costs and high energy costs), heat pump powered heating grids (characterized by moderate investment costs and moderate energy costs) and decentral heat pumps (characterized by high investment costs and low energy costs)
5. The more urban the settlement, the lower the hydrogen price until hydrogen boilers are cost-efficient.
6. The supply temperature of a building's heating system is crucial for the economics of heat pumps. Heat pump powered heating grids are economically viable for supply temperatures of 70°C or below.
7. In urban and village settlements, centralized heating with heat pump powered heating grids is more economical than decentralized heating with heat pumps due to significant scale effects on heat pump investment cost.
8. In cities, both, decentral heat pumps and heat pump powered heating grids can be cost-efficient because large building sizes lead to economies of scale for decentral heat pumps, too.
9. In rural settlements, heat pump powered heating grids are not economical due to high heat losses and heat distribution costs.
0. Except for rural settlements, heat pump powered heating grids are cost-efficient over a wide range of hydrogen prices: Only if hydrogen prices are below 100 EUR/MWh in villages or 70 EUR/MWh in urban and city settlements, hydrogen is clearly cost-efficient compared to the other technologies.
11. Heating with heat pumps, especially via heating grids, may provide a robust solution for decision-makers faced with uncertainty.
12. Regardless of the hydrogen price, air-to-air heat pumps might be the most economical heating technology and serve a double purpose (heating and cooling). However, the comfort of heating is lower compared to systems that use radiators

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Keywords: Heat pumps, Hydrogen, Decarbonization, Techno-economic analysis, Levelized costs of heating, Residential heating

[Abstract:0678] OP-264 [Accepted:Oral Presentation] [Renewables » Biofuels]

Thermal and catalytic pyrolysis of waste biomass towards renewable fuel: A comprehensive characterization of bio-oil and biochar

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Overview:Climate change has become an alarming situation globally. According to a report by the IPCC (Inter government panel on climate change), emissions of greenhouse gases from human activities are responsible for approximately 1°C rise in global temperature from 1850-1900. The report also indicates that global temperature is predicted to rise by 1.5 °C or more over the next 20 years. With this alarming situation regarding the dependence on fossil fuels, the world has started shifting completely towards renewable energy sources. In this respect, the current work concentrated on the thermocatalytic pyrolysis of waste biomass in order to assess the yield and qualities of the bio-oil.
Methods:For each run, 10±0.5 g of feedstock was kept in the reactor for a residence time of 45 minutes, and an inert atmosphere was created by passing N2 gas to evacuate oxygen and other impurities. The purging of N2 gas was started half an hour earlier, and it was maintained constant (100 mL min-1) throughout the pyrolysis process. The reactor is placed inside the furnace in a way that the heat is distributed uniformly across the reactor. The condenser was attached at the lower end to condense the volatiles released from the reactor. After the pyrolysis experiment, the system was led to cool, and the obtained product was collected for further characterization
Results:The results revealed that after catalyst introduction fuel properties enhanced significantly. The hydrocarbon and aromatics increased whereas oxygen content decreased significantly. The FTIR analysis of bio-oil reveals the presence of phenolics, aromatics, ketones, acidic chemicals, esters, alcohol, and aldehyde contaminants. Furthermore, biochar characterisation findings revealed the presence of higher HHV, carbon content, and decreased BET surface area.
Conclusions:The physicochemical properties of biomass demonstrated its enormous bioenergy potential for energy generation. The results of the catalytic bio-oil revealed that its yield was reduced, whereas its physicochemical properties were enhanced than normal bio-oil. FTIR analysis verified the presence of several beneficial functional groups, while GCMS analysis confirmed a considerable increase in hydrocarbons and a significant decrease in oxygenated molecules. The characterization of the biochar revealed its applicability in a multipurpose application. The findings of the present investigation confirmed that the biomass could be used as a substitute for conventional fuel through pyrolysis
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Keywords: Waste biomass, Catalytic pyrolysis, Bio-oil, Biochar

[Abstract:0135] OP-265 [Accepted:Oral Presentation] [Energy System Transition » Policy]

Challenges to a Just Energy Transition in the APEC region: Applying lessons from past energy transitions in Japan

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Overview:Energy ministers of the member economies of the Asia Pacific Economic Cooperation (APEC) endorsed "Non-Binding Just Energy Transition Principles for APEC Cooperation" at the 13th APEC Energy Ministerial Meeting held in Seattle, USA in August 2023. Furthermore, the ministers agreed to task the APEC Energy Working Group, composed of senior energy officials of the member economies, to establish a Just Energy Transition Initiative, based on the Non-Binding Just Energy Transition Principles.

Few disagree on the necessity of "justness" in energy transitions as energy is a basis of social and economic activities and energy transitions have a pervasive influence in all societies. The concept of "fairness", a synonym of "justness", had been previously developed and employed with respect to the crafting of trade agreements as a means of balancing the widely dispersed benefits consumers can receive from those agreements versus the substantial, focused costs on specific domestic industries and their employees that can also result from those agreements. The political processes which have been used to mitigate the focused costs while achieving broad benefits from international agreements might also provide guidance in implementing a just energy transition. Although the implementation processes can be similar, achieving a "just" energy transition may well be more difficult that a "fair" trade agreement because the benefits of decarbonization are more difficult to quantify economically and the energy transition is likely to cause both focused and widely dispersed costs on an economy.

This paper reviews and analyses the challenges and complexities of achieving a Just Energy Transition in the APEC region in light of lessons learned from Japanese attempts to achieve two just energy transitions in the 1950s through the 1970s.

Methods:First, I propose a framework for analysing the justness of energy transitions based on analogies between the issues of free trade versus fair trade and decarbonization versus disadvantaged industries and affordability. I then use this framework to examine two historical examples of Japan's attempts to achieve just energy transitions. This approach demonstrates the high level of complexity associated with "justness" in energy transitions and highlights areas for future work on this topic.

Results:In international trade, fair trade or fairness in trade has been raised against free trade or freedom in trade. As freedom in trade is in general measurable as lower levels of trade barriers. Therefore, fairness in trade is often in tension with the protection of domestic industries and their employees. Like fairness in international trade, justness in energy transition will be decided through political process where interest groups such as labour unions of fossil fuel industry or representatives of fossil-energy producing communities can have strong influence than silent majority of energy consumers.

Problems in the current energy transition are similar to problems experienced in previous energy transitions in Japan: the transition from coal to oil in the 1950s and 1960s, and the transition to increase nuclear energy in earnest in the 1970s. Japan's transition from coal to oil in the 1950s and the 1960s was driven by an economic rationale: Japan's domestic coal was no longer cost competitive against cheap oil imported mainly from the Middle East. However, stopping domestic coal production meant an immediate collapse of coal producing communities in Japan. In order to give some breathing time to those communities to establish alternative industries, the Japanese Government subsidised those communities using revenues from a tax on imported oil. Economically, this policy was designed to transfer of a part of the economic gains which energy consumers were enjoying from the energy transition to the communities that were damaged by the energy transition. This "Development Policies for Coal-Mining Areas", took nearly 40 years to complete, achieved with mixed results. Former coal-mining areas close to large cities could have established new industries such as manufacturing, electricity generation or tourism, but coal-mining areas far from large cities usually could not establish new industries, and in the worst cases suffered bankruptcy. Investment in those distant areas is criticised as fiscal and economic dissipation.

Unlike Japan's energy transition from coal to oil, the current energy decarbonization initiatives are not driven primarily by a desire for lower energy costs but by environmental concerns related to climate change. As we now see, the current energy transition tends to increase energy costs for consumers, and therefore monies to mitigate the impact of the transition on disfavoured industries and their employees must be found elsewhere. The cost for a just energy transition such as subsidy and/or other incentives to fossil-energy producing communities and industries will be an additional burden to energy consumers. This aspect of the current energy transition makes it more difficult to achieve justness than the switch from coal to oil in Japan in the 1950s and 1960s.

After the energy transition from coal to oil, Japan became much too dependent on imported oil for

its energy supply. The oil crises in the 1970s seriously damaged the Japanese economy and Japan tried to reduce quickly its dependence on imported oil by re-introducing coal-fired generation (using inexpensive imported coal), ramping up nuclear energy, and introducing renewable energy such as solar and geothermal. Among them, nuclear energy was the approach most preferred by the Japanese Government since it was a well-established energy technology. However, after the Three Mile Island accident in 1979 and the Chernobyl disaster in 1986, nuclear energy became very unpopular among local communities in Japan. To address this concern, the Government pursued and continues to pursue a very rigorous nuclear safety policy, but it was only partially successful. There is an additional economic problem with nuclear energy. After a large investment at its construction stage, a nuclear power plant requires a much smaller labour force than thermal power plants, resulting in smaller economic contribution to its siting local community. Even if nuclear energy is beneficial to Japan as a nation by enhancing energy security and reducing energy cost (and later also by contributing to climate change problem), no local community was happy to accept its site considering low economic return. This phenomenon was described as "NIMBY (Not in My Back Yard)". To cope with NIMBY, the Japanese Government had to start various measures which compensate low economic returns of nuclear power plants to the siting communities.
Under the current energy transition, renewable energy such as photovoltaic power and wind power is expected to expand in the process of decarbonization of energy supply. Their potential hazard is much lower than nuclear energy, but because solar and wind sources have energy densities that are much lower that nuclear or fossil fuels, solar and wind energy installation can consume large amounts of land and sea. The large area requirement can provoke a NIMBY response. In addition, the most abundant renewable resources are often far from population centres, requiring substantial increases in long, high-capacity power transmission lines, which also engender a NIMBY response from residents close to those lines. As with free trade agreements, political processes need to be utilized to find a feasible balance between the widely dispersed benefits of decarbonization and the focused, more concentrated costs borne by a few.
Conclusions: Examining the techniques and strategies that have been employed to consummate trade liberalisation agreements can provide lessons on ways to also encourage an energy transition that provides widely dispersed benefits to the general population but imposes substantial costs on particular industries and their employees.
Because the two previous energy transitions in Japan in the 1950s through the 1970s were designed to lower the cost of energy, cost savings were generated that could be used to help mitigate for some communities the adverse effects of those energy transitions. Unfortunately, the current energy transition most often appears to raise, rather than lower, energy costs, which makes it more difficult to mitigate the costs imposed on specific industries and their employees.
Finally, because renewable energy facilities often consume so much area and often require incremental power transmission capacity, relying on renewable energy generation for the energy transition may invite "NIMBY" phenomenon just nuclear power plants did in Japan in the 1970s through today.
The additional factors associated with the energy transition relative to the issues associated with trade liberalisation agreements means global decarbonisation will be a political challenge even more difficult that free trade.
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Keywords: just energy transition, justness, trade agreement, fairness

[Abstract:0546] OP-266 [Accepted:Oral Presentation] [Electricity » Generation Technologies]

Impact of Energy Transition on Profitability of Different Zero-Carbon Generation Technologies

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Overview:In order to reduce the absolute levels of carbon emissions, the nature of energy systems has to change dramatically. This is the reason governments are promoting the development and use of renewable energy sources like solar PV, wind turbines, hydropower and biomass. Despite these policies, the growth in renewable energy will likely not be sufficient to reduce carbon emissions to the extent required to meet climate targets. Therefore, the attention is increasingly also going to another non-carbon energy source, which is nuclear power. While nuclear power plants, solar PV installations, and wind turbines may differ significantly from a technical standpoint, they share a key economic characteristic that sets them apart from fossil-fuel plants. Traditional fossil-fuel power plants incur costs for every unit of electricity generated, depending on factors like fuel prices and conversion efficiency. In contrast, nuclear power, solar PV and wind turbines have much less additional costs when they generate electricity. This means that the fixed costs of these types of power plants constitute the major part of their total costs. This has a number of consequences related to the profitability of these generation technologies, including the risk of investments in new capacity, formation of electricity prices, and the electricity production. This article aims to investigate the profitability of various low-carbon electricity generation technologies and analyze how the profitability is influenced by the ongoing energy transition.
Methods:To evaluate the impact of the energy transition on the profitability of various zero-carbon power
generation technologies, our approach encompasses several steps. Firstly, we develop a short-term partial equilibrium model, designed to mimic the dynamics of a power market. The mathematical model is based on the research of Li and Mulder (2021). Our model calibration is centered on the Dutch electricity market. By simulating hourly market dynamics, we determine the electricity prices captured by different technologies and their corresponding production levels. Subsequently, we calculate the Levelized Cost of Electricity (LCOE) and subsidies required to achieve break-even investments (based on the Net Present Value, NPV). This assessment is conducted for different market shares of solar PV, onshore wind, and offshore wind, to show the effects of the energy transition.
Our contributions to the literature is that we not only investigate the effects of increasing shares of renewables on capacity factors and capture prices, but also examine how these dynamics impact investment metrics such as the LCOE and NPV. Secondly, where existing studies only consider the effects of adding more renewables on the renewables themselves, we also consider the effects on the profitability of nuclear power, an alternative low-carbon electricity generation technology. Methodologically, we use an electricity market model that differs from models that minimize generation costs under fixed demand levels. Instead, we treat installed capacities of solar, wind and nuclear as exogenous and incorporate price-responsive demand. This exogenous assumption of capacities is often in line with energy policies, while the price-responding demand enhances the representation of demand side flexibility.
Results:We find that an increasing share of renewables leads to lower overall electricity prices. However, a
closer examination reveals nuanced effects: solar and wind capture prices decrease compared to the mean electricity price. In contrast, nuclear capture prices increase, as these plants can also produce during periods of scarcity. The increasing share of renewables also impacts capacity factors, as more hours occur where available solar and wind energy can satisfy demand. The capacity factors of nuclear and solar PV are affected most, as nuclear power plants have higher generation costs than solar and wind, and the availability of solar energy is much less evenly distributed than the availability of wind energy.
We also find that the Levelized Cost of Electricity (LCOE) of all technologies increases when more renewables are installed. However, due to the different effects on production, the LCOE of wind energy is less sensitive than the LCOE of solar and nuclear power. When we calculate the required subsidy that is needed to make the Net Present Value (NPV) of new investments non-zero, we see that more subsidy is required in an electricity market dominated by renewables. The required subsidy of solar PV is most sensitive to these changes, while the required subsidy of nuclear power increases least fast due to the relatively high capture price.

It also appears that nuclear power plants benefit more from higher gas or carbon prices than wind turbines and solar PV. Because of their high availability factor, nuclear power plants are able to produce electricity when gas-fired power plants set the electricity price, and hence, they experience higher electricity prices when the costs of gas-fired power plants increase. The results appear also to be robust for various values of the discount rate, and do not change substantially when assumptions on energy storage and international trade are changed.
Conclusions:Our findings may form an input for the ongoing societal conversation surrounding future electricity systems, but it's important to recognize that our analysis primarily focuses on the profitability of various technologies. To fully inform this debate, a comprehensive understanding of other critical aspects, such as safety issues, environmental impact, and societal acceptance of different energy generation methods,
is essential. Furthermore, our study did not encompass system-wide effects, like the implications for grid investments, which significantly shape the future energy landscape. Nonetheless, our results provide valuable insights for policymakers, revealing how the costs and advantages of different technologies are depend on the electricity system they are placed in. Notably, our research suggests that installing too many solar PV installations could potentially undermine their economic viability, while investments in wind energy and nuclear power appear to be promising choices in electricity systems with many renewables.

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Keywords: zero-carbon generation technologies, capture price, capacity factor, profitability

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A Framework for Climate Change Risk Assessment for Windfarm Projects

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Overview: Many financial institutions, companies, and investors have recently embraced the Task Force on Climate-related Financial Disclosures (TCFD) recommendations aligned with Equator Principles to improve the understanding of climate-related risks and opportunities in financial markets. Understanding and managing climate-related risks faced by businesses, financial institutions, and other organizations and physical and transition risk assessments is essential. Therefore, climate change risk assessment, including physical and transition risks, summarizes the global and regional climate conditions for targeting GHG emission policies and regulations and an assessment of the Project GHG emissions and climate-related risks for the Project.

According to the 7th National Communication to UNFCCC, the climate-related policy of the Republic of Türkiye is mainly framed by the National Climate Change Strategy (NCCS, 2010-2023) and the National Climate Change Action Plan (2011-2023); moreover, the 10th Development Plan for 2014-2018 introduced the concept of "Green Growth" in several areas (energy, industry, agriculture, transport, construction, services and urbanization), which was confirmed in the 11th Development Plan (2019-2023). The 12th Development Plan (2024-2028) regarding the 2053 Net Zero target was recently prepared. Since the energy sector has the highest GHG emissions share, the Intended Nationally Determined Contribution (INDC) issued in 2015 introduced clear renewable energy generation targets, particularly in the power sector: to reach these targets, policy instruments like the Renewable Energy Sources Support Mechanism (YEKDEM) and By-Law on Renewable Energy Resource Areas (YEKA) have significantly contributed to investments in solar and wind power.

Climate Change impacts on wind farm projects need to be assessed so that institutions, companies, and investors understand the risk to the investments and take appropriate mitigation measures. This Climate Change Risks Assessments (CCRA) and impacts are site specific, and the level of risk can vary depending on geographical location, local climate conditions, and the specific design and resilience measures implemented in wind power infrastructure. Adaptation and resilience strategies are crucial for mitigating the risks and ensuring the sustainable development of wind energy in the face of climate change. A framework was developed and implemented for wind power plant investments in the western part of Turkey. Nine wind farm locations were assessed for future climate change predictions and the project risk levels were identified.
Methods: The EU Taxonomy Climate Delegated Act is a legislative initiative within the European Union related to sustainable finance and environmental sustainability. The EU Taxonomy Regulation, adopted in 2020, establishes a classification system (taxonomy) for environmentally sustainable economic activities. The goal is to create a common language that investors, businesses, and policymakers can use to identify and understand environmentally sustainable economic activities. The Climate Delegated Act is a part of this regulation, and it specifies the technical screening criteria for determining which economic activities can be considered environmentally sustainable with a focus on climate change mitigation and adaptation. It sets out detailed criteria and thresholds for economic activities to be classified as environmentally sustainable.

The Climate-Related Hazards were determined by the EU Taxonomy Climate Delegated Act. Were identified for temperature- related, Wind-related, Water-related, solid mass-related impacts under chronic and acute conditions. These hazards represented the conditions for which CCRA needs to be investigated. For example, the following hazard became apparent for wind farms: changing temperature (air, freshwater, marine water), changing wind patterns, changing precipitation patterns and types (rain, hail, snow/ice)
Climate Change Scenario preference or priority is a controversial issue today. If only RCP scenarios were used in the assessment, the RCP4.5 scenario would have been preferred as the optimistic scenario and the RCP8.5 scenario as the pessimistic scenario because the scientific literature had formed such a consensus. However, with the current scenarios now including SSPs, there has not been a clear consensus on the choice of the four fundamental scenario sets that have emerged. However, the CORDEX (Coordinated Regional climate Down-scaling Experiment) community, which provides high-resolution global climate models on a regional scale, initially gave priority to the SSP1-2.6 and SSP5-8.5 scenarios but then suggested that the SSP3-7.0 scenario which is reasonable worst-case should be studied first instead of SSP5-8.5 (please see Page 6 on https://cordex.org/wp-content/uploads/2021/05/CORDEX-CMIP6_exp_design_RCM.pdf).
SSP1-2.6 assumes aggressive mitigation, well beyond current policies, and it represents a sustainable future with ambitious climate mitigation efforts. It aims to limit global warming to below

2 °C above pre-industrial levels. SSP3-7.0 is a regional rivalry scenario with fragmented development and limited cooperation. It is projected to lead to a warming level of around 3 to 4 °C by the end of the century. For example, these scenarios are expressed and used as "Green Road" and "Rocky Road" in Bayer's 2022 Sustainability Report (https://www.bayer.com/sites/default/files/2023-02/Bayer-Sustainability-Report-2022.pdf).

The outputs were obtained with a high resolution (0.25°) multi-model ensemble approach using thirty-one different model data in the CMIP6 (see Info Box 6) to calculate essential climate variables and indices. A bias adjustment has been applied to the data. Access to raw data is provided via the World Bank Group's Climate Change Knowledge Portal. Wind outputs were calculated using fifteen different model data from the Copernicus Climate Change Service of the ECMWF, since the World Bank Group's Climate Change Knowledge Portal cannot provide wind speed data.

FWI data was generated by dynamically Down-scaling six different General Circulation Models (GCMs) of the CMIP5 using the Rossby Centre Regional Atmospheric Climate Model (RCA4) developed by the Swedish Meteorological and Hydrological Institute (SMHI). Access to raw data is provided through the Copernicus Climate Change Service of the ECMWF.

As suggested by the EU Taxonomy Climate Delegated Act, the climate risk and vulnerability assessment should be proportionated to the scale of the activity and its expected lifespan. Therefore, the lifespan of the project was considered in the assessment. In addition, by the definitional requirement of the climate concept, model projections must be examined in 20-30 years. Within the scope of this assessment, 20-year future periods provided by the Climate Change Knowledge Portal were preferred. Climate change risk assessment used indicators addressing climate change's "physical" risks.

To summarize, the possible risks of climate change in the project area were analyzed using the CMIP6 dataset for three future periods (i.e., 2040-2059, 2060-2079, and 2080-2099) under two different scenarios (i.e., SSP1-2.6 and SSP3-7.0). Future projections concerning the reference period of 1995-2014 were compared. Climate change risk assessment was performed using indicators addressing climate change's “physical” risks.

Physical risks refer to damage and material losses with the long-term financial consequences induced by natural hazards under a changing climate. Physical risks from climate change are examined in two categories: acute and chronic.
Acute Risks: Physical risks are categorized as “acute” from extreme events (e.g., droughts, floods, storms, etc.). In this analysis, acute risks from climate change are defined by nine different indices. Of these nine indices, six are used to define risks related to temperature, two to precipitation, and one to wind extremes.

Chronic Risks: Physical risks are categorized as “chronic” from progressive shifts (e.g., increasing temperatures, rising sea levels, water stress, etc.). In this analysis, chronic risks from climate change are defined by four basic indices. Of these four indices, two define risks related to temperature, one to precipitation, and one to wind speed values.

The physical risk assessment was conducted, including quantified consideration of future climate scenarios using Figure 1 below
Results:Table 1 shows part of the physical risks identified as part of climate change's impact on operations through a literature survey. Table 2 shows the Risk Assessment based EU Taxonomy Climate Delegated Act assessment. The wind turbine design specifications have several builds in mitigation measures that decrease the impact of climate change.
Conclusions:Climate Change impacts on wind farm projects need to be assessed so that institutions, companies, and investors understand the risk to the investments and take appropriate mitigation measures. This Climate Change Risks Assessments (CCRA) and impacts are site specific, and the level of risk can vary depending on geographical location, local climate conditions, and the specific design and resilience measures implemented in wind power infrastructure. A framework was developed and implemented for wind power plant investments in the western part of Turkey. Nine wind farm locations were assessed for future climate change predictions and the project risk levels were identified.
The results indicate that acute and chronic risks will develop under future climate change scenarios. These risks will impact the windfarm design, operation and maintenance conditions under various Risk Based Climate Hazard, Exposure and Vulnerability classifications. Adaptive measures will be required to be undertaken.
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Keywords: Climate Change Risk Asssment, EU Taxonomy, Windfarm, Acute and Chronic Risks, Adaptive Measures

Figure 1

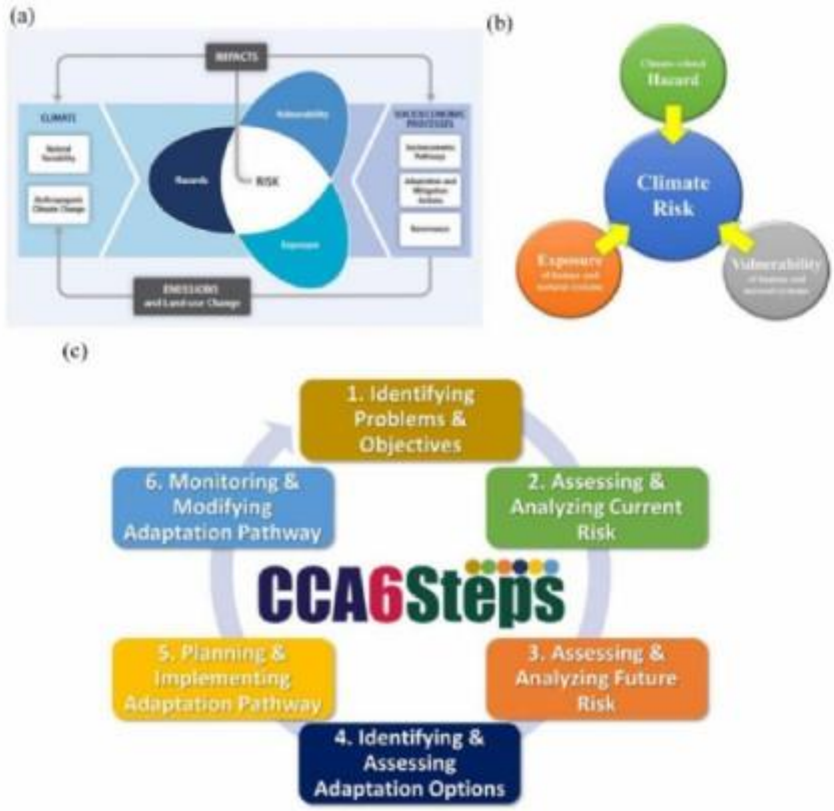
(a)
IMPACTS
RISK
EMISSIONS
and Land-use Change
(b)
Hazard
Climate
Risk
Exposure
Vulnerability
(c)
1. Identifying
Problems &
Objectives
2. Assessing &
Analyzing Current
Risk
3. Assessing &
Analyzing Future
Risk
4. Identifying &
Assessing
Adaptation Options
5. Planning &
Implementing
Adaptation Pathway
6. Monitoring &
Modifying
Adaptation Pathway
CCA6Steps

Figure 1 Fundamental concept of climate risk, including: (a) a schematic overview of climate risk presented by IPCC; (b) the core concept of climate risk; (c) illustration of the procedure of Climate Change Adaptation 6 Steps (CCA6Steps) proposed by Tung et al. (2019).

Table 1

Climate Change-Related Hazard	Likelihood	Direct Impact of Climate Change-Related Hazard	Potential Consequence	Rating				Adaptive Strategy
				Climate Hazard	Exposure	Vulnerability	Risk Based on Climate Hazard, Exposure and Vulnerability	
Mean Temperature Increases	• 1.39 °C - 3.05 °C increase in mean temperature	• Wind Resource Variability • Wind Turbine Performance • Gearbox and Mechanical Stress • Electrical System Efficiency • Cooling Requirements • Infrastructure Adaptation	Changes in mean temperatures may influence wind patterns, potentially leading to variations in wind resources at the WPP site. This could affect the overall energy output and efficiency of the wind turbines.	Increase in mean temperature	High	Wind farm designs have been optimized for energy output and efficiency	Risk considered Moderate due to design specification commitment	
			Higher temperatures may affect the density of the air, leading to reduced turbine efficiency. Wind turbines generate less power when the air is less dense. This decrease in air density can result in lower energy production.	Increase in mean temperature	High	Wind farm designs have been optimized for energy output and efficiency	Risk considered Moderate due to design specification commitment	
			Increased temperatures may contribute to higher mechanical stress on the turbine components, particularly the gearbox. This may lead to increased wear and tear, affecting the equipment's overall maintenance requirements and lifespan.	Increase in mean temperature	High	Operational temperature levels of gearbox and turbine components within changes of temperature	Risk considered Low due to design specification commitment	Periodic maintenance and operation measures
			Elevated temperatures may affect the efficiency of the electrical components in the wind turbine system, such as generators and power electronics. Higher temperatures may reduce the efficiency of power conversion and transmission.	Increase in mean temperature	High	Operational temperature levels of electrical components in the wind turbine system, such as generators and power electronics within changes of temperature	Risk considered Low due to design specification commitment	Periodic maintenance and operation measures

Risk Assessment Based on the EU Taxonomy Climate Delegated Act.

Table 2

Climate Indicator	Impact on Wind Power Plant
Temperature	• Increase in temperature may lead to change in air density and wind pattern. • Extreme temperatures may result in a change in operating conditions and may also cause wind turbines to be shut down. • With increasing temperature, electricity production may increase or decrease depending on other external factors specific to the wind power plant site.
Precipitation	• Higher precipitation may trigger increased turbine wear and edge erosion.
Flood	• Inundation has the potential to cause wear or damage to equipment. • Flooding can lead to interruption or reductions in electricity generation.
Storm	• Increased frequency and/or intensity of storms can result in equipment damage and prolonged shutdowns. • In case of damage to wind turbines or other critical components, a decrease in electricity generation may occur.
Wind	• As long as it remains within the cut-in and cut-out speed range, higher wind speed results in better wind conditions, consequently leading to an increase in electricity generation. • The wind speed exceeding the cut-out threshold results in a decrease in electricity generation due to shutdowns. • A decline in wind speed results in unfavorable wind conditions, leading to a decrease in electricity generation as well. • Change in wind patterns may also cause either an increase or decrease in electricity generation.

Potential Impacts of Climate Change and Climate-Related Hazards on Wind Energy Generation.

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Empowering women for environmental resilience: Unveiling the ongoing and immediate impacts of climate change on female empowerment in East Africa

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Overview:As global temperatures surge, a pressing concern emerges—the heightened vulnerability of women and girls to the intricate interplay of long-term climate change and short-term extreme climate events. This dual challenge jeopardizes the livelihoods of millions of women, propelling them into the precarious realms of poverty and food insecurity. The escalating impact of long-term climate change, marked by shifts in temperature, precipitation, and sea levels, intertwines with the rising frequency and intensity of natural disasters, further exacerbating the vulnerabilities faced by women globally.

Between 2000 and 2019, flooding events alone caused $650 billion in economic losses, affecting 1.7 billion individuals and resulting in over 100,000 deaths. The recent drought in Kenya, Somalia, and Ethiopia in 2022 impacted an estimated 15 million people, with women and girls disproportionately bearing the brunt, being 14 times more likely to lose their lives in disasters. Disturbingly, by mid-century, a worst-case climate scenario could drive an additional 158.3 million women and girls into poverty globally, surpassing the increase for men and boys by 16 million. (UN Women, 2023)

The distinction between the long-term and immediate dimensions of climate challenges underscores the imperative for a multifaceted response to safeguard the well-being and empowerment of women and girls worldwide. While environmental sustainability efforts often focus on technological and economic solutions, this study emphasizes the essential integration of broader social sustainability dimensions, particularly gender equality, to achieve meaningful progress.

However, the scarcity of comprehensive data at the intersection of social and environmental sustainability poses challenges for understanding the impacts on various groups. The recent 'Progress on the Sustainable Development Goals: The Gender Snapshot 2023' report reveals that no country has fully met its SDG 5 target, and 44% of the data needed for monitoring progress on gender equality is missing. This data gap underscores the critical importance of prioritizing SDG 5, as its neglect could have widespread consequences for the 2030 Agenda for Sustainable Development.

Climate change disproportionately affects the world's poorest populations, exacerbating vulnerabilities due to infrastructure gaps, unpreparedness, inequality, and social vulnerability. Unaddressed, climate change threatens to heighten women's vulnerability to poverty and hunger, undermining hard-won development achievements. While women are more susceptible to the impacts of climate change, research indicates that higher levels of female empowerment can accelerate the transition to cleaner fuels, playing a crucial role in climate change mitigation.

This study aims to explore the impact of climate change on female empowerment in East Africa, leveraging data from the Demographic and Health Surveys (DHS) and the Emergency Events Database (EM-DAT). By constructing a Female Empowerment Index (FEMI) from nationally representative surveys between 1995 and 2020, the study delves into six dimensions of empowerment. The research examines immediate and long-lasting consequences of climate change, emphasizing the urgent need for multifaceted responses and gender-inclusive policies.
Methods:Due to the multidimensional nature of gender equality, various measures exist that consider

different aspects of equality. However, mainstream measures focus on national levels and have limited use when evaluating the status of women in the lower economic strata (Rettig et al., 2020). Employment variables within exiting measures typically consider highly educated and economically advantaged women, ignoring informal employment (Cueva Beteta, 2006). Employment in itself does not capture critical dimensions of female empowerment, such as personal security or decision making.

Following Rettig et al. (2020)'s methodology, this study constructs FEMI for East Africa between 1990 and 2020, making use of 62 nationally representative demographic and health surveys (DHS). The first objective is to evaluate the outcomes of each dimension of FEMI for each region nationally. Furthermore, to investigate the deterministic characteristics of female empowerment beyond the dimensions of FEMI, including occupation, income level, age, ethnicity, language, religion, rural vs urban, distance from the coast, individualistic vs collectivist societal structure, historical disease, historical plough use, history of hunter vs gatherer, slave-trade exposure and historical crop domination. Secondly, subnational variation within countries will be considered to get a more in-depth perspective of FEMI mutation across provinces/states/regions.

The DHS datasets include Geographic Information Systems (GIS) data that record geographic information for survey respondents. GIS data allows for linking health data with factors like local infrastructure and environmental conditions. Household clusters in the survey are geographically referenced, although coordinates are displaced to protect respondent confidentiality. The displacement is limited within a country's borders. The DHS also provides Geospatial Covariates datasets, which link cluster locations to ancillary data, including population, climate, and environmental factors. This linkage helps assess vulnerability to climate-related events and allows for the creation of a climate vulnerability/resilience index (Guzmán, 2013). It provides exposure, sensitivity, and adaptive capacity indicators, considering factors like population density, infrastructure, poverty, and health-related data. The DHS data can be used to define an aggregated index of resilience or vulnerability at the cluster level.

Econometric Strategy
This study will firstly estimate a pseudo panel data regression model outline in the equation below, controlling for individual-specific characteristics that do not change over time, to understand how changes in climate vulnerability relate to changes in the Female Empowerment Index, and how their effects vary over time and across administrative wards.

$$FEMI_{it} = \alpha_i + \beta_i X_{it} + \beta_j Z_{it} + u_{it} \quad (1)$$

Where X_{it} represents the climate change vulnerability/resilience index computed, Z_{it} is a vector of control variables identified in the decomposition of individual deterministic and demographic characteristics of FEMI, and u_{it} is the error term in Equation 1.

Furthermore, the study employs a Difference-in-Difference (DID) analysis to assess the causal effect of East African climate events on female empowerment. DID is a robust method for evaluating the impact of events or interventions when controlled experiments are not feasible, as is often the case with natural disasters like droughts. By comparing changes in female empowerment outcomes in areas directly affected by the East African climate events with those in unaffected areas over the same time period, the study isolates and estimates the specific influence of major climate events on female empowerment.

The study recognizes the intersection of energy dynamics with gender vulnerabilities, implicitly delving into how access to energy resources intersects with gender dynamics. By examining the link between female empowerment and cleaner energy use, the research extends its understanding of climate-related impacts on women.
Results:The findings of the study reveal differential impacts of climate change on men and women, particularly in agriculture, food security, health, water, and energy resources. While women are more susceptible to climate change impacts, higher levels of female empowerment are associated with a higher probability of using clean fuel as the primary energy source, highlighting the potential of female empowerment in climate change mitigation.

The research encompasses a comprehensive, sub-national, and geospatial analysis, enriching the literature on gender empowerment and climate change. By deepening the understanding of female empowerment dynamics and underscoring the potential of empowerment in climate change mitigation and adaptation, FEMI offers a nuanced perspective beyond traditional measures. Examining variations in empowerment levels within countries, the study recognizes that

empowerment varies across regions, mirroring the uneven impacts of climate change. This subnational perspective informs more targeted policy interventions.
Conclusions:The study concludes by emphasizing the critical role of geospatial data and climate vulnerability indices in facilitating data-driven decision-making. It highlights the need for policymakers to incorporate gender considerations into climate policies, ensuring that climate initiatives not only mitigate environmental impacts but also empower women and enhance their resilience to climate-related challenges in East African countries. The research advocates for a nuanced, sub-national approach to climate resilience strategies, acknowledging regional variations in female empowerment and vulnerabilities. By aligning with principles of gender-inclusive growth, the study offers insights for targeted policy interventions, promoting sustainable development that benefits women across diverse regions and economic sectors.
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Keywords: Climate Change, Gender, Geospatial Impact

[Page: 269]

[Abstract:0111] OP-269 [Accepted:Oral Presentation] [Energy and the Environment » Other]

Examining the interlinkage between co2 emissions and inclusive human development: unveiling the significance of effective institutions

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Overview:Climate change is threatening the advancements being made with inclusive human development. For many decades, countries have been experiencing the challenge of maintaining sustainable and inclusive human development while mitigating climate change. Human development and climate change issues are so significantly integrated that the United Nations Development Program (2022) indicated climate change has become "the defining human development issue of our generation". Climate change and human development cannot be isolated. Human development assists with the necessary skills and technological advancement to mitigate climate change, yet climate change can stagnate these advancement efforts. To ensure both goals with regard to these issues are met, a mediator between them is necessary, institution's role will be significant in combating these issues as a possible mediator. Therefore, it is imperative to understand to what extent institutions can assist in modulating climate change's effect on inclusive human development.
Methods:A first difference Generalized Methods of Moments (FD GMM) system is used in this study. This model has the advantages of addressing endogeneity as well-being robust to weak instruments; FD GMMs also assist with controlling for time-invariant unobserved factors and provide robust inference. FD GMM's work well with short periods, which assists with the 16 years time period used in this study. The examined time period is from 2003 to 2018.

Equation 1:

$$HDI_{i,t}=\beta_0+\beta_1 HDI_{i,t-1}+\beta_2 CO2_{i,t}+\mu_i+\varepsilon_t+\eth_{i,t}$$

Equation 2:

$$HDI_{i,t}=\beta_0+\beta_1 HDI_{i,t-1}+\beta_2 CO2_{i,t}+\beta_5 Ineq_{i,t}+\mu_i+\varepsilon_t+\eth_{i,t}$$

Equation 3:

$$HDI_{i,t}=\beta_0+\beta_1 HDI_{i,t-1}+\beta_2 CO2_{i,t}+\beta_3 CO2*Inst_{i,t}+\beta_4 Inst_{i,t}+\beta_5 Ineq_{i,t}+\mu_i+\varepsilon_t+\eth_{i,t}$$

Equation 4:

$$HDI_{i,t}-HDI_{i,t-1}=\beta_1(HDI_{i,t-1}-HDI_{i,t-2n})+\beta_2(CO2_{i,t}-CO2_{i,t-n})+\beta_3(CO2*Inst_{i,t}-CO2*Inst_{i,t-n})+\beta_4(Inst_{i,t}-Inst_{i,t-n})+\beta_5(Ineq_{i,t}-Ineq_{i,t-n})+(\varepsilon_t-\varepsilon_{t-n})+(\eth_{i,t}-\eth_{i,t-n})$$

Where $HDI_{i,t}$ represents human development for i country in time period t, CO2 represents CO2 emissions, and Inst represents the six institutional aspects. Ineq represents inequality. Institutions are represented by the proxies for institutional quality aspects: Corruption control perception (CC), Rule of law perception (RL), Regulatory quality perception (RQ), Government effectiveness perception (GE), Political stability and absence of violence/ terrorism perception (PS), Voice and accountability perception (VA). In Equation 1 to 4, μ_i is the country-specific effect, ε_t is the time-specific constant and $\eth_{i,t}$ is the error term. Equation 3 represents the level equation, while Equation 4 represents the first difference equation of the system GMM. Equation 1 represents a basic equation of lagged human development and CO2 emissions however in Equation 2 a control variable is added – inequality.

Results:Certain institutions have been found to significantly assist in modulating CO2 emissions' effect on human development, as the results indicate. When the institutional quality aspects of corruption control, rule of law and political stability interact with CO2 emissions, the variables significantly improve human development. When the quality of these institutional aspects increases, they assist with mitigating CO2 emissions, therefore leading to a positive impact on human development.

When considering the models using corruption control, regulatory quality and political stability, these institutional aspects affect human development significantly. When Corruption control and Political stability are considered in their respective models, an increase in CO2 emissions leads to a decrease in human development.

Institutional quality in literature is generally seen to have a positive impact on human development by promoting equality through fairness; however, in the short run it can have a negative impact on human development due to the transition occurring in the economy (Havrylyshyn & van Rooden, 2003). When the quality of Rule of law, Corruption control and Voice and accountability increases these institutional aspects are found to have a statistically significant negative effect on human development which is in line with Havrylyshyn et al. (2003) explanation of short-run effects.

Conclusions:There is a need for countries to sustain human development while mitigating climate change. These two issues are significantly interlinked with each other. Institutions can play a vital part for more inclusive human development along with assisting in the mitigation of climate change.

The results indicate that overall climate change significantly and negatively impacts human development. When institutions are interacted with climate change the results indicate that institutions assist in modulating climate change's effect on human development. While institutions on their own were found to have a short-term negative impact on human development, this is due to the need for institutions to stabilize after a transition period. As expected inequality also deters human development.

From this study policymakers can observe that specifically enhancing the quality of Corruption control, Regulatory quality and Political stability will assist in modulating CO2 emission's effect on human development. By specifically targeting the enhancement of the quality of these institutions to modulate CO2 emissions impact on human development, this will contribute to climate change target outcomes.

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Keywords: Energy, Climate Change, Institutional quality, Institutional aspects, Human Development

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Collaborative Patterns and Drivers in Carbon Dioxide Removal Academic Studies

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Overview:The successful implementation of large-scale carbon dioxide removal (CDR) initiatives requires the harmonisation of international supply chains. This team effort requires that potential participants exchange ideas and knowledge about CDR as they prepare to implement such large-scale projects. This study examines the academic research landscape on CDR using a bibliometric analysis coupled with econometrics. We examine academic literature data from 2013 to 2023 on 8 CDR technologies: bioenergy carbon capture and storage, direct atmospheric carbon capture and storage, biochar, soil carbon sequestration, afforestation/reforestation, ocean fertilisation, enhanced weathering and blue carbon. We present community networks of CDR literature at three levels: Country, Institution, Author, and analyse the structure of these networks. Coupling these data with macroeconomic and academic data, we perform an econometric analysis to understand the determinants of international CDR academic collaboration. Our goal is to create a map of the CDR research landscape and to provide information on factors that can promote and/or enable CDR collaboration, a necessary step for the deployment of large-scale negative emissions. Our results provide detailed information on the structures of CDR communities at different levels. We present characteristics of the observed communities and potential future links between them. The cooperation analysis shows that some countries are more open internationally, e.g. the UK has more international cooperation than China, despite the difference in the size of the literature. The econometric analysis shows efforts to include researchers from less developed, less climate and research friendly countries in partnerships, although more action is needed. Finally, we offer policy recommendations to promote necessary and efficient collaboration in academic research on negative emission technologies.
Methods:The Web of Science (WoS) is a research database recognized for its rigorous indexing and comprehensive coverage across disciplines, making it one of the preferred tool for bibliometric studies (Luo et al., 2022). Our dataset provides a comprehensive view of international academic collaborations in the domain of CDR over time. Extracted from WoS, it consists of roughly 7,000 publications from 2012 to July 2023, detailing associated countries, authors, and institutions. It relies on a search query designed by Minx et al., 2017, which focuses on eight core CDR technologies: BECCS, DACCS, Blue Carbon, Afforestation/Reforestation, Soil carbon sequestration, Enhanced weathering, Biochar, and Ocean fertilization. The precision of this query, ensures our study's reliance on high-quality and pertinent bibliographical CDR data.

Using data from WoS, we construct a network that captures international academic cooperation. This network is mapped at the country level to discern patterns and collaborations. For a more granular view, we construct sub-networks focusing on collaborations between individual authors and institutions. This enables us to investigate deeper the web of collaborations at a micro-level. Because our dataset contains a vast number of institutions and authors, and some have not been actively working on CDR (e.g., if they have only a few publications), we decide not to

include them in the visualizations. We run an analysis that selects all the publications but visualizes only the top 1% of the most active institutions and authors which represents 5% and 1% respectively of the total literature.

We then estimate a gravity equation to investigate the explanatory factors that favors the observed research collaborations.
Results:The model reveals a significant negative relationship: an increase in academic disparity results in fewer collaborations. Conversely, social proximity emphasizes the role of academic connections and collaborative networks in fostering new collaboration. A country belonging to a more extensive community will naturally cooperate significantly more. We can relate to the nature of CDR technologies needing cooperation to be deployed and scale up. It necessitate the engagement of international collaboration at the technological, supply and policy level. As anticipated, the elasticity of distance to cooperation is negative. Regarding macroeconomic factors, two are especially noteworthy in explaining or fostering cooperation. The number of exchange students between the two countries plays a significant role in academic cooperation; exchange programs may serve as a catalyst. A binary variable indicating a historical colonial relationship reveals that historical ties still influence academic collaborations. A shared language appears to facilitate academic exchanges. Countries that possess common features might hypothetically be more likely to collaborate. However, while on one hand, we observe that countries in the same World Bank income bracket tend to cooperate more, on the other hand, political differences seem to act as a catalyst. Even with very small values, these differences impact cooperation in non-intuitive ways. Differences in the number of researchers, government spending on research and development, and engagement in climate change policies seem to correlate with a slight increase in collaborations. Finally, the inclusion of Time Fixed Effects in model (2) proves to be beneficial.
Conclusions:In our goal to better understand the vast web of international academic cooperation in the CDR literature, we presented collaborations between countries, institutions and authors and their determinants. Using a data from Web of Science and additional new data from OpenAlex API, our analysis provides insight into the cooperation dynamics between the different actors. At the country level, not only do macroeconomic factors like distance, shared language, and historical ties play important roles, but actionable lever such as student exchange programs and even subtle policy differences and environmental pledges emerge as significant determinants. At the same time, our analysis at the institutional and authorial levels emphasizes the role of academic indices, with metrics like the H-index serving as a catalyst for collaboration. The net importance of social proximity in fostering collaboration shows the importance of building and nurturing academic communities, highlighting the need for strategic efforts to cultivate these networks to achieve a large deployments of CDR technologies worldwide. We should also be careful by including more authors from less developed countries into CDR research even if they are not excluded at the moment. Creating new collaboration between entities that are working on similar topic can be catalysed through different strategies such as new or the development of student exchange programs.
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Keywords: Research cooperation, Carbon Dioxide Removal technologies, Network analysis, Gravity model

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[Abstract:0695] OP-271 [Accepted:Oral Presentation] [Energy and the Environment » Other]

Exploration of decarbonising the transport sector in New Zealand

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Overview:Energy production and use contribute to greenhouse gas emissions. In New Zealand, energy-related greenhouse gas emissions account for 41% of total emissions. Among Energy-related emissions, transport is responsible for about 50%. Notably, a large amount of these emissions is caused by road transport, about 91%. Since there is only a limited possibility of reducing methane from the agricultural sector, to reach the government net-zero carbon target by 2050, it is urgent to understand the energy-related emissions profile and its influencing factors in the transport sector. Limited research has been tackled in this area in New Zealand.
Transportation, as a central pillar of the economy, brings inputs into the production phase through the supply chain to deliver final goods to the consumers. The transport sector operates as a system, with different transportation modes, requiring appropriate, associated infrastructure. For example, road and rail networks are closely related to domestic mobility use, providing domestic freight and passenger services. Whereas air and water transportation mainly serve international shipment and passenger travel. According to national input-output (IO) tables, the transport industry accounts for 3% of the gross domestic product in New Zealand. The gross output of the transportation industry continuously increased from $11,567 million in 2007 to $18,818 million in 2020, with road dominating a share of 50% and with air and space transport of 34%. In this study, we use IO analysis and structural decomposition analysis to systematically investigate the driving forces shaping energy-related greenhouse gas emissions for four transportation modes (road, rail, air, and water) in the transport sector. The new evidence will assist policymakers in selecting appropriate policy instruments targeting key areas associated with transportation infrastructure to achieve emissions reduction in the transport sector effectively.

To date, most studies using IO analysis focus on energy (Wen et al.,2021), electricity (Guang et al.,

2022) or energy-related emissions (Jiang et al., 2019) at the national (Wen et al., 2021) and regional levels (Wu et al., 2019). In addition, few studies have further examined the impacts of road, rail, air, and water on other economic sectors in Australia (Wang and Charles, 2010) and Korea (Lee and Yoo, 2016). However, there is no such research in New Zealand. This study will fill this gap by employing the IO approach and structural decomposition analysis to quantify the driving factors that affect emissions in the transport sector by four transportation modes.

OBJECTIVES:
(1) provide a complete energy-related greenhouse gas emissions profile.
(2) quantify the driving factors that influence energy-related greenhouse gas emissions in the transport sector.
(3) identify feasible ways to reduce energy-related greenhouse gas emissions in the New Zealand economy.
(4) recommend policies associated with urban planning and transportation infrastructure that could achieve the net-zero carbon target.
Methods:METHODS: Input-output (IO) Analysis and Structural Decomposition Analysis.

Data are from two sources:
(1) national IO tables for 2007, 2013, and 2020 by Statistics New Zealand.
(2) the greenhouse gas inventory by the Ministry for the Environment.
Results:We observed a significant reduction in the direct energy-related carbon intensity for both road transport and other modes of transportation between the 2012/13 and 2019/20 periods. This research identifies that the primary driver behind the reduction in emissions intensity is the substantial decrease in the energy intensity of these sectors. The study also found notable reductions in the energy-related embodied emission intensity within the transport sector attributed to consumption, government, and investment spending from 2012/13 to 2019/20. Conversely, the export sector experienced only a marginal decline in emission intensity during the same period. Key factors contributing to increased emissions in the road transportation industry include population growth and rises in per-capita consumption.
Conclusions:This study employed a hybrid approach, combining Environmentally Extended Input-Output (EEIO) analysis and Structural Decomposition Analysis (SDA), to develop an emissions profile for New Zealand's transport sector. The limitations and uncertainties associated with this methodology are thoroughly discussed in the literature review section. The carbon intensity, chiefly influenced by energy intensity, has been instrumental in reducing transport sector emissions. The impacts of demand and production structures were less pronounced but shifted directionally across the two periods analysed. A closer examination of the effects on each of the four transport modes reveals that the decrease in carbon intensity from 2012/13 to 2019/20 was predominantly seen in the road transportation industry. The significance of the study will give a complete picture of driving factors affecting emissions in four transportation modes and provide valuable insights for policymakers to use effective policy instruments to decarbonise the transport sector.
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Keywords: input-output analysis, structural decomposition analysis, transport sector, emissions, transportation modes.

AuthorToEditor: I would like to give an oral presentation for the paper. Thank you.

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[Abstract:0390] OP-272 [Accepted:Oral Presentation] [Energy and the Environment » Other Externalities]

Splitting the bill for sustainability: An examination of the behavioral factors that determine consumers' willingness to pay for environmentally friendly product attributes

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Overview:A growing number of firms around the world face a challenge regarding their offering of sustainable products and services. On the one hand, both public sentiment and regulatory pressures (exemplified by the German Supply Chain Act) advocate for the integration of environmentally friendly and equitable products and services into their product portfolios. These green and fair products come with a potential burden to the firms' balance sheets as they usually lead to increases in the cost dimension.

On the other hand, companies often find it difficult to counter this burden by passing on the increased costs to their customers. Although various studies show consumer interest in sustainably produced products, the willingness to pay a premium for environmental friendliness and equity is often limited in reality.

As in most scenarios the higher costs can not be circumvented; it is crucial to understand the behavioral factors that determine the willingness to pay for such product features to overcome this challenge. This can best be learned from those customers who actually agree to pay a premium.
Methods:Based on the theory of planned behavior, I employ a choice experiment conducted in two sub-samples in both Germany (comparatively strict regulatory environment) and Australia (comparatively relaxed legislation). The experimental design features an array of products, green features, and label designs. An extended questionnaire furthermore integrates information on the participants' attitudes, subjective norms, perceived behavioral control, and habits.
Results:The preliminary results show indications of the influence of certain attitudes and habits on decision-making with regard to price premiums of sustainable product features. Furthermore, some of the dynamics involved with the perception of norms and behavioral control may serve as a basis for nudging consumers towards the support of slightly more expensive but also more sustainable products and services.
Conclusions:Although factors such as attitudes and habits are anchored in more long-term personality traits, the findings are of high relevance for the probability of success of price enforcement measures. They enable companies to evaluate future pricing decisions for green products in a more informed way. From an academic perspective, they serve as a basis for further research on the basics of sustainable decision-making.

With regard to the perception of norms and behavioral control, the findings on nudging opportunities could manifest themselves with the help of comparatively simple changes in the presentation and communication of sustainable product features. This will allow firms to obtain better results with relatively incomplex and cost-effective measures when trying to pass prices on to the consumer.
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Keywords: ESG, Sustainability, Willingness-to-pay, WTP, Theory of planned behavior, TPB

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[Abstract:0029] OP-273 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Other]

Can U.S. strategic petroleum reserves calm a tight market exacerbated by the Russia–Ukraine conflict?

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Overview:OVERVIEW:

Recent changes in global petroleum markets have driven the debate regarding the use of strategic petroleum reserves (SPRs) as a price management tool during periods marked by extreme price volatility. We examine the price management role of the U.S. SPR under typical market conditions and in extreme emergencies. Furthermore, we discuss the White House's hypotheses that (a) boosted Organization of the Petroleum Exporting Countries' (OPEC) production and releases from the U.S. SPR result in a negative pressure on U.S. gasoline inflation, and (b) crude oil releases from the U.S. SPR helps balance the global oil market.
Methods:METHODS:
In this study, we provide a brief historical overview of the reasons behind the creation of the U.S. SPR and describe cases when drawdowns were effective and ineffective in countering gasoline and crude oil price inflation. We conduct stylized fact analysis to compare the SPRs of the U.S. and other OECD countries to the OPEC's spare capacity and Russia's production, explain the limited ability of the U.S. to act as a swing producer, and examine the impact of SPR on domestic gasoline prices. Motivated by insights obtained from this analysis, we contribute to the literature on U.S. SPR and gasoline prices by building a model to examine the determinants of gasoline inflation, accounting for the roles of energy security and refineries.

We apply the threshold cointegration and Granger causality to examine the relationship between U.S. SPR releases, OPEC production, and the price of imported intermediate inputs of gasoline production.

We apply a hybrid open-economy Phillips curve to model gasoline inflation, accounting for backward- and forward-looking price settings, domestic and global slackness, energy security, and the role of refineries. We distinguish between normal-, super-, and hyper-backwardation and -contango oil markets using threshold cointegration and regression techniques.

We use the U.S. refinery utilization rates to capture the domestic output gap and U.S. domestic petroleum demand to reflect energy security and the domestic output gap. We contribute to the literature on the hybrid open-economy Phillips curve by taking OPEC production as an observable measure of the global output gap, as supported by the findings of Pierru et al. (2018) and Razek and Michieka (2019). Including OPEC production in the model also enables us to examine the White House hypothesis regarding the impact of the latter on domestic gasoline prices. We incorporate the level of the U.S. SPR in the model, unlike Kilian and Zhou (2020) and Newell and Prest (2017), who included SPR changes and indirectly modeled SPR. We account for gasoline and crude oil price market expectations—which are linked to inventory dynamics and supply shocks—by use of the gasoline futures basis and the long-run West Texas Intermediate (WTI) futures basis. Considering that the price expectations align with the theoretical framework underpinning the Philips curve, we rely on storage theory (Ahmadi et al., 2020; Working, 1949; Kaldor, 1939) to interpret these expectations across oil market regimes.

From a methodological standpoint, we contribute to the literature on the role of strategic reserves in energy markets by applying threshold cointegration and open-loop threshold autoregressive (TAR) distributed lagged modeling to examine the impact of U.S. SPR releases on domestic gasoline prices in contango and backwardation oil markets. This approach alleviates concerns that ignoring non-linearity and cyclicality or using an incorrect non-linear specification could result in misleading results in general (Enders, 2023), and with regard to oil markets in particular (Jiang et al., 2020, 2022). These techniques also enable us to be the first to test the U.S. SPR's controversial role as a price management tool during severe emergencies, such as the 2020 COVID-19 pandemic and the 2022 Russia–Ukraine conflict. Our choice of applying threshold cointegration and regression techniques is consistent with the approaches utilized in previous studies in the literature on the hybrid open-economy New Keynesian Philips curve (Rumler, 2007), on capacity utilization as a measure of the output gap (Chang and Emery, 1997), and on the theory of storage (Considine et al., 2022; Considine and Aldayel, 2020; Koy, 2017; Fattouh, 2009; Larson & DEC, 1994).
Results:RESULTS:
This study provides several insights regarding the impact of U.S. SPR releases on the global oil market. Our stylized fact analysis suggests that the U.S. SPR is no more than a drop in the ocean and highlights the obvious: the U.S. is an oil price taker, rather than a price maker. This claim is confirmed by our results of Granger causality and threshold cointegration tests. Further, our results reveal that the SPR does not impact OPEC production (which is instrumental in affecting global oil prices) and has a limited effect on the price of imported intermediate inputs of gasoline production. We find evidence supporting the view that OPEC production increases generally have a deflationary effect on gasoline prices and that U.S. SPR releases counter gasoline inflation in tight markets, consistent with the White House hypotheses; however, periods of extreme shortage and oversupply show deviations from these expectations. For instance, SPR releases have negligible effects on gasoline inflation in periods of extreme oversupply—a scenario that emerged during the 2020 COVID-19 pandemic.

From an energy security standpoint, it is only of moderate interest that SPR drawdowns do not affect gasoline prices in periods of extreme oil abundance. In contrast, from the same standpoint, it is crucial to understand whether SPR releases and OPEC production increases are effective in moderating gasoline inflation in periods of extreme shortage characterized by low supply buffers. This scenario emerged in 2022, when the oil market was in a hyper-backwardation condition characterized by severely constrained global supply buffers—including OPEC's spare capacity—which was at the time exacerbated by the Russia–Ukraine conflict. Our analysis for the latter scenario indicates that OPEC production increases did not moderate the upward trend of U.S. gasoline prices. Furthermore, we show that SPR release fueled gasoline inflation, rather than countering it—an equally important insight from the perspective of U.S. energy security. Both of these findings contradict the White House hypothesis. We propose that the inflationary pressure exerted by SPR releases in hyper-backwardation markets might be the outcome of the releases acting as an expectation coordination mechanism for oil prices and concerns about the effectiveness of global oil supply buffers to manage future oil price spikes and volatility. However, regardless of the explanation, our findings raise concerns about U.S. domestic energy security, as they reflect a situation of excess domestic demand relative to domestic supply.
Conclusions:CONCLUSIONS:

The threshold cointegration results indicate that U.S. SPR releases impact neither OPEC production nor the price of imported intermediate inputs of gasoline production.

Our results demonstrate that SPR releases and OPEC output increases generally decrease inflation, with a crucial exception being the hyper-backwardation market, as seen in 2021–2022. This period was characterized by severely constrained global supply buffers, including OPEC's spare capacity, exacerbated by the Russia–Ukraine conflict. For this period, we conclude that (1) the impact of OPEC production changes on gasoline inflation would be negligible, (2) excess domestic demand relative to domestic supply raises concerns about domestic energy security, and (3) the unprecedentedly large SPR drawdowns are likely to have caused the market to panic and contributed to gasoline price increases, contrary to arguments suggesting that the 2022 releases eased domestic gasoline prices.

We conclude that the SPR is an ineffective price control mechanism during crises and may not have the strategic value previously thought in an extremely tight oil market.
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Keywords: Strategic petroleum reserves, Gasoline prices, OPEC, Price spread, Refinery utilization rate, Energy security

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[Abstract:0214] OP-274 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Other]

Understanding Jobs Demand and Displacement Outcomes of Decarbonising UK Industrial Clusters

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Overview:The UK Government's 2021 roadmap on CCUS supply chains (DESNZ, 2021a) suggests that CCUS could create up to 50,000 jobs in the UK. Of these, around 10,000 jobs are expected to be associated with the current domestic-facing activity of sequestering emissions from the UK's regional industry clusters. This spans a broad range of activities, including the potential export of sequestration services by what may be termed a UK CO2 Transport and Storage (T&S) sector, as well as other CCUS-related services and technological developments. However, the timeframes involved are not very clear, particularly as the Track 1 and Track 2 (DESNZ, 2023, p. 2, 2021b, p. 1) cluster sequencing process will involve a range of activities and different labour demands across an extended and dynamic time frame. Moreover, existing estimates do not give attention to how wage responses in the supply-constrained UK labour market – characterised by both worker and skills shortages – may affect net impacts on total employment through potential displacement of jobs and activity in other sectors and regions.

This paper focusses on estimating the national and regional labour market implications of the deployment and operation of CCUS transport networks within and across four of the UK's industry clusters. At this stage, the scope of the study is limited to the investment and emergence of nascent CO2 Transport and Storage (T&S) sector activity initially to service sequestration demand from industry actors located within the Track 1 and 2 clusters. The aim is to identify and understand the regional employment implications of such nascent sector activity, with particular emphasis on the location and nature of labour demand and how the potential movement of workers may involve displacement of jobs and activity across regions and sectors of the UK economy.
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Methods:The analysis is conducted using our economy-wide UKENVI scenario simulation model of the UK, updating previous fully peer-reviewed work (Turner et al., 2023) with new data on the structure of the economy and refining of the scenarios to focus on the now-announced Track 1 and

potential Track 2 developments. Here we assume a total of £3,274 million invested between 2023 and 2029 across the four Track 1 and 2 clusters.

The outputs of the national CGE analyses include economy-wide impacts on total and sectoral jobs, but only at a UK-wide level. We then develop a regional mapping approach, to be able to assess and understand the potential employment changes and disceplacement at regional level. Our regional mapping of employment impacts is based on primary and secondary data processing and analysis, where we map national level employment impacts generated by the CGE model to different regions, using ONS available data 'Workforce jobs by region and industry' (ONS, 2022). We also apply a weighting factor to allocate a higher share of employment changes around cluster regions, but this is only done for sectors where we expect activity to be physically concentrated around the clusters. That is the construction sector, with activity linked to the implementation of T&S infrastructure, and the emerging CO_2 T&S sector itself, with employment linked to the operation and maintenance of the sector.

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Results:Figure 1 shows preliminary results on the regional mapping of employment changes linked to the deployment of the T&S sector servicing the Track 1 and Track 2 clusters on peak activity years (2023, 2027) and in the long run (2050). It groups impacts into those sectors where most employment changes take place – the T&S sector itself and the construction sector – and all others. This regional mapping has been developed based on current existing jobs shares per sector and region, from ONS data.

In 2023, Track 1 T&S systems (Figure 1.a) drive high employment needs for construction of over 3,000 FTEs for each of the Yorkshire & the Humber and North East, regions and over 1300 FTEs for the North West region. At this time, the Track 2 T&S systems (Scottish and Viking CCS) have not started activity, so that, for example, there is some displacement of employment in the Scottish region (a net loss of around 260 jobs) that is linked to wage-driven cost and price pressures triggered by the rise in labour demand associated with the investment activity around the Track 1 T&S activity.

Year 2027 reflects the picture when investment activity starts around the Track 2 T&S systems (Figure 4.b), where the Scottish T&S activity requires over 2,300 construction jobs in Scotland, and about 3,200 jobs linked to Viking CCS, located between Yorkshire and the Humber and the East Midlands regions. As observed in the first year of investment in the Track 1 T&S systems, we also see job displacement in other regions and sectors, again particularly where more wage- and/or labour-intensive consumer facing activity is concentrated.

Year 2050 shows the long-term regional employment changes. The CO_2 T&S sector is operating across all clusters, supporting around 400 direct jobs across the clusters' regions. Crucially, and as labour market constraints relax, the job displacement previously seen is reversed and other supply chain and induced jobs across the wider economy are supported in the long-term, reaching an increase of around 4,120 sustained jobs relative to the baseline.

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Conclusions:The CO_2 Transport and Storage industry is a nascent sector and understanding of the associated investment and employment requirements are continuously evolving. Understanding demand and supply issues including transitory peaks and regional and sectoral implications needs to happen across different decarbonisation areas (industry, heating, transport, etc.) at an individual level and at aggregate level in order to understand the scale and nature of both the opportunities and challenges of the net zero transition.

We believe that this analysis provide a range of outcomes that may help policymakers and industrial stakeholders to plan and find solutions that limit negative economic outcomes and facilitate a jus transition to Net Zero.

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Keywords: Industrial decarbonisation, employment impacts, Jobs and skills, CGE, regional analysis, energy policy

Figure 1

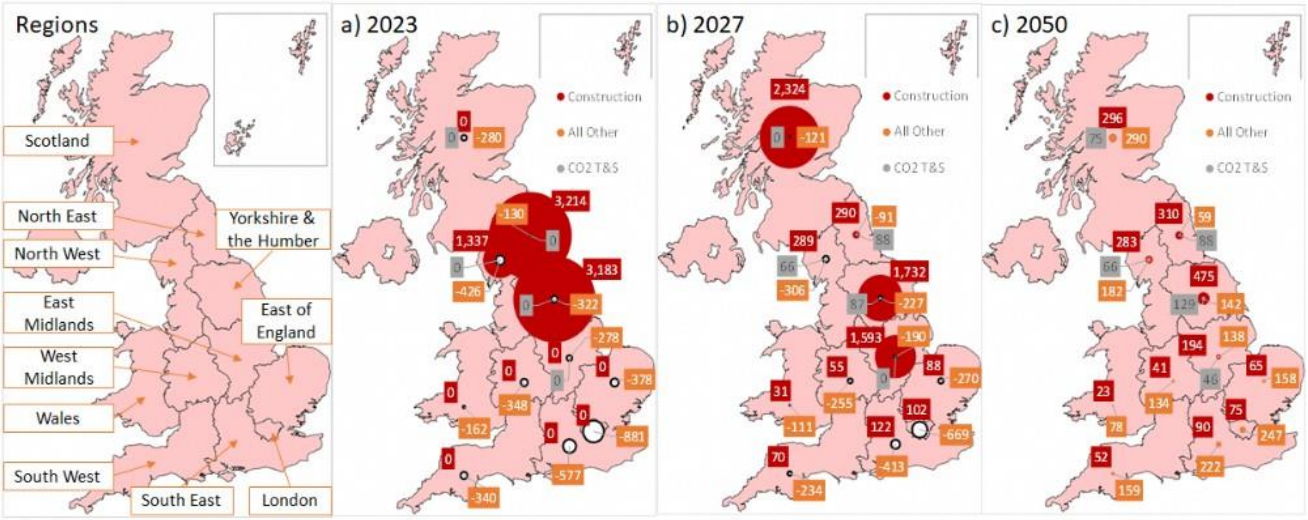

Figure 1. Regional employment changes (FTE) for Track 1 and Track 2 T&S activity relative to baseline – focus on key activity years: 2023 and 2027, and long run (2050), and sectors: construction and CO2 Transport & Storage.

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[Abstract:0272] OP-275 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Other]

Crude Oil Prices and Indirect Tax Revenues: The Positive Impact on Economic Performance and Sovereign Risk Premiums in Oil-Importing Countries – A Case Study of Turkey

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Overview:This study examines how increasing crude oil prices, which increases indirect tax revenue, may improve economic performance by decreasing budget deficits and CDS premiums. Indirect taxes constitute 63% of total tax revenues, and taxes from oil products constitute a significant part of these indirect tax revenues in Turkey. The empirical evidence from Turkey suggests that higher crude oil prices increase indirect taxes and improve economic performance due to lower sovereign risk premiums even in oil-importing countries. The findings of our paper provide several policy implications so that, as a result of rising oil prices, politicians can benefit from increased tax revenues and lower-cost of borrowing opportunities in their budgets. Moreover, the high indirect taxes on oil goods may act as an alternative automatic stabilizer, reducing the economic impact of rising oil prices.

Methods:In order to analyze the effect of crude oil prices on Turkish economic performance, we employ Cushman and Zha's (1995) Block Exogeneous Vector Auto Regressive Model. The block exogenous model incorporates the small open economy structure of the Turkish economy in which we allow oil prices to affect the Turkish economy contemporaneously and with lag, but crude oil prices are affected by the Turkish economic performance neither contemporaneously nor with a lag.

Results:The empirical evidence gathered from Turkey suggests that higher crude oil prices increase indirect taxes and lower budget deficits, leading to higher economic performance due to lower sovereign risk premiums.

Conclusions:The adverse effects of crude oil price increases for oil-importing countries are well documented in the literature. The transmission mechanisms of these adverse effects are also well documented. To the best of our knowledge, this paper is the first to empirically show how indirect taxes on crude oil products act as another transmission mechanism for a country with historically low energy subsidies and high taxes on oil products: Turkey. This paper elaborates on higher crude oil prices increasing indirect taxes, decreasing the budget deficit and creating a positive environment captured with lower CDS may ultimately stimulate the economy. The key feature of the Turkish economy is that indirect taxes accounted for 63% of total tax revenues in 2022, and indirect taxes on oil products constitute a significant part of total tax revenues in Turkey. Thus, the tax structure in question allows for examining an alternative channel to assess the impact of crude oil price shocks on economic performance. The empirical evidence gathered from Turkey suggests that higher crude oil prices increase indirect taxes and lower budget deficits, leading to higher economic performance due to lower sovereign risk premiums.

There are several policy implications of this study. First, based on higher crude oil price expectations, politicians can benefit from increased tax revenues and lower-cost borrowing opportunities in their budgets due to rising crude oil prices. Second, higher taxes on more inelastic demand products may open an avenue to lower taxes on less inelastic demand products by the government, which could stimulate the economy.Third, investors would be able to foresee the lower sovereign risk premium in which they would invest by observing the movement of crude oil prices and will then be able to adjust their investment preferences appropriately. Fourth, the high indirect taxes on crude oil products may serve as an alternative automatic stabilizer. It helps mitigate the adverse effects that a rise in crude oil prices might otherwise have on the economy. Further research should investigate the alternative transmission channel proposed by this study by using cross-country data and considering the tax structures of crude oil-importing countries.

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Keywords: Crude Oil Price Shocks, Indirect Taxes, Sovereign Risk Premium, Block Exogeneity VAR

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[Abstract:0287] OP-276 [Accepted:Oral Presentation] [Energy and the Macroeconomy » Other]

Energy intensity and structural changes: switching perspective

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Overview:Over the past decades, reductions in energy intensity have led the decarbonization processes observed in developed economies. This prompts questions about the true nature of progresses achieved by developed economies, which may be partially attributable to a pollution haven hypothesis rather than to actual shifts in consumption patterns (Bhattacharya et al., 2020). Indeed, part of these progress may be induced by shifts in economic structures that are not mirrored by similar changes in the consumption patterns, by virtue of the outsourcing of carbon-intensive production.
The main objective of the paper is to understand the effects on energy intensity of such shifts, which we call demand-invariant structural shocks, for some of the world top emitters. Given that synchronized changes would be necessary to meet global climate change mitigation efforts, our aim is to understand if, and in which magnitude, a decrease in energy intensity should not be claimed as environmental improving, being its final effect on earth-wide emissions uncertain. Indeed, an observed reduction in energy intensity could be linked to increased offshoring of carbon-intensive production to emerging economies, that typically employ more polluting production technologies and export lower-end products associated with higher carbon emissions (Fan et al., 2021). Previous works have disentangled the role of changes in the production structure of an economy and within-sector efficiency improvements on the energy intensity through index decomposition analyses (IDAs) (Metcalf, 2008; Hardt et al., 2018; Voigt et al., 2014). Other papers investigated the possible implications of international trade on the study of emissions, analyzing the divergence between production-based and consumption-based emissions under different settings (Liu et al., 2016; Cohen et al., 2018; Bhattacharya et al., 2020). We first contribute to these literatures by introducing an IDA of changes in energy intensity which includes an offshoring factor to assess the dynamics of different countries. Moreover, to the best of our knowledge, this is the first attempt to dynamically estimate the effect of demand-invariant structural shocks on the evolution of energy intensity in a VAR framework. This should bring to a greater understanding of energy intensity’s contribution to the decarbonization of advanced economies, which may significantly vary when looking at carbon emissions from a different perspective.
Methods:We employ a two-step empirical procedure. First, we provide a new adaptation of the IDA proposed by Hardt et al. (2018) to evaluate, exploiting historical data, the possible role of offshoring of carbon-intensive production on observed energy intensity improvements. Decomposition techniques are used to quantify the impact of different factors driving changes in environmental

variables. In particular, for this analysis, we rely on the Fisher Ideal index methodology (Ang et al., 2004; Ang, 2015).
For the IDA, total final energy consumption annual data from 1997 to 2018, by country and by sector, are retrieved from IEA's World Energy Balances, while the global sectoral output embodied in domestic demand is as from the OECD Inter-Country Input-Output Tables. The sample of countries analyzed includes the United Kingdom (U.K.), Italy, the United States (U.S.), Germany, China, and India.
We then investigate the dynamic relationship between demand-invariant structural shocks and the evolution of energy intensity. The analysis exploits a multivariate empirical macroeconomic methodology and employs annual data. Specifically, we estimate structural VAR (SVAR) models for the sample countries in the period 1970-2020.
In order to proxy the demand-invariant structural shocks in the estimation, we exploit the divergence between production-based and consumption-based CO_2 emissions, sourced from the Eora multi-regional input-output database. Indeed, a structural variation in the production structure unmatched by the final demand clearly leads to a change in the divergence between the two measures, allowing us to appreciate the possible role of offshoring in the achievement of environmental quality improvements. Consumption-based emissions are those associated with the final demand of each country, while production-based emissions stem from the country's economic activity. A statistical index tracking the time-varying divergence between these two variables provides, therefore, a measure of how much emissions associated with a country's final demand differ from those associated with its production, and of how this heterogeneity varies over time. Opting for a pure computational measure and controlling for other standard drivers which may be responsible for a divergence between the two different measures of carbon emissions (i.e., a proxy for structural effects and a proxy for within-sector effects) assures us about the long-term exogeneity of the shock. Moreover, using a carbon emissions divergence measure to assess the impact of structural shocks on energy intensity is empirically motivated by the lack of similar data with respect to the energy use, which calls for the use of alternative strategies to capture these effects.
The permanent shock is identified through the zero long-run restrictions (Blanchard and Quah, 1989). Employing this framework, the impulse response functions (IRFs) from a shock in the emission divergence efficiently simulate a demand-invariant structural shock in the economy, whose effect on energy intensity is our main empirical interest. Moreover, we use historical decomposition techniques to quantify the contribution of these structural shocks in explaining the observed negative trends in energy intensity.
Results:Through the IDA adaptation of the structural factor, offshoring is shown to explain part of the reduction observed in the energy intensity of the U.S., the U.K. and Italy, suggesting that a great share of the reductions observed at the structural level can be attributed also to a greater reliance on imports of energy-intensive productions. On the other hand, the sectoral demand change, while still negative, has had a much lower influence on the overall decline in the structural effect, rooting for a lower relevance of an actual change in the sectoral composition of consumption. In the remainder of the countries, the sign of contribution is ambiguous throughout the time window of analysis, while a consistent negative contribution of the sectoral composition of demand is observed (Figure 1).
This result is further reinforced by the IRFs coming from the SVAR model estimation, which analyse the dynamic evolution of energy intensity. Indeed, a permanent shock in the divergence measure for emissions leads to a persistent decrease in the energy intensity in some of the advanced economies in the sample (i.e., U.K., Germany and U.S.). As a consequence, part of the decreasing in the energy intensity observed in the last decades may be attributable to structural variations caused by the offshoring of energy intensive activities. Conversely, the results for developing countries report an increase in the level of energy intensity due to a positive shock in the divergence measure. Indeed, in these countries we are simulating a structural variation with an opposite sign to what would be observed after a demand-invariant structural shock. As a matter of fact, China and India are characterised by the most carbon-intensive production processes. This would imply that any offshoring of carbon-intensive production that is not mirrored by changes in the demand's structure would rather lead to a decline in consumption-based with respect to production-based emissions, thereby reducing the divergence. As a consequence, the outsourcing of activities for these countries should be simulated with a negative shock in the divergence measure as it is built in this paper (Figure 2). Looking at the historical decomposition confirms the IRFs' findings, since the contributions of the shocks in the dispersion measure are significant negative drivers of energy intensity for the U.S. and Germany (Figure 3).
Hence, in the absence of these demand-invariant structural shocks, it would not be possible to totally explain the observed decreases in energy intensity, building a case for the need to complement emissions' measures in the assessment of economy-specific progresses towards decarbonization.
Conclusions:The main intuition of the paper is that demand invariant structural shocks (here proxied with the divergence between the two main measure of carbon emission) may have a not negligible

impact on the evolution of the energy intensity of some of the developed economies included in our analysis. Therefore, switching the perspective from which emissions are accounted may affect inferences on energy efficiency improvements in most developed economies. The related implications are straightforward: the two approaches to measuring emissions should always be treated as complements, to provide a complete overview of environmental degradation phenomena from a global and a far-reaching perspective.

More specifically, the role of energy efficiency improvements in the decarbonization processes observed, at the country level, in many developed and emerging economies, may weaken when considering that consumption-based and production-based emissions diverge (i.e., a country's change in the production structure may not be mirrored by changes in the consumption patterns). This implies that, at the global level, emissions' reduction targets should also account for the role of consumption in the attainment of environmental improvements. Emissions' reduction targets posed at the consumption-based levels of emissions could then work as an implicit carbon tax.

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Keywords: Energy Intensity, Decomposition, SVAR, Emissions Accounting

Figure 1

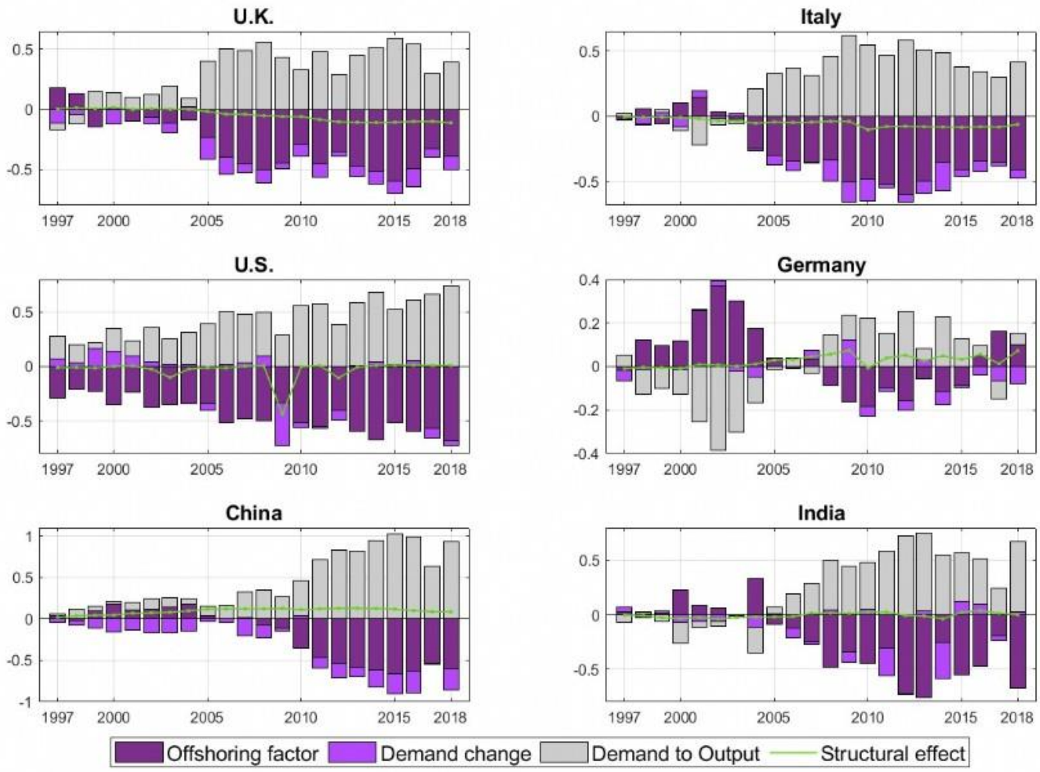

Figure 1 represents the results of the index decomposition analysis of the structural effect for tUnited Kingdom, Italy, United States, Germany, China and India between 1997 (base year) and 2018, through an adaptation of the methodology by Hardt et al. (2018), which includes also an offshoring factor. This allows us to isolate any link that may have occurred between the change in the structural effect and the reliance on offshoring. Source: authors' elaboration on IEA, OECD ICIO and UN data (2021).

Figure 2

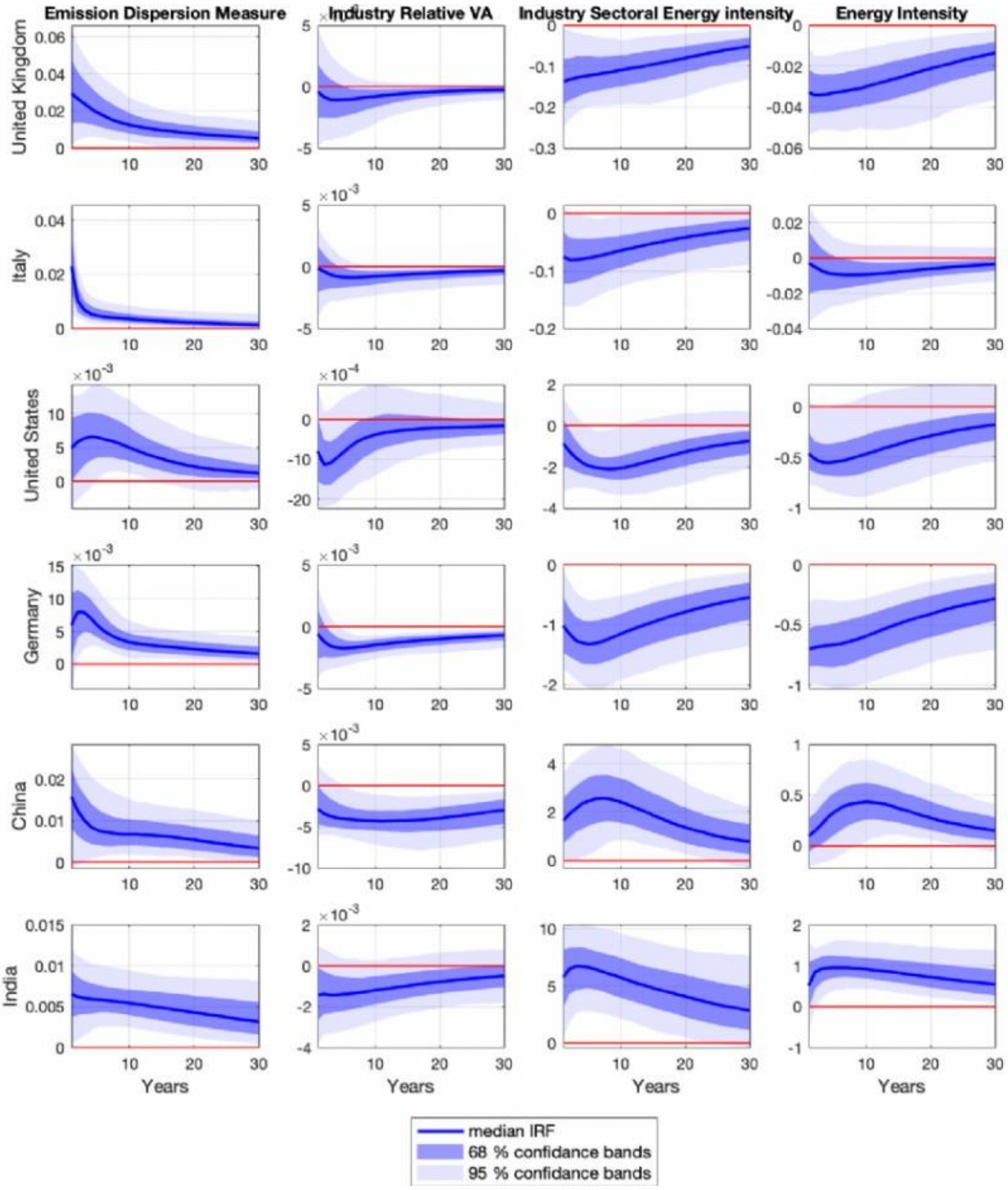

Figure 2 represents the structural impulse response functions to a one standard deviation shock in the divergence measure for: United Kingdom, Italy, United States, Germany, China and India. Shocks have been identified using zero long-run restrictions (Blanchard and Quah, 1989). Source: authors' elaboration on Eora MRIO data (2021), IEA data (2021), UN Data (2021).

Figure 3

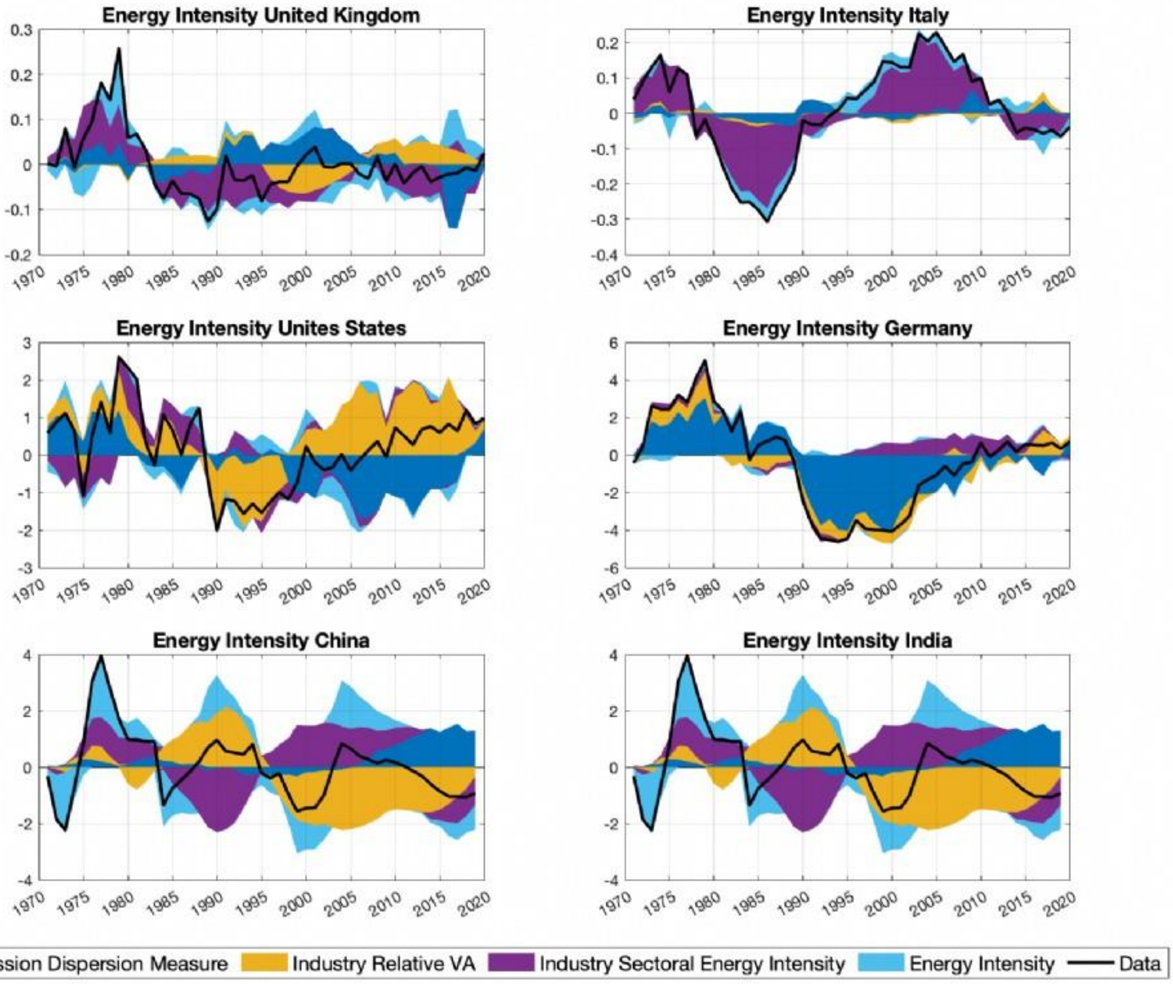

Figure 3 represents the results of the historical decomposition for the variation in energy intensity for United Kingdom, Italy, United States, Germany, China and India. Source: authors' elaboration on Eora MRIO data (2021), IEA data (2021), UN Data (2021).

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[Abstract:0030] OP-277 [Accepted:Oral Presentation] [Energy Finance and Trading » Other]

Climate Change and Corporate Financial Performance

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Overview:Climate change and global warming have led to extreme weather events, such as floods, droughts, and rises in sea levels. The negative repercussions to affected economies are substantial,

with output losses affecting longer term growth potential, investment, employment, and hindering goals towards sustainable development and poverty eradication. Without appropriate action on climate and reducing greenhouse gas emissions, the economic effects of climate change on economies will continue to worsen, making it increasingly important to understand and anticipate the impact of climate change risks (Dell et al., 2014). This paper examines the impact of climate vulnerability on firm performance, with a focus on the People's Republic of China (PRC), with a particular focus on firms located in climate-vulnerable coastal areas and firms located in more affluent Chinese provinces.

The channels through which climate change affects corporate financial performance are well documented in the literature. Sun et al. (2020) notes that the risks of climate change affect corporate financial performance through both direct, or physical risks, and indirect channels. Direct impact includes: core operation implications (e.g. damage of production materials and infrastructure), value chain effects (e.g. disrupted supply of raw materials), infrastructural effects (e.g. damage to transportation, communication, and energy supply networks). Indirect impact includes: climate-related financing constraint (e.g. carbon pricing and other climate-related policies), reputational considerations (e.g. proportion of investors focusing on ESG), and legal matters (e.g. changes in law or regulations related to climate change).

The majority of the prevailing literature highlights the negative impact of climate change exposure on corporate financial performance. Cevik and Miryugin (2022) note the difficulty for nonfinancial firms in climate-exposed countries in accessing debt financing, while also making the point that these firms are less productive and less profitable than firms in countries with less vulnerability to climate change. Wu et al. (2021) found that greater corporate climate risks lead to negative market reactions in the PRC. Other studies have pointed to positive impacts on corporate performance due to adopting more environmental practices in their business models (e.g. Secinaro et al., 2020). Sun et al. (2020) encourages firms to adopt low-carbon strategies and proactively disclose emission information to improve corporate brand value and create new competitive advantages for long-term development. In other work, Ziegler et al. (2011) found a relationship between disclosed corporate responses to climate change and stock performance has been positive for energy firms in the US.

There is a large and fast-growing literature studying the potential economic impacts of climate change. However empirical research studying firm-level impacts of climate change remains relatively scarce. In addition, the existing empirical literature based on firm-level data often uses a country-level climate vulnerability measure (e.g. Acevedo et al., 2020). Such a measure may not be a sufficiently accurate measure for firms' climate exposure assessment, especially in large countries like the PRC. While difficulties in gathering data on firm-level climate exposures remain, it needs to be borne in mind that firm-based analyses using country-level climate exposure measure should be interpreted with caution (e.g. Bernstein et al. 2019; Hong et al. 2019; Choi et al. 2020)

Focusing on the PRC, this paper empirically investigates the impact of firms' climate change exposure on corporate financial performance using a firm-level panel dataset of 173 firms over the period Q1 2018 to Q2 2022. In particular, this paper exploits a climate change exposure and management score measured at firm-level, which is a more comprehensive measure than that used by Wu et al. (2022). More specifically, we use two measures of firms' climate change risks: (i) The Financial Times Stock Exchange (FTSE) climate change exposure score and (ii) FTSE climate change management score. Our results show a significant negative impact of firms' climate change exposure on their rate of return, especially in the long term. The impact is stronger for firms located in coastal areas and in high income provinces. The empirical results imply that activities to reduce climate change exposure (such as integration of climate risk considerations into business models and implementation of emission reduction initiatives) could improve firm performance.

Methods:To investigate the effect of climate change on corporate financial performance in the PRC, we employ a firm-level fixed effects panel model over a sample dataset of 173 Chinese listed firms from 14 provinces. Our dataset spans the period from 2018 to 2022 with a quarterly frequency. Due to variations in levels of economic development and environmental conditions across different provinces in the PRC, we further include three sub-panels in the analysis: coastal provinces, top 25% GDP per capita provinces and top 50% GDP per capita provinces.

The main dependent variable of interest is Return on Assets (ROA), which is used to measure corporate financial performance. ROA is a widely accepted financial performance metric that reflects a firm's profitability and efficiency in generating returns from its assets (Gallego-Álvarez et al. 2014; Sun et al., 2020; Cevik and Miryugin, 2023).

In order to capture the impact of climate change on firms' financial performance, we employ two firm-level variables: (i) climate change exposure score and (ii) climate change management scores data extracted from the FTSE database. The FTSE climate change exposure score measures a company's relevance to climate change-related risk and is largely determined by industrial activity and operational presence. The FTSE climate change management score evaluates a company's efforts and strategies in managing climate-related risks and opportunities.

Results:This research obtains two important results.

First, firms' climate change exposure and negative impact on corporate financial performance. However, the effect is statistically significant only over a longer time horizon. On the other hand, the impact of climate change management on firm performance is not statistically significant at all. It could be the case that the commitments made by firm on climate change mitigation and adaptation and disclosure practices (such as corporate climate change policy, the integration of climate considerations into business strategies, the implementation of emission reduction initiatives, and the level of transparency in reporting climate-related information) are outweighed by the negative effects of exposure, or are simply not sufficiently material to be reflected in firms' financial performance. Second, the negative impact of firm's climate change exposure on firm's financial performance is relatively stronger for firms located in coastal areas and in higher income per capita provinces. The key message from our findings relate to motivating action by firms on climate, which would both boost their own financial performance but also help to contribute to the achievement of wider global goals on transition to net zero carbon emissions and sustainable development.
Conclusions:The lag with which climate exposure affects firm performance implies that firms must be forward-looking and proactive in their efforts at alleviating their exposure to climate change. While climate-related events may not have detrimental impacts on ROA in the short-term, complacency in taking affirmative action should be avoided. As climate-related exposure affects firm performance via macroeconomic and related channels, taking time to materialize, a longer-term perspective on incorporating climate risks into business models will be key. This is particularly the case for firms in coastal and more affluent provinces. Other specific measures should aim to reduce greenhouse gas emissions, improve food security through sustainable agriculture, and enhance the access to affordable, reliable, sustainable and modern energy.
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Common factors behind companies' environmental ratings

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Overview:The surge in sustainability interest in economics and finance has led to the widespread adoption of Environmental, Social, and Governance (ESG) metrics. These metrics, expressed as ratings, rankings, or indices, assess a firm's ESG performance. However, inconsistencies among data providers are not just definitional but also arise from disagreements on measuring ESG factors (e.g., Berg et al., 2022; Billio et al., 2021).
This paper takes a unique approach, positing that ESG metrics can be modeled as a combination of a structural nonrandom part and random interference, expressed as ESG data = structure + noise. The focus is on understanding if a few reference variables can model ESG metrics and if these variables are comparable across data providers.
To identify such possible common structure, we employ three complementary empirical approaches, i.e., correlation analysis, principal component analysis, and panel data regressions. The goal is a nuanced understanding of the structural components shaping ESG metrics, with a focus on the Environmental Pillar, facilitating insights into the available data.
This analysis could be of relevant use to companies, financial institutions, practitioners, scholars, and policymakers, enabling them to focus on a more concise set of information for analyses and decision-making in their respective fields.
Methods:DATA. To investigate the presence of common structures in ESG rating systems, we create an extensive dataset gathered from several sources. We consider three commercial databases, among the most widely used and adopted: MSCI, Moody's, and FactSet. 'MSCI-ESG Scores' service provides ESG ratings for a global cohort of approximately 14,000 issuers since 2007. Moody's 'DataLab' offers ESG rating information for more than 5,000 globally listed companies since 2005. Lastly, FactSet's 'TruValue' service provides ESG ratings relative to a group of around 230,000 worldwide enterprises since 2007. For each provider, we have access to the ratings, the intermediate product indicators, and the documentation with the process of aggregation of the underlying factors. The joint dataset used for the analysis results from our merger of information from these three providers. To ensure the unique identification of companies across databases, we employed the International Securities Identification Number (ISIN) as a standardized key, addressing disparities in company names due to abbreviations, translations, and punctuation. Then, to explore the evolution of ESG ratings over time, we structured the data in a panel format, retaining the last rating within 12 months of the fiscal year-end for firms with multiple ESG ratings. The final dataset is an unbalanced panel comprising ESG ratings from three data providers for 5,128 listed companies across 70 countries over 16 years (2007-2022).
The newly merged dataset considers the differences in the depth of their structures among the three providers (see Table 1 in the attached document). For instance, MSCI adopts four levels of analysis,

Moody's five levels, and FactSet, with three levels, lacks an aggregate in-built score for environmental, social, and governance pillars. Metric ranges also vary, with MSCI on a 0-10 scale and Moody's and FactSet on a 0-100 scale. Even when examined at the same level of analysis, the databases exhibit divergent summary statistics (see Table 2), emphasizing the necessity of nuanced analysis and data normalization for accurate cross-database comparisons, and revealing intricacies in granularity, scale, and topic coverage. In our analysis, we focus on the E (Environmental) score and its sub-scores across the different providers.

Empirical strategy

To identify potential common structures among Environmental scores from different providers, we employ three complementary empirical approaches. These methods aim to explore whether E scores and sub-scores within the same provider exhibit higher correlations compared to those with other providers. For instance, if we find that E sub-score 1 of provider A is correlated with E sub-score 2 of provider B, we could have a hint at the existence of common factors among raters. On the other side, common factors would not be there if we find that E sub-score 1 of provider A is only correlated with the other sub-scores within the same provider.

First, a pairwise correlation analysis establishes descriptive links between E (sub-)scores of the different providers, testing whether sub-scores are more correlated within providers.

Second, we employ a PCA, which reduces data dimensionality to identify common components. This analysis investigates if the most relevant components align with the E sub-scores from the same data provider or if they are influenced by factors common across two or three providers.

Third, leveraging the panel structure, we conduct OLS fixed effect regressions in two ways. On the one side, we use E scores as dependent variables and test the significance of E sub-scores from the same and other data providers. Looking at the significance and magnitude of the estimated coefficients, we can identify those E sub-scores that are significantly and positively correlated both with E scores and sub-scores of other providers, thus being eligible to act as common factors. On the other side, we use E sub-scores as dependent variables and E sub-scores of the same, and other providers as main regressors. In this way, we can further test whether these variables can act as common factors, that is when the relationship between these identified E sub-scores is positive and statistically significant.

Robustness is tested by including various fixed effects and alternative ways of clustering standard errors in all analyses.

Results:Correlation Analysis

Findings from the correlation analysis among the E sub-scores of each data provider (see Table 3) show that a positively mild level of correlation (i.e. > 0.5) emerges only for one pair of scores from the same provider, while the correlation coefficient is approximately zero or negative in most of the other cases (i.e. < 0.25 in 85% of occurrences). Considering a potential pool of common factors, we document only a small number of cases (15% of the total) for which there emerges a modest correlation (between 0.25 and 0.50) across providers, limitedly to MSCI and Moody's.

PCA

All the PCAs based on the different experiments highlight a relatively high number of selected components, due to a relatively low level of correlation of scores across providers (see Table 4 – Panel A). When we look at the core analysis, that is the performed including all the E sub-scores, we find that the E sub-scores driving each of the selected components are in most cases of the same provider, while we find only two components sharing indicators from different providers (see Table 4 – Panel B, Columns 1 and 4). In particular, 'Natural Resources in production' from Moody's seems to emerge as a potential common E factor across data providers, linking indicators from MSCI ('Natural Resources') and FactSet ('Ecological Impact').

Panel Fixed Effect Regressions

All the regressions including as dependent variables the E scores and as regressors the E sub-scores of the same providers show positive and significant coefficients (see Table 5). When we study the relationship between the E score of one provider and the E sub-scores of the others only, we still find a positive and significant relationship when considering MSCI and Moody's (the same cannot be tested for FactSet since it does not provide a built-in E score). When we also introduce the E sub-scores of the same provider, the coefficients of the other E sub-score are not statistically significant in most cases, thus providing evidence of the absence of common factors. A few exceptions emerge, namely MSCI Environmental Opportunities, MSCI Climate Change, Moody's Natural Resources in production, and FactSet Water Waste, with all these indicators sharing the fact that are the one mostly related to quantitative measures for environmental performance. When we focus on the relationships among these relevant variables (see Table 6), we find that these indicators are positively and significantly related only in the case of MSCI Environmental Opportunities with Moody's Corporate Environmental Strategy and with Moody's Natural Resources in Production, providing

evidence on the limited role of common environmental factors in our setting. Overall, the results arising from the three analyses highlight a divergence of ESG scores, since most of the E sub-scores are correlated with other indicators of the same data providers. However, one common factor seems to be emerging around the most 'quantitative' characteristics of companies' performance such as their emissions and their production strategies. Conclusions:The rising interest in sustainability within economics and finance has driven the adoption of ESG metrics. This paper contributes to the literature investigating the (in)consistencies among ESG data providers. Based on a unique dataset merging data from three providers, we model ESG metrics as a combination of a structural nonrandom part and random interference, seeking commonality among them. Through three empirical approaches—correlation analysis, principal component analysis, and panel data regressions—we investigate potential shared structures in Environmental scores across MSCI, Moody's, and FactSet. In broader terms, we confirm the presence of disparities in line with the literature (e.g., Berg et al., 2022; Billio et al., 2021; Gibson Brandon et al., 2021). At the same time, we highlight the emergence of a common factor within the Environmental scores, particularly linked to quantitative performance measures, such as the use of natural resources. These findings hold implications for companies, financial institutions, scholars, and policymakers, urging a focused, nuanced approach to ESG analysis and decision-making.
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Price Discovery and Volatility Spillover in Natural Gas International Markets: Pre- and Post-Russia-Ukraine War Analysis

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Overview:Russia and Ukraine together are prominent exporters in the world. The Russian invasion of Ukraine on 24th February 2022 has led to economic sanctions in the US, Europe, and elsewhere in the world. Further, supply chain distortions amplify the upsurge in commodity prices. In this process, one particular energy product 'Natural gas' has come into focus. Before the Ukrainian invasion, 40% of the European consumption of natural gas was supplied by Russia. The European countries transit from energy consumption through gas pipelines to LNG imports from across the world. This has led to an immense transformation of international gas market dynamics, with analysts and market participants calling it the "new oil". Whereas, Gazprom from Russia has diverted its gas exports to Kazakhstan. The present study analyses shifts in gas market integration pre and post-Russia- Ukraine war. It further examines information transmission between international natural gas markets pre-and post-war. There is an emerging body of literature on the impact of Russia-Ukraine

war on the financial and commodity markets around the world. Prior empirical work investigates stock market and commodity reaction to the Russian-Ukrainian war and finds that post-invasion crisis intensity is noticeably smaller compared to both the Covid-19 and the Global Financial Crisis (See Izzledin et al., 2023). Also, the volatility dynamics of S&P GSCI show that the volatility-of-volatility had been rapidly dying down before the war, subsequently taking a longer time to die down after the invasion (See Chen et al., 2023). Inacio Jr. (2023) finds a significant difference in prices for the pre- and post-war period and also suggests a higher impact of the war on European diesel prices compared to the US diesel. The existing literature does not focus on the integration and transmission of price signals between the international gas markets due to asymmetrical sanctions across the world. Different nations hold different strategic positions towards the war keeping their energy security in mind. In this context, it is important to study the markets that are aligned and the ones that no longer receive price signals from the world market. In our study, we examine the cointegration of the international gas market pre- and post-war. Apart from evaluating the structural shifts we also evaluate short-term adjustment process. The short-term and long-term volatility transmissions between these international gas markets are also examined.

Methods:The present study analyses future contracts on five major international gas markets, namely, NYMEX Henry Hub Natural Gas Energy Future (HH), Intercontinental Exchange Natural Gas Energy TTF Future (TTF), Russian Trading System Natural Gas Energy Future (RTS), Multi Commodity Exchange of India Natural Gas Energy Future (ING) and Intercontinental Exchange UK NBP Natural Gas Energy Future (NBP). The international markets have been selected due to their prominence in the international markets as major Exporters and Importers. We ignore Japan Korea Marks Platts in our analysis. Although, it reflects the spot market value of cargoes delivered ex-ship (DES) into Japan, South Korea, China, and Taiwan and equates to the majority of global LNG demand, but it doesn’t have a liquid future contract.

The study works on the data comprising daily closing futures prices for natural gas of five international markets mentioned earlier. The future price series has been constructed using daily closing future prices of near-month contracts for all markets. The future price series has been compiled for the data period from 6th February 2020 to 25th August 2023. This period is divided into the pre-war period from 6th February to 23rd February 2022 and the post-war period from 31st March, 2022 to 25th August 2023. All the future price series are non-stationary and future return series are stationary. The findings for stationarity test are given in Table 1, Panel A and Panel B for Pre-and Post-War period respectively. The future price series is tested for cointegration using the Johansen cointegration test. The study examines the short-term adjustment process for the pre-and post-war period between markets using the Vector Error Correction Model (VECM). Appropriate lag has been selected for both periods using AIC and SIC criteria. The pre-and post-war mean spillovers, shock transmission and volatility spillovers for all the five Natural Gas markets are studied using VAR(1)-BEKK-GARCH (1,1).

Results:The findings show that there exists long-term equilibrium relationship between all five gas markets. Also, in the post-war period the International Natural gas markets are in long-term equilibrium with four significant cointegrating equations according to the Trace test and two significant cointegrating equations according to the max-eigen value test. The results of Johansen cointegration test are shown in Table 2 Panel A and Panel B for trace test and Max-Eigen value test for pre-and post-war period. Thereby, all the markets are in long-term equilibrium irrespective of invasion by Russia. The results of VECM are shown in shown in Table 3 Panel A for Pre-war period and Panel B for Post-war period. In the Pre-war period, there were significant adjustment error correction terms for three markets, namely, HH, RTS and TTF. Whereas, in the post-war period the error correction terms are significant for four markets, namely, HH, ING, RTS and TTF. Also, the post-war period shows a prominent change for the TTF market. TTF market in the Pre-war period saw a significant causal 1-day lag effect from ING, NBP market, 1-day and 2-day lag effect from its own market and after Russian invasion the TTF market has significant causal lagged effect from all gas markets. The results indicate greater integration for the TTF market.

The VAR(1)-BEKK-GARCH(1,1) results are given in Table 4. The volatility spillovers in the pre-war period and post-war period show significant changes in spillovers across the international market. The findings show that for the pre-war period, the cross-mean spillovers are not significant for any of the markets except for transmission from TTF to HH and NBP to HH. Whereas for the post-war period, cross-mean spillovers are significant between all the markets except from TTF to RTS, NBP to RTS, and NBP to TTF. Also, own market mean spillovers are significant for HH and ING markets. Upon examination of the pre-war period, it is interesting to note that there is no significant shock transmission from any of the Natural gas markets to the HH market. Whereas there is significant shock transmission from HH to all the markets. Also, significant transmissions are observed from ING to all markets except HH. Bidirectional significant spillovers exist between ING and RTS, ING and NBP. Also, there are no significant spillovers from TTF to other markets. In the post-war period, there are significant spillovers from TTF to all the markets. Also, all natural gas markets show significant shock transmission to the HH market. The results show significant bidirectional spillovers

between HH and ING, HH and RTS, ING and RTS, ING and TTF, ING and NBP, TTF and NBP. The study also observes unidirectional short-term volatility from TTF to RTS. Going further, the findings of long-term volatility spillovers between cointegrated markets reveal that in the pre-war period, all coefficients on the diagonal are significant. Also, for off-diagonal coefficients volatility transmission is significant for all markets except from ING to RTS, ING to NBP, RTS to ING, TTF to HH, and NBP to HH. Whereas in the post-war period, all long-term volatility transmission relationships between markets turn significant except from ING to RTS, TTF, NBP, and from RTS to TTF.
Conclusions:The study shows the presence of long-term equilibrium between all the Natural Gas markets in the pre- and post-war period. The VECM results show further integration of the TTF market with other Natural gas markets in the post-war period. The reason for such realignment can be the suspension of Natural Gas imports from the Russian pipeline, and the import of LNG from different importers across the world. Significant mean spillovers across the Natural gas markets in the post-war period. Further, the cross-market shock transmissions from all markets to HH became significant. Also, short term transmissions from TTF to all other markets became significant in the post-war period. Natural gas markets which traditionally were linked to regional and physical dynamics signal a shift and convergence towards globalization.
The study has important implications for policymakers, as it helps them in understanding the international gas market dynamics. The results can also be of interest to investment managers, to formulate appropriate hedging strategies.
The study can be further extended to analyse the impact of the Israel-Hamas war (October, 2023) on Price discovery and spillover in Natural Gas markets. The war can have substantial impact on shipment costs and energy supplies to the rest of the world and thereby effect convergence in the Natural gas market.
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Emerging Economics and Policy Research Priorities for Enabling Investment and Financing of Climate and Energy Initiatives

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Overview:-

We highlight key emerging research priorities for enabling climate and energy investments using a three-pronged approach. It includes examining journalistic reports from a research perspective, corroborating the determined research priorities with recent literature, and consulting a diverse group of experts in policy, energy, economics, and sustainability fields. We delineate ten overarching themes that correspond to distinct research challenges and prospects. Specific emerging research issues related to – (i) examination of investment disparities, political factors, and geopolitical strategies in the sphere of clean energy and climate investment; (ii) an exploration of the challenges, opportunities, and geopolitical considerations in climate financing, particularly for developing countries; and (iii) an assessment of the economic impacts of, and adaptations to, climate change risks – received particularly high scores, computed by integrating expert ratings on importance in enabling climate and energy investments, novelty and feasibility using a multi-criteria decision-making framework. This research agenda is expected to yield valuable insights for policymakers and industry decision-makers, with the objective of facilitating increased investment in climate and energy initiatives.

Methods:-

We first derive overarching themes by summarizing and categorizing the wide-ranging scope of recent media investigations pertaining to the climate and energy investment reported in the Financial Times (FT) between July 2023 and September 2023. We start off with media reports as they frequently shed light on nascent industry, energy economics, policy, and sustainability issues before they are thoroughly examined in scholarly literature. This can be attributed to the delays inherent in securing research funding and the time-consuming peer-review process that characterizes academic publishing. Furthermore, media reports frequently incorporate perspectives from non-academic stakeholders, often underrepresented in scholarly articles. Finally, we delineate specific research challenges and priorities that require more thorough consideration by applying an energy economics and policy research lens (including academic and industrial) on the formulated emerging themes.

We solicit expert opinions to prioritize the identified research challenges surveying a diverse group of international experts in policy, energy, economics, and sustainability fields. The participants were asked to evaluate the identified research challenges and opportunities using a Likert-type (one to five) scale, assessing their importance, novelty, and feasibility. The respondents were also asked to rate the significance of each criterion, i.e., importance, novelty, and feasibility, relative to one another. Furthermore, data was gathered pertaining to the professionals' affiliations with either non-profit or for-profit entities, their educational credentials, years of experience, and their level of familiarity with the research subjects under examination in this survey.

The expert survey results were analyzed using a multi-criteria decision making (MCDM) framework. AHP (Analytic Hierarchy Process) (Saaty 1988) was used to calculate the weight scores for the three criteria – importance, novelty and feasibility – by having respondents make a series of pairwise comparisons. TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) (Hwang et al. 1981) was used to rank the different alternatives based on their normalized scores – a measure of the extent of similarity between alternatives and the hypothetical ideal solution (with importance, novelty and feasibility ratings of five each) - considering AHP-based criteria weights. Given the subjective nature of the expert survey, it would have been better to use AHP for both deriving weights for criteria and ranking alternatives. From a time perspective, however, requiring respondents to make pairwise comparisons between twelve alternatives appeared impractical. A sensitivity analysis was performed using three different schemes to calculate the weighted average of the ratings given by the experts for use in the TOPSIS framework, including: (i) equal weighting, (ii) experience-based weighting, and (iii) familiarity-based weighting.

Results:-

Table 1 displays the identified set of contemporary research challenges, their respective rankings based on the normalized AHP-TOPSIS scores, and the sensitivity of these rankings to the selected weighting scheme. Bold ranks indicate issues that scored the highest. Overall, the results are fairly robust as 3 out of 9 alternatives encounter a maximum change of two ranks only across three weighting schemes.

"Table 1 comes here"

Conclusions:-

This work systematically explores the multifaceted challenges and emerging research priorities pivotal for enabling the climate and energy investments. By delving into diverse themes, it provides a comprehensive analysis of the current state and future directions of research.

By employing three distinct respondent weighting schemes within the AHP-TOPSIS framework, we identify key emerging issues in enabling climate and energy investments that are critical in terms of importance, novelty, and feasibility. Among the high-ranking research challenges that merit in-depth exploration include – (i) examining investment disparities, political factors, and geopolitical strategies in clean energy and climate investment; (ii) challenges, opportunities, and geopolitical considerations in climate financing for developing countries; (iii) assessing economic impacts and adaptation to climate change risks.

While this study offers a broad overview of the issues at hand, it acknowledges certain limitations. The rapidly evolving nature of emerging issues in climate and energy investments field implies that findings might require continual updates. Moreover, the reliance on expert inputs, although valuable, may not fully capture the diversity of perspectives in this global industry.

This work contributes to the field by offering a structured framework to analyze and prioritize research areas in climate and energy investments. It bridges the gap between academic discourse and practical application. In particular, the delineated priorities could serve as a potential roadmap for guiding forthcoming research endeavors within both the industrial and academic domains. Research findings from such initiatives may yield practical recommendations for policymakers and industry stakeholders, consequently fostering the formulation of strategies aimed at expediting the investments in climate and energy initiatives. In conclusion, the emerging issues identified through journalistic reports, a review of published literature, and expert consultations provide a solid foundation for identifying the imperative research priorities required to facilitate increasing investments in climate and energy initiatives.

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Keywords: Energy investment, Climate investment, Climate finance

Table 1: Expert ratings-based ranking of potential research challenges, considering 3 cases: (a) equal weights, (b) respondent experience-based weights, and (c) respondent familiarity-based weights. The rankings were obtained using the combined AHP-TOPSIS

Alternatives	Equal weights	Experience based weights	Equal weights
Challenges and Opportunities in Climate Change Mitigation Investment • Competitive dynamics within the clean energy industry, including how global competition, especially from China, influences the investment prospects • Why only 5% of global clean hydrogen projects have received	5	6	5

final investment decisions and how policy can create demand certainty to solve the problem • Short- and long-term impact of government policy signal on investors to invest in renewables and oil & gas extraction to balance climate and energy security priorities			
Dilemmas in Oil & Gas Investments & Financing Amidst Climate Change Concerns • "Prisoner's dilemma" for financial institutions on divesting before "peak oil," including exit strategies, economic (dis)incentives, and risks • Credibility assessment of UN specialists' concerns on banks violating human rights law due to climate change impacts from banks' financing of oil and gas industry	9	8	9
Exploring Climate Finance Instruments and Strategies • Lessons learned from past blended finance initiatives, across varied regional and contextual settings, accounting for local conditions, regulations, and market dynamics • Comparing Development Impact Bonds (DIBs) with traditional grants, loans, and public-private partnerships as climate finance instruments: advantages and limitations • Appeal for donor-advised funds (DAFs), which give donors immediate tax breaks while letting them choose when and how charities receive their donations, to be channeled into impact funds for positive social and environmental outcomes • Whether transition financing, which helps carbon-intensive companies go green, aids energy transition for the entire economy or divert funds from green energy companies	6	5	6
Oil Funds' and Companies' Investment Strategies Amid Energy Crisis Windfalls, Climate Risk, and Diversification • Role of - (i) sovereign wealth funds, like Norway's oil fund, Saudi's PIF, (ii) oil and gas companies' diversification strategies, and (iii) their windfall profits from energy crisis – in advancing climate investment and finance • Impact of OPEC's oil price stabilization on investor sentiment, risk perceptions, and investment decisions in historical and energy transition context • Comparing major oil companies' climate investment strategies, particularly in the context of receding supply threat brought by Russia's invasion of Ukraine	7	7	7
How Climate Change Economic Impacts Are Shaping Investor and Government Adaptation Strategies • Evaluating whether economic impacts of climate change-related risks are appropriately valued in investors' asset valuations Insurance industry's losses and adaption to climate change, and strategies to maintain insurance affordability in high-risk areas • Property value assessments in cities with high heat risk, particularly in low-income regions, and climate change adaptation costs • Examining the need for reorienting economies to adapt to increasing heatwaves	3	4	3
Climate Finance in Developing Countries: Challenges, Opportunities, and Geopolitics • Challenges for developing countries with limited green	2	1	2

investment resources and risks to their companies' global competitiveness from carbon border adjustment taxes • Opportunity cost of allocating developing countries' limited financial resources to mitigation instead of adaptation, and elsewhere including healthcare, education, etc. • Geopolitical implications of using climate financing in great power competition, and how it could influence international climate cooperation • Feasibility, effectiveness, and legality of nature-rich global south countries' sellers' clubs, like OPEC, to negotiate fair biodiversity and carbon credit prices in international markets • Investigating the UN's capacity to manage more and complex climate finance initiatives, focusing on transparency, accountability, and duplication reduction			
Climate Finance for Developing Countries • Effectiveness, challenges, and benefits of global green bank, temporary pause clauses for loan repayments during climate-induced disasters, and concessional financing type mechanisms for climate action in developing countries • Progress on countries' climate finance pledges to developing nations, including challenges and potential consequences of not meeting them • Examine effectiveness of measures implemented by institutions like the World Bank to increase lending to poor countries for addressing climate change • Risks and benefits associated with guarantee programs and their potential to encourage investments in climate-related projects in developing nations	4	3	4
Policy Impacts on Clean Energy and Technology Investments • Reasons for disparities in investment between European clean technology start-ups and their US counterparts following U.S. IRA • Factors influencing majority of IRA-supported clean energy project investments in Republican congressional districts, despite their opposition and anti-ESG rheoteric • How U.S. Treasury IRA tax credit guidelines for power usage cleanliness for green hydrogen may affect investment decisions, project viability, and sector growth • Climate investment impacts of China's measures to maintain geopolitical leverage from its dominance in the clean technology mineral supply chain and Western countermeasures	1	2	1
ESG Integration and the Pushback: Implications for Climate Finance • Trade-offs involved in incorporating ESG criteria and climate-related considerations in the stock selection process within investment portfolios • Factors driving the anti-ESG investing push and short- and long-term implications of companies and financial institutions adapting their strategies and messaging in response • Case studies on ESG shareholder proposals to determine if the reasons cited by major asset managers for rejecting proposals as "overly prescriptive" are supported	8	9	8
Impact of Auditing Practices on Climate-Related Investments • How financial reports' inclusion/omission of climate-related risks and opportunities affects investors' decisions, company valuations, and financial markets	10	10	10

• How auditing practices can encourage responsible corporate behavior and investments			

[Abstract:0179] OP-281 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Other]

Evaluating criticality of strategic metals: Are the Herfindahl–Hirschman Index and usual concentration thresholds still relevant?

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Overview:The ongoing global energy transition, aimed at reducing greenhouse gas emissions and shifting towards low-carbon technologies, has led to substantial demand for specific metals and minerals. Consequently, the availability of metal and mineral resources has become a central concern in the energy transition dynamic, as these resources could potentially become limiting factors to net zero ambition in the future. Within this context, correctly measuring the criticality of minerals and metals is crucial.

In response to the renewed interest in the security of metal and mineral supplies, multiple criticality assessment methodologies have been developed to identify materials of concern and assist decision-making processes, drawing on the pioneering work of the National Research Council (2008) and the European Commission (2010). Two key aspects are commonly used as criteria to identify critical raw materials: (i) their economic and/or strategic importance, and (ii) the likelihood of supply disruptions, often referred as supply risk. However, the measurement of these criteria varies from one study to another, from the selection of the indicators used to the way they are aggregated. The absence of a standardized theoretical framework for criticality measurement and the proliferation of such studies has led to the emergence of a distinct field in the scientific literature reviewing the various criticality assessment methods. It is commonly observed that certain indicators lack sufficient relevance. Therefore, experts and researchers recommend identifying best practices, primarily through acquiring more robust empirical evidence on widely used indicators.

This paper tackles this crucial issue. Specifically, it aims to empirically assess the validity of the country production concentration indicator, which is the most used indicator for evaluating the supply risk of a specific material. The rationale behind using such an indicator is that as the production of a given raw material becomes more concentrated in a few countries, the likelihood of supply disruptions increases due to various factors, including economic, political, or environmental considerations.

The Herfindahl–Hirschman Index (HHI) is the dominant measure for assessing this indicator. The HHI is a widely recognized measure of market concentration, calculated by summing the squares of individual firms' market shares, thereby assigning greater weight to larger market shares. It was initially developed in the field of industrial organization to assess market structure and quantify market power and has since been extensively used, particularly in the field of competition law. In this context, the US Federal Trade Commission has established benchmark values to identify markets of concern: markets are categorized into three groups based on the HHI—unconcentrated markets (HHI below 1500), moderately concentrated markets (HHI between 1500 and 2500), and highly concentrated markets (HHI above 2500). Mineral criticality studies frequently incorporate these thresholds when using the HHI to quantify production concentration, even if their relevance in this

context has not been proven.
The second objective of our study is to examine whether a threshold exists within the HHI values to assign the criticality of specific non-fuel minerals.
Methods:Our analysis focuses on evaluating the HHI of countries' production concentration as a reliable indicator for measuring supply risk, specifically in distinguishing between different materials. Furthermore, we aim to analyze the presence of a distinct threshold in the HHI values for assigning the criticality of particular metals. Based on the hypothesis that metal prices can indicate to some degree their criticality, we rely on a panel regression analysis to examine the impact of HHI on metal prices. The use of a panel data framework provides the significant advantage of working with a sizable dataset, thereby enhancing the statistical robustness of our findings. Furthermore, it is necessary to rely on a panel data approach because using a single metal's HHI values over time is insufficient for determining a consistent threshold due to their limited variability.
To address our research questions, we consider several panel regression models. The first model examines the effect of an annual change in HHI on the annual metal price fluctuation. In the other models, we introduce two dummy variables to differentiate the effects of an HHI variation on prices based on the HHI level or/and the magnitude of this variation. These variables are defined based on threshold values. Therefore, including a dummy variable based on the level of the HHI can provide evidence of the existence of a threshold within the HHI values. This is achieved by evaluating the model for different threshold values. Differences in the results could be a positive indication of a threshold.
Results:The study emphasizes the importance of considering both the concentration level and the extent of concentration variation when examining the impact of metal production concentration on prices. The results show that there is a threshold for the HHI values (2 700) and a threshold for the magnitude of the HHI variation (10%) that delineates different regimes of metal price fluctuations. Additionally, we find that the effect of HHI on metal prices is more pronounced for lower HHI levels. Within the scope of our analysis, the dummy variable that captures the magnitude of the annual variation of the HHI can be considered a proxy for disturbances or shocks to material production. A minor fluctuation in the HHI indicates the absence of market disruption, while a substantial fluctuation signifies market disturbance. A significant HHI shift can be traced back to a sudden drop in major producers' production or a decline in output from smaller producers, which magnifies the dominance of the leading producer. Consequently, our findings indicate that a disruption in markets with lower concentration positively affects prices but has a negative effect in markets with higher concentration. Under the assumption that a major commodity producer can more easily reduce the HHI in the short term by lowering production than increasing it, market participants may view a negative impact as riskier. This is due to the potential increase in prices resulting from the decisions of a few key players. This underlines the rationale for avoiding excessively concentrated commodity markets. Nonetheless, a disruption has a greater impact in less concentrated markets compared to their more concentrated counterparts in absolute terms. This apparently paradoxical result can be explained by the stabilizing effect on prices provided by cartels' market power.
Conclusions:The HHI applied to world production of a given commodity by country is a fundamental component of most raw material criticality assessments. This operates on the premise that analyzing mineral supply concentration is crucial since increased concentration heightens the potential risk of supply disruption.
In the present paper, we rely on a large panel of 33 metals to analyze the influence of HHI on market prices. Interestingly, our results challenge the commonly held assumption since they indicate that the variation of HHI has more impact on prices at lower HHI levels. Furthermore, our findings question the existence of a threshold that clearly distinguishes high-risk markets from less risky ones based on their concentration levels. Hence, using the HHI as a supply risk indicator, especially in conjunction with a threshold, may result in underestimating risks in less concentrated markets. Additionally, our paper highlights the importance of assessing the potential for fluctuations in production concentration, since it directly influences the impact of HHI on prices. This variable, which poses a challenge to measurement, has yet to be included in studies on criticality.
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Keywords: Strategic metals, Criticality, Herfindahl–Hirschman Index, Metal prices, Panel regression

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[Abstract:0672] OP-282 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Energy Security]

Zero Emission or Net Zero Emission Scenario! Which One Is Good for Sustainable Development?

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Overview:This work will address the concept of global energy security and the need to adopt a more realistic approach to address the 3 factors of global economy, social development and environmental protection. IEA unrealistic 2050 zero emission roadmap and the announced Oil and Gas industrdy's net zero emession target by 2050 and thier impact on Economic Growth and Sustainable Development, including Human Development Index, Lifestyle and Energy Poverty indices.
Methods:Environmental challenges associated with Fossil Fuels Energy sources have been recognized by the Oil & Gas Industry as the most critical and strategic challenge facing, he industry in the 21st century. Whether the industry has recognized this challenge as the main source of the Climate Change, as prescribed by the environmentalist, or not, no one can deny the fact that emissions, mainly Methane and CO2, are not good for health and environment. Hence, the industry has shifted its denial strategy into more proactive strategy calling for addressing both Methane and CO2 emission associated with the Oil & Gas Industry, or what is called category 1 and 2 emissions. Since then, the industry, unofficially, articulated a Methane emission reduction and Decarbonization strategy calling for an immediate near-zero Methane flare strategy and net-zero CO2 emission by 2050. IEA has developed its unrealistic 2050 net-zero emission roadmap which reflect zero emission rather than net zero emission strategy. This work will address both strategies and highlight the main differences between them focusing more on the impact of each on Economic Growth and Sustainable Development, including Human Development Index, Lifestyle and Energy Poverty indices. Furthermore, the net-zero CO2 emission strategy will be highlighted through the industry’s effort to arrest the CO2 through a comprehensive decarbonization roadmap including the current and future required technologies. The paper will highlight the positive impact and need of adopting the Net Zero Emission strategy and the Oil and Gas Industry's effort towards a comprehensive Net Zero Emission roadmap including the current and future technologies to achieve the 2050 Oil and Gas Industry's announced Net Zero Emission target.
Results:The need for the global sustainable energy security to continue enriching the global economy, social sustainable development while arresting any environmental impact of fossil fuel led by oil and gas.
Conclusions:The energy industry has no choice except to collaborate together to scale up the current decarbonization technologies and develop new advanced technologies to further arrest any environmental impact of fossil fuel led by oil and gas.
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Keywords: Energy Security, Decarbonization of oil and gas, UN SDGs, Zero Emission, Net Zero CO2 and Methane Emission

AuthorToEditor: This can be considered for Energy Security, Energy Transition and/or Decarbonization of Oil and Gas technical sessions.

[Page: 283]

[Abstract:0571] OP-283 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Regional Analysis (Europe)]

Modelling the implications of the European Critical Raw Materials Act on the value chain of lithium: can European sovereignty be achieved without sufficiency?

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Overview:Achieving raw materials security of supply has become a top priority for governments and policymakers worldwide. In the European Union (EU), interest in raw materials deemed "critical" and "strategic" to the EU economy has strengthened over the past 15 years. This is due to recent crises that have disrupted supply chains and the growing needs associated with the energy transition dynamic. Previously focusing on evaluating the criticality of materials, in 2023 the European Commission has proposed policy objectives aimed at addressing this issue. The Critical Raw Materials Act (CRM Act) [2] sets targets for domestic extraction, processing, and recycling, as well as diversification of foreign suppliers, which will apply from 2030, to ensure the security of supply of strategic raw materials (SRMs). Battery-grade lithium is particularly crucial among the SRMs, as the EU heavily relies on imports, and demand is soaring to meet the needs for batteries used in electric vehicles, energy storage, and digital technology. The aim of this article is to assess the feasibility of the CRM Act for lithium, alongside complementary industrial policies that impose minimum local battery production requirements. Currently to the best of our knowledge, no paper has been found on this particular issue. Several prospective scenarios are modelled to explore technological and demand-side options that can help achieve the EU objectives. A special focus is put on the recycling of lithium from electric vehicle batteries, trying to establish coherence between the many European policies on this subject and assessing its potential contribution to the European lithium supply. Finally, a geopolitical analysis of the scenarios is carried out, focusing on the use of imports in the European lithium value chain and the associated supply risks that need to be anticipated.
Methods:This study is based on the TIAM-IFPEN global energy system model, which integrates a wide range of existing and future energy technologies competing to meet the energy demand of all sectors in each of the 16 different regions represented [4]. The model used was designed to optimize the evolution of the energy system by following a least cost paradigm, while respecting several

constraints including the limitation of global warming to 2°C in 2060. The methodology adopted for this study involves endogenizing the detailed value chain of lithium in this model, including some links with the detailed road transport sector. The initial stage of the value chain involves mining lithium from existing deposit types (granitic rocks and salars) as well as other deposits currently under consideration (sedimentary rocks, geothermal brines and oilfield brines) [7]. Subsequently, we model various processing routes to produce lithium concentrates and chemicals such as carbonate, hydroxide, chloride, lithium metal, and other compounds, which are necessary for manufacturing industrial products [5, 9]. The production costs of the different routes vary depending on the technology type and world region. These costs were determined based on feasibility studies of current and planned lithium production projects. The lithium used in batteries is endogenously linked to the deployment of electric vehicles. The amount of lithium in each battery is determined by its chemistry and size, based on data from Argonne National Laboratory [8]. The other uses, which represent less than 10% of the total lithium uses by 2050, are projected exogenously. The vehicles modelled in the road transport sector are derived from the IEA's 2023 APS Mobility Model. The model allows for trade between the 16 different regions at different stages in the lithium value chain (concentrate, chemical, battery), with different transport costs associated to each product and each transport route.

To investigate the impact of the CRM Act on the European supply of lithium, we model several scenarios. The first one, S1, referred to as 'Economic Efficiency', serves as a control case and does not impose the CRM Act objectives for the optimization process. The second one, S2, or 'European Objectives', includes these targets. S3, also known as 'Sustainable European Objectives', proposes additional assumptions for sufficiency in the road transport sector. These include increasing the load factor and occupancy rates, reducing mobility and freight demands, and decreasing the average battery size for personal cars and light commercial vehicles. S4 'Full sovereignty over domestic battery needs', while still assuming sufficiency hypotheses, aims to achieve complete domestic production of batteries, meeting 100% of the EU's electric vehicle needs from 2030 onwards. Finally, S5 'Limited industrial sovereignty' abandons the sufficiency hypotheses and reduces efforts towards achieving industrial sovereignty over domestic battery production. We model exogenous assumptions for the evolution of end-of-life recycling rates, differentiated by region. In Western Europe, the recycling rate is projected to reach 26% by 2028 and 49% by 2031, in line with the combined targets for collection and recovery rates set by the New Batteries Regulation [3].

Results:On a global scale, we find that the cumulative primary lithium extraction required by 2060 could amount to 37% of the resources identified in 2023. The current major producers, South America and Australia, could account for more than two-thirds of cumulative production, followed by Africa and China. In the S2 scenario, Western Europe emerges as the next largest cumulative producer, while the US takes this position in all other scenarios. Due to increased recycling and slower demand growth, global primary lithium production could peak between 2038 and 2047 at around 800 kt per year in the scenarios without sufficiency assumptions in Western Europe.

For Western Europe, one of the main findings is that the CRM Act's target of domestic processing production of 40% of European lithium demand cannot be met in scenario S2. Achieving this objective would necessitate the development of further lithium processing capabilities, which carry a significant industrial risk. Thanks to the sufficiency hypotheses, Scenario S3 meets the objectives of the CRM Act without much difficulty, as does Scenario S4, which suggests that sufficiency could allow the EU to achieve full sovereignty over its battery production and still meet the objectives of the CRM Act. Alternatively, scenario S5 also meets the targets set by the CRM Act but does so at the cost of surrendering a significant portion of its sovereignty over battery production. With regards to the recycling aspect of the value chain, none of the scenarios can meet the recycling target of the CRM Act, which requires 15% of European processed materials to be covered by domestic recycling by 2030. The only scenario that comes close to meeting this target is S5, due to the reduced domestic production requirements for batteries. Finally, regarding imports, our results suggest that enforcing the CRM Act objective, in addition to increasing domestic production, may reduce reliance on imports of lithium chemicals (specifically battery-grade lithium carbonate and lithium hydroxide) from South America and China as compared to scenario S1. Instead, there could be a shift towards importing lithium concentrate that is further processed on European soil, primarily sourced from Australia and Africa.

Conclusions:Based on our findings, implementing the CRM Act would divert the European lithium supply from the most cost-effective path, which is explained by the higher production costs of European projects compared to foreign import costs. However, the purpose of the CRM Act targets is not economic, but rather to enhance resilience and sovereignty in SRMs production. The results further suggest that all the ambitious European objectives are unlikely to materialize in the medium term. This is due to the recycling targets around 2030, followed by the domestic processing target. Previous studies have highlighted inconsistencies and undesired effects of the recycling targets at different stages of the recycling chain, as they do not fully consider the lifetime parameter of batteries, for example [6]. The results indicate that reducing the industrial needs of battery grade

lithium is one way to decrease the supply risk of processed lithium. However, this approach may increase European dependence on imports for batteries and battery components, thereby shifting the burden of supply risk downstream.
Alternatively, the study also points out that implementing sufficiency policies in the road transport sector could significantly contribute to mitigating the supply risk inherent to European objectives on SRMs supply and industrial sovereignty, as indicated by previous prospective studies [1]. Furthermore, such policies could also bring many co-benefits, such as reducing the socio-environmental impacts of local mining and processing activities, decreasing air pollution from vehicle tires and brakes in cities, and lowering industrial CO2 and other pollutant emissions from electric vehicle manufacturing, which would require further investigation. Therefore, the lack of demand-side policies in the CRM Act and other EU legislation is a matter of regret. While material efficiency is often encouraged, sufficiency is largely overlooked. It is worth noting, nonetheless, that implementing policies to promote sufficiency would require comprehensive legislation that addresses various aspects of individual and collective lifestyles. This could involve rethinking urbanization, business spatialization to reduce the need for transportation and freight, promoting soft mobility, and encouraging the use of light vehicles.
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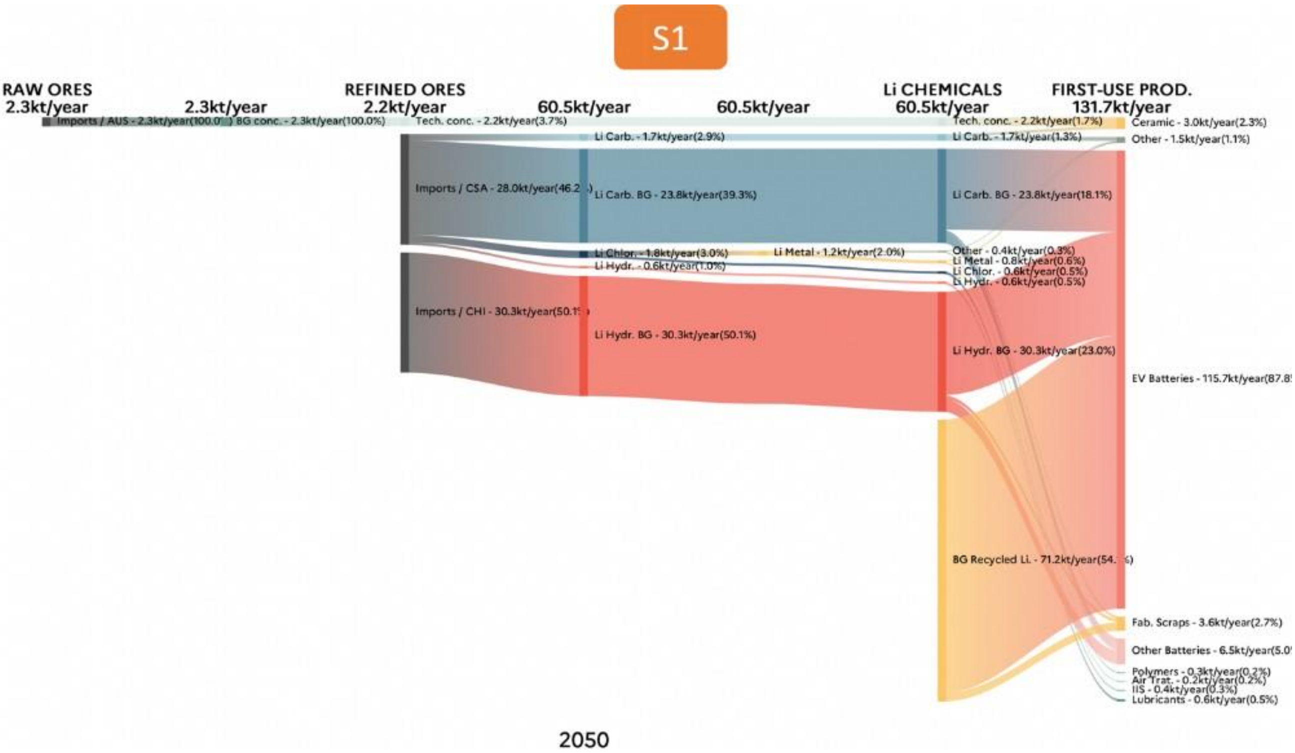
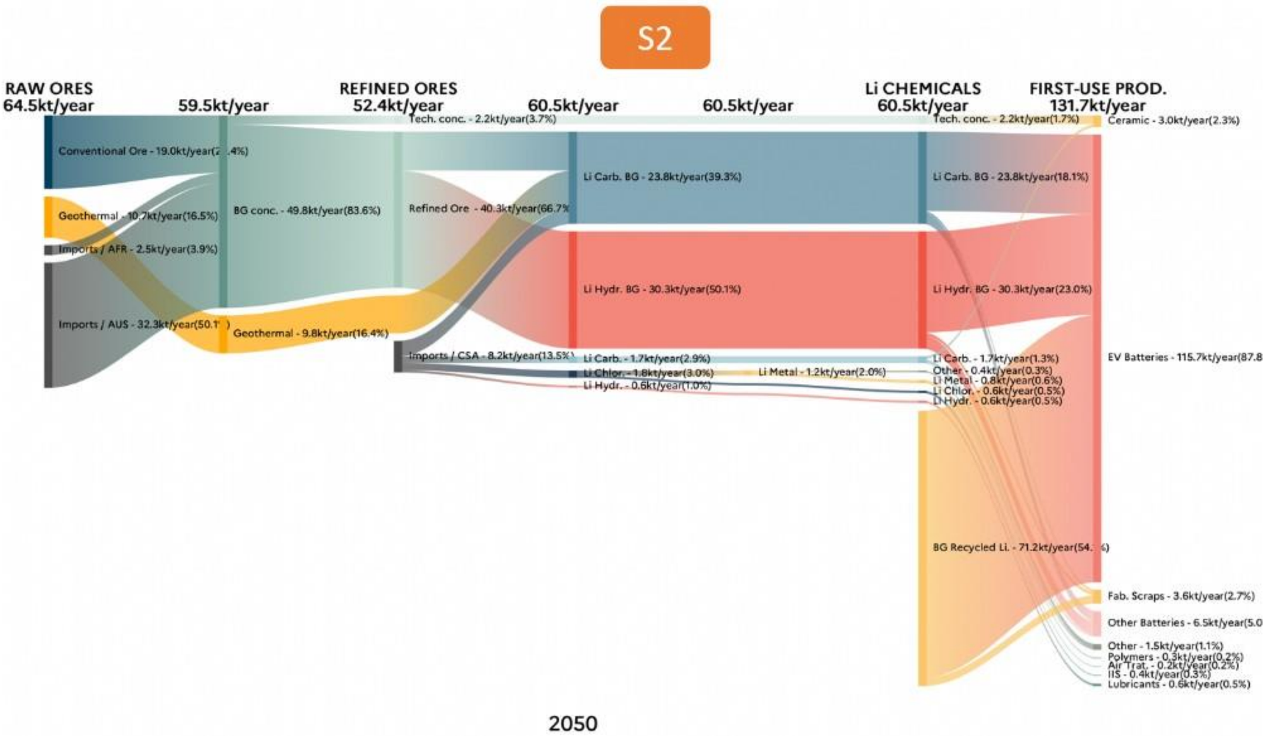
Keywords: Critical Raw Materials, Lithium, Prospective modelling, Geopolitics, Electric vehicles

Sankey diagram of the lithium value chain - Scenario S1 - 2050



Sankey diagram of the lithium value chain - Scenario S2 - 2050



Scenarios assumptions

	S1 Economic efficiency	S2 European objectives	S3 Sustainable European objectives	S4 Full sovereignty over domestic battery needs	S5 Limited industrial sovereignty
Global Warming	2°C	2°C	2°C	2°C	2°C
Percentage of battery needs produced on the European soil	90%	90%	90%	100%	40%
CRM Act	No	Yes	Yes	Yes	Yes
Mobility sufficiency assumption	No	No	Yes	Yes	No

Model assumptions for each of the 5 scenarios considered in this study.

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[Abstract:0670] OP-284 [Accepted:Oral Presentation] [Transportation » Electric vehicles & systems]

Enhancing Disaster Response through Electric Vehicles (DAETEM)

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Overview:In regions susceptible to natural disasters, the utilization of electric vehicles, commonly referred to as V2X, can play a crucial role in both initial intervention and subsequent support. The devastating earthquakes experienced in Türkiye in February 2023, resulting in significant loss of life, underscore the need to address seismic risks. Istanbul, specifically, is expected to face a magnitude 7 or greater earthquake, necessitating immediate and sustainable electricity delivery to disaster areas. This abstract focuses on leveraging electric vehicles for efficient post-earthquake response, encompassing the rapid supply of electricity, tools, equipment, medications, first aid materials, food, and essential necessities for relief efforts.
Methods:Given the seismic risk in Istanbul, particularly on the European side of the Marmara Sea coastline, proactive measures are imperative. The selected pilot project area is the İspark Yenikapı Square parking area, chosen for its proximity to heavily affected buildings, flat terrain, and accessibility to major roads and the coastline.
Project Components: The project comprises six main components: 1.) Solar Energy System (SES) 2.) Energy Storage System 3.) Electric Vehicle Charging Stations 4.) Electric Vehicles with V2L Feature 5.) Container-Mounted Display Unit 6.) Other Supporting Hardware
Solar Energy System: The İspark Yenikapı Square, covering approximately 11,500 m2, can accommodate a solar energy system with a capacity of around 1.72 MWp. This system is projected to generate about 2,000 MWh of electricity annually, with a significant output of 60,000 kWh in December alone. Excess electricity will be sold to the grid.

Energy Storage System: A 2 MWh capacity Energy Storage System, along with 10 units of 120 kW DC fast-charging stations, will be installed on a trailer. This system can simultaneously charge 40 vehicles, each with an average capacity of 50 kWh, in about half an hour. During a power outage, the system ensures a continuous supply by storing generated electricity.
V2G, V2H, or V2L Electric Vehicles: Electric vehicles can be charged using grid electricity. Vehicles with V2X capability can utilize the stored energy from the energy storage systems. Electric vehicles, continuously powered by solar energy, will be dispatched to disaster areas to meet urgent electricity needs.
Container-Mounted Display Unit: In times of disaster, communication interruptions can occur. A container-mounted display unit with a 360-degree rotating (or dual-sided) feature will be installed for public communication, guidance, announcements, and visual/audio information sharing during emergencies.
Other Supporting Hardware: Although not the main purpose of the project, containers containing essential items will be placed near the energy storage container. Container 1: Supermarket or storage (non-perishable food items, hygiene products, drinking water, etc.). Container 2: Equipment for initial intervention (tools, first aid supplies, stoves, etc.).
Summary of System Technical Specifications: 1.) 1.72 MW Capacity Solar Energy System in the form of a car park canopy 2.) 2 MWh Capacity Energy Storage System on a container-type trailer 3.) 10 Units of 120 kW DC fast-charging stations on the same trailer 4.) Electric Vehicles with V2X capability 5.) 6 x 3.5 m Container-Mounted LED Display Unit with 360-degree rotation 6.) Other supporting hardware/containers
Results:(Expected) Usage of DAETEM in Emergency Situations: Electric vehicles reach DAETEM within 1 hour, get charged, and then reach affected areas. Fully charged vehicles carry necessary equipment and materials from DAETEM-supporting containers to the incident site. With 10 vehicles charging per hour, dozens of vehicles (minimum 40, maximum 160) can be charged on the same day. Each electric vehicle, with its battery capacity, can store enough energy to meet the entire electricity needs of an average home for a week.
DAETEM can facilitate the operation of electric equipment such as drills and breakers, commonly found in the inventory of Istanbul Metropolitan Municipality's Fire Department. A single charge of an electric vehicle can power a 900 kW breaker for 50 hours or a 2.2 kW breaker for 20 hours.
In addition to electric vehicles assisting in search and rescue operations, they can also provide essential services to disaster victims in the following hours and days, including heating, lighting, cooking, and water heating. Vehicles with depleting energy levels can recharge at DAETEM from solar-powered storage centers.
Non-Emergency Use of DAETEM: The solar energy system is expected to generate approximately 2,000 MWh of electricity annually, resulting in a reduction of 900 tons of greenhouse gas emissions per year. The surplus electricity will be stored in the energy storage system and can be sold to the grid. Energy storage systems can provide a solution for electric vehicle charging in areas with limited grid access or where high-capacity charging devices are needed.
With 10 electric vehicles simultaneously charging, DAETEM, located on one of Istanbul's busy main arteries, can become a preferred charging location as the number of electric vehicles increases. The LED display can be used for advertising and promotional activities visible to passing vehicles and the surrounding area. Collaboration with supermarket chains or companies specializing in technical machinery sales can be considered for the installation of supporting hardware containers.
Project Potential for Development and Expansion: The continuous solar energy production and storage system will make electricity available at all times in the project area. Even if not directly related to the project, a field hospital or earthquake coordination and logistics center could be established in the same region.
While the project is initially designed for the İspark Yenikapı Square, it can be expanded to other İspark locations along the Marmara Sea coastline, especially in areas with a high earthquake risk. Given that many cities outside Istanbul are also in earthquake-prone regions, the project can be implemented in these regions as well.
Conclusions:The recent earthquakes in Kahramanmaraş resulted in significant human losses and injuries. It is well-known that earthquakes do not kill; poorly constructed buildings do. In Istanbul, a considerable portion of the building stock remains vulnerable to earthquakes. The presented project aims to address the critical need for electricity immediately after an earthquake, providing rapid and efficient energy delivery to numerous locations. This initiative has the potential to save lives and improve the living conditions of earthquake victims in the aftermath.
References:https://ispark.istanbul/park/15C277F6-EC49-4E78-A4E6-FB3DCCF67011

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https://www.mdpi.com/1996-1073/16/8/3580

Keywords: Electric Vehicles, Natural Disaster, V2X, Solar Energy, ESS, Fast Charging

[Page: 285]

[Abstract:0327] OP-285 [Accepted:Oral Presentation] [Renewables » Biofuels]

Necessary and sufficient conditions for the sustainability of biofuels in africa: a qca case study of uganda

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Overview:The growth prospects and sustainability of biofuels in Africa appears contingent on the degree to which new interventions are aligned with comparative advantage and strategies intended to enable African countries cope with the vagaries of climatic change. One prospective areas of intervention could be to direct the support towards enhancing biofuel sustainability ventures in within the African continent. The effectiveness of such an intervention is subject to the degree of appreciation of the necessary and sufficient conditions at play, in the growth of the biofuel subsector in low income countries.
Methods:The study applied the Qualitative Comparative Analysis (QCA) methodology whose logical foundation is traceable to the works of Mill (1967). Mill (1967) labeled the QCA a 'method of agreement' and a 'method of difference'. The former connotes circumstances in which the various occurrences of a phenomenon represent the commonality of an occurrence which is designated as the cause of an outcome. Mill (1967) further conjectured that, in order to establish the cause of specific phenomena, it starts with the identification of the occurrence of the phenomenon of interest, then working back to isolate the causal combination of the occurrence (Ragin, 1987) and ultimately ending in the search for patterns. The findings are buttressed by a cross assessment of the cases to establish the negation of both the cause and outcome. According to Rihoux & De Meur (2009) a configuration denotes a categorical combination of factors or stimuli that explain the presence of a specific outcome of interest. In configurational methodology, such ingredients, stimuli, causal conditions or determinants are labeled conditions (Ragin, 1987). As a result, the reference to making comparisons in the QCA methodology invokes the act of matching configurations. Anchored on a critical realist perspective (Bhaskar, 1978), case based research is understood to be comprised of complex configurations of actions, elements and structures (Ragin, 1997). Accordingly, the QCA methodology treats the study of case elements as exhibiting prospects of being similar or separate and affords effective space for comparison (Ragin and Becker, 1992). It assumes a holistic view of specific cases as comprising complex combinations of properties (Rihoux and Ragin, 2009).

Causal conditions were calibrated in line with the QCA criteria which guided the assignment of the individual set membership scores to the study cases (Schneider and Wagemann, 2012). Under the QCA, two approaches were applied. The first being an older version of the QCA (Ragin, 1987), the crisp set QCA (csQCA) which involved a dichotomous assignment of "1" or "0" values to the case members whose results are presented in Figure 02. The csQCA applied solely on sets whose cases reported full members or full non-members. The second and more contemporary version is the fuzzy set QCA (fsQCA) whose data scores were assigned on the basis of membership degrees scores falling between "1" and "0" subject to their respective position above or below the midpoint, for full membership or non-membership respectively. The fsQCA results summary is provided in Figure 01. Subsequently the truth table was generated as reflected in Table 10. The values in the truth table were further analyzed using the R SetMethods software (Oana Ioana-Elena, Schneider & Thoman, 2021) into configurations of the likely logical casual combinations which sought to explain the presence or absence of the necessary conditions for the sustainability of biofuels. An explanatory model was subsequently generated in line with the works of Ragin (1987), Rihoux and Ragin (2009) and Schneider and Wagemann (2012).

Finally, the model minimization was achieved through the deployment of the Boolean algebra to reduce the model expressions to such limits that revealed causal consistencies with theory. The Boolean minimization algorithm rule postulated that whenever two Boolean algebraic functions contradicted each other, with reference to the presence or absence of specific causal conditions under a similar outcome, such a causal conditions were deemed redundant and were thus dropped, leaving a minimized or more simplified combination of the model expression. The Boolean algebra ultimately enabled the study to express how the presence or absence of particular conditions contributed to the existence of the target outcome.
Results:The findings reveal that the status of the sustainability of biofuels in Uganda is defined by uncertainty and bounded rationality as the necessary and sufficient conditions respectively. The resultant implications of these conditions were the basis on which recommendations to minimize uncertainty and bounded rationality are suggested to inform policy actions towards the sustainability of biofuel products in low income countries.
Conclusions:The study found out that the transactional cost attributes set out under the transactional cost theory, overall satisfy the pre-requisites of a necessary condition that influences the commercialization of biofuel products. Special attention needs to be focused at minimizing the drivers of uncertainty which appears dominant in influencing the future of biofuel products in Uganda. The results also shed light on the increased levels of bounded rationality and accordingly satisfy the pre-requisites as a sufficiency condition for the commercialization of biofuel products in Uganda. Therefore any effort to address bounded rationality serves to increase the acceptance of the biofuel products across low income countries. This could be achieved through increased community awareness that seeks to highlight the function and benefits of biofuel products and ultimate commercialization. It also suggests the need for capacity building to enable the efficient use of assets and related technologies.
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Schneider, C. and Wagemann, C. (2012). Set-theoretical methods for the social sciences. a guide to qualitative comparative analysis. New York: Cambridge University Press

Keywords: Biofuels, Commercialization, Green fuels, Climate Change, QCA

AuthorToEditor: Sorry i could not upload my figures and tables as i could only convert into pdf which was not compatible with the required upload

[Abstract:0645] OP-286 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Regional Analysis (Africa)]

Energy Issues and Energy Transition: Case of Tanzania

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Overview:This study (discussion) is on selected energy issues and transitions in Tanzania. There are four key issues on energy and energy transition in Tanzania. First, it's the issue of energy transition itself in Tanzania.. like in many other developing countries, traditional and culture aspects is the major constraints in the transition to green energy in Tanzania. Despite massive efforts on the transitions, Tanzania is witnessing little uptakes of changing vehicles powering systems from fossils fuels to gas. While most of this emanates on limited centers for fixing the gas turbines as well as limited refiling stations, but culture and traditions plays a key role as well. In some situation, green energy projects can cause or exacerbate conflicts and tensions with the local communities as demonstrated in the southern Tanzania during the early days of natural gas exploration and production. This indicates that if investments are not done right, there is a significant risk of the green transition coming at the expense of conflict and suffering.
Secondly, power loss remains a major challenge in the energy sector in Tanzania. Power loss are split into transmission and distribution losses. Power system losses in Tanzania are still higher as demonstrated earlier, currently standing at around 16.4%.

Third challenge, is Low Energy Access. Electrification access in total is around 33%, with Urban access being 65% and rural access is 17%. Access to clean cooking is around 2%.
Methods:this is meant for the panel discussion
Results:this is meant for the panel discussion
Conclusions:this is meant for the panel discussion
References:this is meant for the panel discussion

Keywords: Energy Issues, Energy Challenges, Energy Transitions

AuthorToEditor: This submission is meant for the Panel Discussion and not subject for review

[Page: 287]

[Abstract:0666] OP-287 [Accepted:Oral Presentation] [Energy System Transition » Other]

Uganda's Perspective of the Just and Sustainable Energy Transition: Impact and Issues

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Overview:Uganda faces the complex challenge of navigating towards a just and sustainable energy system while balancing its energy resource needs for growth and the imperatives of the energy transition agenda. This presentation and discussion explores the impact and issues surrounding Uganda's energy transition journey, focusing on energy resource developments, policy dynamics, Uganda's transition with its oil, natural gas, and the East African Crude Oil Pipeline (EACOP), the threat of asset stranding, and Uganda's role in the supply chain of critical minerals.

The objectives of the presentation include to:
1. Highlight Uganda's energy resource needs for growth and analyze the challenges in aligning these needs with the goals of the energy transition agenda.
2. Highlight the developments in Uganda's energy resources, particularly focusing on renewable energy sources such as hydropower, solar, wind, and biomass, to support the transition.
3. Examine the policy and regulation dynamics facilitating Uganda's energy transition.
4. Discuss the case for Uganda transitioning with its oil, natural gas, and the East African Crude Oil Pipeline (EACOP), considering environmental sustainability, social-justice, and the potential threat of asset stranding.
5. Analyze Uganda's role in the global supply chain of critical or transition minerals, including lithium, cobalt, and rare earth elements, and explore sustainable extraction practices and responsible supply chain management strategies.
Methods:The paper methodology will involve a comprehensive literature and document review, including summaries of published data, reports, and scholarly articles pertaining to Uganda's energy transition, policy frameworks, resource developments, and global energy dynamics.
Results:The presentation highlights the following key points:

1. Emphasizes the importance of tailoring the energy transition agenda to meet country-specific needs, capacities, and capabilities, promoting equitable and socially just transitions.
2. Advocates for developing countries, including Uganda, to utilize their natural resources, including fossil fuels, to expedite growth and support their own energy transitions, emphasizing the role of economic growth in achieving sustainable outcomes compared to aid and donations.
3. Acknowledges Uganda's progress in renewable energy and the implementation of supportive legislation for the transition.
4. Identifies Uganda's significant contribution to the supply chain of transition minerals but notes challenges related to the fair distribution of rents.
Conclusions:Uganda's journey towards a just and sustainable energy transition is multifaceted, requiring home-grown holistic approaches and strategic interventions. To address issues related to energy resource needs, developments and fair distribution of rents and benefits from the supply chain of critical minerals. Uganda can navigate towards a more resilient, inclusive, and sustainable energy future by adopting home grown solution developed through local research and development to exploit its energy resources and achieve faster growth and the transition agenda.
References:Not needed yet

Keywords: Uganda, Energy Transition, Energy resource needs, Socially-Just, Sustainable

[Abstract:0334] OP-288 [Accepted:Oral Presentation] [Petroleum » Exploration and Production]

Analyzing the relationship between carbon emissions, GDP growth and petroleum production in Uganda

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Overview:The relationship between carbon emissions, GDP growth, and petroleum production is a critical aspect of understanding the environmental and economic dynamics of modern societies (Huang, 2021). As nations strive for economic development, the environmental impact of increased carbon emissions and reliance on petroleum becomes a significant concern (Mitić et al., 2023). This

is relevant as Uganda is on the verge of starting oil and gas production within a year (TotalEnergies, 2019). The estimated discovery is around 6.5 billion stock tank oil, of which 1.6 billion barrels Albertine graben in 2006 (TotalEnergies, 2019). Anticipations are that extracting oil may lead to increased emissions, adding to the global concerns about climate change (Huang, 2021). Furthermore, while petroleum production is expected to boost the countrys' GDP, it could also escalate environmental damage. However, existing literature lacks details on the precise emissions the petroleum project might contribute, leaving Uganda without robust policies to address this issue. Additionally, understanding how carbon emissions will impact the population's well-being compared to the benefits from the petroleum sector is crucial and needs further investigation (Huang, 2021). This research delves into the background and potential importance of understanding the connection between carbon emissions, GDP growth, and petroleum production in Uganda. The study involves evaluating both the benefits and drawbacks of petroleum production in Uganda, with a specific emphasis on the emissions associated with oil and gas extraction. The aim is to uncover the complexities of this relationship and highlight its implications for sustainable development. The primary focus is on proposing policy options that can improve the well-being of the population, both during and after the exploitation of these resources.
Methods:Addressing this matter involved a comprehensive review of existing literature, statistical analyses, and econometric modeling. A multi-faceted approach was employed to understand the intricate connections between carbon emissions, GDP growth, and petroleum production. The analysis incorporated data from the World Bank sources by examining CO2 emissions and GDP in Uganda from 1990 to 2020. Additionally, a Stock pollution model developed by Perman et al. for non-renewable resources was applied to determine the costs and benefits associated with Uganda's upcoming oil production, set to commence in one year from now. Techniques such as regression analysis were utilized to identify patterns, correlations, and potential causal relationships. The econometric models aimed to disentangle the complex web of factors influencing carbon emissions and GDP growth, with a specific focus on the role of petroleum production in Uganda.
Results:Key findings reveal that the petroleum industry, by its nature, has the potential to be environmentally harmful. During the exploration phase, significant environmental impacts include the loss and destruction of vegetation, along with emissions from combustion or gas flaring during exploration drilling. In the project development stage, activities such as constructing processing facilities, production drilling, pipeline construction, and commissioning put strain on social amenities like electricity, waste disposal facilities, and water supply, impacting the environment. Liquid waste discharge, especially in the production and refining stages, is also observed. Moreover, the industry contributes to climate change and global warming through air pollution from power and process plants, encompassing emissions like air, noise, light, vibration, and flaring, leading to the migration or displacement of wildlife.
Ancillary findings underscore the importance of policy interventions and technological advancements in influencing the trajectory of this relationship. Nations with diversified energy sources and robust regulatory frameworks tend to demonstrate a more sustainable pattern of development. Additionally, the results emphasize the significance of transitioning towards renewable energy sources to mitigate the environmental impact associated with petroleum production.
Conclusions:In conclusion, it is crucial to maximize the benefits of petroleum production in Uganda while minimizing carbon emissions. Achieving this involves advocating for targeted policies that support sustainable development by separating economic growth from carbon emissions. Policymakers and stakeholders must recognize the environmental impacts and prioritize sustainability in business policies, especially concerning greenhouse gas (GHG) emissions. Uganda should also adopt and enforce environmental policies like carbon taxation, carbon pricing, cap and trade, and similar measures to ensure sustainable economic growth. The environmental toll of heavily relying on petroleum for GDP growth underscores the urgency of transitioning towards cleaner energy alternatives.
The study offers several lessons for policymakers and stakeholders involved in environmental and economic decision-making. Firstly, there is emphasis on the importance of global cooperation in addressing climate change. This is because the interconnectedness of economies and environmental systems requires collaborative efforts to develop and implement effective strategies. Secondly, to achieve sustainable development there is need for a harmonious relationship between economic progress and environmental responsibility.
The next steps in research can involve further exploration of the specific mechanisms through which nations achieve decoupling, with a focus on policy frameworks, technological innovation, and societal attitudes. Additionally, continuous monitoring and evaluation of the effectiveness of existing policies will contribute to refining strategies and adapting to the evolving dynamics of carbon emissions, GDP growth, and petroleum production.
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TotalEnergies. (2019). Tilenga project Environmental and social Impact assement report submitted to NEMA, 2o19.: Vol. Vol 1.

Keywords: Carbon emissions, GDP growth, petroleum production and Uganda.

AuthorToEditor: The submitted abstract aims at Analyzing the relationship between carbon emissions, GDP growth and petroleum production in Uganda. This is motivated by the fact that as nations strive for economic development, the environmental impact of increased carbon emissions and reliance on petroleum becomes a significant concern (Mitić et al., 2023), which is relevant as Uganda is on the verge of starting oil and gas production within a year. Hope this will be put into consideration.

[Page: 289]

[Abstract:0221] OP-289 [Accepted:Oral Presentation] [Hydrogen » Production]

Techno-Economic Analysis of Floating Offshore Nuclear Systems for Hydrogen and Ammonia Production

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Overview:We implement a Techno-Economic Analysis (TEA) of an integrated floating offshore platform with a nuclear power plant driving production of low-carbon hydrogen and ammonia. The platform includes an electrolysis plant, a Haber-Bosch plant and an Air Separation Unit, as well as a desalination plant so that it can be fed from ocean water. The final product of the system is ammonia. The intermediate products are hydrogen, desalinated water, electricity, and heat. The system can be moored along the shore. Floating nuclear power plants have the potential advantage of lower nuclear power plant OCC (Overnight Capital Costs) due to modular mass production in shipyards. Methods:The TEA employs a discounted cash flow model to calculate a levelized cost of ammonia (LCOA). We use this model to identify the major cost drivers. We apply the TEA to four versions of the platform using different combinations of two types of reactors and two types of electrolyzers. The PWR and MSR reactors define the low and high extremes for delivered heat. The PEM and SOEC electrolyzers make different use of heat and electricity. The models employ identical desalination, air separation and ammonia synthesis units.

The economic analysis can also be structured by the flows of commodities from one facility to another. In doing so, we can calculate a levelized cost of heat (LCOH), a levelized cost of electricity (LCOE), a levelized cost of water (LCOW), and a levelized cost of hydrogen (LCOH2) and understand the LCOA as a product of these. In the case that high temperature steam electrolyzers are used, the system efficiency is maximized by recovering heat from the exothermic Haber-Bosch process and using it in the electrolysis process. Our TEA recognizes the value of this heat in determining the values of the component flows.

We marry the economic analysis with parameter inputs obtained from leading international authorities in the energy industry (NREL, IEA, EU Joint Research Centre etc.) as well as from widely cited academic literature providing TEAs of green ammonia or hydrogen systems. Where available,

projected parameters for the years 2030 and 2050 were also used to determine the competitiveness of the system in the coming decades.
Results:Based on preliminary results, for the 2023 Base Case parameters, the LCOAs produced by the system are 1,575 $/ton NH3 and 1,524 $/ton NH3 for PEM and SOEC electrolysers, respectively. The corresponding LCOH2s from the integrated platform are 7.70 $/kg and 7.40 $/kg for PEM and SOEC electrolysers, respectively. Both PEM and SOEC configurations have approximately the same LCOE of 106 $/MWh. By 2050, the LCOAs are expected to reduce to 1,140 $/ton NH3 and 842 $/ton NH3 for PEM and SOEC electrolysers, respectively. The corresponding LCOH2s are expected to reduce to 5.3 $/kg, and 3.6 $/kg, respectively.
Conclusions:The integrated platform LCOAs are high in comparison to the current market price of conventional ammonia, which is between 200-800 $/ton NH3 [1]. Underlying this is that the integrated platform LCOH2s are high in comparison to the current cost of conventional, natural-gas derived hydrogen, which is 1.0-2.5 $/kg H2 [1]. The most significant cost driver of hydrogen and ammonia production is electricity usage from the nuclear power plant, which has a very high LCOE due to the high OCC value assumed in the TEA model (8000 $/kWe). Using the Best-Case scenario for nuclear power plant OCC, which is 3500 $/kWe, by 2050, SOEC derived ammonia and hydrogen would cost 532 $/ton NH3 and 2.1 $/kg H2, respectively, finally achieving cost parity with conventional ammonia and hydrogen. It is evident that nuclear power plant OCC is currently the most significant cost driver of ammonia and hydrogen production and should be the focus of attention for future cost reduction considerations.

In terms of reactor choice, while MSR’s have higher thermal efficiencies compared to PWR’s, with their heat output better put to use in the High Temperature Steam Electrolysis (HTSE) process, based on our results, using only the exothermic heat from the Haber-Bosch process in the HSTE process is more economical, making the thermal advantage of MSR’s redundant [2]. As a result of this, the reactor choice type comes down to OCC on a $/kWe basis, and current studies show no conclusive evidence of whether either reactor type has lower OCC [3].

In terms of electrolyser choice, SOEC electrolysers are more efficient than PEM electrolysers, which results in lower electricity costs due to reduced electricity usage [4,5,6]; however, they also have higher CAPEX, degradation rates, and lower stack lifetimes [4,5,6], which makes their economic appeal depend on the values of these parameters. Based on 2023 Base-Case parameters, there is no conclusive difference between the economic appeal of SOEC or PEM electrolysers. By 2030, however, our result indicate that based on the projected parameters for both the SOEC and PEM electrolysers, SOEC electrolysers will be much more appealing, producing hydrogen at a significantly lower cost than PEM electrolysers.

The integrated floating nuclear platform concept shows some promise. Shipyard manufacturing of modular floating offshore nuclear power plants can reduce their Overnight Capital Costs by 20-25% [7,8]. The system can be moored to different locations worldwide depending on demand and political appetite. However, the high capital costs of the system, especially in terms of the nuclear power plant OCC, are still important barriers to their implementation, and should be addressed if these systems are to be widely implemented worldwide.
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Keywords: Hydrogen, Techno-Economic Analysis, Nuclear, Ammonia

Bar charts of LCOA cost drivers

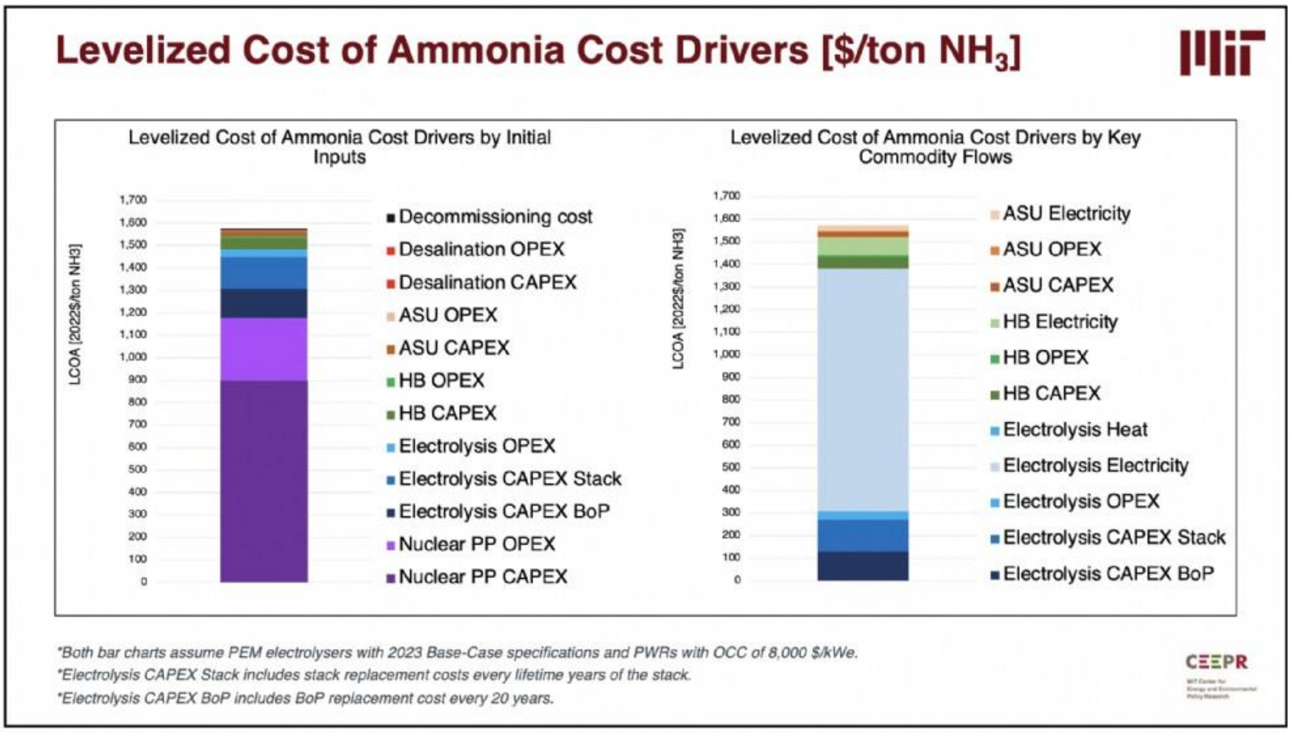

Diagram of floating offshore nuclear system for ammonia production

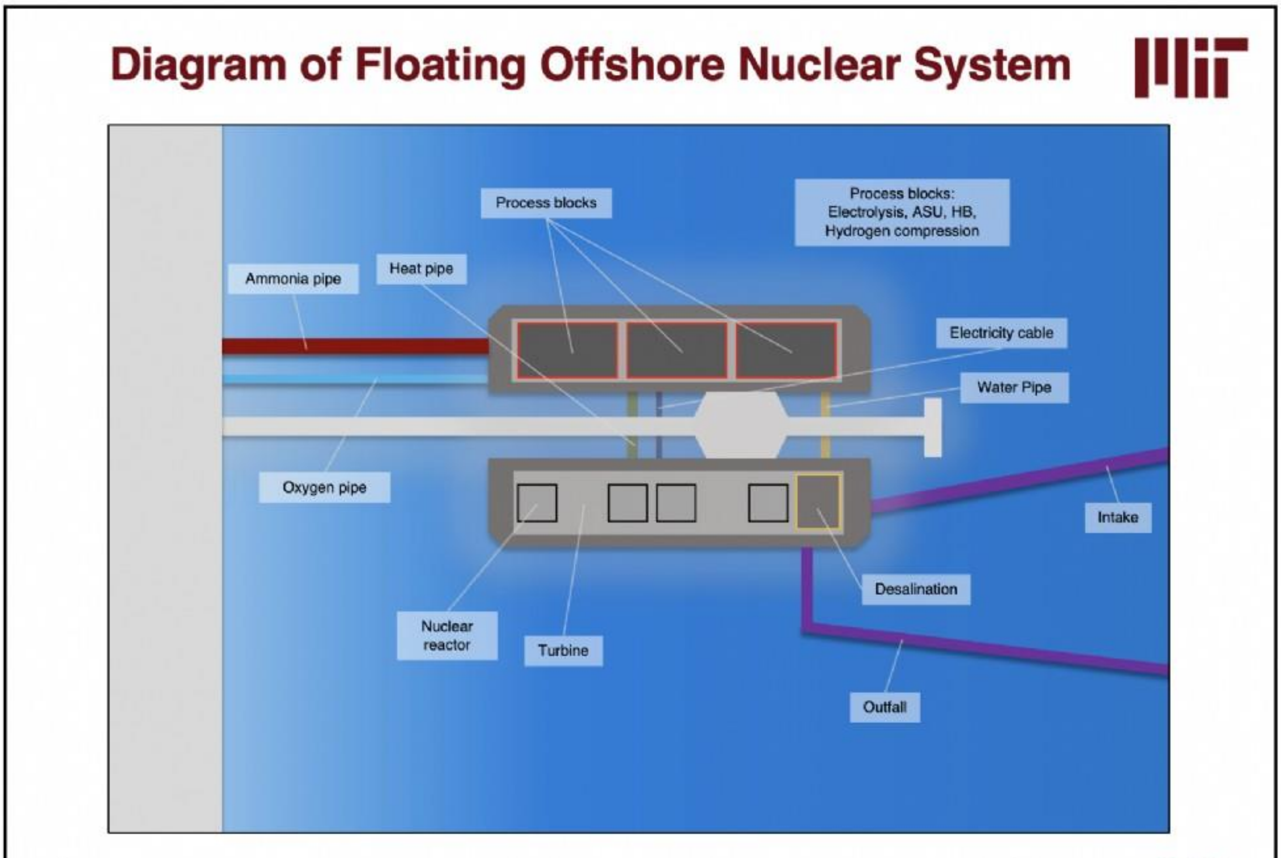

Figure: *Conceptual diagram of floating offshore nuclear system for ammonia production. Figure not to scale.*

Sankey diagram of LCOA cost flows

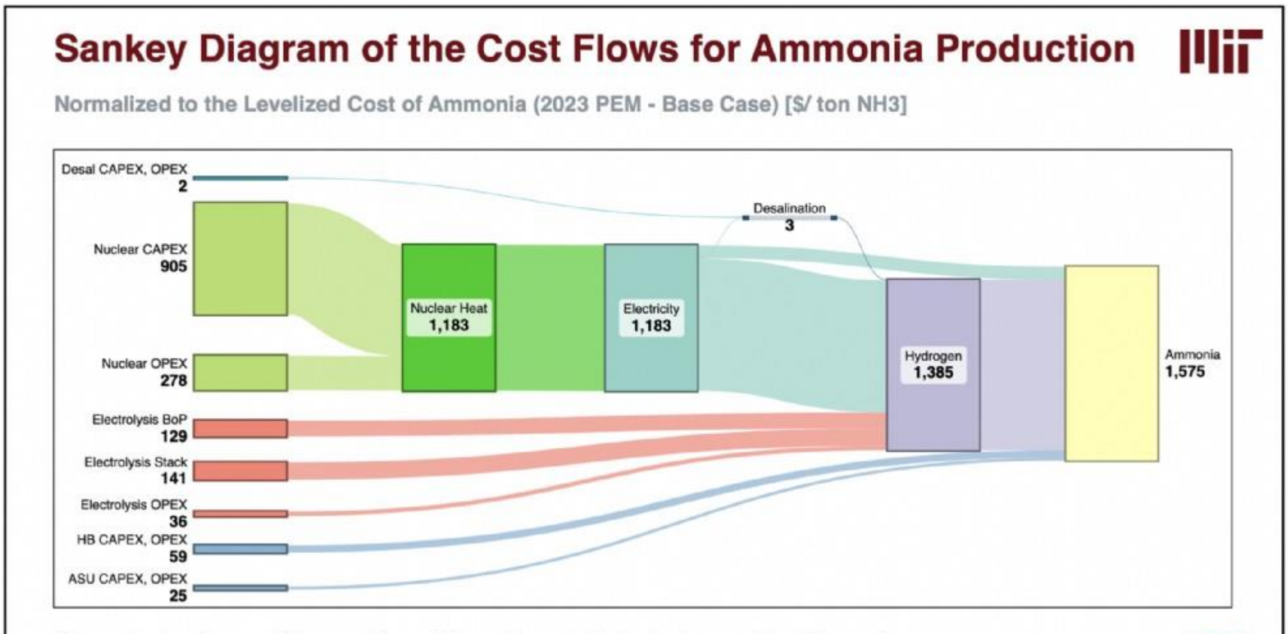

Figure: *Sankey diagram of the cost drivers of Ammonia production by the integrated maritime nuclear system, normalised to the Levelized Cost of Ammonia, given in 2022$ per ton of NH_3 produced*

[Abstract:0342] OP-290 [Accepted:Oral Presentation] [Hydrogen » Production]

Global perspectives on low-carbon hydrogen deployment: a multi-regional feasibility study

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Overview:Around 41 countries have planned national strategies for low-carbon hydrogen deployment by 2050. The International Energy Agency (IEA,2023) estimates that we need to double hydrogen production and final consumption by 2030 and reach 450 Mt annually by 2050 to align the net-zero target. Hydrogen and its derivatives[1] could account for 12% of the final energy demand by 2050 (IRENA, 2022). However, this deployment seems to struggle as firms' investment decisions have concerned only 5% of new projects of low-carbon hydrogen production (IEA, 2023). It demonstrates the uncertainty surrounding clean hydrogen development due to a lack of clarity about certification and regulation, or a lack of delivering infrastructure. This article aims to establish a multi-regional feasibility measurement of low-carbon hydrogen deployment by 2050. We first project a probabilistic space of each regional low-carbon hydrogen production installed capacity by 2050 using Odenweller et al. (2022)'s method. Then, we compare this projection with the final low-carbon hydrogen demand resulting from a multi-regional techno-economic model (TIAM-IFPEN). Our paper brings new insights into low-carbon hydrogen deployment feasibility as it assesses this feasibility for the expected future regions that would act as leaders in hydrogen development. Indeed, we provide an actual mapping of which countries are most likely to play a crucial role in the hydrogen economy, both on supply and demand sides.

[1] We classify ammonia, methanol and synthetic fuels as hydrogen derivatives.
[2] We assume similar dynamics for hydrogen deployment as renewable installed capacity.
Methods:Our methodology encompasses a three-step approach. First, we use a model that embeds current and potential future hydrogen production technologies, which compete with other energy production technologies to fulfill final energy demand across sectors. This model relies on a bottom-up approach to optimize the energy system, minimizing the total cost under constraints. Indeed, it is a multi-regional TIMES-type model (TIAM-IFPEN) that allows us to examine the hydrogen economy under given scenarios. This model has been used in previous studies dedicated to demonstrate the place of hydrogen in European decarbonization pathways (Seck et al., 2022; Shirizadeh et al., 2023). The aim of this model is to provide us with each regional final hydrogen demand by 2050. Second, we replicate the low-carbon hydrogen probabilistic space projection until 2050 as in Odenweller et al. (2022). To do so, we parametrize a set of logistic diffusion models with hydrogen project infrastructure known in 2023 (IEA Hydrogen Project Infrastructure Database, 2023) as initial capacity, and the distribution growth rate of renewable capacity installed using Monte Carlo simulations. Then, this distribution logistic diffusion model gives us a path of projected distribution (probabilistic space) of the hydrogen installed capacity by 2050. We apply this method to each region of our analysis. Third, we compare the final hydrogen demand from TIAM-IFPEN for each region to the low-carbon hydrogen production distribution that would fulfill it based on our projections. Indeed, we determine hydrogen supply to a domestic region as the weighted sum of the hydrogen projected capacity. We measure the weight as the share of imports from a region to the domestic one resulting from TIAM-IFPEN. Finally, we examine the gap dynamics between each region's final energy demand and different levels of hydrogen installed capacity distribution to highlight the feasibility of hydrogen deployment for each region worldwide.
Results:We find that global hydrogen demand could reach nearly 200 MtH2 per year by 2030 worldwide, and 450 MtH2 per year by 2050. More precisely, regions such as Europe, Eastern Asia

(Korea, Japan, and China), and the United States would emerge as major consumers of hydrogen by 2050, with 100, 130, and 70 MtH2 per year respectively. On the production side, our probabilistic space projection provides us with a global production ranging between 10-400 MtH2 per year (0.05-0.95 quantile) with 275 MtH2 per year on average. Zooming at the regional scale, regions such as Australia, MENA, North America, China, a part of Latin America, and Europe could rise as key producers of low-carbon hydrogen. We find a positive gap between demand and adjusted supply[3] for all regions at any time from 2023 to 2050. It means that low-carbon hydrogen production could not be sufficient to fulfill hydrogen demand even in optimistic cases[4].

[3] Weighted sum of hydrogen projected capacity.
[4] Top 5% of projected low-carbon hydrogen production distribution.

Conclusions:Low-carbon hydrogen deployment studies mainly focus on projecting hydrogen infrastructure development based on real data or implementing techno-economic models to extract hydrogen demand and supply under given scenarios. Summarizing these two approaches, we demonstrate—using the TIAM-IFPEN model—that although low-carbon hydrogen development is crucial for decarbonizing the energy system, all regions tend to have a near zero probability of reaching the hydrogen demand. As shown by our "realistic hydrogen deployment" scenario, current hydrogen deployment dynamics follow a path that would yield an energy system that could not be decarbonized entirely by 2050.

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Keywords: hydrogen, TIMES modeling, feasibility

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Flexible electrolyzer operation: rethinking hydrogen supply and industrial demand in France by 2030

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Overview:From industry to transport and electricity storage, low-emission hydrogen is poised to play a significant role across diverse sectors in the path toward carbon neutrality. A new value chain based

on electrolysis is set to emerge, where the price of electricity is the main cost driver, and its source determines the emission factor of hydrogen. Industrial sectors typically have a constant hydrogen demand throughout the year. To satisfy this demand, different operation modes are envisioned for grid-connected electrolyzers under a mainly low-carbon power supply. On one hand, baseload operation reduces the need for infrastructure (smaller electrolyzer, no need for storage), but the electricity inputs at certain hours are expensive and natural gas-based. On the other hand, a more flexible operation mode, where electrolyzers run at a reduced number of hours, allows cheaper and cleaner electrical input. However, it requires larger electrolysis capacity and access to underground storage via pipeline to supply low-emission hydrogen when electrolyzers are not running. Our research question is the following: what are the infrastructure needs of flexible electrolyzer operation and how exactly does it affect the system sizing, costs, and emissions? In addition, is the hydrogen demand truly constant or could a part of it be flexible?
Methods:The low-emission hydrogen demand sectors considered are steel, refining, e-kerosene, ammonia, methanol, and other chemicals produced with hydrogen. We quantify the demand by 2030 and locate it geographically, resulting in five hubs: Dunkerque, Le Havre, Fos-sur-Mer, Vallée du Rhône, and the East of France. We then calculate the distance to the closest potential salt cavern location for hydrogen storage. On the supply side, we create a Mixed-Integer Linear Programming (MILP) optimization model to better understand the flexible operation strategies. We use PERSEE, a proprietary tool developed by CEA for modeling, simulation, and optimization, all along the life cycle of a complex energy system, used for technical, economic, and environmental studies. We first examine the generic case of a grid-connected electrolyzer that supplies a constant hydrogen demand and may or may not function flexibly, which would require resorting to underground storage via a pipeline. We optimize the sizing and hourly operation of the system (electrolyzer, pipeline, and storage) over a year with perfect foresight using historical electricity spot prices in France as input time series. Afterward, we transition from the generic case to more realistic applications by adapting the demand volume and pipeline distance in our optimization model to the five hubs in France. A first analysis is made assuming the demand is spread evenly throughout the year, and then a second set of runs is performed after questioning the hypothesis of constant demand. We use technical literature and industrial expertise to identify possible areas for demand-side flexibility, for instance, by pushing the flexibility along the supply chain and storing intermediate or final products instead of the hydrogen inputs. In particular, we plan to perform an in-depth analysis of one application explaining all the required process changes and constraints incurred by demand-side flexibility.
Results:Preliminary results in the constant demand generic case indicate that the main determinant of the operation mode is the time evolution of electricity prices. A flexible operation mode is favored when electricity prices are contrasted, and remain relatively high, for a significant (nearly continuous) amount of time. This corresponds to situations with seasonal variations or sustained crises in the power sector, instead of isolated price peaks. In the application hubs, since the potential storage locations are unevenly distributed across France, hubs far from storage locations are prone to opt for baseload operation despite the potential environmental gains of flexibility. There will likely be differentiated operation modes in the five hubs with sizing adapted to the demand volume. However, if demand-side flexibility options in industrial processes are identified, then depending on the flexibility level, the need for storage and an associated pipeline could be eliminated. Flexible electrolyzer operation would require less infrastructure.
Conclusions:This study aims to examine the conditions and advantages of flexible operation modes of electrolyzers to supply mainly industrial low-emission hydrogen demand in France in 2030. We use a MILP tool to model supply-side flexibility, but our main contribution is on the demand side. We quantify a spatially explicit demand scenario in 2030 and explore industrial demand-side flexibility. The goal is to optimize operation modes for the best economic and environmental results and paint a more realistic approach to low-emission hydrogen deployment in 2030 with a focus on infrastructure.
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Keywords: Hydrogen, electrolyzer operation, industrial demand, flexibility, hydrogen infrastructure, optimization

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Green Hydrogen: A Cost-effective Energy Storage Solution for Saudi Arabia

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Overview:The global energy landscape is undergoing significant changes as the world is transitioning to cleaner and more efficient energy resources. This transition is driven by an ever-growing adoption of renewable energy sources such as solar PV and wind. As the penetration of renewable energy increases, challenges such as grid stability and energy storage become more critical to address. Green hydrogen offers a cost-effective and efficient solution to utilize excess renewable energy that can be used for power generation, transportation, chemical production, and in other industries. Saudi Arabia, the world's largest hydrocarbon exporting country, has launched several renewable energy and green/blue hydrogen projects in the last five years with a view to expand its energy portfolio. The Kingdom has committed to increase the deployment of renewable energy in the coming years to meet 50% of its total power generation capacity by 2030 [1]. Additionally, Saudi Arabia is building the world's largest green hydrogen hub in NEOM with a targeted annual production of 200 thousand tons of green hydrogen [2]. However, the role of green hydrogen as a flexible energy storage medium has not been explored in detail in the Saudi Arabian context. Therefore the current study focuses on performing a detailed techno-economic analysis of using green hydrogen as an energy storage medium in Saudi Arabia's northwest coast, which is blessed with excellent renewable energy resources. In this regard, three locations in Saudi Arabia's western region namely NEOM, Yanbu and Jeddah have been selected to assess their viability in producing green hydrogen for energy storage in comparison to conventional battery storage.

Methods:The current study presents a detailed techno-economic analysis of the production of green hydrogen for energy storage in three different locations on the west coast of Saudi Arabia. The three locations were selected due to their excellent renewable energy potential coupled to their proximity to major population centers, industrial cities, and logistic hubs. The study is conducted to meet an annual load requirement of 600 GWh, which is equivalent to the electrical energy needs of 20,000 households [3]. The electrical energy needs are met using a hybrid system consisting of solar PV panels and wind turbines. The intermittent and unpredictable

nature of these renewable energy resources necessitates the use of energy storage solution to match the hourly supply and demand.
In this regard, the study uses levelized cost of electricity (LCOE) as the primary metric to compare and contrast green hydrogen and Li-ion batteries as potential energy storage options.
For the hybrid system, the PV array is assumed to consist of polycrystalline PV panels of 350 W rated power and the annual power output is calculated considering numerous factors including derating factor, solar irradiance, and temperature coefficient[4]. Here, a horizontal axis wind turbine with a rated power of 6500 kW is selected, and the hourly power generated is calculated based on air density, swept area, wind speed, and hub height. The hourly household demand is matched with power output of the hybrid system consisting of solar PV panels, wind turbines, and energy storage. In terms of energy storage, the hourly production and consumption of green hydrogen is modeled by using the PEM electrolyser capacity, hydrogen PEM Fuel Cell efficiency, and hydrogen storage tank level selected. The operation of the electrolyser is adjusted based on the availability of excess renewable energy and the green hydrogen is converted back to electricity when demand exceeds supply using the PEM fuel cells. Li-ion battery storage is also modeled based on parameters including its capacity, depth of discharge, and state of charge limits. Excess renewable energy is also stored in batteries, and when demand exceeds supply, energy is withdrawn from the batteries to meet the required demand.
The LCOE for each energy storage solution is estimated based on the project lifespan, discount rate, costs of PV power, wind power, electrolyzers, fuel cells, and batteries, as well as their respective operation and maintenance costs. The LCOE is calculated by dividing the total annualized cost of the system by the total electrical load served.
Results:The results show that the utilization of green hydrogen has lower LCOE compared to battery storage regardless of PV – Wind split and hybrid system size. The lowest LCOE of green hydrogen is $0.08/kWh while the lowest LCOE with battery storage is $0.21/kWh, which is about 2.5 times higher than green hydrogen storage.
The LCOE decreases as the percentage of wind power increases in the PV – wind system with 48.9% and 40% wind energy share resulting in the lowest LCOE for green hydrogen and battery storage respectively. The higher LCOE for battery storage can be explained by the battery's limited capacity and high initial cost compared to green hydrogen production.
For the three locations considered here, the LCOE for green hydrogen is the highest at $0.187/kWh for a 100% PV system and dramatically decreases as the percentage of wind power in the hybrid system increases up to 20%. However, beyond 20% wind energy share, the LCOE stays almost the same at around $0.08-$0.09/kWh.
The lowest LCOE at the three sites is similar with Yanbu at $0.0805/kWh, NEOM at $0.0830/kWh, and Jeddah at $0.0836/kWh. However, the optimal wind-PV split is different in the three locations with Yanbu at 56%, NEOM at 49%, and Jeddah at 59% Wind energy respectively in the overall PV – Wind system. Interestingly, the cost of hydrogen production shows three distinct trends. Initially, the hydrogen levelized cost of storage (LCOS) starts at $6.0-$6.65 per kg when the renewable energy system is 100% PV. Then, it drops to $4.14-$4.18 per kg as the

share of wind power increases to 10-20%. Subsequently, the LCOS increases dramatically as more wind power is added up to 70-75%. The lowest green hydrogen LCOS in the three sites are similar with Yanbu at $4.15/kg with 9% wind share, NEOM at $4.18/kg with 22% wind share, and Jeddah at $4.14/kg with 20% wind share.

Conclusions:A detailed techno-economic assessment has been performed to identify the lowest LCOE for maintaining 100% renewable energy generation using a hybrid system consisting of Solar PV and Wind with green hydrogen as energy storage. The hybrid renewable energy system has been designed to meet the energy demand for 20000 households with hourly variation taken into account. The LCOE calculation was performed at three locations namely NEOM, Yanbu, and Jeddah on the west coast of Saudi Arabia. Battery storage was also considered and was found to result in larger LCOE of $0.21/kWh as compared to $0.08/kWh for green hydrogen. Under all scenarios considered, the addition of Wind power to the hybrid PV – Wind system results in the reduction of LCOE by 44 – 48%. Future work will consider the influence of water desalination on LCOE for green hydrogen production and explore the life cycle CO2 emissions for the three locations considered here.

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Keywords: Green Hydrogen, Energy Storage, Hybrid Renewable Energy System, LCOE, LCOS, Batteries

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Exploring cost drivers for region-scale development of subsurface hydrogen storage in Northern Appalachia, United States

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Overview:Hydrogen energy is emerging as a promising major carrier of energy to enable a net-zero energy system. According to Baldwin, et al., (2022), a 20% hydrogen (H2) blend could lead to a 6-7% reduction of GHG emissions for energy delivered through natural gas utility systems. A transition to a U.S. hydrogen future will be driven by the demand for low-carbon energy carriers and a robust hydrogen supply chain (Goodman et al., 2022). Storing large quantities of H2 in the subsurface will likely be vital to this process. Technological challenges, safety concerns, and economics of underground hydrogen storage are some of the major challenges in expanding the hydrogen economy (Mishra et al., 2023). To enable scaling up of underground hydrogen storage to support H2 economy, the cost effectiveness of H2 storage needs to be understood. There is an increasing interest in cost analysis of H2 storage (Gorre et al., 2020). Technoeconomic analysis is a tool that is used to identify the ways to reducing the costs including the H2 storage costs.
Methods:To improve our understanding of the costs of underground hydrogen storage in Northern Appalachia Region of the United States, we built upon a local scale technoeconomic analysis framework developed by Mishra et al., (2023) and Lord et al., (2014). The framework consists of a demand model – Bass adoption model – to project H2 demand for 2050, an assessment of H2 storage potential (based on Lackey et al., 2023), and a technoeconomic analysis to quantify the storage cost (or levelized cost of hydrogen storage). We used the framework to conduct a regional cost analysis for Northern Appalachia expanding over eight states of the United States: Delaware, Maryland, New Jersey, New York, Ohio, Pennsylvania, Virginia, and West Virginia. We conducted technoeconomic analysis of three types of storage facilities: depleted underground hydrocarbon reservoirs, salt caverns, and aquifers. We conducted cost analysis for 129 hydrocarbon reservoirs, 1 aquifer, and 1 salt cavern-based storage sites in the region that have total storage volumes ranging from 70 to 167,500 million cubic feet (MMcf).
Results:We calculated how the cost of underground hydrogen storage is affected by various site construction, energy procurement, and cushion gas availability scenarios. We constructed a Bass adoption model to project hydrogen demand and use that to construct a staged, demand-based cost analysis for the conversion of existing underground storage facilities. Generally, we find that the levelized cost of underground hydrogen storage ranges from $0.72 to $2.07/kg hydrogen in the study area. We found that the cost of underground hydrogen storage in depleted hydrocarbon reservoirs is predominantly driven by the cushion gas, compressors, and electricity procurement costs. We calculated the costs to build new underground H2 storage facilities as well as the costs to refurbish the existing depleted hydrocarbon storage and the calculated the differences in the levelized costs of H2 storage between the two options. We found that one way to reduce the storage costs is by reducing the electricity costs to operate the facility by integrating H2 storage sites with renewable energy sites or by procuring other less expensive electricity. A 50% reduction in the price of electricity could reduce the H2 storage cost by 11-29%. Similarly, use of less expensive cushion gas for e.g., H2 produced by fossil fuels with or without carbon capture (or another, less expensive cushion gas alternative to H2 produced by renewable energy sources such as nitrogen) could decrease the LCHS by 17-33%. We will present at the conference, the sensitivities of these factors we found on the cost of hydrogen storage across the various capacity facilities and the spatial variabilities in costs of storage for the selected facilities in the eight US states.
Conclusions:The outputs from implementing this framework improve understanding of the potential H2 market, evaluating storage costs for a range of storage capacities and, more broadly, understanding key cost drivers and sensitivities of storage costs to various factors. The analysis will inform cost reduction strategies to bring down the total cost of H2 delivered to less than $1/kg. This framework could be deployed across the nations to enable an energy economy that leverages the versatile H2 molecule to enable a net zero energy system.
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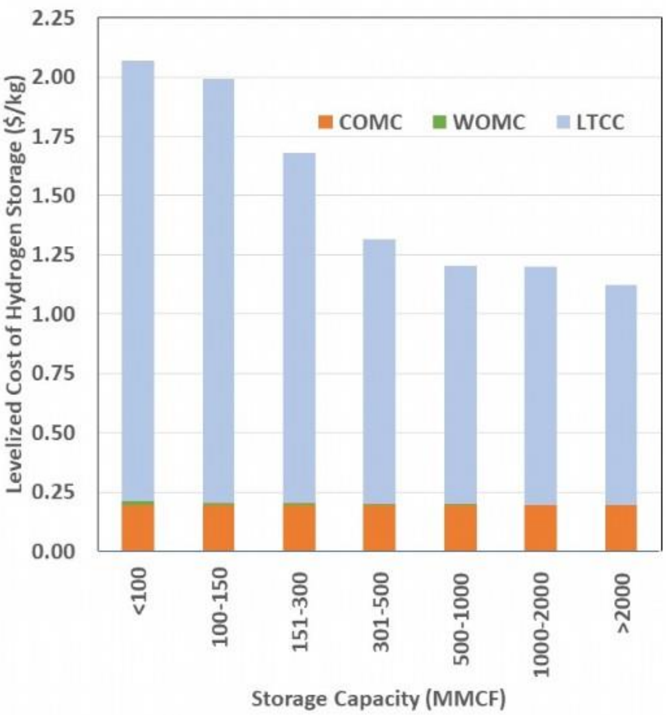
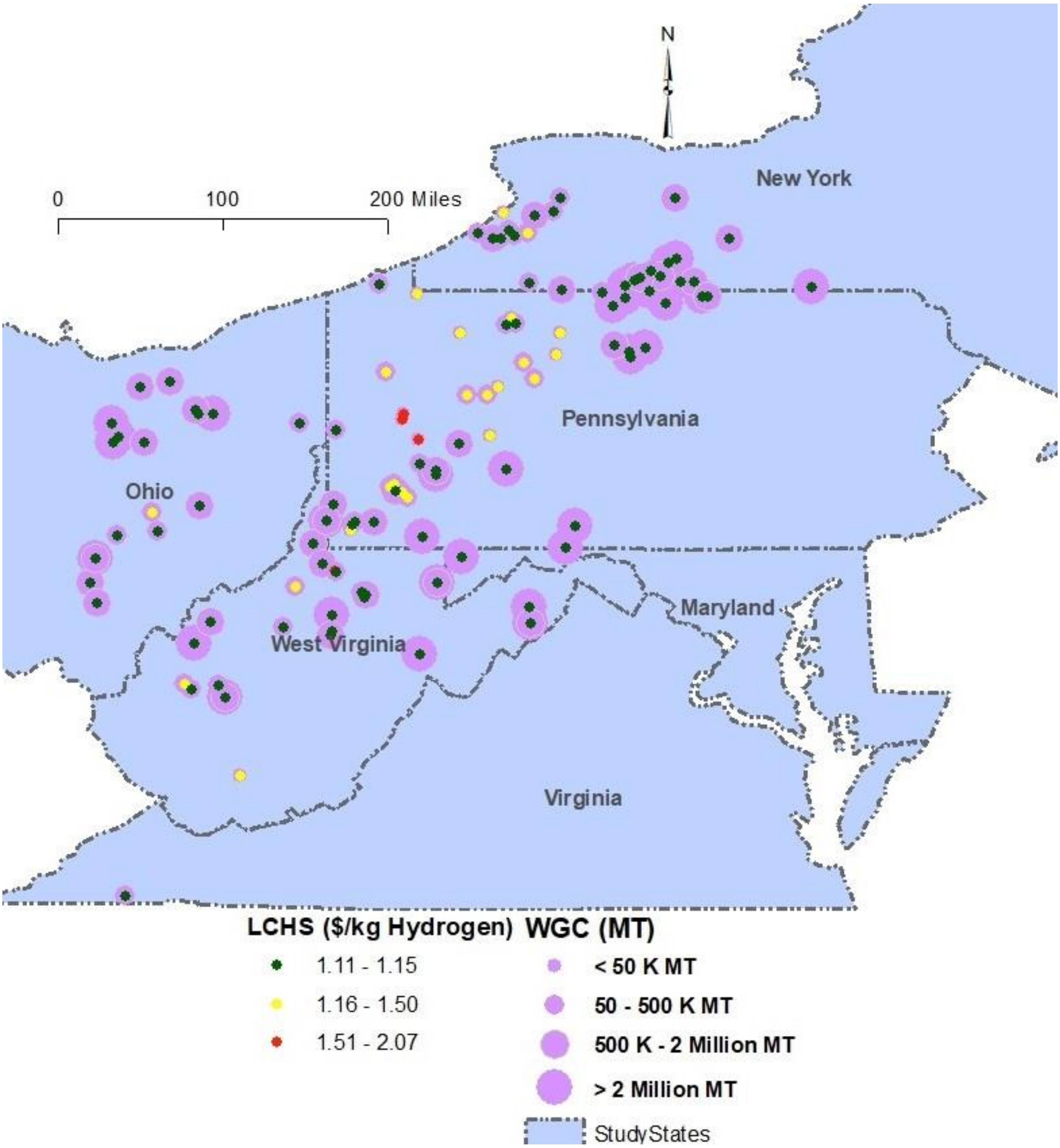
Keywords: Hydrogen energy, underground hydrogen storage, technoeconomic analysis, cost of hydrogen storage

Cost of storage for across various capacities hydrogen storage facilities



Spatial variabilities in the cost of underground hydrogen storage in North Appalachia, United States



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[Abstract:0605] OP-294 [Accepted:Oral Presentation] [Energy Modeling » Other]

Correlating Datacenter Energy Consumption to Renewable Sources and Emission Targets

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Overview: Background

There are approximately 10,978 datacenter locations worldwide as of December 2023, with the United states topping the list with 5,388 locations [1]. Datacenter growth and their electricity demand are increasing exponentially, 55% increase in just a year, from 2022 to 2023 [1]. The Information and Communication Technology (ICT) industry electricity demand in 2022, including datacenters, cryptocurrency mining and data transmission networks was about 710 TWh, ~3% of the global electricity demand, with a Green House Gase (GHG) emissions footprint of about 330 Million tons annually, based on International Energy Agency (IEA) data [2].

The electricity consumption for 2022 of datacenters in the United States was about 149 TWh, inferring estimates from different sources [3], [4], [5]. In contrast the renewable power generation by the Technology and Telecom industry in the United States in 2022 is a mere 26 TWh, spread over 112 projects, based on the Green Power Partnership Project [6], i.e. about 17% of the electricity demand.

The ICT industry manages renewable power generation demand gap with the aggressive acquisition of Renewable Energy Certificates (RECs) [7] through Power Purchase Agreements (PPAs) [8], [9], [10]. Availability of renewable energy sources vary- sunlight, wind, depletion of stored energy in fuel cell/battery. PPAs allow dislocation of energy supply from demand. Correlating renewable energy generation capacity with demand is therefore complicated, a problem that has been identified by the ICT industry [1].

Even if we consider the total renewable power generation across all industries in the United States in 2022, it is just 53 TWh, spread over some 2,175 projects [6]. This is just about 36% of the ICT industry electricity demand and a mere 1.3% of the 4,070 TWh of the total electricity demand in the United States [11]. Using PPAs without having the generation capacity is a bigger problem, that is not being addressed by the industry, directly.

Although companies like Google, Microsoft, and Iron Mountain have announced 2030-2040 targets to source and match zero-carbon electricity on a 24/7 basis within each grid where demand is located [2], there is no clean direct mechanism currently to match renewable power generation capacity to ICT industry demand.

Motivation

The ICT industry is subject to Environmental, Social, and corporate Governance (ESG) audits [12]. ESG scores that drive stock valuations of the industry [13] are based on Corporate Sustainability Reports (CSR)s. GHG protocol [14] is the de facto standard for the energy and emission footprint reporting in the annual CSRs. Gaps in emission targets are covered by the acquisition of RECs through PPAs.

While the financial motivation of the ICT industry to report net zero emissions in their annual CSRs is great, it decorrelates the industry's electricity demand from actual renewable energy annual capacity. We reviewed the CSRs of a few leading ICT companies and present information from Google's CSR as an example.

Google's CSR [15] claims the company reached 64% carbon-free energy globally in 2022. A deeper look at their 2022 CSR filing [16] reveals the following data on their datacenter's electricity demand and supply:
Only about 23% of the 21.776 TWh of electricity demand was met from in-grid renewable electricity supply and a mere 0.04% met by on-site renewable electricity generation. While about 77% of the electricity demand was met by renewable electricity acquired through PPAs. The methodology of accounting for renewable energy purchase is summarized in their CSR [16] as:

"To achieve our 100% renewable energy match goal, we first consider both our on-site renewable energy generation and the renewable energy that's already in the electric grids where our facilities are located, then procure renewable energy through PPA agreements and utility renewable energy tariffs. We have a few facilities located in geographies where we're not currently able to source large volumes of renewable energy, so we currently make up for this by buying surplus renewable energy in regions where it's abundant. For example, by buying larger amounts of wind energy in places like

Europe, we compensate for our lack of renewable energy purchases in Asia.”

The renewable electricity PPAs are therefore Virtual PPAs [10], where the power is not physically delivered to Google. Google receives offsets for renewable energy generated, which can be used to meet their sustainability or carbon reduction goals.

Examining in-grid renewable electricity for 2022 in the United States we observe: Google’s datacenters consumed 15.501 TWh, while the total renewable energy supplied to the grid by the ICT industry was 26 TWh [6], a little more than the electricity demand of a single company. Studying the Green Power Partnership project data sources, many of the renewable energy supply options themselves are in turn from PPAs. Given PPAs do not require physical delivery of power, the 26 TWh in-grid, may not be actual generated renewable power.

PPAs provide a great financial impetus for the shift to renewable power generation, however they do not control or measure the actual power generated nor the extent of demand addressed. Both the place and point in time of power generated are completely dislocated from where and when the energy is needed, by PPAs. This is very different from the traditional electricity grid, which is designed to deliver electricity where, when, and how much of it is needed. The Key Performance Indicators (KPI)- Capacity to meet demand and availability, are very loosely, if at all, applied to renewable electricity generation.

Given the explosive growth in the demand for electricity by datacenters [1], these traditional KPIs need to be applied to renewable power as well. KPIs need mechanisms and tools to measure the generation capacity, availability- need for storage or re-charging, refurbishing spent renewable sources/fuel, sustained average demand, demand time slices - peak periods, etc.

This problem has been identified by Google and others through the 24/7 Carbon-Free Energy Compact [17] formed in 2021. Although the movement has begun, mechanisms and tools to monitor and track the KPIs are not available yet.

Developing the mechanisms and tools to correlate renewable generation to demand through well-defined KPIs to address the critical gap in the availability of renewable energy to meet ICT industry demands, is the key motivation of our work.
Methods:Our Contribution

Open-Source energy Modelling System (OSeMOSYS) [18], [19] [20], [21] together with Climate Land Energy Water Systems (CLEWs) [22] provide a starting framework to model energy supply-demand and understand impacts of land water usage on the climate i.e. GHG emissions. The OSeMOSYS framework defines the Reference Energy System (RES), a simplified aggregated, graphical representation of an energy system. The RES can be extrapolated along any required dimensions- possible new renewable energy supply chains, technology initiatives, etc. [18].

The aggregates in the RES model are:
SETS or components: [Region, Year, Time slices, Emissions, Commodity, Technology]

Input data (Parameters): [Historical Capacity; Annual Demand; Load; Efficiency; Capital, fixed, variable costs; Emission Activity Ratio; Availability factors]

Output variables (Results): [New Capacity; Total annual production by technology; Annual emissions; Discounted costs; Model period cost]

SET time slices of supply and demand accommodate variability across different industry sectors and regions. The time scale of variance can be intra-day: [day, night]; seasonal: [Summer, Winter]. The intra-day time scale can be further sliced down into 24 hourly windows of demand. The supply of energy can then be matched to these demand time slices.

OSeMOSYS tool chain provides mechanisms to have all the RES aggregates entirely represented in a flat YAML [23] file with the activity relationships scripted in python. OSeMOSYS tool chain converts the YAML representations in line with the scripted relationships to matrix structures that can be fed into existing linear programming tool sets such as the GNU Linear Programming Kit (GLPK) [24] to optimize for GHG emissions for different initiatives, constraints, and investment scenarios.

Our contribution will extend the OSeMOSYS-CLEWs framework, develop the plug-ins needed and provide a comprehensive set of tools to track energy supply sources with demand, in time, space, energy buffering or storage in the transmission grid.

For a given electricity demand by ICT datacenters in any given region the objective function presented to the frontend GLPK solver, for each time slice will be:

Minimum renewable energy generation [Operational Cost ($), Capital Investment ($)] => Maximum [Renewable energy Capacity (TWh)]

Our extended tool chain will generate correlated outputs of renewable energy capacity (TWh) required together with the best suited fuel source for each time slice at the lowest generation cost.

Our extensions will be packaged with OSeMOSYS-CLEWs, GLPK or similar solver in an end-to-end integrated datacenter NetZero (dcNZ) software stack that will be open sourced for ready availability to the industry. dcNZ will provide data on how much of the demand was met from renewable sources in each 24-hour operational window of the ICT infrastructure. Our contribution will align renewable energy generation to the established electricity grid KPIs.

We will use our work to extend the GHG protocol standards to enable the ICT industry to publish dcNZ measurements of absolute emission, increase/decrease in carbon footprint, effect on climate, land, energy, and water systems in their annual CSRs. Our work will help the 24/7 Carbon-Free Energy Compact [17] realize its goals.

Results:In progress

Conclusions:In progress

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Keywords: Information and Communication Technology (ICT) industry, Renewable Energy Certificates (RECs), Power Purchase Agreements (PPAs), Corporate Sustainability Reports (CSR)s, Open-Source energy Modelling System (OSeMOSYS)

AuthorToEditor: Please note: Our model is under development. We will have our results and conclusions in time for the full paper submission deadline of April 19 2024.

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[Abstract:0131] OP-295 [Accepted:Oral Presentation] [Energy Modeling » Artificial Intelligence Techniques]

From Words to Watts: Applications and Trends of Sentiment Analysis in Energy Research - A Literature Review

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Overview:Understanding public opinion is crucial for transitioning to sustainable energy sources and reducing our dependency on fossil fuels. A major challenge in energy research has been accessing consistent opinion data over extended periods, often relying on polls, surveys, or manual coding. However, technological advances in the past decade, particularly in computing capacities and the sophistication of sentiment analysis algorithms, can help address this shortcoming in longitudinal opinion data. These tools have been effectively applied in other research fields, such as politics and marketing research. In contrast, their application in energy research remains relatively unexplored despite their vast potential. Therefore, this study provides an overview of how the relevance of sentiment analysis has evolved in energy research and its future development. Another goal is to guide researchers through the dynamic and rapidly evolving ecosystem of sentiment analysis models, equipping them with tools to extract opinion data that align with their specific research needs in energy research.
Methods:I conducted a structured literature review focusing on peer-reviewed research papers from the last ten years to explore how sentiment analysis has evolved in energy research. To further assess future potential, I also included recent conference proceedings and working papers in a separate analysis. I identified 460 papers using carefully chosen search terms on major databases such as ScienceDirect and IEEE Xplore. These were first screened based on their abstracts, applying

predefined inclusion and exclusion criteria. Following this initial screening, I thoroughly reviewed the full texts of 102 papers for detailed analysis.
Results:This review reveals an increasing relevance of sentiment analysis in energy research, as indicated by the surge in publications since 2019. However, there is still untapped potential in this area. For instance, I identified numerous well-cited papers that used models already deemed outdated by machine learning standards at the time of their publication. Additionally, notable regional variations emerged. For instance, East Asian studies heavily focused on consumer opinions regarding technologies like electric vehicles, whereas research from Europe and America tends to concentrate more on opinions about energy sources, such as wind and solar power.
Conclusions:This review provides an overview of applications and the potential of sentiment analysis in energy research. On the one hand, it can be used to monitor shifts in public sentiment towards energy sources in response to policy changes or notable events, such as attitudes before and after wind park installations or during geopolitical events like the Russia-Ukraine conflict. On the other hand, sentiment analysis is also valuable for understanding consumer perspectives on energy-related appliances such as electric vehicles or private solar panels by analyzing reviews. I encourage more researchers to adopt these methods, especially now that sentiment analysis has become more accessible with generative AI tools like ChatGPT. By providing guidance through the evolving sentiment analysis landscape and highlighting accessible tools and data sources, I aim to enable research into public opinion and social acceptance. In turn, I hope this contributes to a deeper understanding of crucial issues in combating climate change and informs more effective policies and initiatives.
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Keywords: Sentiment Analysis, Energy, Review, Social Acceptance, NLP, Longitudinal Opinion Data

[Page: 296]

[Abstract:0631] OP-296 [Accepted:Oral Presentation] [Energy Modeling » Time Series Analysis]

Generating Probabilistic Scenario Ensembles for Stochastic Unit Commitment

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Overview: Increased probability of extreme weather events and ongoing and planned increases in the penetration of Variable Renewable Energy (VRE) resources in electric power systems highlight the need for improved uncertainty characterization.

Currently, the day-ahead and real-time operational decisions for power generators and storage devices are made based on single-point forecasts of electricity demand and energy supply for the planning period. Cognizant of the error in such forecast, electricity system operators schedule assets so that the system has enough "operating reserves" to cope with the deviations in demand and renewable energy production that will be observed in real-time. In current practice, operators use a single-point-forecast and a level of reserves targets as inputs to the Unit Commitment problem which is a mixed-integer linear program deciding the on/off status of electric power plants and their level of power generation production to minimize their costs while ensuring supply meets demand, reserves exceed the targeted levels, and the technical constraints of the generators are not violated. Under this practice, the higher the uncertainty on future demand, renewables-sourced electricity, and availability of conventional generators, the higher the reserves targets must be, and the higher the costs of satisfying demand.

An alternative to the current approach, is a Stochastic Unit Commitment which, rather than taking a single-point-forecast (i.e., a single time-series), takes an ensemble of plausible forecasts (multiple time-series) and their probability of occurrence to minimize the expected value of the cost of satisfying system demand. Under this approach, the system will pre-position all power generating and storage units to satisfy demand at each time period of the planning horizon under any of the possible scenarios. The literature shows that system costs are reduced, and reliability improves when a Stochastic Unit Commitment (SUC) is used instead of the widely used deterministic Unit Commitment (UC) [1]. However, this superiority of the SUC relative to its deterministic counterpart (i.e., the UC) is a function of the quality of the scenario ensembles representing the probabilistic forecast used as input.

Quality probabilistic forecasts for SUC cannot be presented as quantile trajectories -as often presented [3]- with unrealistic temporal patterns of electricity demand (i.e., load) and/or renewable generation, where all hours have a load in the same percentile.
This paper proposes the Probabilistic Forecast Generator (PFG), an approach for generating high quality Probabilistic Forecasts of weather variables, load, and variable renewable energy, for use in a Stochastic Unit Commitment. The outputs of the PFG are ensembles of time-series each with the same probability of occurrence. Each multivariable time series represents a plausible trajectory for weather variables, load, and wind solar energy production for each hour of a week-long planning horizon, in a specific geographical area. The probabilistic forecasts are of high quality as assessed by four measures described in the methodology section.
Methods: 3.1. The proposed Probabilistic Forecast Generator (PFG):

The PFG requires two data inputs: 1) Historical time-series data of weather forecasts, 2) Historical time-series of (coincident) weather actuals, load actuals and renewable energy production actuals. The approach follows four steps:

i) Characterization of the stochastic process followed by the weather forecast error.
ii) Generation of the probabilistic weather forecast using weather actuals and the process characterized in step (i).
iii) Characterization of the relationship between weather and electrical load, and between weather and renewable energy production.
iv) Generation of the probabilistic load and renewable energy production using the relationship characterized in (iii), and the probabilistic forecasts obtained in step (ii).

Steps (i) and (iii) of this approach are conducted ahead of time, once a year, using historical data of prior years. Steps (iii) and (iv) can be conducted every day or every hour, using updated weather forecasts for the next hours in the planning horizon. Steps (i) and (ii) are illustrated in Figure 1, step (iii) is illustrated in Figure 2, and step (iv) is illustrated in Figure 3.

The PFG characterizes weather forecast error (figure 1) using a vector autoregressive approach that considers weather variables found to explain most of the variability in electrical load and solar and wind power production: humidity, dew point, temperature, clouds, wind degree, wind speed and direction. The vector y, containing actual data of these variables, across various climate zones/regions, is decomposed into the component predicted by the deterministic forecast x and the residual or forecast error ε

$y(t+\tau|t)=x(t+\tau|t)+\varepsilon(t+\tau|t), \quad \tau=0,\ldots,168. \quad (1)$

The analysis of the residual structure $\varepsilon(t+\tau|t)$ provides insights on the quality of the deterministic forecasts and how uncertainty increases with respect to the lead forecast hour.

The load and renewable energy models are neural networks (NN) trained with historical load / PV / wind power, and weather variables. There is a plethora of methods and research on such artificial neural network models [4-7]. For the results presented in this abstract the NN has an input layer with the 7 weather variables, month, day, hour, and lagged output values (of load and renewable energy) and two hidden layers with 256 and 128 neurons, respectively.

3.2. Metrics to assess the quality of the Probabilistic Forecasts generated by the PFG:

1. PDF / CDF: The Kullback-Leibler divergence and the Wasserstein distance quantify the differences in the distributions of the historical observations and the ensemble of scenarios comprising the probabilistic forecast. We allow and desire the probabilistic forecast to exhibit higher extreme values than the historical observations to account for extreme conditions (yet to be observed but still realistic).

2. ACF: The forecast's ACF should be like the ACF in the historical actuals and forecasts (as measured by the Euclidean norm).

3. Step changes: The PDF & CDF of the hourly-step changes of each time series shall be like the historical observations to avoid unrealistic differences in demand and solar production between two consecutive hours.

4. Forecast errors: The PDF of the forecast error in a probabilistic forecast shall be like historical forecast errors. (PDF compared using the Kullback-Leiber divergence and the Wasserstein distance).

5. Region & variable cross-correlations: The cross-correlation between (i) different regions and (ii) different variables in the probabilistic forecast shall be similar to that observed in the historical data. (Measured with Kullback-Leibler divergence and the Wasserstein distance).

6. Continuous Ranked Probability Score (CRPS) [8]: Maximize the CRPS between observation y and the CDF F associated with an empirical probabilistic forecast

3.3. Data

The PFG is tested by generating probabilistic forecasts of aggregated electricity demand and aggregated solar PV power production in the Duke Energy Carolinas / Duke Energy Progress for each hour of the years 2022 and 2023. Weather, load, and PV data come from OpenWeatherMaps and the EIA.

Results:The forecast errors generated with our vector autoregressive process (for six weather variables) follow a similar distribution to the forecast errors found in historical data (Fig. 4). The correlation between the forecast errors in the weather variables obtained with the model is nearly identical to the correlation observed in historical forecast errors (Fig 5). Probabilistic weather forecasts (grey lines) and quantile bands (colored areas) for six weather variables in one location are shown (Fig 6). A probabilistic forecast of net load (equal to electrical load minus PV solar generation) for one territory is shown in Fig 7.

Conclusions:The PFG produces Probabilistic Forecasts of high quality. The approach is easily extendable to other regions. It can be used with minimal input data that is publicly available for the entire U.S.

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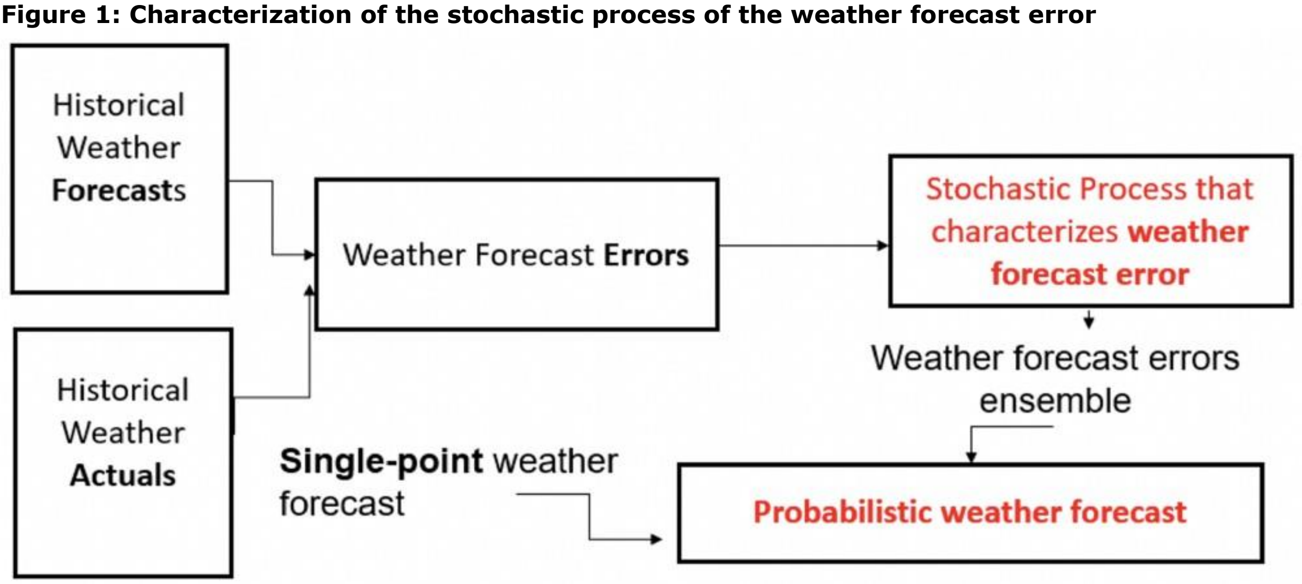
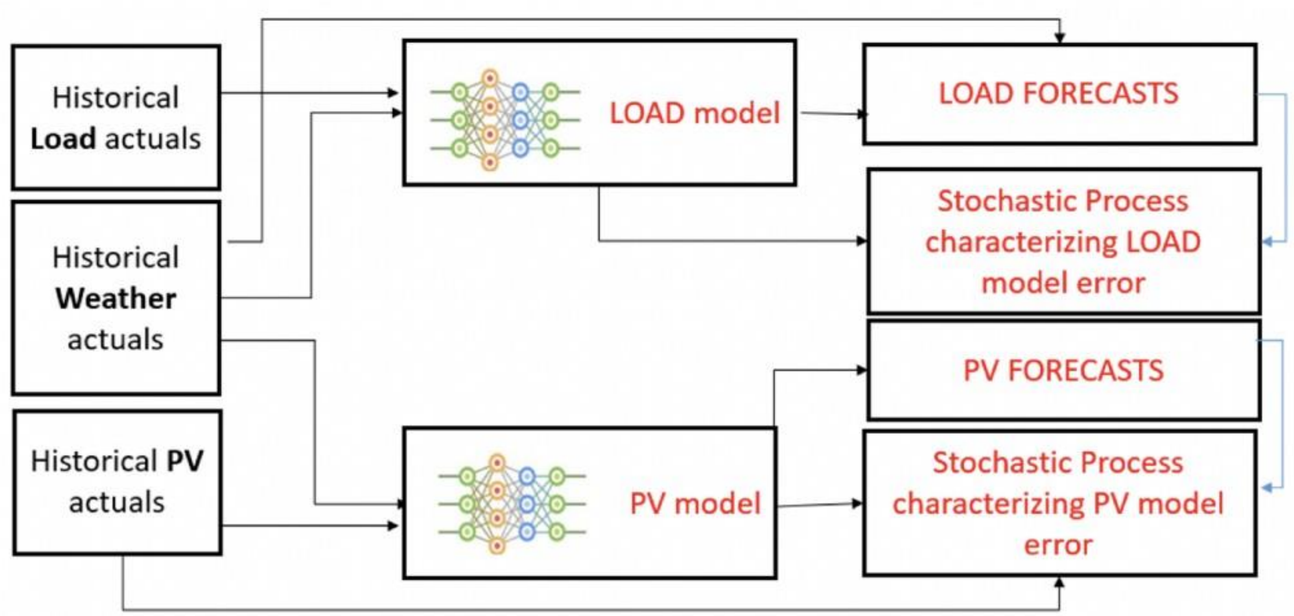
Keywords: Stochastic unit commitment, probabilistic scenario ensemble, uncertainty characterization

Figure 1: Characterization of the stochastic process of the weather forecast error



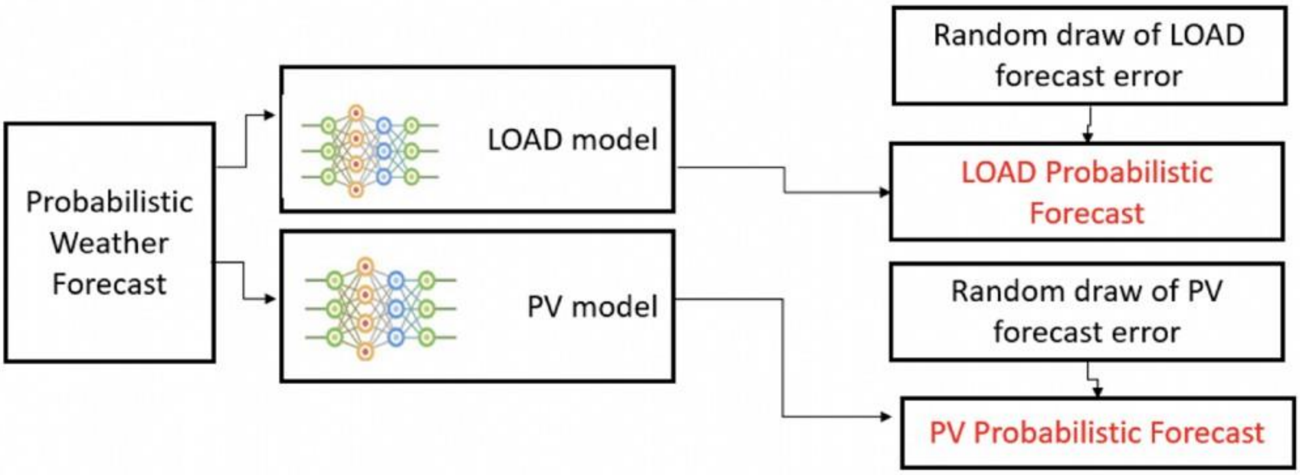
Characterization of the stochastic process of the weather forecast error (step (i) of the PFG) and generation of a weather probabilistic forecast (step (ii) of the PFG approach).

Figure 2: Characterization of the relationship between weather and load / renewable energy production



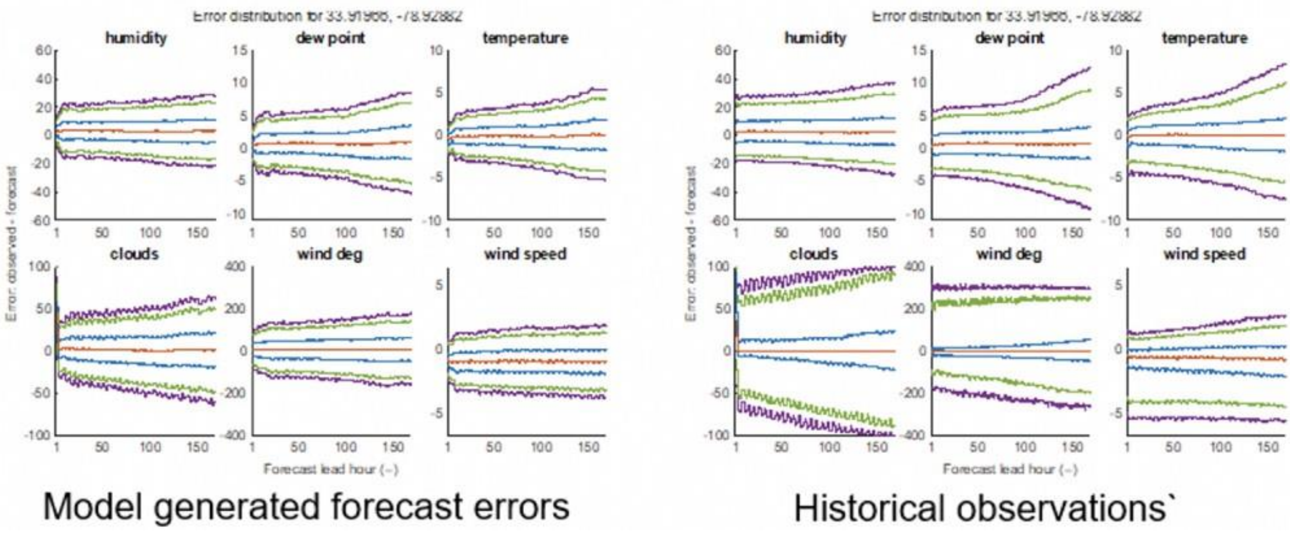
Characterization of the relationship between weather and load / renewable energy production (step (iii) of the PFG).

Figure 3: Generation of probabilistic forecast of load and renewable energy production



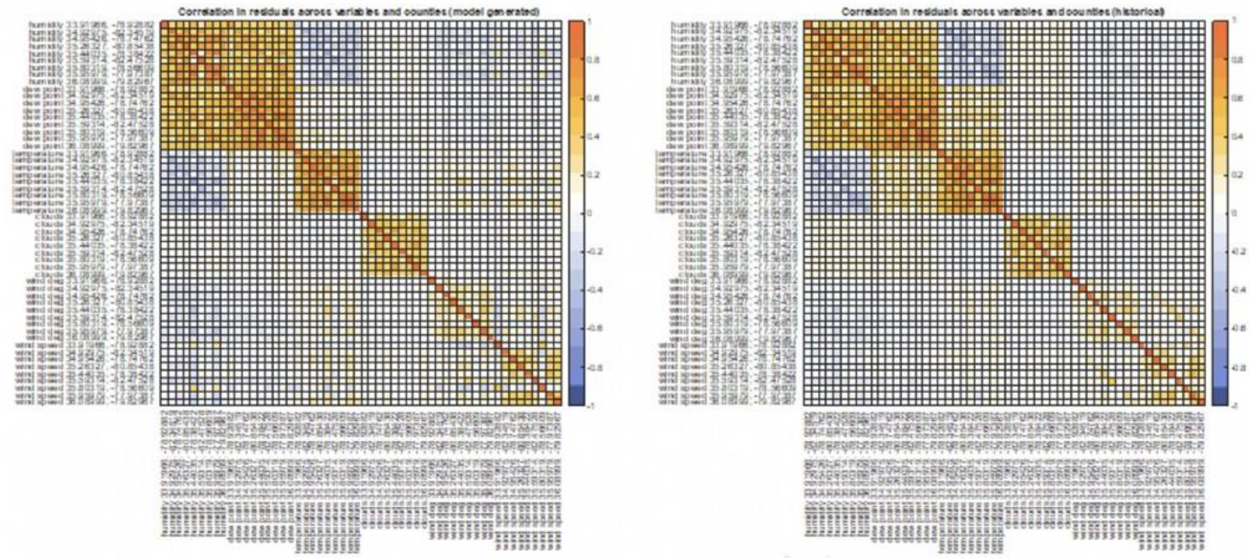
Generation of probabilistic forecast of load and renewable energy production (step 4 of the PFG).

Figure 4: Comparison of the quantiles of weather forecast errors



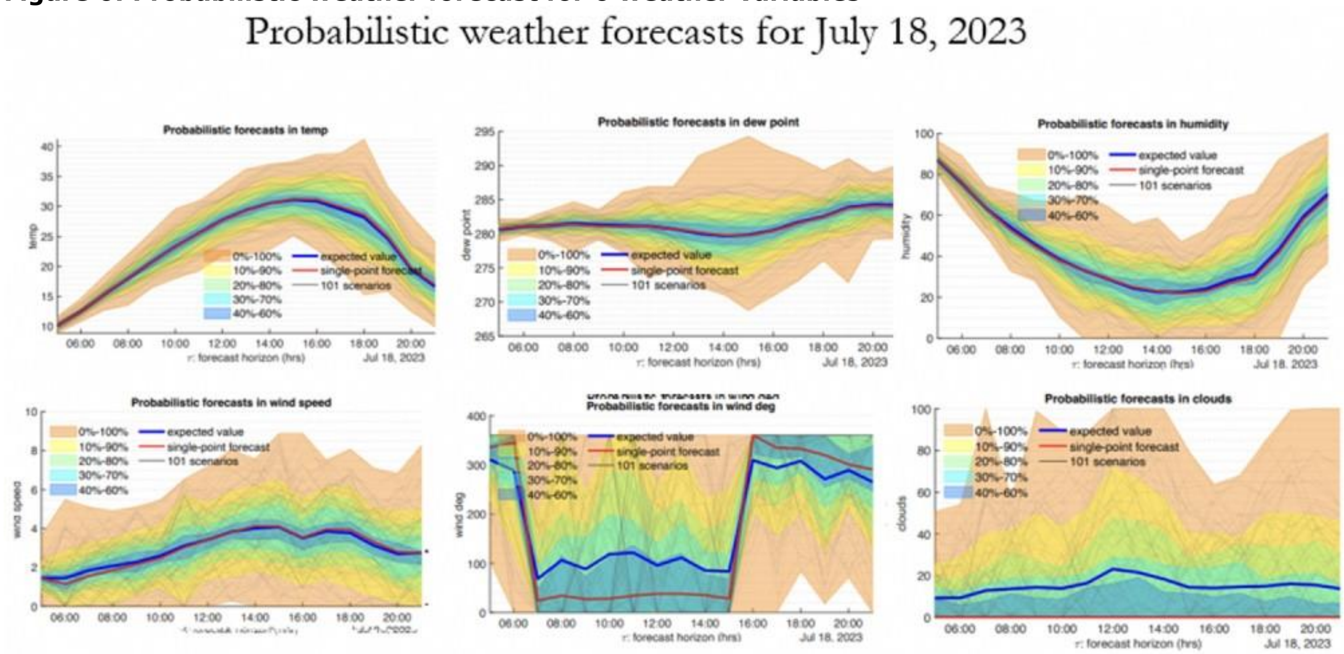
Comparison of the quantiles of weather forecast errors in the PFG forecasts (left) and historical forecasts (right).

Figure 5: Comparison of correlation across errors in the forecasts of six weather variables



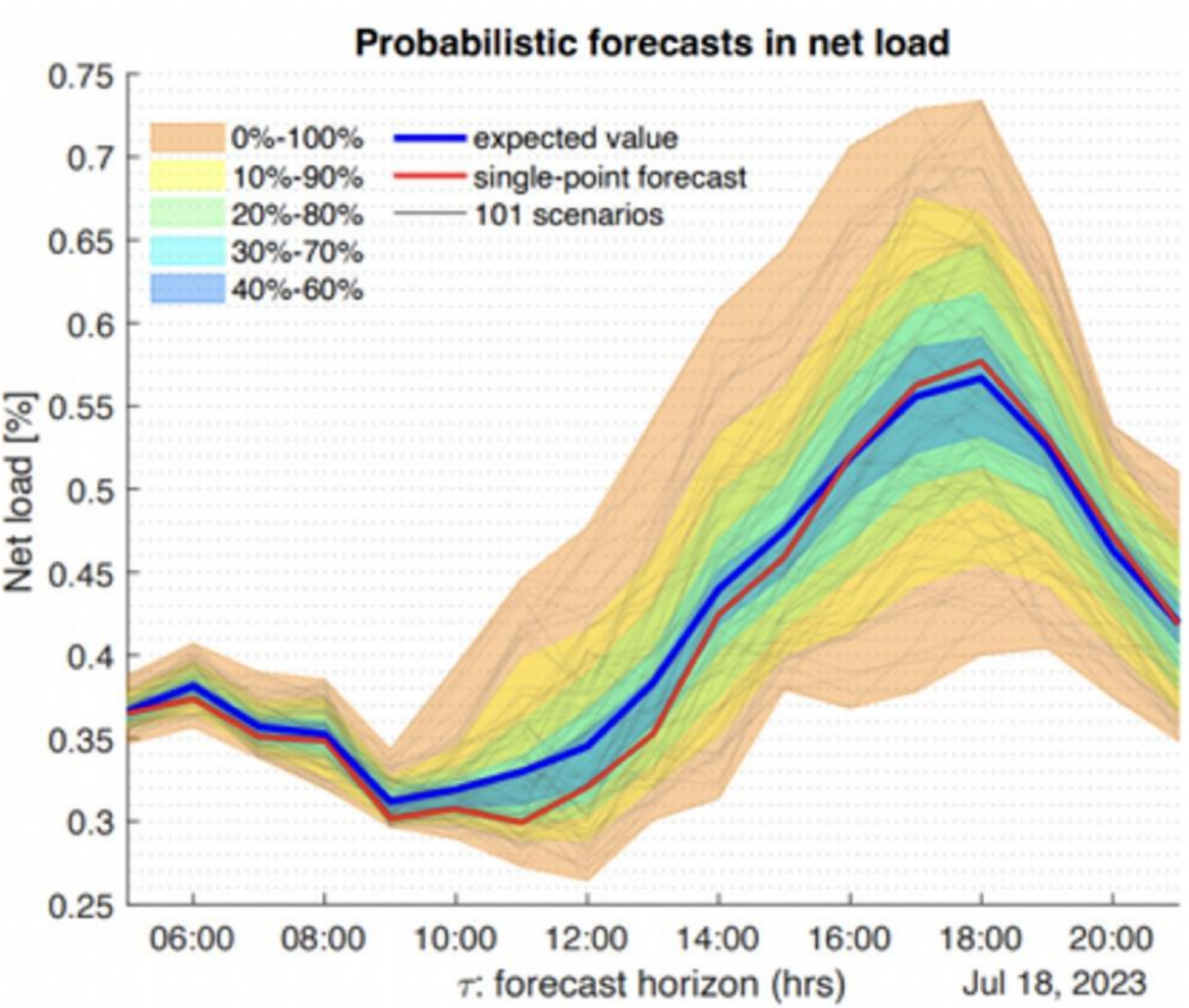
Comparison of correlation across errors in the forecasts of six weather variables for 9 different locations in the PFG forecasts (left) and historical forecasts (right)

Figure 6: Probabilistic weather forecast for 6 weather variables



Probabilistic weather forecast for 6 weather variables and quantile bands for one location.

Figure 7: Probabilistic forecast of net load



Probabilistic forecast of net load (i.e., electricity demand minus solar production) for the next 24 hours.

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[Abstract:0521] OP-297 [Accepted:Oral Presentation] [Energy Modeling » Market Equilibrium]

Power to the Regions - A Mixed Complementarity Problem (MCP) Model for Regional Perspectives on equilibrium RES expansion paths

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Overview:The energy transition represents major challenges worldwide and is characterised by a profound change in economic conditions. Organizing the energy transition requires an immense coordination effort at all political levels. The political processes, systems and plans according to which the energy transition is to take place vary considerably, even if the climate protection targets can be similar.

The European Union sets climate targets and has political competences that are relevant to the European interconnected energy system (EU Commission, 2019). At the same time, all member states are pursuing national targets, either to fulfil EU requirements or to achieve their own goals, which leads to a complex hierarchy of political targets. These targets vary in terms of speed, costs, choice of technology and the question of where the transformation of the energy system should take place. The federal republic of Germany demonstrates a further level of complexity, as not only national and supranational energy transition and climate protection targets exist, but also the federal states have set own targets (Monstadt and Scheiner, 2015).

Due to these regional targets, the federal states play a decisive role in Germany for reaching climate protection goals, and more specifically for the planning and design of the German national power system. The self-imposed energy transition and climate protection targets of the federal states, such as RES expansion pathwaysare often much more ambitious than the national targets.

The federal states are striving for a cost-optimised energy supply, whereby there is a strong interdependence between the decisions of all federal states, as the national targets must continue to be met and imports from neighbouring federal states are only possible through corresponding exports and a corresponding increase in generation capacity in the neighbouring federal state. The federal states differ not only in terms of the need to expand capacity, but also regarding electricity demand and the potential of wind and solar energy. This difference is reflected, for example, in windy federal states in northern Germany with a tendency towards low demand for electricity compared to coal states such as Brandenburg, North Rhine-Westphalia and Saxony, as well as the southern federal states of Baden-Württemberg and Bavaria with high demand and lower potential for wind energy. These heterogeneitieshave a significant influence on investment strategies within the energy transition (Zinke & Schmidt, 2020).

The question therefore arises as to how these regional goals relate to the overarching national and supranational goals. Of particular interest is what an energy system and a corresponding transformation scenario towards climate neutrality would look like that does not result from a top-down optimisation, but rather represents an equilibrium between self-interested regions with self-imposed goals. On the one hand, the expansion of renewable energies as well as imports and exports from neighbouring federal states will be compared between a top-down optimisation and the balance between self-interested regions. On the other hand, it will be examined how the system costs are distributed among the federal states if the regions minimise their own costs, considering both national and regional climate protection targets.

The next step is to analyse policy measures to approximate the first-best scenario. This raises the question of how investments can be efficiently incentivised where they are efficient from a system perspective, even if they are not optimal from a regional perspective. Then, distribution measures to reach a "fairer" distribution of costs at regional level can be discussed.

This question is closely linked to the question of optimal bidding zones but goes beyond this. The questions posed here are relevant for both zonal and nodal wholesale systems, no matter the number of zones and nodes, respectively.

Methods:If there are no market distortions and no market failure, top-down optimised (energy system) models and equilibrium models with utility-maximising agents produce the same results (cf. Gabriel et al., 2013), due to the first welfare theorem or duality, respectively. However, real-world energy systems are not frictionless, so that there are several market distortions whose effects can be analysed by an explicit model comparison. For example, in liberalised markets, investments in the energy system are made by private actors who lack complete information (Qiang et al., 2020). Incomplete markets, resulting for instance from information incompleteness, also stem from the dynamic nature of the energy system undergoing rapid transformation guided by evolving political objectives. For example, incompleteness of markets arises from the fact that the profitability of private investments in the power plant park is dependent on grid expansion, which is usually state or at least state regulated (Höffler & Wambach, 2013). Furthermore, risk management instruments are often inadequate, also leading to market incompleteness.

These points lead us to the hypothesis that energy system transformation scenarios that are calculated using equilibrium models, considering the market distortions on the part of the market participants, are better suited to generate realistic scenarios and can also generate valuable insights for political decision-makers regarding the effects of various market failures compared to a first-best scenario. In the first-best scenario, the optimal capacity expansion for Germany is determined by means of cost minimisation. This is contrasted with an energy system in which the regions minimise their own costs and not the social planner for Germany.

Using an equilibrium model, we divide Germany into 12 regions, each with a benefit-maximising/cost-

minimising actor. Each region corresponds to a region of Germany. The spatial division into regions corresponds to the borders of the federal states. The city states of Bremen, Hamburg and Berlin and the smallest federal state, Saarland, are grouped together with their respective neighbouring federal states. This approach makes it possible to avoid significant imbalances between the areas. Load profiles and specific potentials for wind and solar energy are determined for each defined region. The transmission capacities between the individual regions are decisive for the exchange of energy between the regions. In addition to the national energy transition and climate protection targets, the regional energy transition and climate protection targets are also considered.
Using a Mixed Complementarity Problem (MCP)Model, the energy to be generated, the required capacity of each component in all regions and the required transmission capacities between the regions are calculated for each year. The total system costs of each region are minimised, considering the constraints. The costs depend on variable operating costs such as fuel costs and include year-specific investment and operating costs for different power plants. Using this approach, the operation of existing power plants is optimised and the most cost-effective investment decision for new power plants is determined for each region.
Results:Several results can be achieved through this project. These include insights into the distribution of renewable energy capacities, backup capacities, transmission lines and in perspective electrolysers at regional level, considering external demand influences. A particular focus can be placed on the costs of energy supply, especially the cost delta compared to a top-down model. Analysing the factors influencing deviations from the optimum will play a central role. This includes analysing market failures and conducting sensitivity calculations to quantify their effects. Ultimately, policy measures will be researched and derived with the aim of increasing efficiency in the energy system and efficiently addressing market failures.
Conclusions:The regional perspective is important to consider in two respects. On the one hand, the regional targets are often more ambitious than the national targets and in turn influence the national target. It is therefore less realistic to consider only the national goal. Secondly, regional actors are self-interested actors, which might lead to a different distribution of system costs among the federal states than in the top-down modelling of the energy system.
This research paper analyses the interfaces and areas of tension between the different levels of political objectives and looks at the practical implementation at regional level. In particular, the question of how an effective balance between the different objectives can be maintained to meet the challenges of the energy transition at both national and regional level is examined.
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Höffer and Wambach, 2013: Investment coordination in network industries: the case of electricity grid and electricity generation.

Keywords: Energy Modelling, Energy Transition, Mixed Complementarity Problem, Regional targets

[Abstract:0503] OP-298 [Accepted:Oral Presentation] [Energy Modeling » Market Equilibrium]

The cost of missing regional investment incentives in zonal electricity markets – Case study for the German electricity system in a European context

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Overview:The transformation of the European electricity system towards non-fossil energy sources takes place in an electricity market with bidding zones. In most cases, the bidding zones still follow national borders instead of regional and temporal surplus or scarcity in supply and demand. This raises questions on the efficiency of market incentives for investment and operation decisions for flexible supply and demand installations within each bidding zone. One important example is the uniform bidding zone in Germany which can be seen as a show case due to the fast transition towards renewables, restrictions in transmission investments, and consequently required investments in regional flexibility [1]. In the short-term, market results on the spot market neglect internal constraints in the transmission network. Therefore, market outcomes are often infeasible in the physical electricity system and require costly adjustments. An increasing demand for congestion management has already been observed, with rising costs for adjusting market outcomes as well as an increasing need for network expansion, which is expected to continue in the future [2], [3]. In the long-term market equilibrium with investment, the investors in renewable capacity, (fossil or renewable) gas power plants and various other flexibility options (e.g., electrolysis capacity) do not observe regional scarcity signals for their investment decisions from the spot market. This can result in inefficient spatial investment and also an inefficient composition of technologies due to the correlation of spatial and temporal market prices.
Methods:In our work, we analyze the German electricity market in a European context within a two-level electricity market model [4]. At the first level, the model allows private firms to decide on their long-term investment decisions in spatial and temporal flexible generation and demand capacities considering the resulting market equilibrium in the European electricity market. Trading between bidding zones is considered with inter-zonal trade capacities. At the second level, we evaluate market outcomes for a core region with a more detailed spatial resolution. In our case study, we look at Germany with higher spatial granulation (11 zones), take the market outcomes of the spot market, evaluate the spatial location of installations within the German electricity system and determine resulting transmission constraints and least-cost congestion management. For investments without spatial incentives, we assume different tie-breaking rules for their allocation to the 11 zones. In order to compare investment and operation outcomes to the first best, we compare results to a nodal pricing model for Germany on the spot market (11 zones) and optimal allocation within Germany of investment levels determined in a zonal electricity market.
Results:The application uses an aggregated data set of the European electricity system for the target year 2030. The first preliminary results show that from a system-optimal perspective and despite of an early coal-exit in Germany, additional investments in gas power plants are especially needed in the south of Germany whereas new flexible demand (e.g., electrolysis capacity) is more beneficial in the north. It is expected that network congestion and redispatch cost decrease since investments are placed in regions with either a scarcity or surplus in electricity production.
Conclusions:The current lack of regional incentives in the uniform bidding zone raises concerns if this spatial allocation which is beneficial for system efficiency can be reached. In case of inefficient placements and technology choice we can show that the system, in addition to the spot market outcomes, requires procurement of investment in additional flexibility with related costs to allow for physically feasible system operation.
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Keywords: regional investment incentives, zonal electricity pricing, electricity market modeling

[Abstract:0620] OP-299 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

Market Power and Incentive-Based Capacity Payment Mechanisms

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Overview:Electricity generation firms have three main sources of revenue: the sale of electricity in the short-term wholesale market, the sale of long-term forward contracts for electricity, and the sale of generation capacity. The last of these is becoming increasingly important as electricity markets implement capacity payment mechanisms to ensure that sufficient capacity is available in case of sudden shortfalls in intermittent renewable generation. A major design challenge for capacity mechanisms is how to provide generators with an incentive to have their capacity available in exactly the moment when it is required.

In this paper, we study a popular form of capacity mechanism based on reliability option contracts. Generators receive a fixed payment for a regulated generation capacity (known as firm energy) that they are assumed to be able to provide even under system stress conditions. The requirement to supply this capacity is triggered when the spot price exceeds a regulatory threshold known as the scarcity price. When the spot price exceeds the scarcity price, generators must produce their firm energy, otherwise they pay a penalty equal to the shortfall quantity multiplied by the difference between the spot and scarcity price. Generators producing more than their firm energy receive a similar payment for their generation surplus. Otherwise, the settlement price for all transactions between market participants is capped at the scarcity price.

Using a stylized model of the wholesale electricity market, we demonstrate severe flaws in capacity mechanisms based on these reliability option contracts. In the short-term, generation firms with market power can choose whether the scarcity condition is triggered. The incentive to withhold generation and create a scarcity condition depends on the relative magnitude of the generator's forward contract and firm energy positions. The reliability option contracts eliminate the usual disincentive to exercise market power provided by fixed-price forward contracts. In turn, these short-term distortions affect the long-term incentives of generators to sell forward contracts. We show that hydroelectric generators have an incentive to sell more forward contracts and store less water under the reliability mechanism.

We test our theoretical predictions using 24 years of data from the Colombian wholesale electricity market, covering the period before and after the introduction of the reliability payment mechanism in that market in 2006. We show that the largest generation firms change their bidding behavior in the short-term market in response to the incentives created by the mechanism. The largest firms can determine whether a scarcity condition exists, and we show that they make the optimal choice in 90 percent or more of hours. Moreover, as predicted by our model, we show that hydroelectric

generators sold more fixed-price forward contracts and reduced their reservoir levels after the introduction of the mechanism.

Our paper contributes to the existing theoretical literature on strategic behavior under capacity payment mechanisms. Fabra (2018) develops a simple analytical framework that incorporates both generation investment and short-run pricing decisions. She studies the cases of reliability options and their potential to mitigate market power but acknowledges the crucial role for regulators in setting the scarcity price. Léautier (2016) also develops an analytical model to compare reliability options with physical capacity certificates and develops conditions under which these are equivalent. Most closely related to our paper, Teirilä and Ritz (2019) construct a computational model of the Irish electricity market to study the potential exercise of market power under a system of reliability options. In contrast to these existing papers, the focus of our analysis is on the interaction of reliability options and fixed-price forward contracts for energy in the short-run and long-run wholesale markets.
Methods: We develop a stylized model of the wholesale electricity market incorporating the interaction between short-term electricity sales at the spot price, long-term fixed-price forward contracts, and the reliability option contracts. Our theoretical model provides several predictions about the effect of the reliability payment mechanism on wholesale market outcomes. First, the mechanism will affect the bidding behavior of generation firms in the short-term wholesale market. Large generators will have the unilateral ability to withhold their generation and create a scarcity event in which the spot price exceeds the scarcity price. It may be profitable for generators to do this, depending on the quantities of their firm energy and fixed-price forward contract obligations. The response of generators to these short-term incentives will be apparent in their bidding behavior.

The reliability payment mechanism will also affect long-term market outcomes. Hydroelectric generators will sell a greater quantity of fixed-price forward contracts, crowding out the thermal generators, who will sell a lower quantity of contracts. Moreover, hydroelectric generators will have less incentive to store water as insurance against future low inflows, so hydro storage levels (relative to forward contract obligations) will drop.

We test these predictions using 24 years of data from the wholesale electricity market in Colombia, covering the period before and after the introduction of the reliability payment mechanism in 2006. Our data includes the price and quantity offers, the system demand, the generation output, the market price, the capacity contract quantities and prices, and the fixed-price forward contract positions of each firm. We supplement the hourly data with daily information on hydroelectric inflows, storage levels, fossil fuel usage, and input prices.

For our short-term analysis, we focus on the three largest generation firms. For each firm, we calculate the profitability of triggering the scarcity condition each day over a ten-year period. This requires solving for the optimal generation quantities in each hour of the day given the hourly residual demand curves faced by the firm. Because the net firm energy position is determined for the whole day, based on the firm capacity and the total generation for the day, it is necessary to solve this optimization problem simultaneously for all 24 hours of the day. For each firm, we recover the monthly opportunity cost of water that minimizes the deviation between the actual and optimal generation quantities.

For our long-term analysis, we estimate the change in the sales of fixed-price forward contracts and hydroelectric storage levels after the introduction of the reliability payment mechanism. Because the short-term incentives are determined by the relative magnitude of forward contract and firm energy quantities, we compute counterfactual firm energy quantities for the period before the introduction of the mechanism.
Results: Our analysis of the short-term market outcomes shows that the largest three generation firms can choose whether a scarcity condition exists based on their output level. The largest generator can trigger scarcity in 16% of sample hours. Calculating the optimal generation quantities for the three largest generators given their hourly residual demands, we find that best response levels accurately predict scarcity conditions. In the case of the largest generator, 90% of predicted scarcity hours occur, and 98% of predicted non-scarcity hours do not occur. Analysis of plant-level bids shows bunching below the scarcity price when it is optimal to avoid scarcity, and above the scarcity price when it is optimal to trigger scarcity. Overall, our results demonstrate that generators respond to the short-term incentives created by the reliability option mechanism.

Our results for the long-term market outcomes also match our theoretical predictions. After the introduction of the reliability payment mechanism in 2006, hydroelectric generation firms increased their sales of fixed-price forward contracts, from 64 percent to 72 percent of total system demand.

This increase crowded out sales of fixed-price forward contracts by thermal generators, who reduced their contract sales from 24 percent to 16 percent of total system demand. Moreover, hydroelectric generators also reduced their reservoir storage levels after the introduction of the mechanism: from 130 to 95 days of forward contract coverage. These changes increased the susceptibility of the system to shortfalls in hydroelectric inflows.
Conclusions:The design of the reliability payment mechanism had three primary OBJECTIVES: (i) incentivizing investment in generation, (ii) mitigating market power, and (iii) ensuring plant availability. Fixed-price forward contracts are already effective at addressing the latter two objectives. However, our findings suggest that combining reliability options with forward contracts is less effective than using forward contracts alone.

As an alternative to the reliability payment mechanism, we propose adjusting the design of the forward contracting mechanism to better incentivize generation investment. The existing contracts do not provide sufficient time to bring new generation resources online. To address this, we propose that regulators could mandate retailers to purchase forward contracts three to five years in advance. This adjustment would not only ensure price certainty for consumers but also guarantee a revenue stream for generators, providing ample time to build new generation units. Under this approach, forward contracts alone would satisfy the objectives of the reliability payment mechanism at a lower cost to consumers.
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Keywords: capacity mechanisms, reliability options, wholesale electricity markets, market power, hydroelectricity, Colombia

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A model-based analysis of investments and dispatch in residential energy usage with different electricity rate designs

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Overview:Residential energy demand is changing significantly due to the energy transition to renewable sources. It is increasingly electrified, e.g., by switching from Internal Combustion Vehicles (ICVs) to Electric Vehicles (EVs) and switching from gas-based space heating, water heating, and cooking to electric technologies such as heat pumps and electric stoves. This adds a significant amount of electricity demand. Moreover, a substantial share of this demand is flexible: EV charging typically only needs to fulfill a certain amount of battery charge, and heat pumps can pre-heat homes or storage tanks, especially when well insulated.

Simultaneously, the electricity supply from the energy system is increasingly based on intermittent renewable sources. This may lead to lower average generation prices, as these sources have no fuel and low levelized electricity costs, which are expected to decline further in the future (Sens et Al.). However, fluctuations in the price of electricity in the market are expected to increase because of the intermittent availability of these sources. There may be high price spikes when renewable energy is unavailable due to a lack of wind and solar radiation, as more expensive backup power plants must fill in then.

Lower average prices of generation should eventually be passed on to the end-users by electricity retailers, which has a beneficial impact on the electrification of end-uses. However, electricity rates are often designed as simple flat rates per kWh. These do not pass on the price fluctuations of the electricity market price signal to the consumer. This means that customers have no incentive to react to these price fluctuations and use the flexibility of their loads to adjust their electricity consumption.

Furthermore, consumers' final electricity rate includes not just the electricity generation price but also other components. The most significant of these components is often the distribution network tariff: the price customers pay for using the electric distribution network (Prettico et Al.). Currently, distribution network tariffs are often either fixed payments (per year or month) or added to the per kWh price that users pay for the electricity generation component and other components, such as taxes, retailer margins, and transmission fees. When network tariffs are fixed or based on per kWh prices, they do not give incentives to users to reduce their peak consumption (Hennig et Al.) and, therefore, they may not prevent network overload that happens due to significant simultaneous peaks of, e.g., of EV charging or heat pump usage.

This contribution presents the impacts of different rate designs and network tariff choices on residential household energy consumption patterns. We combine different choices for the electricity generation-related component and the network tariff to four final rate designs: a flat per kWh rate for both generation and network tariff, a Time-of-Use kWh rate for both with higher prices during the day on weekdays, a real-time market price for generation with a fixed network tariff and a real-time market price with a network capacity based network tariff. We investigate the impact of these rate design choices on investments in electrification, dispatch of the chosen technologies, costs, network load, and resource usage. Furthermore, we investigate model runs with tighter carbon constraints to investigate increasingly higher levels of electrification.
Methods:We use the open-source energy system model Calliope (https://www.callio.pe/) to build a 25-household neighborhood modeled according to a typical Dutch population that is connected to the distribution network through an LV transformer. We map investment options for decarbonizing residential energy demand, retail rates, and network tariffs onto input assumptions for Calliope. We employ a first-order approximation where we use an instance of the Calliope model for the whole European energy system in 2030, including the stated capacity targets of the Netherlands and an assumption on flexible demand in this year. We do not explicitly model the feedback of electrifying residential energy demand on the national level power prices. Based on electricity prices from this model, we compute the optimal investment and dispatch decisions on the residential level.
Results:We calibrated the price parameters of each design to lead to roughly the same total costs in the no-investment run. In unconstrained runs, rate designs where the network component is based on fixed or capacity payments lead to lower total costs due to lower variable costs. This is because, in the other designs, the network price is added to the per-kWh price of electricity. Thus, electrification is relatively more expensive in the kWh-ToU and Flat designs. At tighter carbon budgets, the differences between rate designs become smaller again. This is likely due to the impact of using ground-source heat pumps and solar panels, which is triggered in all rate designs at tight carbon budgets. Because ground-source heat pumps have much higher efficiencies than air-sourced heat pumps, users need less electricity for heating, and solar panels further reduce their reliance on grid electricity. Thus, the impact of high grid electricity prices diminishes.

Electrification has a profound impact on networks. Load peaks increase when investments are allowed and households electrify their space heating and cooking demand. Interestingly, at higher decarbonization rates, load peaks and average usage declines again. This is due to installing PV panels with batteries, the higher efficiency of GSHPs, and improved renovation in the model. On the other hand, feed-in peaks increase massively at higher decarbonization levels, which may present a challenge for networks.
Capacity-based network tariffs give a strong incentive for peak load reduction but not a reduction of average load. They only tend to spread out the load more. They limit feed-in peaks to the same level

as load peaks at higher decarbonization levels, which reduces the average feed-in since generation cannot be spread out in the same way as consumption.

Peak and average gas consumption decline strongly and quickly in all rate designs. Capacity-based electric network tariffs lead to a higher gas peak in the unconstrained runs. This is because, in this case, gas still fulfills peak heat demand to a larger degree, as higher electric peaks incur higher costs. However, the average gas load is very low in all rate designs when investments are allowed; it drops from almost 70 kWh to around 13 kWh. At these low levels, it may be questionable whether running a gas network is still worth the cost or whether the gas network should be built back completely. Conclusions:We found that volumetric network tariff designs lead to higher total user costs in our model. Higher variable electricity costs mainly drive this, as users cannot make use of low electricity generation prices when the network tariff is added on to the per kWh price of electricity. Due to the higher cost of electricity, the volumetric tariffs also incentivize the deployment of rooftop solar PV, even when this may not be economically efficient at the system level.

Electric network peaks increase significantly under all rate designs due to the increasing electrification of end-uses that are expected with lower electricity prices. The capacity-based network tariff strongly dampens the increase in peaks. It does this mainly by incentivizing the installation of home batteries on the order of 1.5 to 4 kW, which allows households to reduce their peak consumption from the grid.

Both flat volumetric and capacity-based network charges may lead to higher heating costs, as it becomes expensive to heat at high power. This may induce more energy efficiency investments, such as building insulation upgrades. In contrast, in volumetric ToU prices with low prices during the night and fixed network tariffs with RTP for the energy component, users can often heat at high power levels with relatively low prices during the night. Thus, these options do not incentivize efficiency measures as much.

At higher decarbonization levels, we observe additional electrification of end-uses: ICEVs are increasingly switched to EVs, GSHPs are added to supplement ASHPs, building insulation is improved, and more PV panels and batteries are installed under all rate designs. The cost differences between different rate designs become smaller again in these model runs as households become less dependent on grid electricity, and therefore, the per kWh price differences do not matter as much anymore. The impact on network peaks is mixed: the additional electricity demand from EVs is offset by efficiency gains from improved insulation and GSHPs and self-generation from PV panels and home batteries. In the rate designs with no network capacity charges, network peaks are dominated by PV generation feed-in. The capacity-based network tariff caps feed-in at the same level as grid consumption.

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Keywords: retail rates, network tariffs, calliope, flexibility

AuthorToEditor: Dear Committee, I know I missed the submission deadline, but I hope you can still accept this abstract submission. Thanks and best regards, Roman Hennig

[Abstract:0676] OP-301 [Accepted:Oral Presentation] [Electricity » Power System Planning & Management]

An Energy Systems Planning Model for the Sector Coupling

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Overview:This study introduces a novel energy planning model that incorporates internal capacity investment, energy dispatch, Power-to-X, and demand response technologies for long-term planning. The suggested model focuses on an energy system with the goal of minimizing the combined cost of capacity investment and operational expenses associated with meeting energy demand across all technologies. The model also takes into account the interconnections between other demand sectors, such as electricity, heat, and transport. An illustrative case study will be employed to assess the applicability of the proposed approach. The results demonstrate that Power-to-X technologies can effectively offer the necessary flexibility for increased capacity investments in fluctuating renewable energy sources, resulting in systems with reduced levels of excessive energy production. The primary application of battery storage and Power-to-heat technologies is for variable renewable shares and achieving CO2 reductions. The proposed optimization framework can provide useful insights on the determination of the optimal energy transition pathways that address the new market operating challenges of contemporary power systems subject to technical and economic constraints.

Methods:The power sector model considers two types of power sector units: dispatchable and non-dispatchable. The non-dispatchable units primarily involve solar, wind, and hydro-river technologies. The model's modular framework enables for the simulation of several solar/wind/hydro-river zones, each with its own hourly availability profile, capital cost, and installed and maximum capacity levels. Given the information about these technologies and zones, the model optimizes capacity investments in each zone and period (long-term planning) while ensuring that the annual Critical Excess of Energy Production does not exceed a predetermined level (for example, 5% of total yearly demand). The second group of units includes dispatchable units for coal, oil/diesel, natural gas, biomass, nuclear, and hydro. Hydro-dam and hydro-pump systems separate hydro-based units even further. In the case of fossil-fuel power plants, the model may optimize dispatch and seasonal storage for each hydro-dam and hydro-pump system unit in a region independently.

The model incorporates principles that are comparable to those of other energy planning models when examining the transportation sector. The electric vehicles module necessitates a collection of basic parameters, which comprise the vehicle-to-grid (V2G) cost, the total number of vehicles (including fuel and electric vehicles), the electric demand generated by EVs, data pertaining to EV batteries (including their size and charging rate), and availability curves (indicating the percentage of EVs that are connected to the grid each hour). As a result, storage capacity and demand profiles in the transportation sector are variable, as they are contingent on the number of EVs connected to the grid during each period.

Stationary batteries offer yet another alternative for electric storage. To facilitate analysis, the model focuses on a solitary storage unit as opposed to the quantity of stationary batteries that are accessible. After determining the initial capacity of the stationary storage, the model optimizes both annual capacity additions in the future. The inputs and outputs of electricity, as well as the state of charge of the storage, are optimized on an hourly scale.

The heating sector is depicted in the model by means of two direct connections that exist between the electrical and heating sectors. To begin with, the model incorporates Combined Heat and Power (CHP) power facilities. A District Heating (DH) demand is directly linked to each combined heat and power (CHP) plant; each CHP plant can only be connected to a single DH demand. CHP plants may be powered by biomass, gas, oil, diesel, or coal, and the number of DH demands and CHP plants accounted for in the model is not restricted. Additionally, DH demand can be met through the installation of conventional fuel-based boilers, whether new or existing. Ultimately, electric heating, the second link between the electricity and heat sectors, can also meet the demand for DH. Electric heating technologies consist of heat pumps, including air-to-water and air-to-air heat pumps, as well as electric boilers. The model takes into account a COP (coefficient of performance) for every heat pump technology.

Non-DH demand, which includes individual space heating and hot water requirements, is also accounted for by the model. Existing and new installations of conventionally fueled boilers and electric heating can meet this specific demand. Individual demand and DH demand are both distinguished by their hourly level. As a consequence, the model achieves hourly optimization of the dispatch of

all feasible technologies (CHP, conventional boilers, and electric heating), while determining the magnitude of new capacity additions for each technology in each year of the modeling horizon. In addition to variable cost, efficiencies/COP, capital cost, and storage capacity, every technology has its own set of attributes. The structure of cooling demand is comparable to that of heat demand. Individual space conditioning is governed by a single demand curve, whereas district heating is governed by a single demand curve. The model operates under the assumption that heat pump technologies are the sole viable options for meeting this demand in both DH and individual demand. The model applicability has been assessed in an illustrative case study of a medium-sized power system considering also its interconnections with neighboring power systems. The problem is to be solved to global optimality making use of the ILOG CPLEX 12.6.0.0 solver incorporated in the General Algebraic Modeling System (GAMS) tool. An integrality gap of 0% has to be achieved in all cases.
Results:In terms of optimization, the integrated model takes into account three key groups of decision factors. First, it analyzes the annual investment capacity options for each technology (dispatch and storage size). The model assumes that if a capacity expansion is built for a certain technology, it will become accessible at the start of the year. Second, it considers dispatch factors across all technologies. The dispatch of the technologies takes into account hourly resolution for each year of the modeling time horizon. The use of hourly resolution above the typical time-slice technique greatly increases computational time. However, this provides the capability to better illustrate the relationship between fluctuating renewable sources and Power-to-X technology. The third set of variables corresponds to storage capacities (hydro, heat, electricity-electric vehicles-Stationary). Storage levels for each unit or technology, when available, are also depicted at an hourly resolution for each year in the planning horizon.
Conclusions:The implementation of carbon restrictions has impacted the utilization of energy storage systems and stimulated further investments in renewable power generation technology. Emissions from all sectors under consideration are substantially decreased in all situations. The reduction is partly attributed to the enforced regulations such as renewable penetration targets (or alternatively CO_2 emissions limits) and carbon limits, as well as the economic aspects of the energy system.
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Keywords: Optimization, Energy systems, Power systems, Electric vehicles, Heating sector, Sector coupling

[Page: 302]

[Abstract:0622] OP-302 [Accepted:Oral Presentation] [Electricity » Power System Planning & Management]

What are the economic conditions for the feasibility of a high renewable penetration power systems? Profitability and

investment considerations for a hydrogen long duration storage

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Overview:Variable renewable electricity sources such as wind and solar power, key technologies in the decarbonization process, exhibit production variability on different timescales. In particular, in some countries there is a significant seasonal and even annual variability, which calls for high levels of long-term flexibility to ensure a balance between production and demand at all times. Among these flexibility solutions, the transfer of generated electricity from periods of surplus to periods of deficit is envisaged through long duration storage, of which hydrogen, produced electrolytically and stored in salt caverns, represents a solution of choice. However, this is not the only option, and it is possible to formulate several combinations of flexibility sources with different characteristics: some of the literature, such as [1,2], lists them, amongst others, decarbonized pilotable means with stock of origin exogenous to the power system, oversizing of renewables, development of interconnections. These combinations of flexibility come at different costs: so another part of the literature proposes economic evaluations [3–6].

When long duration storage systems are used as the main source of long-term flexibility to balance power systems with very high renewable penetration, the equipment is under-utilized. Indeed, the load factors of electrolysers are low, insofar as large installed capacities are required to absorb periods of surplus, thus reducing their profitability: [7] shows that the costs of electrolytic H2 production can vary by a factor of three, depending on whether the electricity supply is continuous or based on a variable renewable production profile. What's more, part of the storage system, designed to cover the worst all year-combined hazards, will not be used every year, which significantly reduces its profitability, similarly to an ultra-peaker.

Methods:These two characteristics motivate our research and lead us to look at the impact of long duration storage costs on full system costs, according to different mix configurations. In particular, we are interested in the economic impact of adding a final hydrogen consumption system backed by the electricity sector on the complete costs of the system, as well as on the price of electricity, on the price of hydrogen and the sharing of the value derived from the gains of mutualizing storage system technologies. Finally, we look at the financing characteristics of such storage as a function of mix configurations, insofar as the services provided change as does the profitability of such an asset, impacting the cost of capital required by a potential private investor and shaping the future economics of a decarbonized power system. To this end we use a probabilistic model of the power and energy sector.

Results:The first step in our work consists in formulating a large number of power system configurations with high renewable penetration, whose multi-year equilibrium is achieved through long-term hydrogen storage. The originality of this work lies in the consideration of long duration storage on multi-year scales through probabilistic dimensioning. Our results show that the costs associated with long duration storage are substantial, and in some cases represent a significant proportion of the total system cost. However, while the use of long duration storage decreases with the inclusion of other sources of long-term flexibility, the cost of introducing the latter offsets the costs previously associated with storage. However, those considerations are only valid in the cost range hypothesis considered and for which the litterature is not enough developped.

The second part of our work consists in extending the scope of the system under consideration, by adding hydrogen final consumption, under different profiles, supported by the renewable electricity system. Renewable electricity production then meets this demand via electrolyzers already used in long duration storage, enabling these systems to be mutualized. This approach is similar to [8] who explores the impact of an electrolytic hydrogen consumption outlet on the cannibalization of variable renewable energy revenues. We then observe a reduction in the sizing of long-term energy storage capacity, as well as several economic effects: the overall costs of the energy system (electricity and hydrogen combined) fall - due to additional consumption and mutualization - but the average cost of electricity production rises - due to additional renewable production. So, to benefit from the overall drop in costs, the power system has an interest in selling electricity at least a certain price to the electrolysers and so to the H2 consumers. At the same time, the H2 consumers have to buy this

high-cost electricity. A corridor of subsidies for electricity consumption for H2 electrolytic production then emerges, enabling final consumers of electricity to benefit from an average decrease in costs compared to the reference situation, and final consumers of hydrogen to benefit from cheaper electricity to produce hydrogen. In addition, these results underline the need for significant coordination between the electricity and hydrogen final consumption sectors, a result aligned with [9].

Finally, the third stage of our work looks at the economics of long duration storage and its ability to recover its costs, again depending on the mix configuration and the various long-term flexibility solutions deployed in a power system. Indeed, in order to enable a level of security of supply comparable to that currently experienced in European power systems (equivalent to 3h of average consumption loss of load every year), long-term flexibilities are installed without economic criteria. We then study the price thresholds to which a long duration storage should be exposed in order to recover its costs, based on storage cycling, investment costs and a cost of capital fixed exogenously to the calculation. Considering high capital costs for long duration storage is similar to [10], which highlights the high WACC of a peaking facility in a conventional power system. Our results show that, depending on the transfer services rendered and on the mix configurations, a part of the storage that cycles more can be profitable by being exposed to reasonable prices, while a part of the storage, in particular that which performs multi-year transfer and ensures security of supply in the face of an extreme weather event, cannot and requires an adapted market mechanism. These results enable us to highlight the economic impact of long duration storage on the system costs, the size of the investment required, and the role of the cost of capital and the state planner in security of supply when based on long term energy transfer.
Conclusions:Our work thus highlights the important role of long duration storage in the economics of power systems with high renewable penetration, its profitability, the interest of a private investor in investing in it, and the importance of the role of a planner in the deployment of these technologies. Similarly, we show the interest of coupling a hydrogen final consumption sector. Therefore, the originality of this work lies in the study of the economic feasibility of configuring given power systems, the increased profitability of storage systems when offered an additional hydrogen final consumption, and the size and nature of the financing required for these same configurations. These results will help power system planners in their choice of decarbonization trajectories and the types of financing to be provided.
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Keywords: long duration storage economics, hydrogen final consumption economics, seasonal flexibility profitability

[Abstract:0245] OP-303 [Accepted:Oral Presentation] [Electricity » Storage]

Optimal electricity storage in a carbon free system - Taking things week by week!

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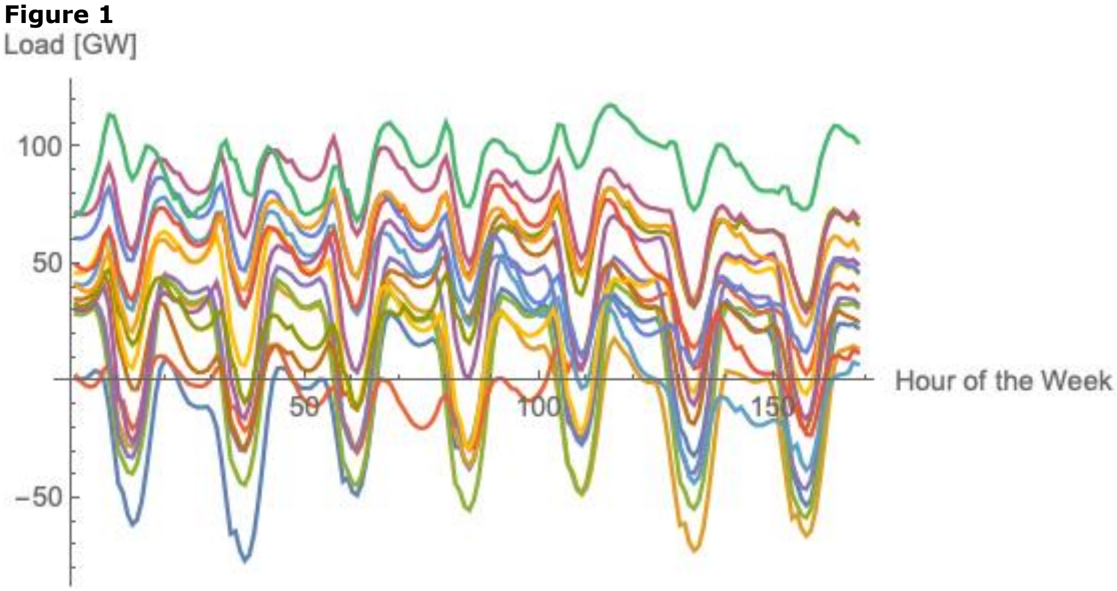
Overview:Renewables provide CO2-free electricity with the drawback that their supply seldom matches energy demand. Therefore, intermittency requires a dynamic redistribution of electricity, even though future supply and demand are quite uncertain more than a few days ahead. One way to organize the redistribution is the large-scale operation of electricity storage. However, the determination of sensible storage strategies in a stochastic environment remains a difficult task, especially if the interplay with long run investment decisions is considered.
We have proposed (Geske and Green, 2020) modelling uncertain net demands (demand less wind and solar generation) as a Markov process. Our algorithm solves the storage strategy for given capacities with a linear program and then plugs the resulting post-storage residual load into a screening curve approach to update generation capacities. Optimal generation outputs, storage (dis-)charging and capacities can be derived by repeating this scheme until a fixed point of capacities is reached. We have shown that the expected state of charge of storage is much higher under this approach than in a typical perfect foresight model, because of the need to hold energy back in case of a prolonged period of high net demand. This reduced the value of storage by 30% compared to perfect foresight estimates.
However, the application was based on a sequence of hourly net demand levels with transition probabilities that varied by time of day for winter and for summer, creating seasonal generation-duration curves which we combined to produce annual totals. This dramatically overstates the short-term uncertainty in electricity net demand. In this paper, we reflect system operators' ability to forecast future developments by dividing annual load profiles into representative weekly "patterns". The pattern transitions occur randomly with probabilities varying over the year. We assume that there is perfect foresight over the entire week: using a rolling horizon remains a possible approach for a future paper.
Weekly generation and storage operations are optimized with a linear program to avoid high expected costs in case of high electricity demand. Investments in CO2-free generation technology can then be planned based on expected load durations, which are straightforward to determine in a Markov setting.
The results provide a much more realistic and accurate view on the structure of optimal energy systems and its interplay with optimally managed storage.
Methods:Two key steps are essential for the application of this approach: 1. Modeling the residual load as a Markov process, representing load vectors on a weekly basis with hourly resolution, and based on this, 2. solving the deployment and capacity of generation technologies and storage as a Markov Decision Process.
To this end, a residual load time series was initially compiled for the period from 2011 to 2019 for Germany, supplemented with loads that are expected to constitute the energy system of 2050. Weather-dependent renewable generation (from capacity factors of wind and PV weighted with the expansion targets for 2050 of 150 GW wind and 200 GW solar), was subtracted from heating load (from a temperature time series), EV load, and the existing loads scaled for 2050. This synthetic residual load for 2050 now contains correlations of load, temperature, solar irradiance, and wind strengths – factors that would be difficult to consider if their modelling were kept separate.
This time series was divided into weeks, and these were clustered into 15 weekly residual load vectors (patterns) (Figure 1). Transition probabilities for each week were determined from those observed in practice, for that week and its near neighbours. These transition probabilities imply a stationary

distribution of the patterns (Figure 2), which expresses the seasonal course of the residual load from the distribution of the patterns. This method achieved accurate, highly efficient stochastic modeling of the residual load, which additionally approximates the knowledge about future temperature and wind strength development from weather forecasting due to its weekly timing.
Within each pattern, there is complete foresight. In each week, the cost-minimizing electricity generation that covers the residual load is determined, given the capacities of the technologies Nuclear, Gas Turbine with CCS, Bioenergy, Coal with CCS, and Lost Load. In the case of hydrogen storage, additional capacities for fuel cells and electrolysis are considered. The energy capacity for storage was taken to be 15 TWh. Specific to this approach is the inclusion of a storage buffer that takes into account future storage requirements – for instance, in anticipation of a "Dunkelflaute" with high electricity prices. For each combination of pattern, state of charge, and buffer size - approximately 3000 LPs (Linear Programs) - the minimum variable costs of electricity supply and the associated load durations for type of generator were determined.
The cost-minimizing optimization of the buffer was also carried out using a linear program (130,000 variables and 12,500 constraints), which considers the random development of the load over the course of the year, given the generation capacities. In the third stage, these capacities are updated through a screening curve approach and the whole process repeated until it converged to a fixed point.
Results:We simulated two scenarios using this method to identify the effects of storage: an energy system which must produce the energy to charge its storage (base case) and one which is able to import hydrogen as an alternative to electrolysis.
The patterns we considered can reach a peak residual load of 118 GW and a minimum of -76 GW. The average residual load is 26 GW, or 230 TWh annually. The base case simulation of a cost-minimal energy system shows that electricity production from nuclear power plants or coal with CCS is not efficient – neither reaches the minimum utilization to become profitable. In contrast, investments are made in 54 GW of bioenergy and 9 GW of gas with CCS, with a total capacity of 64 GW.
To compensate for this large difference between peak load and installed generation capacity, the storage is operated with a seasonal pattern (Figure 2's triangles indicate the charging strategy). In the PV-rich late summer months, the storage is fully charged until September and is then available to cover the peak load in patterns 15, as well as 14 and 13. From April, the winter season with the risk of load peaks is over, and the storage is no longer charged in any of the patterns 5-12 (higher loads never occur), gradually depleting it. From April to August, the storage is then operated in a cycle, discharging in pattern 5 and charging in pattern 3, thereby balancing the variations in solar irradiance. In summer, the storage is used to exploit arbitrage opportunities, and then charged with inexpensive renewable energy in late summer, substituting the rarely used peak load capacity in winter.
Contrary to this intuitive pattern of storage usage, the storage could also be operated based on imported hydrogen, which we allow at a charging rate of 10 GW. In this scenario, no domestic electrolysis capacity is created, but 42 GW of fuel cells are utilized for discharging. Slightly less bioenergy and much more gas with CCS are used. In this context, the storage slowly fills up during the summer, so that its contents can be used again for peak load coverage. Thus, there is no storage of domestic renewable energy during the summer.
Conclusions:The model demonstrates, through its strategy, how the storage is utilized. With this transparency, the model significantly contributes to the understanding of optimal storage processes in an electricity system tailored to them. This is particularly relevant in weighing the role of storage as a buffer against uncertain seasonal peak loads for capacity substitution, for arbitrage, and in covering intra-week load fluctuations.
The art of the approach lies in using highly efficient Markov chain modeling of the annual stochastic residual load to model a nonlinear stochastic program as a Markov Decision Process. This optimization problem can be divided into two sub-problems: the storage optimization problem, which is linear, and the capacity problem, which is nonlinear but can be easily solved through the screening curve approach. Iteratively, a stationary point can be found as the optimum.
We now plan to compare this approach with the results of a Perfect Foresight optimization of Monte Carlo simulations of the pattern paths, to quantify the errors of the Perfect Foresight modeling. Furthermore, the model provides an excellent framework for future investigations that are not possible in a Perfect Foresight context, such as analyzing the impact of forecast accuracy on the energy system. The approach offers rich possibilities to consider much finer energy system structures, such as trade or network infrastructures.
References:Joachim Geske and Richard Green, 2020: "Optimal Storage, Investment and Management under Uncertainty: It is Costly to Avoid Outages!", The Energy Journal, vol.41, no. 2, pp. 1-28

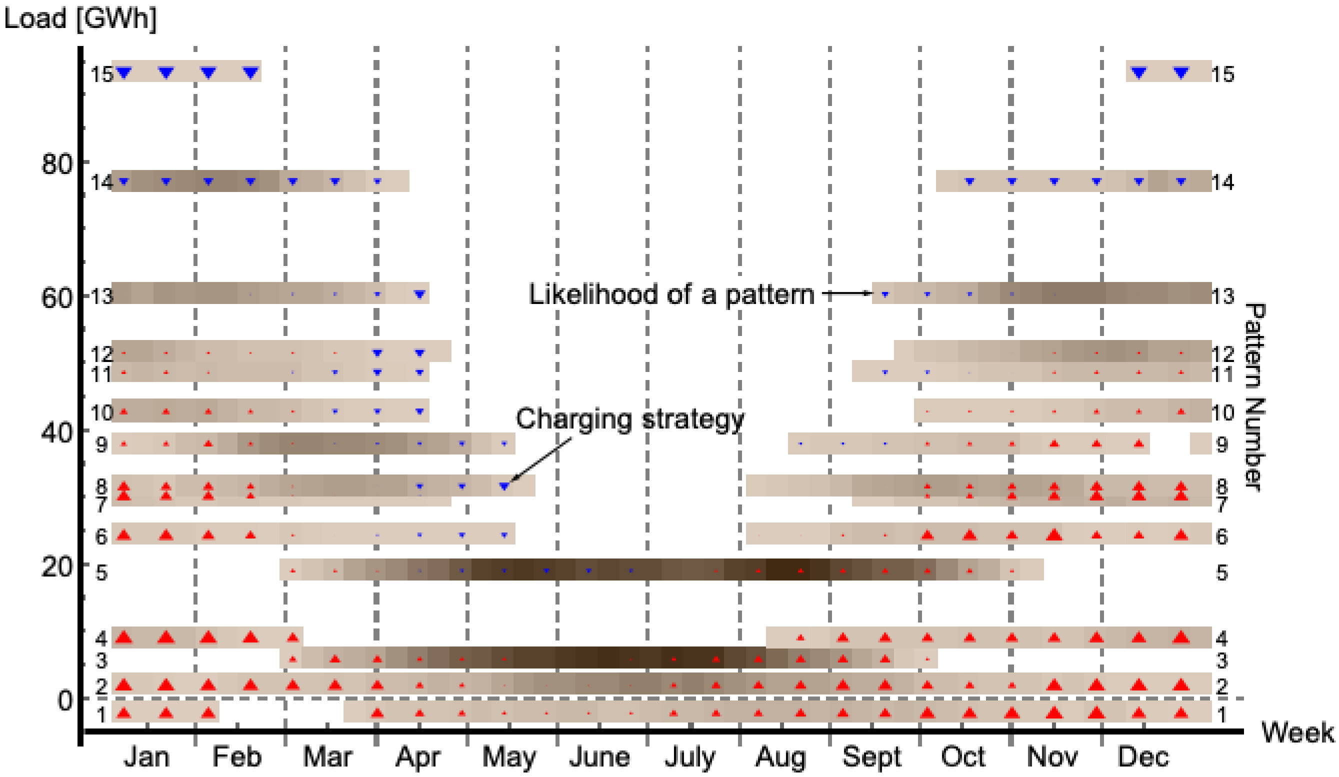
Keywords: Electricity Storage, Uncertainty, Stochastic Electricity System Model, Precautionary Storage

Figure 1



15 pattern residual load profiles; Residual load in GW on the vertical axis and hour of the week on the horizontal axis

Figure 2



Stationary distribution of patterns by average residual load and number of the week; dark shading indicates high likelihood; triangles visualize the optimal strategy (blue – discharging, red charging; size proportional to speed)

[Abstract:0296] OP-304 [Accepted:Oral Presentation] [Electricity » Storage]

An Efficient, Load-Optimizing Algorithm for HVACs Load for Demand Response Applications

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Overview:This paper presents a novel approach to optimizing the operational schedule of Photovoltaic-Battery Energy Storage Systems (PV-BEES) and HVAC (Heating, Ventilation, and Air Conditioning) systems, integrated with electricity procurement from the power grid. The primary objective is to achieve cost and energy savings while improving the load profile of the system. To this end, we formulate a mixed-integer nonlinear programming problem that seeks to identify the optimal operating mode for this integrated energy system.

Given the complexity and mathematical challenges associated with finding a comprehensive solution, which entails determining not only the optimal operating mode but also the control policies for minimal transition costs, we propose a decomposition strategy. This strategy aims to offer a practical, albeit suboptimal, solution. The methodology involves initially solving the scheduling problem with a set transition time to minimize the total operating costs. Following this, only the first scheduled transition is implemented in the system. The next step includes the optimization of controller parameters to economically manage transient profiles effectively.

The process is characterized by its iterative nature, adopting a receding-horizon optimization approach. After each completed transition, the scheduling and control problems are reformulated and resolved. This cyclic process allows for continuous adaptation to changing conditions, ensuring an efficient and dynamic operation of the PV-BEES and HVAC systems in harmony with grid electricity, thereby achieving the desired objectives of cost and energy efficiency along with a more favorable load profile
Methods:System Integration and Modeling:
-Integration of PV-BESS and HVAC Systems: Develop a comprehensive model integrating Photovoltaic-Battery Energy Storage Systems (PV-BESS) with HVAC systems, coupled with grid electricity procurement. This model aims to simulate the interactions and energy flow between these components.
-Load Profile Analysis: Analyze the current load profile of the building to identify key areas for optimization and potential energy savings.

Formulation of the Optimization Problem:
-Mixed-Integer Nonlinear Programming Problem: Formulate a mixed-integer nonlinear programming (MINLP) problem to determine the optimal operating mode for the integrated energy system. This formulation considers various constraints such as energy demand, storage capacity, and grid regulations.
-Decomposition Strategy Implementation: Employ a decomposition strategy to manage the complexity of the MINLP problem. This involves breaking down the problem into more manageable sub-problems that can be solved sequentially.

Scheduling and Transition Management:
-Initial Scheduling with Fixed Transition Time: Start by solving the scheduling problem with predetermined transition times to minimize total operating costs.
-Implementation of First Transition: Implement only the first scheduled transition in the actual system to evaluate its impact.
-Controller Parameter Optimization: Optimize controller parameters for managing transient profiles economically, ensuring minimal transition costs.

Iterative Receding-Horizon Optimization:
-Receding-Horizon Approach: Adopt a receding-horizon optimization strategy, where after each completed transition, the scheduling and control problems are reformulated and resolved based on the latest data and conditions.
-Continuous Adaptation: Allow for ongoing adjustments to the operational strategy in response to changing environmental conditions and grid requirements.

Demand Response and Energy Flexibility Analysis:
-Demand Response Strategy Evaluation: Assess the effectiveness of integrating PV-BESS and HVAC systems in managing load peak shaving and ramp-rate reduction for demand response contracts.
-Ancillary Services Potential: Investigate the capacity of the integrated system to provide ancillary services to the grid and evaluate the impact of grid incentives on building participation in load following programs.

Simulation and Results Analysis:
-Scenario-Based Simulations: Conduct simulations under various scenarios, including the use of passive thermal mass and active storage tanks as energy flexibility resources.
-Energy and Cost Savings Assessment: Evaluate the energy and cost savings achieved by the proposed algorithm, comparing it with traditional ON/OFF load control methods.
-Load Shifting Analysis: Analyze the capability of the algorithm to shift building loads from peak to off-peak times and its impact on the overall energy utilization cost.

Validation and Testing:
-Real-Time Data Utilization: Utilize real-time outside temperature information and dynamic electricity pricing data to optimize the scheduling in real-world settings.
-Performance Metrics Evaluation: Establish metrics to measure the success of the approach in terms of cost savings, energy efficiency, load profile improvement, and grid stability enhancement.
Results:The findings highlight the potential benefits of optimizing the power flow between the MicroCSP, HVAC system, and thermal zones to maximize the benefits for both the building and the power grid
The study demonstrates how the integration of MicroCSP and the building HVAC system can help the building deal with constraints related to load peak shaving and ramp-rate reduction set by the power grid as part of long-term demand response contracts.
The paper presents an in-depth investigation of the potential of MicroCSP to provide ancillary services to the power grid, focusing on evaluating the effect of incentives provided by the power grid on building participation in load following programs.
The proposed load control scheme for residential HVAC loads achieved significant energy and cost savings compared to the commonly used ON/OFF load control method.
By utilizing real-time outside temperature information and concurrent electricity pricing, the approach was able to optimize scheduling and reduce building energy utilization cost.
The results showed remarkable diminishing in energy utilization cost, indicating that the load control scheme effectively reduced energy consumption
The paper proposes two demand response (DR) control strategies for office building HVAC systems: rule-based and prediction-based. These strategies aim to shift 24-55% of the building's total load from peak load time to valley load time, resulting in a duration of over 2 hours.
The results show that the utilization of energy flexibility and the implementation of the proposed DR controls can smooth the net load demand curve of the grid and improve its ability to adopt renewable energies.
The analysis of the rule-based and prediction-based DR control strategies for office building HVAC systems using passive and active energy flexibility was conducted. The simulation results were obtained for two scenarios: one with passive thermal mass as an energy flexibility resource and the other with an active storage tank as an additional flexibility resource.
The simulation running time for each scenario was approximately 50 seconds on Dymola (Version 2018) on Windows 10, with a 2.6 GHz processor (Intel Core i7-10700) and 16 GB RAM
Conclusions:This research successfully demonstrates a novel and effective approach to optimizing the operational schedule of Photovoltaic-Battery Energy Storage Systems (PV-BESS) integrated with HVAC systems and grid electricity. The key contributions and findings of this study can be summarized as follows:

- The integration of PV-BESS with HVAC systems, supported by a robust mixed-integer nonlinear programming framework and a practical decomposition strategy, has proven to be an efficient method for managing energy flow and operational scheduling. This approach significantly enhances the operational efficiency of the building's energy system.

-The study reveals that the proposed algorithm and control strategies yield substantial energy and cost savings compared to traditional ON/OFF load control methods. By harnessing real-time data, such as outside temperature and dynamic electricity pricing, the system effectively optimizes scheduling, leading to a notable reduction in energy utilization costs.

- The research highlights the ability of the integrated system to effectively manage load peak shaving and ramp-rate reduction, aligning with long-term demand response contracts. Moreover, the capability of the system to shift a significant portion of the building's load from peak to off-peak hours demonstrates its potential in enhancing grid stability and facilitating the adoption of renewable energies.

-The system's capacity to provide ancillary services to the power grid and respond to grid incentives further underscores its utility in modern energy systems. The findings suggest that buildings can play a more active role in grid support, particularly in load following programs.

-The adoption of both passive and active energy flexibility resources, as evidenced in the scenario-based simulations, indicates that the proposed approach is scalable and adaptable to different building requirements and environmental conditions.

The research outcomes contribute valuable insights into the development of more efficient, cost-effective, and grid-responsive building energy systems. The integration of renewable energy sources, coupled with advanced control and optimization strategies, sets a precedent for future energy management solutions in the built environment.

In conclusion, this study not only achieves its objectives of cost and energy efficiency but also paves the way for future innovations in building energy management and grid interaction. The methodologies and findings have practical implications for the design of energy systems in buildings, offering a template for achieving energy sustainability and grid harmony.
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Keywords: Energy Storage System, Renewable Energy, Demand Respons, Sustainalbe Building

[Page: 305]

[Abstract:0365] OP-305 [Accepted:Oral Presentation] [Energy Efficiency » Residential and Commercial Buildings]

Agent-based modelling of building energy-efficient retrofit adoption in neighbourhoods

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Overview:Reducing energy demand for space heating in buildings is crucial for tackling Europe's climate and energy crises. In the Netherlands, homeowners, who correspond to about 70% of the total population, depend heavily on combi-gas boilers for heating. To facilitate the transition to sustainable heating, the Dutch government has set a course to regulate the energy tariffs, incentivise heat pumps and insulation, and introduce a ban on the purchase of gas boilers starting in 2026. While a substantial body of literature addresses the technical, economic and policy aspects of building retrofits, a significant gap remains in our understanding of the homeowner decision-making process. Such decisions were often thought to be more rational, i.e., a homeowner renovates her home when the building components degrade or to save money (e.g., InvertEE building stock model) and chooses the most cost-optimal renovation measure. However, more recent studies involving methods from such domains as psychology, behavioural economics and sociology show that various factors play a role. To mend this gap, we propose an agent-based model that compares the two decision-making algorithms regarding building retrofit adoption: financial (i.e., rational) and social (i.e., boundedly rational). The model shows the impact of several policy interventions on adopted measures, namely, different household electricity and gas price scenarios, combinations of insulation and heat pump subsidies and gas boiler ban.
Methods:We apply agent-based modelling (ABM), which is a computer simulation of an artificial world populated by agents – discrete decision-making entities (e.g., individuals, households, firms). Its advantage over traditional equation-based modelling approaches in energy systems analysis (i.e., system dynamics, optimisation models, computable general equilibrium models) is its ability to incorporate heterogeneity and adaptivity of the agents [1], which steps outside the microeconomic assumption of the representative economic agent. Hence, it is a suitable method to challenge the idea of a rational economic agent, who has full information, decides to renovate once it becomes

economically profitable and chooses the most cost-optimal renovation package.
Using ABM, we aim to compare the outcomes of the rational decisions (we call these "financial" or short "FIN") to the outcomes of the boundedly rational decision-making (we call them "social" or "SOC"). In two separate simulations, agents decide (a) whether to renovate and (b) if yes, which of the 38 retrofit packages, including 19 measures with heat pump replacement and insulations of different building components and 19 measures – insulation measures with gas boiler replacement. The agents' start considering renovation when a currently installed gas boiler approaches its end-of-life (in future version of the model, also when the gas prices increase sharply). In "FIN" model, rational agents calculate the difference in NPV of the 38 options to renewing the gas boiler and adopts the package with maximum NPV difference. The "SOC" model is a more complex decision-making based on the Theory of Planned Behaviour, which considers the effect of such factors as attitude towards renovation, payback period of packages, age of a building, complexity and energy-saving of renovation packages.
Preliminary results in Figure 1 show the cumulated adopted packages over 20 years of simulation for FIN and SOC under three different price scenarios presented in Table 1.
Results:The results show the uptake of retrofitting packages for a generic residential neighbourhood in the Netherlands with building archetypes from Tabula Episcope [2]. We present the comparative results of the two decision-making models, i.e. rational and social, for several electricity and gas price, as well as policy scenarios are include (but not limited to) such policy approaches as gas boiler ban and subsidies for heat pump and insulation. The results indicate that if agents were rational, a significant portion of neighbourhood homeowners would switch to heat pumps and/or insulate under all price scenarios. Low electricity prices as in 2022 would incentivise heat pump installation, without any insulation, whereas high electricity prices like in 2023 would make insulation profitable. Under the social decision-making, agents persistently choose gas boiler replacement only, except for low electricity prices as in 2022. The final conference contribution will include further calibration and sensitivity analysis in order to understand and better present the model behaviour and robustness of results.
Conclusions:This study, through agent-based modelling, offers novel insights into the decision-making processes of homeowners regarding energy-efficient retrofit adoption in residential neighbourhoods. The findings reveal a marked divergence between outcomes based on rational (financial) decision-making and those based on social (boundedly rational) influences. Under scenarios of rational decision-making, homeowners are more inclined to adopt heat pumps and insulation measures, swayed significantly by fluctuating electricity and gas prices. In contrast, when social factors dominate, homeowners demonstrate a persistent preference for gas boiler replacement, except under specific conditions of low electricity costs. These results underscore the importance of considering not just economic factors but also social and behavioural aspects in policy design and implementation. This broader approach is crucial for more effective strategies in promoting energy-efficient retrofits. The study also highlights the need for further research and refinement in the modelling approach, particularly regarding the calibration and sensitivity analysis, to enhance the understanding and robustness of the outcomes.
By bridging the gap in understanding homeowner decision-making processes, this research contributes valuable insights to the ongoing discourse on sustainable heating transitions and energy-efficient building practices, particularly in the context of the Netherlands. It underlines the complexity of decision-making in this realm and the necessity for multi-faceted policy approaches that address not only economic incentives but also social and psychological barriers to adoption.
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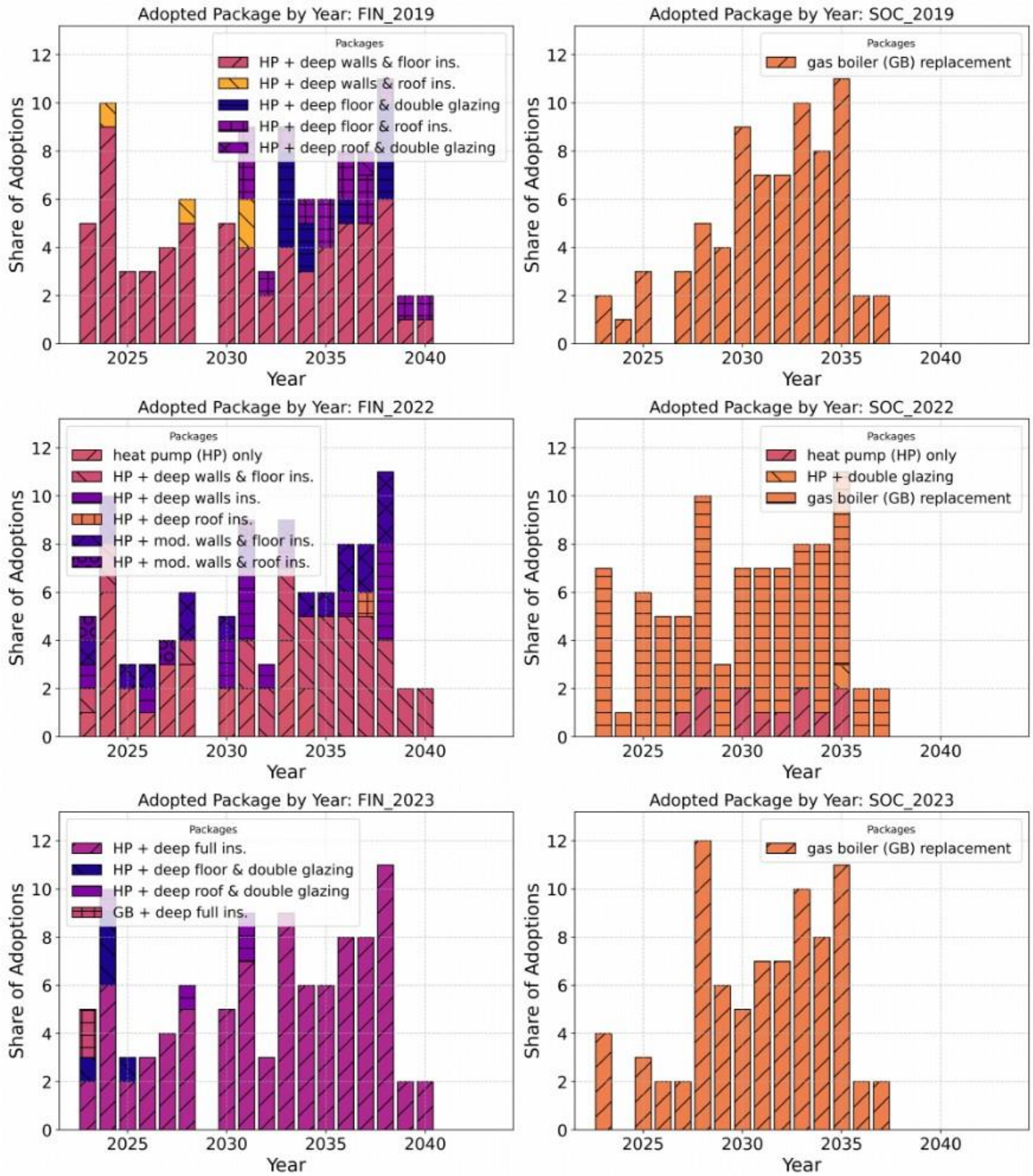
Keywords: investment decision, energy efficiency measures, energy-efficient retrofit, agent-based modelling, residential buildings, homeowners

Figue 1



Retrofitting packages adopted yearly in six scenarios - two different decision-making (FIN, SOC) and three price scenarios

Table 1

	household electricity prices [EUR/kWh]	household gas prices [EUR/kWh]
NL2019	0.206	0.094
NL2022	0.090	0.158
NL2023	0.475	0.248

Household electricity and gas prices in the Netherlands (NL) in 2019, 2022, and 2023 (Eurostat, 2023)

[Abstract:0570] OP-306 [Accepted:Oral Presentation] [Energy Efficiency » Residential and Commercial Buildings]

Assessing the impacts of building monitoring system in the identification and assessment of energy efficiency measures

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Overview:Building energy efficiency retrofitting (BEER) projects have a central role in the Net-zero transition. However, the current global BEER rate is under the level required to achieve the Paris Agreement's objectives (IEA, 2022, 2020). BEER refers to the adaption of the latest technologies or features to obsolete systems, enhancing both energy efficiency and renewable use, and reducing the greenhouse gas emissions of the existing building stock (Torgal et al., 2017). BEER projects include a range of Energy Efficiency Measures (EEMs). EEMs specifically pertain to the specific practices and technologies utilised to improve the energy performance of buildings.
The identification of EEMs is a key objective of an energy audit. An energy audit is a systematic examination and analysis of energy usage within a building aiming to identify opportunities for enhancing energy efficiency, achieving cost savings, reducing environmental impacts, and improving comfort. Energy audits contribute to informed decision-making through the assessment of the benefits and costs of the EEMs proposed. Energy audits typically involve a systematic on-site assessment of various factors, including building envelope insulation, lighting, HVAC systems, and appliances.
The presence of a Building Monitoring System (BMS) enables detailed data collection, essential for EEM, regarding both the energy usage (e.g., electricity and gas) of appliances and key building environmental conditions (e.g., carbon dioxide concentration and temperature). BMS use sensors, meters, and advanced software to collect real-time data. By detecting anomalies and irregularities, organizations can quickly identify and rectify issues, preventing unnecessary waste. Moreover, BMS enable the benchmarking of the performance pre- and post-measures. The BMS is crucial to enable highly informed decision-making regarding the adoption of EEMs. The presence of more comprehensive, detailed, and precise data improves the quality of the estimates of the adoption of EEMs, reducing the uncertainties in BEER project assessment. Building owners and tenants are historically risk-averse (Belaïd and Massié, 2023; Heutel, 2019; Wu et al., 2023). Therefore, the reduction of uncertainties in the BEER project decision-making process is crucial to speed up the renovation rate. However, the impact of building monitoring on the identification and adoption of specific EEMs is overlooked by the literature and needs to be further investigated. Therefore, this paper aims to explore the potentialities of Building Monitoring System as a crucial tool to identify context-specific EEMs and assess the impact of their implementation.
Methods:This paper is based on a single case study (Yin, 2015) of the introduction of a Building Monitoring System in a complex of office buildings in northern Italy. The single case study explores the potentialities of BMS as a key tool in identifying and assessing context-specific EEMs. We performed two energy audits of the building complex conducted in accordance with the European Norm (EN) 16247 (CEN, 2022a, 2022b, 2022c). EN 16247 is a European standard that provides guidelines for conducting energy audits.
The first energy audit, compared to the second one, was conducted without utilising data from the BMS. For the first energy audit, we collected both primary and secondary data from the local environmental monitoring agency, the building's complex energy bills, multiple on-site technical data collection, and the firm's employees responsible for the building's complex energy management. The energy audit process included the development and validation of a detailed energy model using specialised software tools. The energy model was designed to accurately depict both the physical and operational characteristics of the building's complex. The validation of the energy model was achieved through a comparative analysis with real energy consumption data obtained from energy bills. The primary outcomes of the first energy audit encompass the computation of key Energy

Performance Indicators and the identification and assessment of adequate EEMs. We benchmarked the Energy Performance Indicators of the building's complex against Italian reference Energy Performance Indicators values. Moreover, we analysed each proposed EEM, considering energy, economic, and environmental performances. In the second energy audit, we integrated into the first energy audit the quarter-hourly data from the BMS, expanding and refining the first analysis. Data collected from the BMS regards the energy and power consumption of relevant appliances and systems and employee attendance. This integration resulted in a comprehensive proposal of EEMs implementation and in a more precise examination of energy, economic and environmental performances. Finally, we conducted a comparative analysis of the results of the two energy audits, assessing the impact of BMS-derived data on EEMs identification and on potential enhancements in energy, economic, and environmental performances achievable through the proposed EEMs.
Results:The integration of BMS-derived data expanded and refined the first analysis. In the second energy audit, we identified several EEMs not present in the first one, and we improved the initial estimates, both providing a more precise assessment of the opportunities for the improvement of energy, economic and environmental performances, and recommending the adoption of different EEMs. Therefore, the analysis increases the number of EEMs proposed, and the improvement of the opportunities for energy savings, economic gains, and greenhouse gas emissions savings achievable through the proposed EEMs. Particularly, the improvement of the expected economic gains from the adoption of the proposed EEMs exceeds the cost of the introduction of the BMS.
Conclusions:We systematically analysed the impacts of the introduction of a Building Monitoring System in the identification and assessment of the opportunities for the adoption of Energy Efficiency Measures through a single case study of an office building complex in northern Italy. The BMS enabled a comprehensive identification and a detailed and precise assessment of recommended EEMs, resulting in an improvement of the identified expected energy savings, emission savings, and economic gains exceeding the cost associated with the introduction of the BMS.
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Keywords: Building monitoring system, Building energy efficiency retrofitting, Energy efficiency measure, Energy audit, Sustainability, Net zero

[Abstract:0596] OP-307 [Accepted:Oral Presentation] [Energy Efficiency » Residential and Commercial Buildings]

Role of portable air-conditioning on future energy demand in the French residential sector

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Overview: With climate change, temperatures are rising, forcing people around the world to adapt to increasingly intense and frequent heatwaves by adopting and using air conditioning (AC) systems. The rate of AC ownership varies around the world, but the number of systems is increasing everywhere. The future evolution of AC equipment and consumption has been discussed in recent years, but the technological detail is often insufficient to characterise the type of AC used in the residential sector. This is however a challenge as portable systems are particularly energy inefficient compared with split systems. We estimate a two-to-one ratio in terms of annual energy consumption, which is problematic given the objectives of reducing energy consumption and GHG emissions. Portable systems are particularly widespread in France, where they account for over 40% of domestic air conditioning (representing around 12% of the population). There are a number of reasons for this high equipment rate: these portable systems are quicker and simpler to install, cost less and do not require structural changes to the building (which may be forbidden in some historic urban areas or difficult as a tenant). Their low energy efficiency and ease of purchase lead us to characterise their adoption and consumption, in France in recent years and up to 2050.
Methods: The methods and modelling used in this study are divided into three parts, corresponding respectively to the modelling of the split-system air-conditioning equipment rate, the portable air-conditioning equipment rate, and the conventional energy demand projections for residential building cooling in France.

In line with the methods described and implemented in the literature, the split-system air-conditioning equipment rate is calculated in two ways. The first is probit econometric modelling applied to data from two surveys carried out in France in 2020 and 2023 (by ADEME and CEREN), coupled with weather and climate data supplied by Météo-France and EURO-CORDEX climate simulations, from which we recover cooling degree-days (CDD), with a threshold of 18°C. This first method allows us to assess the divergence in the parameters that determine the adoption of each type of air conditioning, among age, gender, socio-professional categories, type of residence, urban density, climate, annual energy expenditure and insulation.
We also carry out explicit modelling, in order to highlight the functional forms linking CDD to regional equipment rates in France.
These two methods show that the adoption dynamics between climate and equipment rate are different for the two types of air conditioning, and require a more dynamic approach for portable air conditioning.

The response of the equipment rate to changes in climate is modelled using an explicit dynamic calculation linking the stock of air conditioners in operation in the country to annual sales (taking into account the lifetime of the systems), and sales to summer CDDs. The national equipment rate is then equal to the stock per inhabitant.

The energy requirements for cooling residential buildings are calculated conventionally using the 3CL-DPE method. This is a standard implemented in Energy Performance Diagnostics (*Diagnostics de Performance Énergétique* DPE) in France. We have slightly modified the tabulated parameters of the official method to allow climate change to be taken into account in the calculation.

Once all the parameters have been set, the projections of equipment rates and consumption for each type of air-conditioning system are based on population projections provided by the French statistics institute (INSEE) and the shared socioeconomic pathways (SSPs), and the temperature projections are based on a set of 9 climate models from the EURO-CORDEX ensemble.
Results: We show in this study that the adoption dynamics between different air conditioning systems are very different. For this reason, technological disaggregation is important when trying to project energy demand for cooling. Indeed, the sensitivity of portable air conditioning sales to summer cooling degree-days leads to additional uncertainty about household equipment and therefore about final consumption.

Currently in France, portable air conditioning accounts for 40% of residential systems, but is responsible for two-thirds of cooling consumption, due to the low efficiency of these systems. This share tends to increase between now and 2050, via the increase in CDD in all the Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios. However, the difference between these two scenarios is not significant in 2050, as population trends play a greater role in the short/medium term.

Conclusions:In most European countries, summer peak consumption is becoming and will continue to become more intense on the electricity grid due to the increase in stocks of air-conditioning equipment and higher consumption (these two variables being a function of temperature). Quantifying the evolution of energy demand for cooling and its uncertainty is therefore essential for the design of future electricity networks. This study is part of that objective.

In addition, France has an extremely varied climate, which means that our results can be applied to different European countries. For example, the temperature increases in the south of France could be partly generalised to other countries around the Mediterranean. Conversely, the results for the north of France could be transposed to other countries such as the UK and Germany.

Finally, this study is part of a wider model of the energy consumption of residential buildings in France and should be pursued to explore the energy performance gap of air conditioning, to move from conventional standardised consumption to actual consumption taking into account the diversity of uses.

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Keywords: Portable air-conditioner unit, Cooling, Projections, Energy Consumption, Residential

[Abstract:0452] OP-308 [Accepted:Oral Presentation] [Energy Efficiency » Other]

Empirical Analysis On Influencing Factors of Home Energy Management System Implementation

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Overview:The home energy management system (HEMS) helps consumers' energy saving behaviour. HEMS is an important tool for promoting energy conservation in the household sector that can also contribute to CO2 reduction from the sector. Many studies have verified that consumers are willing to pay (WTP) to address environmental problems or for environment protection items (e.g., Wu,2012). Nakano and Washizu (2018) focused on several barriers impeding HEMS's acceptance, though advances in its technology, and a questionnaire survey conducted. They found that awareness of the technology was necessary for the acceptance and adoption of smart technologies. Moreover, Stenner et al. (2017) found that the level of trust in the power companies was important. Chen et al. (2020) investigated the factors that influence residents' WTP for HEMS in New York and Tokyo and suggested that social norms are positively correlated with the intention to implement HEMS. This study aims to reveal consumers' HEMS selection factors using revealed preference data. Hence, I conduct an analysis using the individual votes from the Survey on the Actual Status of CO2 Emissions in the Household Sector (Household CO2 statistics), which has investigated by Ministry of the Environment in Japan.
Methods:The Household CO2 statistics is a survey that has been ongoing since 2017 and targets households aged 20 and over across Japan. It was a mixture of random sampling conducted by enumerators (50%) and online surveys conducted using monitor sampling (50%), and asked questions about energy consumption, solar power generation, households, housing, and implementation of energy-saving actions.
This study uses the Household CO2 statistics in 2018, which asked on possession of HEMS, and the number of surveyed households was 13,000, and responses were 9,996 households (valid response rate 76.9%). For analysis applies a logistic regression Model, and the Equation is as follows.
[Equation is here]
where the dependent variable Y* means whether possession of HEMS or not. Concretely, Y=1: subject had the HEMS, while Y=0: means that did not have it. β is a regression coefficient, X_i (i = 1,…,m) is the ith independent variable, and ε is a random error term. Two Models are constructed: Model 1 does not use the district classification, which were divided the entire country into 10 regions, and Model 2 uses its classification.
Results:Logistic regression analysis is performed using Stata 16.1, and Table 1 shows the results. As a result of the analysis, it is confirmed Models adaptability from Prob > chi2 of the Hosmer-Lemeshow test (Model 1 is 0.2445 and Model 2 is 0.0628). Increasing factors of the probability on having HEMS are confirmed switching to a new electric power company, owning an EV, and living in a detached house. Conversely, decreasing factors of the probability on having HEMS are someone stays in home during the day, and the installation of solar panels. In the case of model 1, a house with a large floor area is also a factor that reduces on having HEMS. Similarly, in Model 2, older construction is a factor in the decline.
[Table 1 is here]
Switching to a new power company increases the probability on having HEMS, it shows a similar trend to Stenner et al. (2017), who found that trust in the power company is the key to acceptance it. Together with the fact that EV ownership is statistically significant, it is suggested that active

consumers for new technology choose HEMS.
The result of installing solar panels lowers the probability of having HEMS is unexpected despite it is most efficient to introduce HEMS at the same time as solar panels are installed. Furthermore, it was found that annual household income, which has been confirmed in previous research, has no effect on having HEMS. Similarly, the social norms were verified effectiveness by Chen et al. (2020), but the pro-environmental behavior was not adopted with statistical significance in this study. This seems to be a difference between stated preference and revealed preference data, but another detailed investigation is required.
Conclusions:This study uses logistic regression analysis to clarify the influence factors of the probability on having a HEMS. It is also found that because most of the previous studies were analysed using questionnaire surveys, they emphasized different factors than this study. The results of this study suggest that in order to popularize HEMS, actions such as providing information when installing solar panels are necessary. Furthermore, it became clear that there was a need to appeal to multifamily housing, which is less HEMS ownership than single-family homes. Decreasing factors of the probability on having HEMS overlap with the conditions that increase energy consumption. Therefore, the energy efficiency due to HEMS can be expected for these factors, indicating the need for future HEMS dissemination and improvement.
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Keywords: HEMS, Energy efficiency, Influence factors, Household, Logistic regression analysis

Equation

Equation:

$$Y^* = \beta_0 + \sum_{i=1}^{m} \beta_i X_i + \varepsilon$$

$$Y = \begin{cases} 1 & (Y^* > 0) \\ 0 & (Y^* \leq 0) \end{cases}$$

Table

Table 1 The result of logistic regression analysis

	Model 1						Model 2					
	Coef.	Std. Err.	z	Odds Ratio	[95% Conf.	Interval]	Coef.	Std. Err.	z	Odds Ratio	[95% Conf.	Interval]
Family size	-0.0361	0.0809	-0.45	0.9645	0.8231	1.1303	-0.0305	0.0820	-0.37	0.9700	0.8260	1.1391
Child dummy	0.3347	0.2246	1.49	1.3976	0.8999	2.1705	0.3391	0.2271	1.49	1.4037	0.8994	2.1906
Elderly dummy	0.0561	0.1911	0.29	1.0577	0.7272	1.5384	0.0506	0.1927	0.26	1.0519	0.7211	1.5346
Home during weekdays dummy	-0.3131 **	0.1578	-1.98	0.7312	0.5367	0.9962	-0.3213 **	0.1582	-2.03	0.7252	0.5319	0.9888
Pro-environmental behavior dummy	0.0656	0.0562	1.17	1.0678	0.9564	1.1921	0.0659	0.0564	1.17	1.0682	0.9564	1.1930
New electricity dummy	0.6975 ***	0.2362	2.95	2.0088	1.2644	3.1913	0.5068 **	0.2430	2.09	1.6599	1.0309	2.6726
Household income	0.0388	0.0612	0.63	1.0396	0.9220	1.1721	0.0105	0.0626	0.17	1.0105	0.8938	1.1425
Detached house dummy	0.5324 *	0.3052	1.74	1.7030	0.9362	3.0978	0.5744 *	0.3039	1.89	1.7761	0.9791	3.2221
Home ownership dummy	0.2756	0.3450	0.8	1.3173	0.6699	2.5901	0.1811	0.3445	0.53	1.1985	0.6101	2.3544
Housing ages	-0.0103	0.0064	-1.61	0.9898	0.9775	1.0022	-0.0107 *	0.0064	-1.66	0.9894	0.9770	1.0020
Total floor area	-0.0035 *	0.0020	-1.79	0.9965	0.9927	1.0003	-0.0028	0.0020	-1.43	0.9972	0.9934	1.0010
Window insulation dummy	0.2246	0.1661	1.35	1.2518	0.9040	1.7335	0.2631	0.1758	1.5	1.3010	0.9217	1.8362
Solar power	-2.3372 ***	0.1734	-13.48	0.0966	0.0688	0.1357	-2.3202 ***	0.1765	-13.15	0.0983	0.0695	0.1389
EV dummy	1.0556 **	0.4431	2.38	2.8736	1.2057	6.8486	0.8936 **	0.4523	1.98	2.4438	1.0071	5.9302
Big city dummy	0.1819	0.2094	0.87	1.1995	0.7957	1.8081	0.0644	0.2134	0.3	1.0665	0.7019	1.6205
City dummy	0.1662	0.1991	0.83	1.1808	0.7992	1.7444	0.0057	0.2057	0.03	1.0057	0.6720	1.5052
District classification			No						Yes			
_cons	-0.2048	0.5343	-0.38	0.8148	0.2859	2.3222	0.2375	0.5715	0.42	1.2680	0.4137	3.8870
Number of obs			9,005						9,005			
Pseudo R2			0.1658						0.1734			
Hosmer-Lemeshow chi2			10.3000						14.82			
Hosmer-Lemeshow Prob > chi2			0.2445						0.0628			

Note: Superscripts ***, **, * denote significance at the level of 1%, 5%, 10%, respectively.

AuthorToEditor: Dear the Scientific Committee members, Thank you for your work in organizing the conference. I'm not used to this system. I've attached a JPG file, but it's not pretty. Therefore, I have attached the file "IAEE2024_abstract" which follows the format of last year's summary. I look forward to hearing good results from you. Best regards, Mieko Fujisawa

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[Abstract:0257] OP-309 [Accepted:Oral Presentation] [Transportation » R&D and Emerging Technologies]

How does carpooling impact private car usage and ownership?

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Overview:The global fleet of private vehicles is estimated to be around 1 billion cars. The United States and the European Union alone each have a fleet of about a quarter billion passenger car. In a context where oil consumption –and therefore carbon emissions– from the transportation sectors is

not decreasing, it is criticial to assess whether private vehicles could be used more efficiently both at the intensive margin (i.e., can occupancy rates be increased?) and at the extensive margin (i.e., can car ownership be reduced?).

With the rise of the sharing economy, carpooling, both for long-distance trips and daily commutes, has emerged as a possible low-cost behavioral solution to make progress on both margins. For example, the platform BlaBlaCar offers match-making services for long-distance travel in more than 20 countries, and claims over 100 million registered users world-wide. Similarly, a number of digital solutions exist to facilite carpooling for daily commutes.

The net effect of carpooling on car usage and ownership is however not clearly quantified and further research is needed to assess to which extent (i) carpooling substitutes for solo driving and (ii) is carpooling associated with a rebound effect due to the decrease in travel costs for both drivers and passengers.

Most available evidence rely on stated preference methods and suggest that the net impact of carpooling on carbon emissions is a reduction despite a sizable rebound effect. However, the literature does not provide large-scale revealed-preference evidence on the impact of carpooling on private car usage and ownership. This work aims at filling this gap.
Methods:Through data sharing agreements with both the French Department of Transportation and the carpooling platform BlaBlaCar, we assemble an original dataset from two sources of data for the period 2013-2021.

First, we observe vehicle-level information about the universe of private vehicles in France: type of vehicle, municipality of residence of the owner, kilometers travelled in each year (retrieved or extrapolated from odometer readings during inspections), etc. As a first step, we aggregate this information at the municipality level and build a panel of the size of the fleet of cars and the yearly-km travelled by this fleet, broken down by broad categories of vehicles.

Second, we retrieve a number of summary statistics aimed at measuring the intensity of carpooling at the municipality-year level, separately for long-distance carpooling on the one hand, and for daily commuting on the other hand: number of driver/passenger-km travelled from/to a given municipality in a given year, number of unique users whose most frequent stop is in a given municipality, etc.

As a first step, we use panel regressions with fixed effects to estimate the impact of carpooling (long-distance on the one hand, and commuting on the other hand) on (i) the number of km-vehicle travelled; and (ii) car ownership. Next steps will involve the use of instrumental variables and possibly other empirical techniques.
Results:The datasets have already been assembled. Very preliminary results show that naive empirical strategies are very likely to suffer from significant endogeneity issues. Intuitively, when trying to measure which fraction of km-passengers travelled would have been driven with a private car, any omitted variable that impacts both the number of km travelled and carpooled (e.g. population growth, exogenous shocks changing the equilibrium modal share of cars, etc.) will bias estimation. More in-depth analyses are on-going to get a better understanding of the patterns observed in the data.
Conclusions:This work aims at providing revealed-preference estimates of the impact of carpooling (both long-distance and daily commutes) on private car usage and ownership. We have already assembled original and very detailed data on both the full fleet of private vehicles and municipality-level carpooling data in France over a ten-year period.

The next steps of the project will shed light on the research questions of interest.
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Keywords: revealed preferences, carpooling, sharing economy, intermodal substitution, rebound

effect

[Abstract:0267] OP-310 [Accepted:Oral Presentation] [Transportation » R&D and Emerging Technologies]

Total Cost of Ownership analysis for passenger vehicles in Saudi Arabia

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Overview:As Saudi Arabia aims to diversify its economy and promote sustainable technologies under its Vision 2030 agenda, this study examines the Total Cost of Ownership (TCO) of Hybrid Electric Vehicles (HEVs) versus Internal Combustion Engine Vehicles (ICEVs) in the Kingdom. With limited local research on TCO for different vehicle types, this analysis fills the gap by considering purchase cost, operation, maintenance, and resale value expenses. The findings reveal that SUVs have higher TCO than sedans, primarily driven by their premium purchase price and relatively higher fuel use per km driven. Hybrid vehicles demonstrate a slightly higher TCO than their conventional counterparts despite having better fuel efficiencies. Depreciation costs play a significant role in the TCO, emphasizing the need for cost-competitive financing and incentives to mitigate the initial purchase cost. These insights can aid consumers in making informed decisions and guide policymakers in designing interventions that promote sustainable transportation choices with favorable lifecycle economics.
Methods:This study uses Mid-sized sedans and SUVs as case studies, considering their popularity among private vehicle owners in KSA. Generally, the TCO analysis summarizes a product’s present and future costs under certain assumptions. For emerging technologies like HEVs, the TCO is important for customer decision-making beyond the purchase price but also enables manufacturers and policymakers to design interventions that promote more sustainable transportation. Vehicle replacement rates are higher among private vehicle owners in KSA, with an average ownership period of 3.8 years for purchasers of new vehicles (Abdulkareem and Ellaboudy, 2022). However, despite the relatively short ownership periods for new vehicle purchasers, the active second-hand market plays a pivotal role in extending the lifespan of vehicles within the KSA fleet (Pandey, 2021). In that light, two holding periods for vehicle ownership are assumed – 5-year (TCO-5) and 10-year (TCO-10) holding periods. In addition, it is assumed that the vehicles are purchased on an automobile loan. The loan model assumed a 10% down payment of the Manufacturer Suggested Retail Price (MSRP) for a specific vehicle. The MSRP is taken as the initial vehicle cost. The remainder of the vehicle cost (i.e., 90% of the MSRP) is financed by a 48-month loan and a balloon payment at the end of a loan term (based on the Riyad Bank online finance calculator www.riyadbank.com/). Note that the unit of cost in this study is in Saudi Arabian Riyals (SAR). Thus, the one-time cost (OTC) of owning a vehicle based on the assumptions in this study can be expressed as in Equation (2):

$$\text{One time cost} = \text{Upfront cost} + \text{Baloon payment} \quad (2)$$

The main component of the upfront cost is the down payment, including the taxes and fees:

$$\text{Upfront cost} = \text{Down payment} + \text{Sale taxes} + \text{Admin fees} \quad (3)$$

The balloon payment and resale value are discounted to their present value considering the time value of money and the principles of financial analysis. Thus, these parameters are expressed as in Equation (4) and (5):

$$\text{Baloon payment}_n = \frac{\text{Lump sum payment at the end of a loan term}_n}{(1+r)^n} \quad (4)$$

$$\text{Resale value}_n = \frac{\text{Salvage value after five years ownership period}_n}{(1+r)^n} \quad (5)$$

where, n is the future years and r is the annual discount rate. TCO studies commonly assumed discount rates between 5% and 8% (Breetz and Salon, 2018). A discount rate of 6.5% is assumed in this study.
The salvage values of the vehicles after five- and ten-years ownership periods are estimated based on the resale calculator from drivearabia.com. the input parameters include the vehicle brand and model, model year and trim level, resale year and mileage in km.
The recurring costs (RC) include the monthly installment for the financed vehicle, maintenance and repairs, insurance, fuel, and vehicle taxes. The recurring costs are also discounted through the vehicle ownership lifetime and can be expressed as in Equation (6):

$$RC = \sum_{n=1}^{N} \frac{MR_n + Insurance_n + Vehicle\ taxes_n + Financing_n + Fuel_n}{(1+r)^n} \quad (6)$$

Average fuel consumption is assumed for each vehicle based on the official values reported by their manufacturers. Thus, the fuel cost is estimated as in Equation (7):

$$Fuel_n = \sum_{n=1}^{N} VMT_n * Fuel\ consumption_n * Fuel\ price_n \quad (7)$$

The vehicle miles traveled are assumed to be fixed throughout the vehicle ownership period and are modeled as 25,000 km per annum (Sheldon and Dua, 2020).
Results:Figure 1 illustrates the TCO comparison between the conventional vehicles and their hybrid counterparts over 5-year (TCO-5) and 10-year (TCO-10) holding periods in KSA. The findings indicate that SUVs have a higher TCO than sedans due to their relatively higher purchase cost. Conventional vehicles exhibit a slightly more favorable TCO than hybrid vehicles. This finding is more evident for the conventional SUV with a 7% and 6.5% cost advantage over the hybrid SUV for TCO-5 and TCO-10, respectively. The ICEVs show a less than 1% cost advantage for the sedan vehicles for both holding periods. These findings align with the TCO literature, which generally acknowledges that mid-sized hybrid vehicles tend to have slightly higher TCO than conventional vehicles without government subsidies/incentives (Letmathe and Suares, 2017). The higher TCO of hybrid vehicles in KSA can be attributed to their relatively high purchase cost. This shows that despite hybrids having better fuel efficiency and slightly lower maintenance costs due to their regenerative braking capabilities, they still require competitive retail costs to become cost-competitive for consumers.

The depreciation costs across the vehicles make up a large share of the TCO in Figure 1. After five- and ten-year holding periods, the share of the depreciation costs for the hybrid vehicles is higher than their conventional counterpart - Camry_ICEV (73-78%), Camry_HEV (77-82%), RAV4_ ICEV (72-78%), and RAV4_HEV (78-83%). This difference in depreciation rates could be linked to the current challenges of adopting low-carbon transportation in Saudi Arabia, specifically, the uncertainties surrounding battery aging and performance in Saudi Arabia's Hot Climate (Almatrafi et al., 2023). However, the cumulative financing and the resale value are key parameters influencing the depreciation cost, as shown in Figure 2. This outcome suggests the importance of using quality data and informed assumptions for these parameters in TCO studies. For policymakers, more efforts should be directed toward ensuring cost-competitive financing models for automobile loans in KSA. Since cumulative financing directly dictates the possible savings after resale, more efforts to reduce the net capital cost would make TCO more competitive for vehicle owners in KSA.

Future studies will include sensitivity analysis of key cost parameters and extend the scope to cover the different finance methods and passenger vehicle classes in KSA.
Conclusions:The study compared the TCO between conventional vehicles and their hybrid counterparts over 5-year- and 10-year holding periods in KSA. SUVs had a higher TCO than sedans due to their relatively premium purchase cost. The study further underscores the slightly higher TCO of hybrid vehicles in KSA and the need to mitigate their initial purchase cost. Likewise, depreciation costs comprised a significant portion of the TCO, with cost parameters linked to the cumulative financing and resale value as key influencing factors. on one hand, buying the vehicle outright could eliminate interest payments and reduce capital cost of the vehicle. However, the decision to buy a vehicle upfront or finance it depends on the buyer's financial situation, goals, and preferences. On the other hand, policymakers should consider measures to support cost-competitive financing for vehicles to improved economic viability for consumers in KSA.
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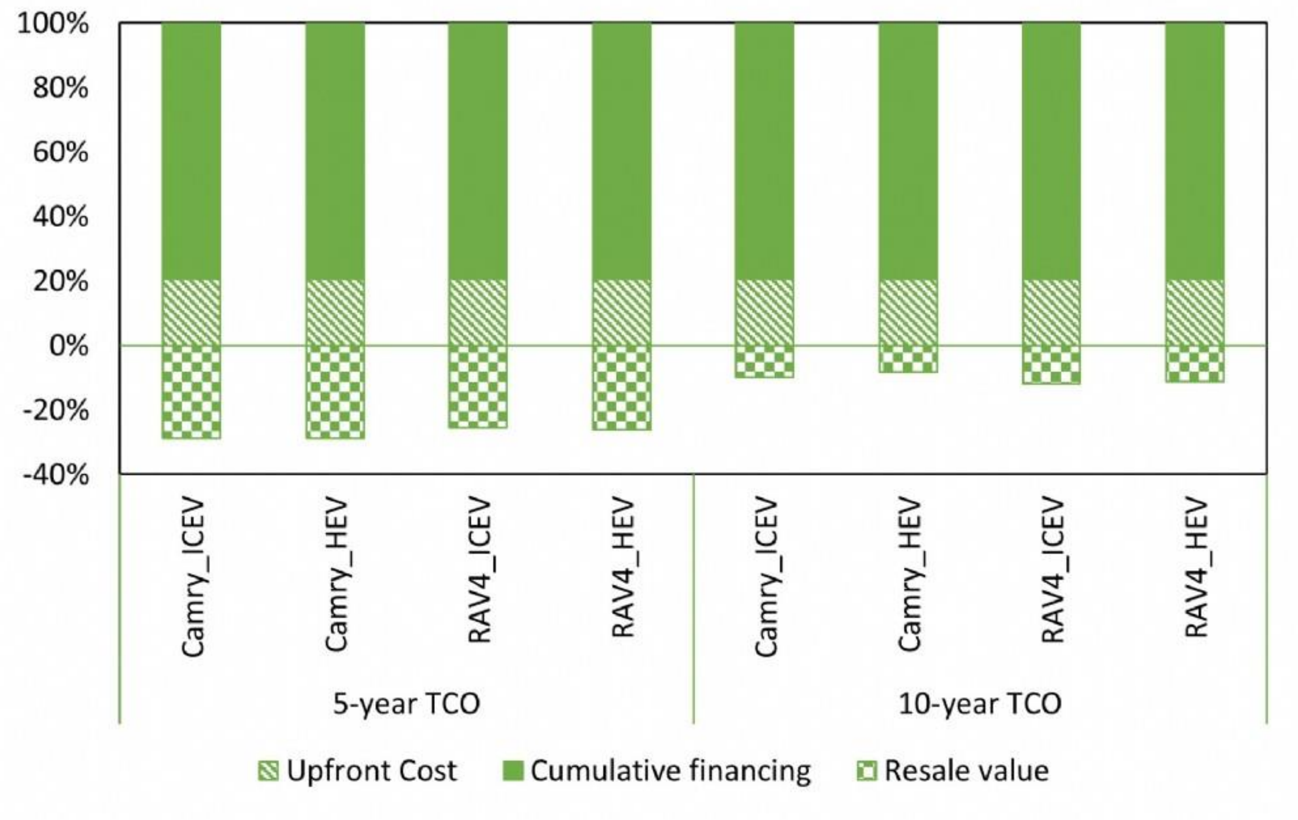
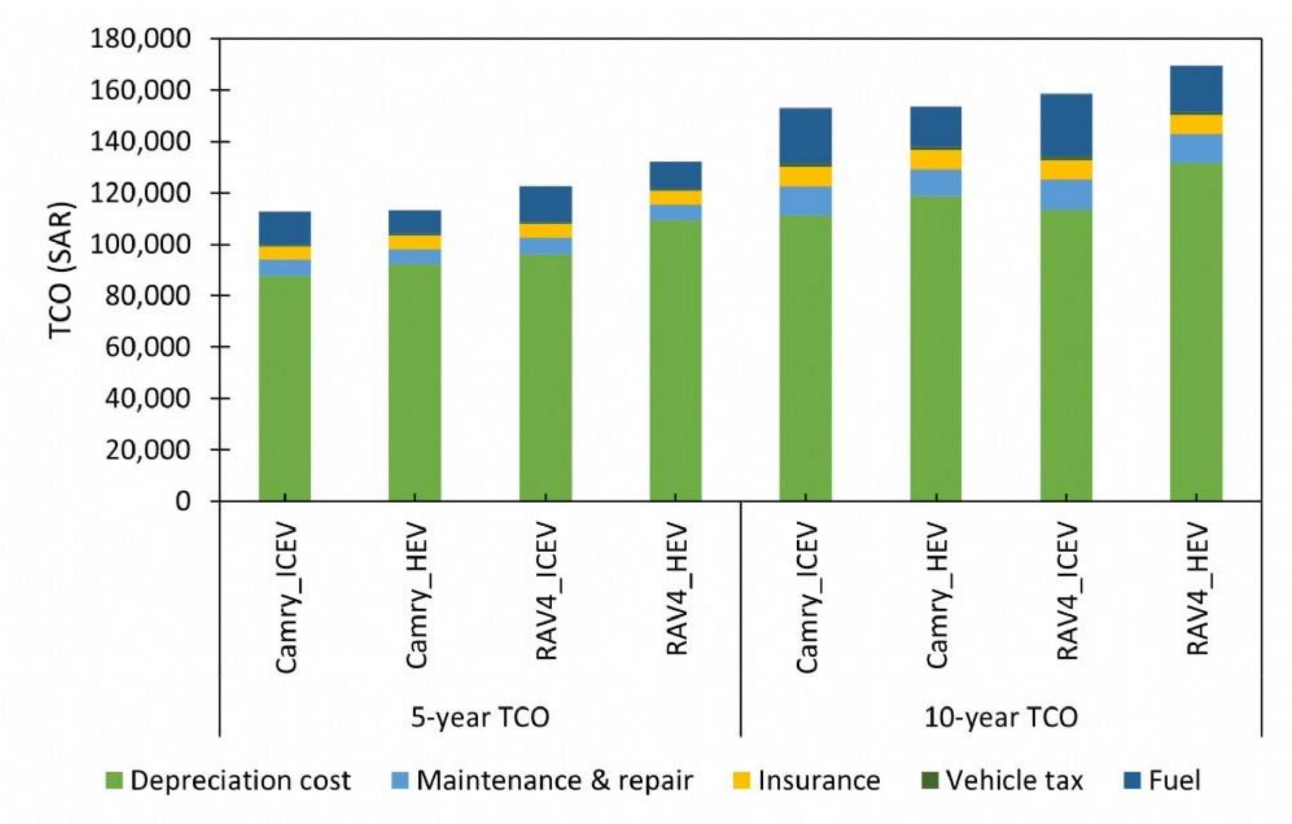
Keywords: Total Cost of Ownership, TOC, Saudi Arabia, HEV, ICEV, Sustainability

Depreciation cost - contribution of relevant cost parameters as a percentage of the net capital cost



TCO for 5-year and 10-year holding periods. SAR is Saudi Arabian Riyals; ICEV is internal combustion engine vehicle, and HEV is hybrid electric vehicle.



[Page: 311]

[Abstract:0298] OP-311 [Accepted:Oral Presentation] [Transportation » Policy and Regulation]

Is carbon pricing policy effective in the shipping sector? A partial equilibrium model for fleet optimisation

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Overview:Maritime shipping sector significantly contributes to greenhouse gas emissions (~1 $GtCO_2$/yr) and will face difficulties in reducing emissions due to high costs of clean fuels and technology fleet inertia (Cariou et al., 2022). In line with policy makers' agenda to design norms and market instruments (Annex VI Marpol for CII carbon intensity index and EEXI energy efficiency; the European Union Emission Trading Scheme), this paper estimates the sensitivity of key parameters of the shipping industry to future carbon tax regulation. We consider the trade market segment of liner container shipping that features predefined routes and vessel capacities, with few margins to reduce costs under carbon constraint. By means of a partial equilibrium model, we minimise the annual fleet operational and investment cost, carbon tax included, for a key industry operator (CMA CGM), under the constraint of six route supply-demand equilibria. Results show sensitivity of vessels' speed to carbon tax starting with 140 €/tCO_2 level, resulting in an increase in the number of vessels, in particular for medium and small capacity vessels, while large vessels respond at 220 €/tCO_2 rates

only. When new technologies and vessel retrofit options become available, vessels gradually adopt abatement options and best reduce emissions (-55% compared to -35% initially). Hence, carbon tax alone cannot decarbonise the shipping sector and needs complementary approaches in terms of e-fuels and innovation. This study provides valuable insights to policymakers and industry stakeholders on the implications of carbon tax policies and the role of technological innovation in the maritime shipping sector.

Methods:We consider a liner container shipping firm, operating on several routes with different capacity vessels to meet route-specific demands (Herrera Rodriguez et al., 2022). The model minimizes the firm's annual cost and returns, at given carbon prices, the optimal fleet operator decision in terms of number of vessels, speed, quantity shipped and vessel technology choice. The total cost is made of annual operation costs and, for new vessel acquisition, the annualized investment cost. The operating costs include canal fees, maintenance, repair, crew and administration cost, loading/unloading and energy cost (Stopford, 2010). The energy cost is based on exogenous fuel prices following the common cubic law of the speed square multiplying the distance (Corbett et al., 2009).

By means of the software GAMS / solver Mixed Integer Non Linear SBB (Standard Branch and Bound), we minimise the total annual cost of the CMA CGM company, operating on six routes (cma-cgm.fr), at given demands by route and estimated distances between ports (searoutes.com): French Asia Line 1 (FAL1), French Asia Line 3 (FAL3), Europe Pakistan India Consortium (EPIC), Bosphorus Express (BEX), Phoenician Express (BEX2), and Mediterranean Club Express (MEX) (see Table 1). The fleet made of 45 vessels is disaggregated into three capacity types: small vessels (8000 TEU), medium (12500 TEU) and large vessels (18000 TEU). The motorization of the fleet is here homogeneous, so that fuel (VLSFO, Very Low Sulphur Fuel Oil), energy efficiency (0.000542 in Wang et al., 2015), emission coefficients (2.75 in Comer and Osipova, 2021) and life expectancy (25 years in Dinu and Ilie, 2015) are identical among vessels. We document the operational cost, port entrance fee, berthing cost and time from Herrera Rodriguez et al. (2022) and canal tariffs from Suez canal toll calculator / Leth Agency. We use Rotterdam Bunker Prices for VLSFO from Ship & Bunker, and for ship building costs, three vessel type prices (small: 100m€, medium: 120m€, large: 150m€).

Results:In response to a progressive carbon tax in the range 0-400 €/tCO2, the optimal strategy adopted by the liner container shipping firm is to reduce the speed (starting with 140 €/tCO2, at ratio of one knot less every 150 €/tCO2) and to buy new vessel (starting with 140 €/tCO2, at ratio of 10% more ships every 200 €/tCO2). When carbon-reducing technologies are available, the operator trade-off is between paying the carbon bill and investing in abatement solutions. About twenty options are investigated, being either well established techniques (ballast optimization, air lubrication etc) or more advanced technologies (waste heat recovery, carbon capture storage, hydrogen fuel cells, etc). Qualitatively, similar results are obtained as initially, yet at much higher tax rates and for lower magnitudes: the speed is reduced starting with 260 €/tCO2 and attains 1.3 knots less at 400 €/tCO2 (compared to -2.5 knots less in the scenario without technologies), and the number of vessels remains stable for large scales (routes FAL 1 and MEX) and increases by 1 for the other routes at 300 €/tCO2 price signal. At fixed demands by route, the fleet operational efficiency computed as the annual cargo quantity transported divided by the total fleet capacity, decreases (Fig. 1). Ultimately, the annual costs are lower with technologies compared to the non-technology scenario (in the range -1% - 5%).

Conclusions:As container shipping segment covers 40% of the global tonnage maritime trade and emits more than 25% of the sector carbon emissions, this study focusses on abatement strategies for a firm operating on this market. By means of a partial supply-demand equilibrium model, we study the interactions between investment decision, operational costs, fleet adjustment, route optimization and environmental outcomes. Main findings suggest that the carbon tax policy proves inefficient to reduce emissions starting with 250 €/tCO2 and that other policies, i.e. technology driven, become essential to accelerate transition. This undertakes complementarity between carbon policies, energy efficiency standards and more regionally, FuelEU Maritime regulation, initiated by policy-makers to decarbonise the industry through both penalties and incentives to innovation.

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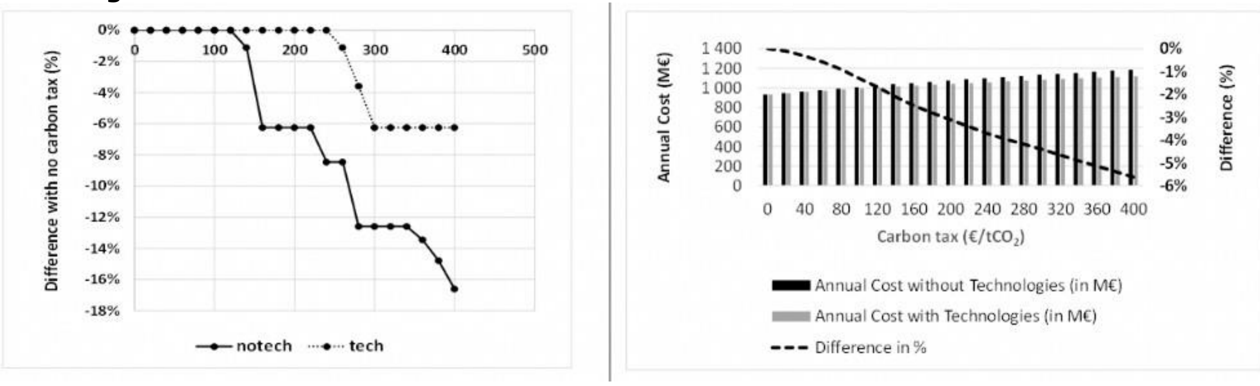
Keywords: Maritime Shipping, Carbon Pricing Policy, Partial Equilibrium Model, Innovation

Operational efficiency (left-side) and annual cost (right-side) with/without abatement technologies



Left-side: The figure shows the % change in the fleet's operational efficiency as a function of the level of carbon tax set for the two simulated scenarios. Right-side: The figure shows the evolution of the company's annual cost as a function of the level of carbon tax set. It also shows the evolution of the difference between the costs of the two scenarios.

Route characteristics

Route	Duration (days)	Vessels number	Port calls	Vessel type	Demand (TEU/Year)
FAL 1 - French Asia Line 1	98	12	12	Large	764265
FAL 3 - French Asia Line 3	84	10	11	Large	743036
EPIC - Europe Pakistan India	63	6	15	medium	412798
BEX - Bosphorus Express	70	5	14	Small	198143
BEX2 - Phoenician Express	70	3	12	Small	118886
MEX - Mediterranean Club Express	91	9	17	Large	617291

Durations, number of vessels, port calls, vessel type, annual demand for each selected route.

[Abstract:0482] OP-312 [Accepted:Oral Presentation] [Transportation » R&D and Emerging Technologies]

Evaluating Urban Traffic CO2 Emissions via Spatial Analysis with Floating Car Data

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Overview:The escalating vehicular traffic in Saudi Arabia's cities, exacerbated by swift urban growth, is a pressing concern for carbon dioxide (CO_2) emissions. Aligned with the country's bold goal to cut emissions by 278 million tons per annum by 2030 [1], There's a significant opportunity to address the growing challenge of emissions from various aspects including urban transport.

This study addresses the imperative of quantifying vehicular CO_2 emissions in metropolitan landscapes by leveraging Floating Car Data (FCD) sourced through advanced network-connected technologies. We present a spatial model that utilizes FCD for granular, road segment-specific estimates of CO_2 emissions. Dynamic data such as FCD provides a deeper insight into the interplay between urban traffic flow and environmental impact, offering a transformative approach for urban sustainability studies. We aim to develop a replicable model applicable across diverse city settings. The tool is envisioned to enable tailored evaluations of CO_2 discharge associated with different traffic scenarios. The study's objective is to provide policymakers with practical tools for active monitoring, enabling them to understand and implement solutions that effectively reduce CO_2 emissions amidst rising urban traffic congestion.
Methods:This study aims to use detailed traffic data from Riyadh to measure CO_2 emissions from vehicles on urban roads. By analyzing hourly traffic patterns within a defined Riyadh's geographical boundaries, the study seeks to identify variations in CO_2 emissions at different times of day including weekdays and weekends. This methodological approach employs a micro-scale analysis, focusing on the detailed, segment-level data that encompasses diverse speed metrics. The incorporation of this granular data into a Geographic Information System (GIS) framework is intended to yield an exhaustive spatial depiction of CO_2 emission patterns arising from urban road traffic. The data, collected at the level of individual road segments, allows for a granular examination of specific locations within the city, providing insights into the relationship between traffic flow and CO_2 emissions.

In this analysis, the traffic data is composed into several key components:
- Road Segments: Focused on individual segments to provide an hourly average.
- Vehicle Count: Number of cars per segment within the hour.
- Speeds: Average speed of the road during the hour.
- Segment Lengths: Measurement of each road segment.

These elements are crucial for a nuanced understanding of vehicular movement patterns in the selected areas of study.

In the context of this paper, we do not engage in a detailed analysis of the driving behaviors of individual cars. However, we recognize the importance of understanding how congestion impacts emissions. To address this, we have incorporated behavior-related factors from existing literature into our data, enhancing our emission estimates. These factors are tailored to the attributes of each road segment and the regional vehicle specifications. [2][3][4]

The methodology for estimating vehicle emissions for each road segment involves several steps:
1- Vehicle Kilometers Traveled (VKT): Calculated by multiplying the road segment length by the traffic counts on that segment.
2- Fuel Consumption (FC) for Each Hit or Car: Determined using the formula adopted from [5], which incorporates urban driving parameters and vehicle speed.
3- Total fuel consumption per segment: Found by multiplying VKT by FC for each segment.
4- CO_2 emissions per segment: Estimated by multiplying the fuel consumption of the segment by the CO_2 emissions factor, reflecting the conversion of fuel burned into CO_2 emitted.

In the context of this paper, our examination will be restricted to LDVs, the exclusion of Heavy-Duty Vehicles (HDVs) from our analysis is necessitated by data constraints. Incorporating HDVs into the assessment requires access to a comprehensive dataset that reflects their operational characteristics and emissions profiles, which is not readily available.
Results:The CO_2 emissions in Riyadh were analyzed using a hexagonal clustering approach with a spatial resolution of 1 square kilometer each, focusing specifically on tail-pipe emissions. This technique allows for a more accurate spatial examination of variations and concentrations of emissions throughout the city instead of relying on the road network view. The data collection spanned a 24-hour period, during which average traffic conditions, fuel consumption, and hourly emissions were recorded and analyzed.

Nonetheless, the stark contrast in emission levels when comparing peak and non-peak hours is an expected outcome, given that the increased usage of internal combustion engine (ICE) vehicles during peak traffic hours directly correlates with heightened CO_2 emissions. The sheer volume of vehicles contributes proportionally to the emissions generated. Therefore, portraying the impact of urban driving on a city-wide scale, particularly in metropolises like Riyadh, may somewhat obscure the specific effects of urban driving.

In examining the rise in CO2 emissions linked to urban driving, we target a section of roads with notably higher traffic density and congestion levels as shown in Figure 1 (A). Analysis of our results reveals that emissions in this area increase by about 11% during the afternoon peak hour.

We also noticed greater CO2 emissions on highways, which is attributable to their capacity to accommodate a larger number of vehicles traveling at higher speeds compared to other roads, as well as their function as direct routes that facilitate increased vehicular flow. This can be noticed in Figure 1 (B).
Conclusions:The study presents a replicable model for assessing CO2 emissions from urban traffic, highlighting the adaptability of the approach for various locations. It underscores the advantages of leveraging IoT-sourced data as a valuable substitute for traditional survey-based data, which may lack spatial precision and involve numerous assumptions. The analysis reveals a direct correlation between the number of vehicles, their driving patterns, and fuel consumption, emphasizing the impact of traffic volume on emissions.

In addressing urban CO2 emissions, a strategic approach goes beyond immediate solutions like road expansions, which can unintentionally encourage more driving—a concept known as induced demand [6]. Instead, the focus shifts to sustainable transportation planning. This includes advocating for and implementing alternative transportation modes to provide viable options that reduce reliance on personal vehicles. Such measures not only alleviate congestion but also aim to create a more environmentally friendly urban landscape.

The utility of this analytical tool may be extended to encompass Heavy Duty Vehicles (HDVs) in the future, contingent upon the refinement and finalization of the current data and model.
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Keywords: FCD, GIS, CO2, Emissions, Traffic, LDV

Figure 1: Model results showing CO2 emissions of peak hour traffic congestion in a weekday for October 2022

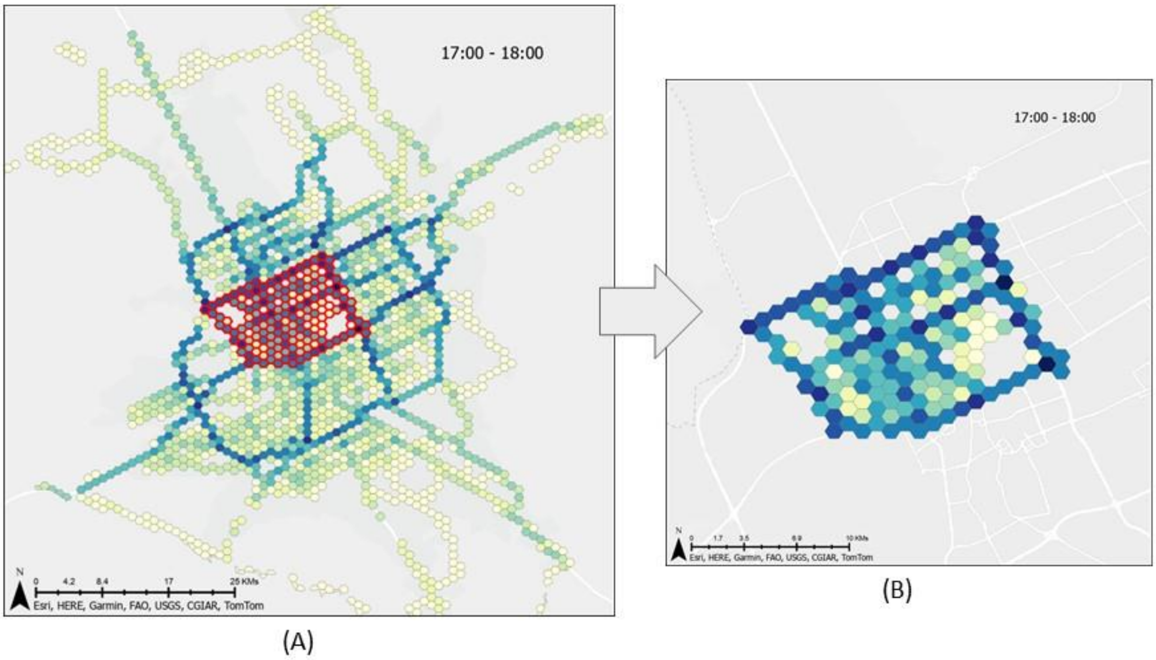

Figure 1 – (A) Model results showing CO2 emissions of peak hour traffic congestion in a weekday for October 2022 in a city level, (B) Zoomed in level targeted areas of congestion and traffic..

[Page: 313]

[Abstract:0492] OP-313 [Accepted:Oral Presentation] [Transportation » R&D and Emerging Technologies]

Future of shipping: fuel cells or dual-fuel engines?

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Overview:The shipping sector is a crucial pillar of the global economy, facilitating the transportation of goods and fostering connectivity between nations across the world's oceans. However, this industry accounts for around 3% of the world's CO2 emissions.
Dual fuel engines offer a significant step toward a more sustainable shipping industry. These engines can operate using a combination of conventional fossil fuels, such as diesel or heavy fuel oil, alongside cleaner alternatives like LNG subject to minimal leakage and slip, biofuels, or synthetic fuels such as hydrogen, methanol or ammonia. Depending on the fuel origin (whether derived from fossil, green, or synthetic sources), dual-fuel engines have the potential to achieve zero emissions in theory. Given the anticipated evolution of bunkering options over time, dual-fuel engines offer a flexible solution during this transitional phase.
In the future, fuel cells could be strong competitors of dual fuels engines in shipping thanks to their higher efficiency. Using hydrogen or light derivatives (methane, ammonia, methanol) as fuel they produce electricity directly making them good substitutes for conventional Diesel gensets. Fuel cells as prime movers are also foreseeable but probably on a longer run as their price, energy density and availability is not yet competitive.

There exists a strand of literature an optimization based on costs to determine one's ship optimal configuration (Trivyza et al. 2022). The following gaps in this literature were identified:
-Due to the prospective nature of this study, predicting the future costs of technology introduces uncertainty. This uncertainty in costs is frequently disregarded in the optimization process or is addressed only post hoc through sensitivity analysis (Trivyza et al. 2018).
- Limited research has been conducted on utilizing fuel cells as the primary propulsion system for large vessels. Existing studies (Baldi et al. 2020) frequently assume a specific type of fuel cell without comparing various types.
-The comparison between ammonia and methanol as fuels has received inadequate attention. While some studies have compared them (Law et al. 2021), none have approached the analysis from the perspective of a cost optimization algorithm.
-Many studies typically employ linear analysis (MILP) to determine the optimal configuration. However, the nonlinear behavior of technology efficiency, when analyzed for their required power, is often overlooked (Baldi et al. 2020).
Methods:The primary objective of this study is to conduct a comparison between dual fuel engines and fuel cells, and also between fuels drawing inspiration from existing published algorithms. To address this challenge, an optimization algorithm using Mixed Integer Programming methods (MIP) is implemented. The MIP algorithm determines the optimal ship configuration based on cost analysis.
To determine which technology would be the most interesting for various uses, the optimization process consists of several stages. Firstly, the total energy demand of ships is extracted from representative journeys. It is then analyzed and decomposed into electrical, mechanical, and thermal energy components. For each journey, these three components vary according to different navigating conditions: in port, during maneuvering phases, and in the sea in winter or in summer. This energy demand serves as an input to the model, derived from authentic data sources.
The algorithm uses the structure described in the graph below to determine what component can provide which types of energy with which fuel.

The different possible components of the ship energy systems are the following:
- A Solid Oxide Fuel Cell (SOFC) that is able to generate both electrical and thermal energy
- A Proton-Exchange Membrane Fuel Cell (PEMFC) that generates only electrical energy
- A dual-fuel engine
- A battery
- A boiler
- An auxiliary engine
Different fuels are also available. The dual-fuel engine and the SOFC could use either methanol (CH3OH) or ammonia (NH3) or LNG. The PEMFC has to be fueled by pure hydrogen.
With energy demand as input, the algorithm's objective is to determine the optimal configuration. While minimizing costs, the algorithm gives as an output which components to install or not, their power ratings, and their contributions at each step to fulfill the ship's energy requirements. An additional constraint is set: both ammonia and methanol cannot be installed simultaneously. The additional costs induced by additional weight and loss of volume when taking a less energy-dense fuel are also taken into account.
Two different studies are performed, each one answering a question in the existing literature. The first study introduces linearities in the optimization process, as fuel cells and dual-fuel engines have a nonlinear relationship between their efficiency and their load.
The second study deals with uncertainties in the costs. An advanced algorithm described in (Li Z., Ierapetritou MG. 2007) was chosen for its capability to determine the optimal ship configuration across different cost ranges. The algorithm can determine the conditions on costs for which the optimal choices of the system would be different.
Results:The algorithm's nonlinearity enhances the ability to discern efficiency differences between dual-fuel engine and fuel cells, facilitating a more cost-effective load allocation between the two. Addressing uncertainty, the algorithm is able to determine for several whole ranges of prices different optimal configurations. More precisely, the algorithm identifies cutoff values for efficiency, fuel cell capital expenditures and CO2 prices, determining conditions under which fuel cells are optimal for main propulsion. But, it is never cost effective to have a fuel cell alone to get complete propulsion generation, necessitating the presence of a dual-fuel engine. A trade-off exists between ammonia and methanol: while the latter has higher energy density, it emits CO2 when burned. Consequently, achieving carbon-neutral methanol proves more expensive. The algorithm computes CO2 prices at which ammonia becomes a preferred choice over methanol.
Conclusions:Fuel cells could definitely be part of the main propulsion for container ships given that they have sufficiently low capex but a dual fuel engine is required in all costs optimal configurations.
The additional features could be implemented in the optimization algorithm:
-The energy demand is provided as an input in the algorithm. Further work should install the energy

demand as endogenous. More specifically, due to lower density of low-emitting CO2 fuel than oil or LNG, they would probably be able to transport less fuel and would have to reduce their speed. This will result in a lower energy consumption over the whole journey. An optimization algorithm should include this feature and enable a decision on optimal energy consumption, with the time lost counted as an additional cost.
- One understudied feature is transient regimes. While steady states are commonly discussed in literature, transient regimes (the transition from one constant speed to another) are often neglected resulting in imprecise results, especially for short journeys with many maneuvering phases.
References:Trivyza N., Rentizelas A., Theotokatos G., Boulougouris E., « Decision support methods for sustainable ship energy systems: A state-of-the-art review », 2022, Vol. 239.
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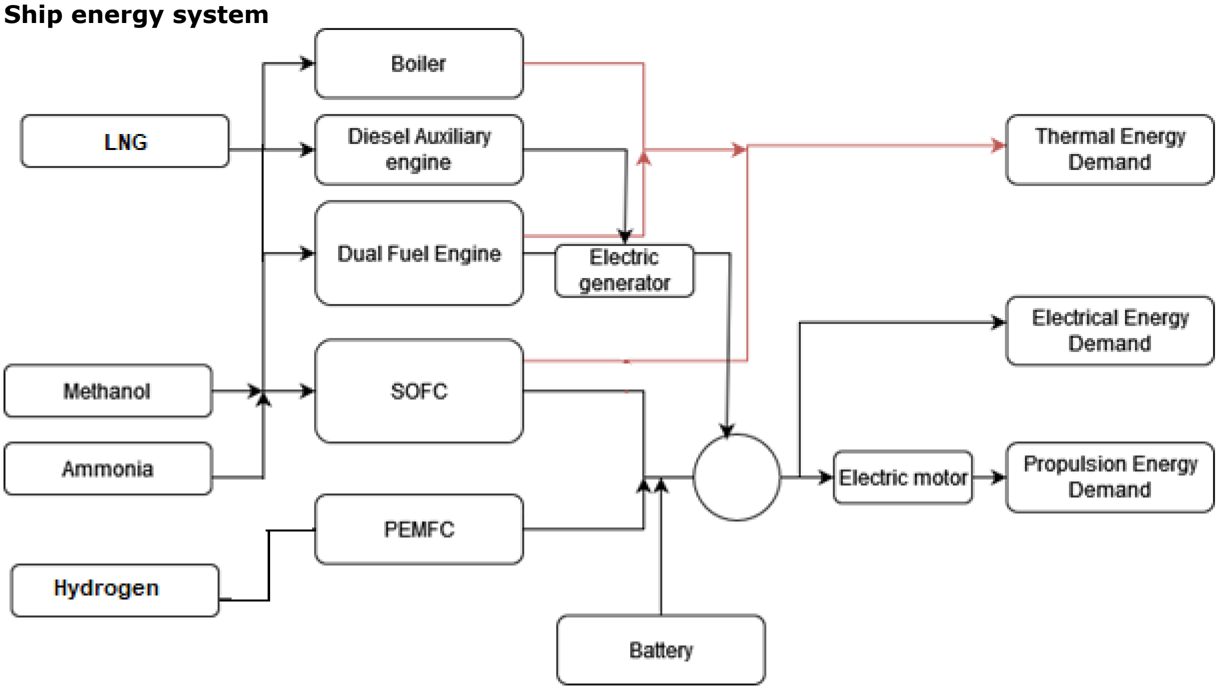
Keywords: fuel cells, dual-fuel engines, optimization, uncertainty, ammonia, methanol

Ship energy system



The algorithm uses the structure described in the graph attached to determine what component can provide which types of energy with which fuel.

[Abstract:0421] OP-314 [Accepted:Oral Presentation] [Energy and the Environment » R&D and Emerging Technologies]

Cost path of hydrogen fuel cell technology based on multi-staged learning curve

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Overview: Hydrogen energy is considered as one of the most promising clean energy, with hydrogen fuel cell technology serving as a pivotal breakthrough in its utilization (Geissler and Maravelias, 2022). However it still faces severe challenges in high production costs (Mohammed et al., 2019; Mohideen et al., 2023). Policy support from the promotion of technological progress (Santhakumar et al., 2022), technology application (Chambers, 2004; Böhm et al., 2019) and infrastructure deployment (Young et al., 2023) and other aspects of the effort, help to make hydrogen fuel cells less costly. The dynamic change of cost will have a profound impact on the technology application and promotion, and even the energy supply pattern (Wilson et al., 2012). It is of obvious policy significance to clarify the factors affecting cost changes and predict their trends for the sustainable development of the industry.

Existing studies have mainly focused on basic cost trend forecasts based on technology learning rates (Williams et al., 2017; Ji et al., 2019). Scolars have developed a one-factor curve model by considering cumulative production in analyzing the cost-influencing factors of energy technologies (Alberth, 2008). Others have further employed a two-factor curve model by considering the effect of cumulative production and R&D inputs on costs (Criqui et al., 2015; Wei and Zhao, 2022). Several studies have also focus on cost reduction trends driven by crucial factors (Elia et al., 2021; Santhakumar et al., 2022). However, dynamic nature of technology development and the role of its cost-influencing factors at different stages have been less focused. Moreover, very limited studies have discussed the dynamic cost change of hydrogen fuel cell technology in different technology development scenarios (Lee et al., 2019; Criqui et al., 2015).

This study endeavors to analyse the dynamic cost change of hydrogen fuel cell technology in China, which is vigorously promote the development of hydrogen energy industry. We consider the possible impacts of hydrogen fuel cell technology innovation and cumulative production on cost changes, and employ a multi-stage learning curve model to track the learning rate at different stages based on patent activity, cumulative installed capacity and system cost. We also develop scenarios for different technology cost projections to derive insights for policy makers.

This study makes potential contributions from three aspects. First, we integrate the both the technological innovation and scale effects on hydrogen fuel cell costs, and examine their dynamic cost paths across different technological stages. Second, we construct a multi-staged learning curve model and improve it by incorporating a bottom-line cost setting. It helps the analysis to be more realistic and conducive for a better understanding of the hydrogen fuel cell cost change mechanisms. Third, this study considers the divergences in the application scale of hydrogen fuel cells, the diversity of hydrogen production sources, and the fluctuation of patent activities and production activities, and sets up different scenarios for cost prediction to explore the cost evolution pattern of hydrogen fuel cells. It is conducive to the promotion of technological stage replacement from the perspective of segments of the hydrogen fuel cell industry chain.

Methods: 1 The multi-stage learning curve model for hydrogen fuel cell technology

This study constructed a multi-stage learning curve model of hydrogen fuel cell technology with bottom-line costs. In our research model, a one-factor learning curve model is applied to the first and third stages of hydrogen fuel cell technology development, and a two-factor model is applied to the second stage.

[Insert Figure 1 about here]

We employ a two-step regression method with the introduction of residual variables (Zheng and Kammen, 2014; Kittner et al., 2017), and the construction of a two-factor learning curve model to examine the dynamic cost changes of hydrogen fuel cell technology.

2 Data and variables

For a hydrogen fuel cell vehicle, the system cost constitutes more than 60% of the total vehicle cost. Combined with the industry research report and the data of research institutions, we collected the system cost data of hydrogen fuel cells, laying the foundation for the subsequent analysis of results. This study uses the number of patent applications (IN) to measure the technological innovation of hydrogen fuel cells. We obtain hydrogen fuel cell technology patents, including invention patents and utility model patents. The installed capacity can reflect the production efficiency and application scale of a certain technology in the market, thus helping to determine the market development status

(Zaman and Borsky, 2021; Lerede and Savoldi, 2023). The cumulative production (CY) in this study is measured by the installed capacity of hydrogen fuel cell technology.

Results:1 Calculation of learning rate

To calculate the learning rate, the elasticity coefficients of the learning rate were obtained using the least squares method for the one-factor learning curve model in the first and third stages, and the two-factor learning curve model in the second stage (Table 1).

[Insert Table 1 about here]

According to the formula for the learning rate, it can be obtained that the elasticity coefficient of technological innovation in the one-factor learning curve model is -0.72, and its learning rate is 39.4 %, while the elasticity coefficient of cumulative production in the one-factor learning curve model is -0.22, and its learning rate is 14.1%, as shown in Figure 2. In the two-factor learning curve model, the elastic coefficients of technological innovation and cumulative output are -0.97 and -0.036, and the learning rates are 48% and 3%, respectively, as shown in Figure 3. Results of P-value of the coefficient of cumulative yield and R2 indicate that our model has a good fit.

[Insert Figure 2 about here]

[Insert Figure 3 about here]

As depicted in Figure 2, we can track changes in the cost of hydrogen fuel cell technology using the number of patent applications. Before 2014, hydrogen fuel cell technology was primarily driven by technological innovation, and its overall performance can be measured by the LBR rate. The effect of LBR shows that whenever the number of patents doubles, the cost of hydrogen fuel cell systems will be reduced by 39.4%. In the second stage of technology development, 2015-2030, when hydrogen fuel cell technology is in a phase of combined R&D and production, we measure the effect of technological innovation and cumulative production on cost changes through LBR rate and LBD rate, with a learning rate of 48% and 3% for the two factors, respectively. In the third stage, the market scale of the technology continues to expand, and our model mainly considers the role of learning. Hydrogen fuel cell technology has experienced significant growth in terms of installed capacity since 2015. The installed capacity has increased substantially, rising from 0.6 MW in 2015 to 507 MW in 2022. The effect of LBD shows that when the cumulative installed capacity of hydrogen fuel cells doubles, its system cost will be reduced by 14.1%. The expansion of the hydrogen fuel cell market makes an important contribution to the decline in technology costs.

2 Cost prediction of hydrogen fuel cell technology

2.1 Basic cost prediction

In order to predict the future cost of the technology, it is necessary to determine the key parameters such as learning rate, initial cost, bottom line cost, number of patent applications, and cumulative installed capacity. This study referred to DOE's (2017) setting of the baseline cost of hydrogen fuel cell system and set the baseline cost in this model at 220 yuan /kw for the cost predition. The cost trends for hydrogen fuel cell systems from 2006 to 2040 are shown in Figure 4. The predictions show that the cost of hydrogen fuel cell system is expected to decrease to less than 1000 yuan/kw by 2026. Furthermore, from 2031, the predicted cost of hydrogen fuel cell system is projected to drop to less than 500 yuan/kw. We observed similarities between our results and the trend outlined by Zachmann et al. (2012), albeit with slight variations in the predicted cost values.

[Insert Figure 4 about here]

2.2 Scenario analysis of cost predictions

To further clarify the factors affecting the cost of hydrogen fuel cell systems and their influencing effects. We further conduct sensitivity analyses of different scenarios for future cost projections. Specifically, we considering the growth scale difference of technology application, differences in hydrogen production technologies, and differences in technological innovation and cumulative output. Results are shown in figure 5-7.

[Insert Figure 5-7 about here]

Conclusions:Combining the development process of hydrogen fuel cell technology in China, this study constructed a multi-stage learning curve model with bottom-line costs, studying on the importance of innovation and production of hydrogen fuel cell technology to its technological development. We found that learning by researching holds a more significant role in cost redection at present stage, while learning by doing takes precedence in the long term, with a learning rate estimated at 14%. It implies that the cost of hydrogen fuel cell system is expected to break through 500yuan/kw after 2030. It thus becomes imperative to strategically enlarge the scale of production and application within the appropriate policy timeframe. Paying attention to the economy of the industrial chain segments at various stages proves more conducive to improving hydrogen cost competitiveness.

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Keywords: Hydrogen fuel cell, learning curve, scale effect, technology cost

Figure 1 Multi-stage development process of hydrogen fuel cell technology

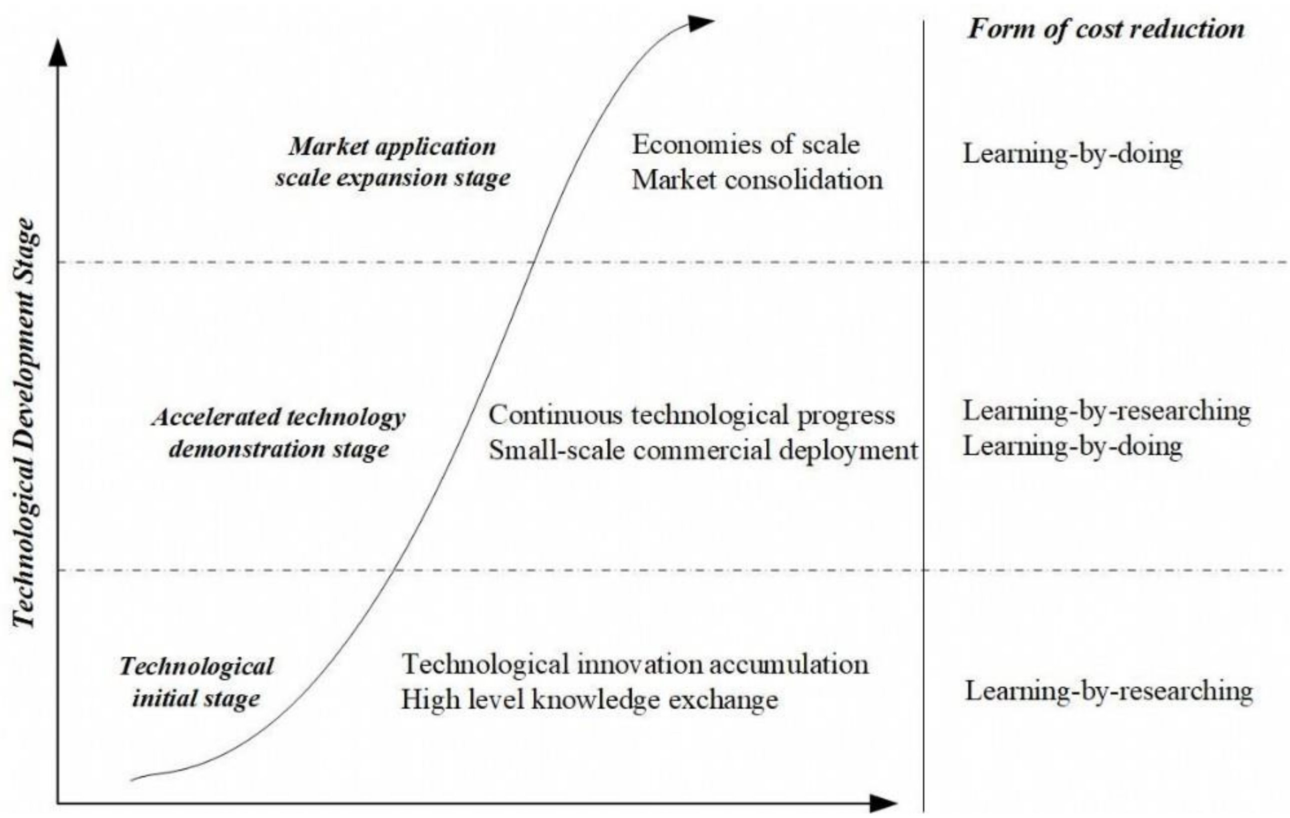


Figure 2 The single-factor learning curve for learning by researching and learning by doing

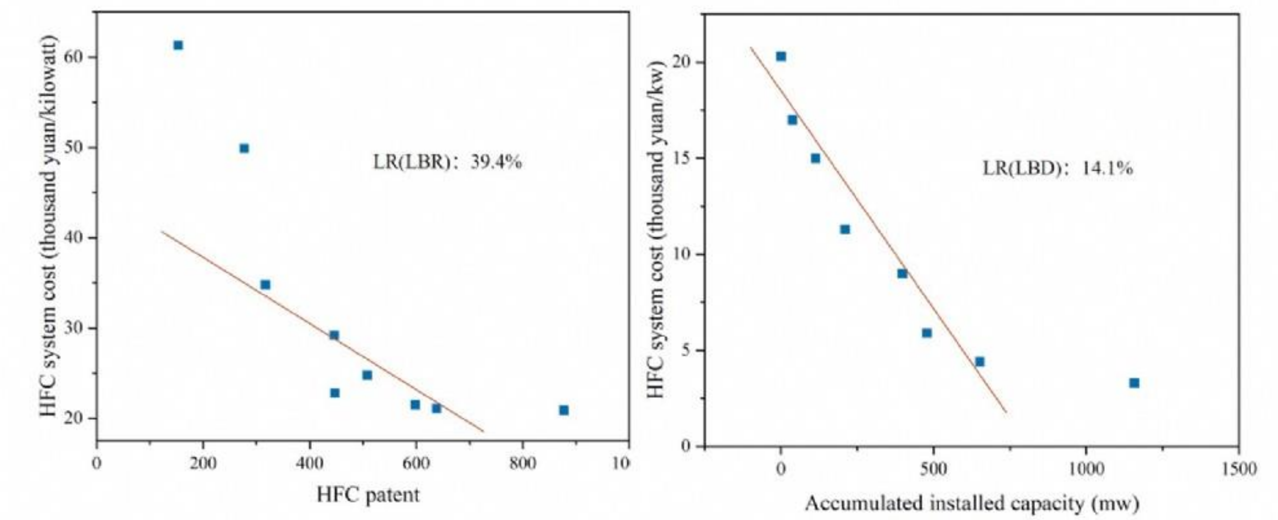


Figure 3 The two-factor learning curve for learning by researching and learning by doing

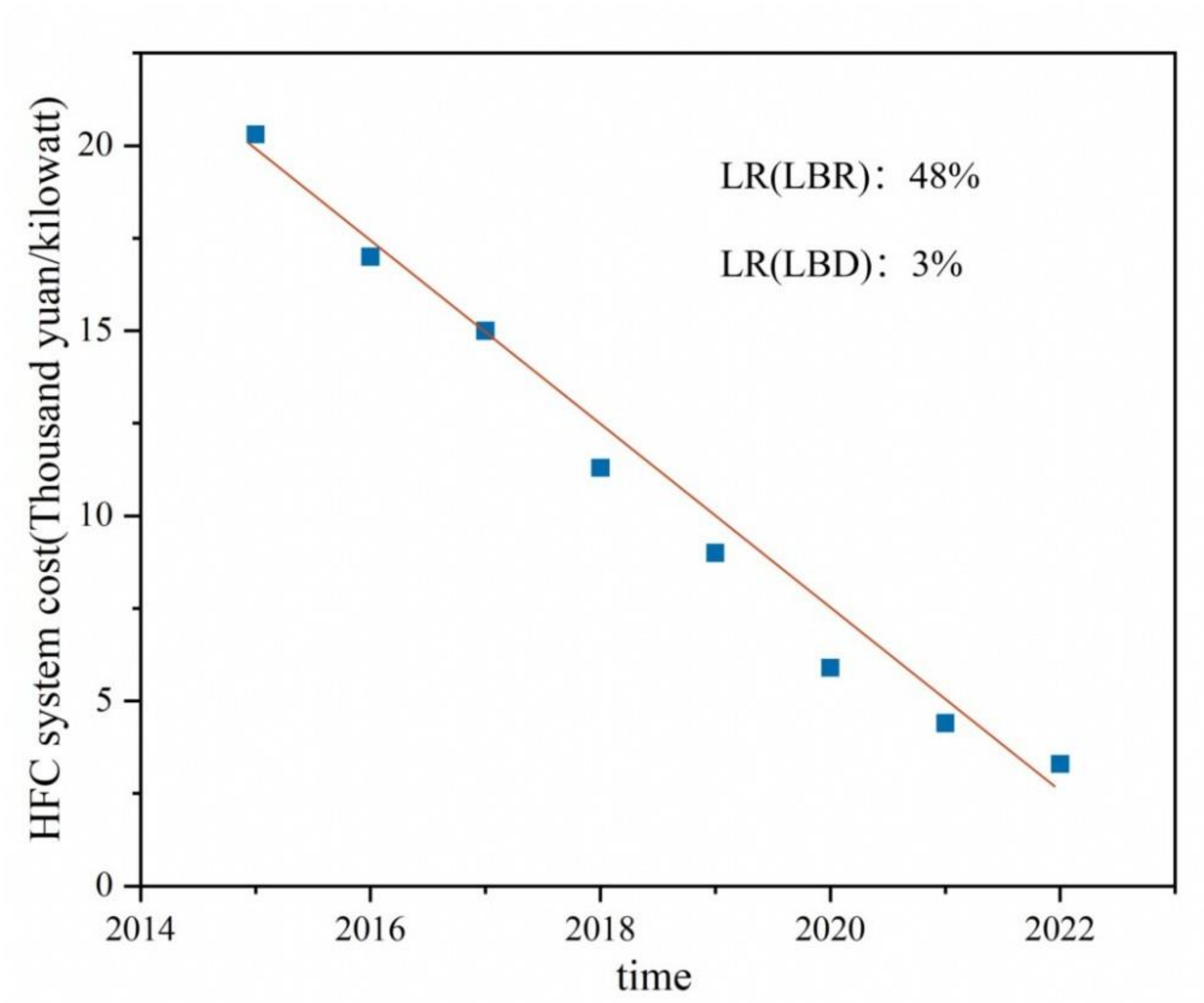


Figure 4 Cost trends of hydrogen fuel cell system

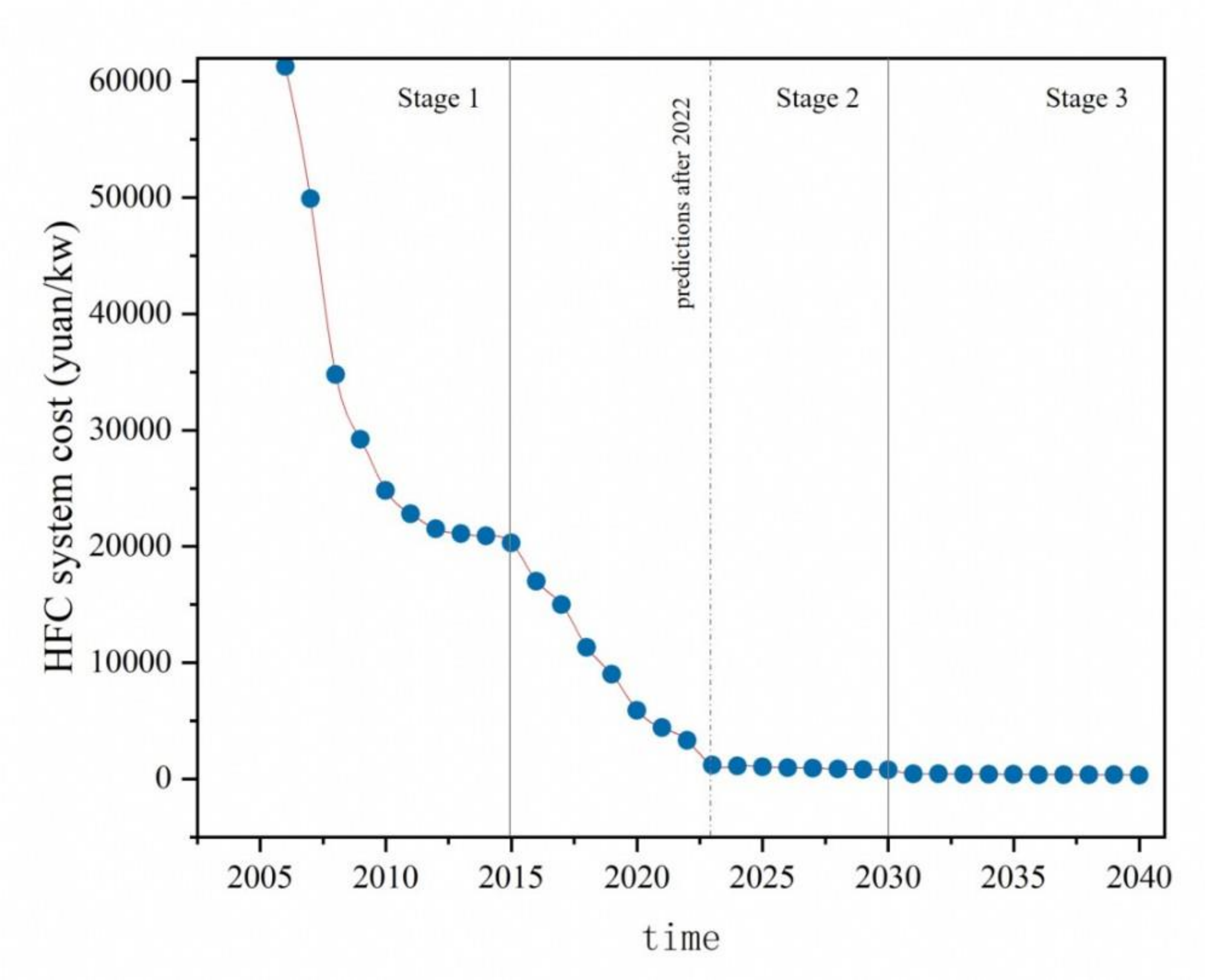
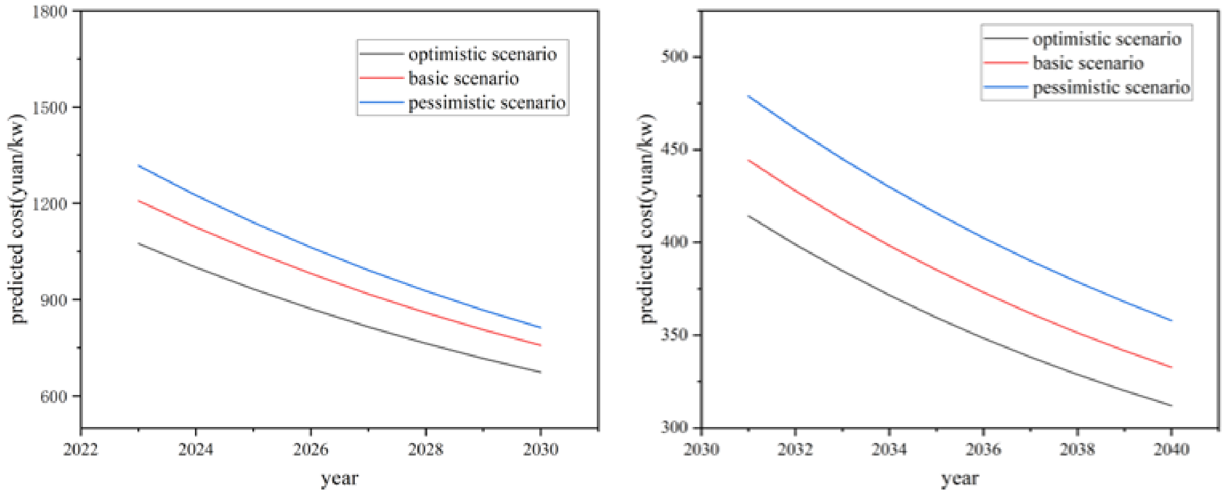


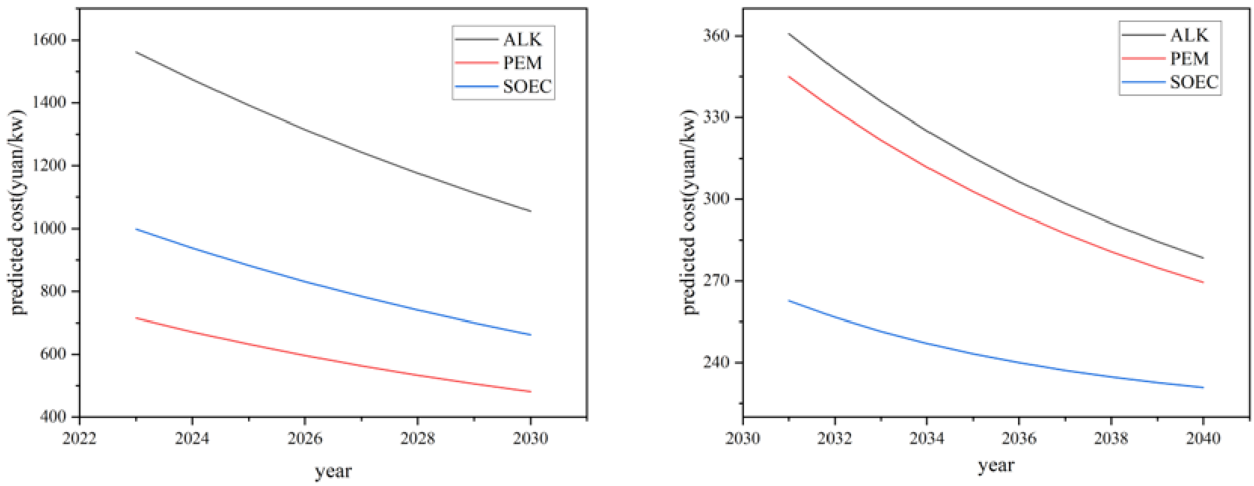
Figure 5 Cost trends under different growth scales



(a) Stage 2 **(b) Stage 3**

Figure 5 Cost trends under different growth scales

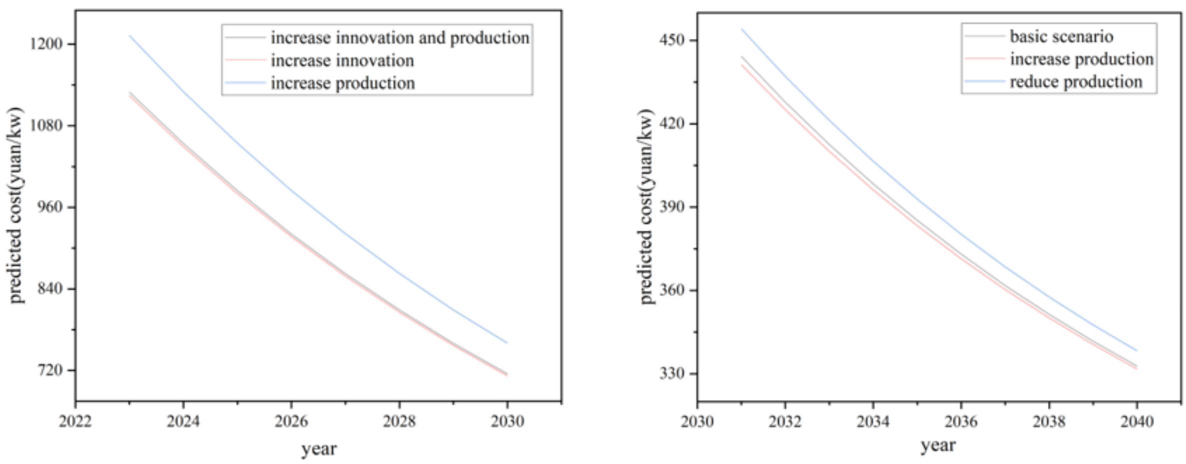
Figure 6 Cost trends under different hydrogen production methods



(a) Stage 2 (b) Stage 3

Figure 6 Cost trends under different hydrogen production methods

Figure 7 Cost trends under differences in technological innovation and cumulative output



(a) Stage 2 (b) Stage 3

Figure 7 Cost trends under differences in technological innovation and cumulative output

Table 1 Results of one-, two- and three-factor models

	One-factor model	One-factor model	Two-factor model	Three-factor model
	(1)	(2)	(3)	(4)
Innovation	-0.72*** (-5.43)		-0.97*** (-21.14)	-0.717** (-3.55)

Installed capacity		-0.22** (-3.30)	-0.036*** (-28.65)	-0.003 (-0.09)
Deployment				-0.143 (-1.28)
Cons	7.76*** (9.42)	3.27*** (9.16)	9.73*** (18.19)	8.191*** (6.60)
F	29.47	10.90	633.97	476.33
Prob>F	0.000	0.016	0.000	0.000
R2	0.890	0.645	0.996	0.997
Adj.R2	0.875	0.586	0.994	0.995

[Page: 315]

[Abstract:0566] OP-315 [Accepted:Oral Presentation] [Energy and the Environment » Other Externalities]

Reuse of Abandoned Mining Sites as a Pumped-Storage Systems

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Overview:As part of its nationally determined contribution (NDC) to reduce emission levels under the Paris Agreement, Chile is commited to fully decarbonizing its energy matrix by 2050. Even though the plan for the retirement of all coal-fired power plants was a voluntary agreement between the private sector and the government, it is an ambitious goal not easy to achieve. One difficulty to accelerate this process is that new renewable technologies, mostly solar PV and wind, have intermittence and a long investment recovery period compared to conventional technology currently present in the market. This implies that, economically and in terms of network stability, it is difficult to further increase the penetration of renewables in the market to be able to fulfill the decarbonization goal.
On the other hand, the country has a major social and environmental liability related to abandoned mining sites. Until 2019, SERNAGEOMIN, the Chilean mining service, had a tally of a total of 5,148 abandoned mines in its records, and this number is estimated to grow by 2025 as it is expected that around 20% of the current operating mines will shut down in the next 5 years. Most of these sites are massive in volume and some of them have few hundreds of meters in depth difference. Additionally, many of these abandoned sites, due to their previous mining operation, already have transmission lines and electrical substation equipment.
In this context, this study analyzes and proposes to convert these abandoned sites into pumped-storage energy systems, which would allow to both accelerate the decarbonization of the energy matrix and reduced the environmental liability associated to abandoned mines.
Methods:The research develops and implement an economic evaluation to convert abandon mining sites into pump-storage plants using both the volume and the depth difference left by the mining process. The methodologuy is then tested in two specific abandoned mines (Mina Triunfo and Mina Vaca), with depth differences of 203 [m] and 526 [m], both of them are underground operations located in northern Chile.
The simulation considers a Francis-type pump/turbine -a turbine with great adaptability regarding

different altitued and water flow- with a capacity of 300 [MW] for each mine. Accordingly, the characteristics of the power plant were calculated and the necessary spaces for the construction of the power plant inside each mine, including its reservoirs and other facilities (Fan et al., 2020; Madlener and Specht, 2020; Guo et al., 2020). The technical evaluation considers the efficiency of the pump and the turbine, the water flow, the energy generated, and the losses associated. The economic evaluation considers the initial investment in the mine, investment in the power plant equipment, fixed and variable operation costs and annual maintenance. The technical simulations and the economic evaluation allow to calculate the Leverized Cost of Storage (LCOS), the Net Present Value (NPV), the rate of return (ROR), and the payback period, which are all different and complementary measures of profitability of the project.
In order to fully dimension the role of the power plant, the evaluation considers different scenarios and the sensitivity to different assumptions. In particular, the sensitivity analysis evaluates the impact of changes in the required initial investment, the discount rate, the marginal cost of generation, the number of hours operating, and the equipment depreciation.
Results:The estimated investments for both mines are 396 and 206 MUSD, with an average energy production of 633 and 659 [GWh] per year. According to the economic analysis carried out, a Net Present Value of 42 MUSD was obtained in the best case of the Triunfo mine and one of 240 MUSD for the Vaca mine. The Rate of Return is around 10% for the Triunfo mine and 16% for Vaca mine. The significant differences between them is due to the higher costs of reservoir construction in the case of Triunfo mine.
Conclusions:The study concludes that converting abandon mines, although not always technically or economically feasible, is an attractive investment that should be properly analyzed and considered. It is important to highlight that the average storage cost is very competitive compare with other technologies offered in the market. In particular, the two mines considered in the simulation show a Levelized Cost of Storage (LCOS) of 143 [USD/MWh] and 108 [USD/MWh]), making then an interesting alternative to offer stability to renewable projects, encouraging investments in more of such projects, and at the same time giving a second life to abandon mines, which otherwise would be a liability.
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Keywords: Storage, Renewable Energy, Mining

[Page: 316]

[Abstract:0371] OP-316 [Accepted:Oral Presentation] [Energy and the Environment » Other]

The impact of social media discussions about installing photovoltaics on public perceptions: evidence from Chinese TikTok

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Overview:Since 2020, Chinese TikTok, the most trafficked social media platform in China, has experienced a surge in videos about photovoltaic installation (PVI), leading to extensive public

engagement in discussions on this topic. With social media's growing ability to shape public opinion, this research investigates the impact of social media discussion on public perception of PVI, aims to foster a more positive public perception of new energy. We collected a dataset of 911 PVI videos along with over 140,000 comments. ChatGPT 4 model was utilized to extract content features from the videos and categorize the comments. Empirical results indicate that including low uncertainty features, such as installed capacity, PVI cost, and PVI lifespan, can increase positive perceptions in comments by approximately 3%. Conversely, including high uncertainty features like potential profits and payback periods can decrease positive perceptions in comments by 3% and 6%, respectively. Additionally, based on whether the PVI videos were intended to promote PVI or to gain traffic by exaggerating the disadvantages of PVI, we categorized these videos into PVI advocacy videos and PVI traffic-oriented videos, respectively. The publication of PVI traffic-oriented videos significantly reduced the number of positive comments on PVI advocacy videos by 3.5% to 8.9%, with this impact lasting for at least two years. Further investigation reveals that exaggerating the disadvantages of PVI has a lasting and profound negative impact on public perception. This is evidenced by the empirical result showing that corrective descriptions of PVI disadvantages in advocacy videos did not increase positive perceptions in comments. The results lead to two key policy implications. Firstly, it is recommended that manufacturers engage more in social media discussions on new energy, cautiously addressing uncertain aspects like profitability and payback time. Secondly, regulatory authorities and social media platforms should enhance their supervision of exaggerating new energy disadvantages, to mitigate further negative public perceptions of new energy.
Methods:The study employs a variety of research methods. Firstly, Chinese TikTok videos and their comments were collected using a web crawler technique. Secondly, the iFLYTEK large language model was used to convert the videos into text, and the ChatGPT-4 large language model was applied to extract features of the videos and categorize the comments. Thirdly, the impact of social media discussions on residents' views on photovoltaic installations was assessed using the least squares estimation and difference-in-differences method.
Results:Empirical results indicate that including low uncertainty features, such as installed capacity, PVI cost, and PVI lifespan, can increase positive perceptions in comments by approximately 3%. Conversely, including high uncertainty features like potential profits and payback periods can decrease positive perceptions in comments by 3% and 6%, respectively. Additionally, based on whether the PVI videos were intended to promote PVI or to gain traffic by exaggerating the disadvantages of PVI, we categorized these videos into PVI advocacy videos and PVI traffic-oriented videos, respectively. The publication of PVI traffic-oriented videos significantly reduced the number of positive comments on PVI advocacy videos by 3.5% to 8.9%, with this impact lasting for at least two years. Further investigation reveals that exaggerating the disadvantages of PVI has a lasting and profound negative impact on public perception. This is evidenced by the empirical result showing that corrective descriptions of PVI disadvantages in advocacy videos did not increase positive perceptions in comments.
Conclusions:Considering the findings of this study, reducing high-uncertainty content such as profits and payback periods during the discussion of PVI on social media can significantly enhance positive public perception of PVI; even further clarification cannot reverse the trend of a significant decline in positive public perception caused by the exaggeration of PVI's disadvantages on social media.
References:None.

Keywords: social media, public perception, photovoltaic installation (PVI), Chinese TikTok.

[Abstract:0473] OP-317 [Accepted:Oral Presentation] [Energy and the Environment » Other]

The Determinants of Household Cooking Fuel Transition: Evidence from Rural India

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Overview:This study investigates fuel choice transitions within rural households using the data from the Indian Human Development Survey (IHDS) for 2005 and 2012. The research aims to identify factors influencing the preference for mixed fuel transition. Through spatial analysis, the study observes the changes in fuel preferences across regions for 2005 and 2012. Regional consumption patterns are identified by constructing a fuel choice transition matrix. The variables impacting the shift from dirty to mixed fuel in rural areas are analyzed utilizing a multinomial logit model. The results also show the importance of household expenditure on LPG and kerosene, illustrating the impact of cost differences and subsidies on the use of cleaner fuels. Furthermore, education, household size, income, and gender substantially shape the fuel preferences of rural households. The implications of these findings are vital for policymakers aiming to formulate strategies promoting cleaner energy choices in rural areas, considering diverse socioeconomic factors. Thus, the study offers insights into rural household fuel choices, advancing the development towards sustainable energy transitions.
Methods:This study constructed a spatial map to understand the prevalent trends in household fuel transitions across various regions. A notable shift towards mixed fuel usage was observed across most states, thereby guiding further investigations to understand the underlying factors influencing these transitions. Subsequently, leveraging the fuel choice transition matrix provided insights on fuel trends in rural and urban areas. The transitions matrix highlights the prevalence of mixed fuel usage among rural households, unlike the urban areas where clean fuel prevails. Building upon these findings, our objective is to investigate the reasons underlying rural households' preference for transitioning from dirty fuel to mixed fuel over clean fuel. To address this objective, we propose applying a multinomial logistic model (MNL), specifically focusing on rural households using dirty fuel in 2005. This approach allows us to identify the factors influencing their transition choices and understand the drivers behind the preference for mixed fuel. To understand the dynamics of these transitions, we categorized the households into three distinct groups based on their fuel choices in 2012. The first category comprises rural households that did not transition from dirty fuel and continued to use it in 2012. The second category consists of households transitioning from dirty fuel to mixed fuel. The third category includes households transitioning from dirty to clean fuel.
Results:Fuel transition among rural households across different stages of transition. Expenditure on kerosene and LPG emerges as critical determinants: higher spending on kerosene perpetuates reliance on dirty fuels. It poses obstacles to transitioning towards mixed and clean fuels, possibly due to financial barriers and existing subsidies. Conversely, increased spending on LPG facilitates transitions towards cleaner options, encouraging shifts to mixed and clean fuels. Improved chulha usage significantly influences transitions, reducing reliance on dirty fuels and facilitating smoother transitions to mixed and cleaner fuel options. Household income plays a pivotal role, catalyzing transitions to cleaner fuels, indicating the income-energy ladder relationship. Additionally, caste dynamics reveal socio-cultural impacts on fuel choices, influencing transitions to mixed fuels. These findings underscore the multifaceted nature of influencing factors, highlighting the need for tailored interventions addressing financial, infrastructural, socioeconomic, and cultural aspects to foster sustainable energy transitions in rural areas.
Conclusions:This study explored the patterns of fuel choice transitions within rural households. The three primary objectives of our research were to identify the factors affecting preferences for mixed fuel consumption; construct a fuel choice transition matrix in order to identify regional fuel consumption patterns, and analyze the variables influencing the switch from dirty to mixed fuel in rural areas. By examining the spatial patterns of fuel transition, we observed how these choices evolved across regions from 2005 to 2012. The transition matrix revealed how households switched to different fuels during this time period. Moreover, our analysis using the multinomial logit model divided rural households who were using dirty fuel in 2005, into three distinct groups: (a) no transition, (b) transition to mixed fuel and (c) transition to clean fuel. This categorization enabled us to identify the factors impacting each type of transition and gave us a comprehensive understanding of the various fuel choices made by rural households. The results indicate that household expenditure on kerosene and LPG significantly influences fuel transition. Kerosene subsidies deter households from adopting cleaner fuel alternatives, while the higher cost of clean fuels impedes the transition to cleaner options. Education level, specifically higher levels of education among household heads, positively affects the likelihood of transitioning from dirty fuel to clean fuel, suggesting that education promotes awareness of the benefits of clean fuels. Household size and income also play a role, with larger family sizes leading to a higher probability of transitioning to mixed fuels to meet increased energy demand and higher household income promoting the shift away from traditional fuels. Gender

also influences fuel choice, with female household heads displaying a higher propensity for transitioning to clean cooking fuels than male household heads. The data constraints and assumptions inherent in the analysis are some of the study's limitations. Nevertheless, it opens the door to future investigations that can delve deeper, examining additional factors and regions to expand our understanding. The findings of this study have implications for policymakers and other stakeholders interested in improving energy choices in rural areas.
Thus, by understanding the determinants of mixed fuel consumption and the factors driving transitions, we take a step closer to a cleaner and more energy-efficient future for rural communities. The transition matrices further highlight the dynamics of these fuel shifts, providing a comprehensive view of the evolving energy landscape within rural households.

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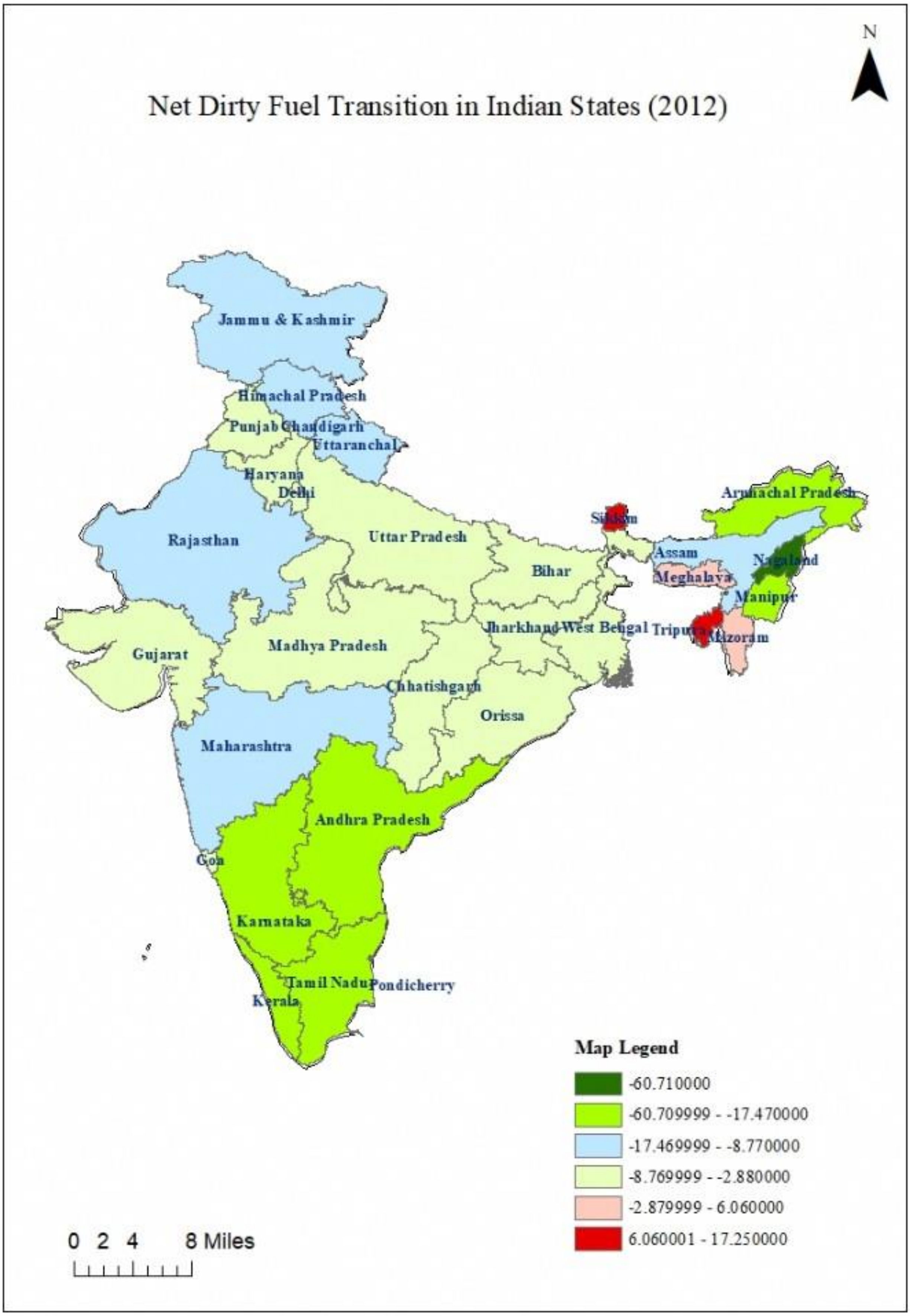
Keywords: Cooking fuel, Clean energy transition, Mixed fuel, Fuel stacking, Pradhan Mantri Ujjwala Yojana (PMUY), Fuel choice transition matrix

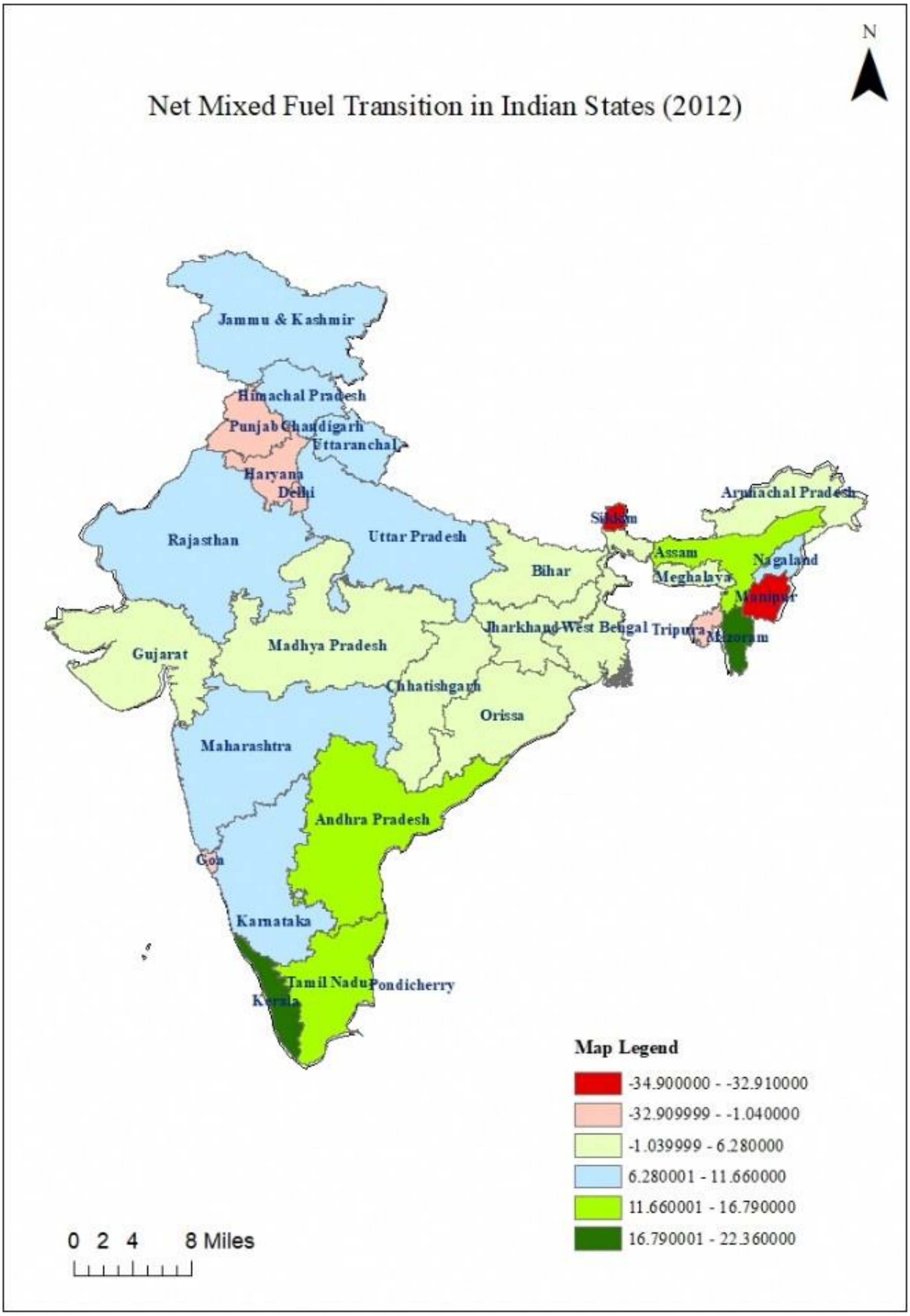
2.1.1 Dirty fuel transitions across Indian states



N
Net Dirty Fuel Transition in Indian States (2012)
Jammu & Kashmir
Himachal Pradesh
Punjab
Chandigarh
Uttaranchal
Haryana
Delhi
Rajasthan
Uttar Pradesh
Bihar
Sikkim
Arunachal Pradesh
Assam
Nagaland
Meghalaya
Manipur
Jharkhand
West Bengal
Tripura
Mizoram
Gujarat
Madhya Pradesh
Chhatishgarh
Orissa
Maharashtra
Andhra Pradesh
Goa
Karnataka
Tamil Nadu
Pondicherry
Kerala
Map Legend
-60.710000
-60.709999 - -17.470000
-17.469999 - -8.770000
-8.769999 - -2.880000
-2.879999 - 6.060000
6.060001 - 17.250000
0 2 4 8 Miles

In Figure 2.1 A, the initial spatial fuel transition map reveals that household reliance on dirty fuels has significantly decreased across several states. For instance, in Andhra Pradesh, households witnessed a substantial - 21.8% decrease in the use of dirty fuel. Similar changes were observed in Arunachal Pradesh, where a notable transition from dirty fuels was evident at -17.66%. Overall, the percentage change in dirty fuel consumption across all states during this period amounted to approximately -3.22%. These findings indicate an encouraging shift towards other energy sources from a household perspective.

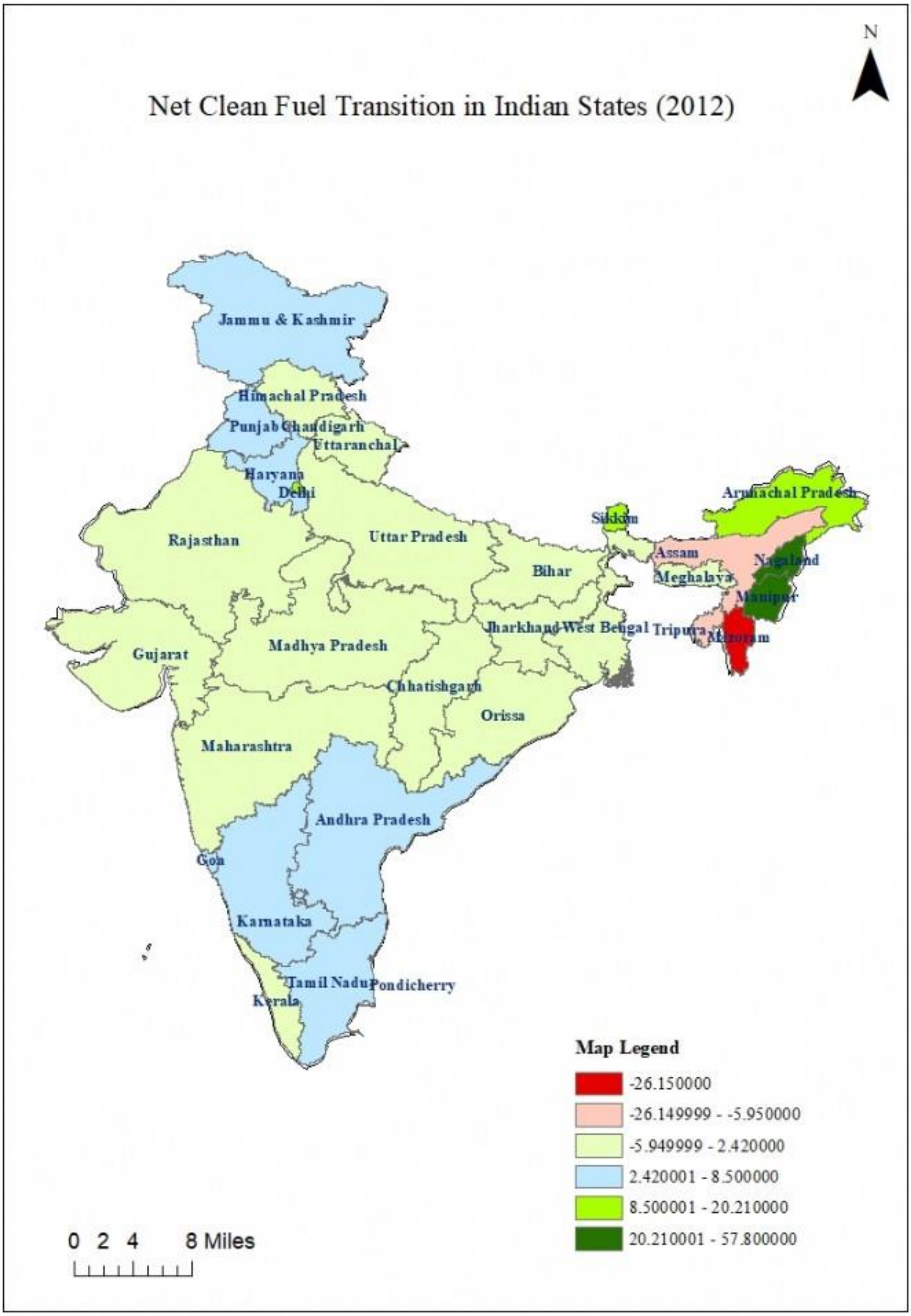
2.1.2 Mixed fuel transitions across Indian states



In our analysis of the transition to mixed fuel usage (Fig.2.1 B), we found significant changes in several Indian states. In

Karnataka, there was an 11.43% increase in the use of mixed fuels, indicative of changing household energy preferences within the state. Kerala, conversely, reported a substantial transition to mixed fuel of 22.36%, marking a significant change in the energy landscape. In contrast, Manipur stood out as having a significant -34.9% shift away from mixed fuel, indicating a remarkable decrease in its mixed fuel usage. The collective percentage change in mixed fuel usage across all states during this period was about 6.17%. This highlights how fuel changes can differ in various places and how factors specific to each region can impact these transitions.

The trends in clean fuel adoption are depicted in Fig. 2.1 C. States like Manipur and Nagaland exhibited significant increases of 57.8% and 49.06%, respectively, indicating a solid move towards cleaner energy sources. However, Mizoram has faced a dec



Net Clean Fuel Transition in Indian States (2012)
N
Jammu & Kashmir
Himachal Pradesh
Punjab
Chandigarh
Uttaranchal
Haryana
Delhi
Rajasthan
Uttar Pradesh
Sikkim
Arunachal Pradesh
Assam
Nagaland
Meghalaya
Manipur
Bihar
Jharkhand
West Bengal
Tripura
Mizoram
Gujarat
Madhya Pradesh
Chhatishgarh
Orissa
Maharashtra
Andhra Pradesh
Goa
Karnataka
Tamil Nadu
Pondicherry
Kerala
Map Legend
-26.150000
-26.149999 - -5.950000
-5.949999 - 2.420000
2.420001 - 8.500000
8.500001 - 20.210000
20.210001 - 57.800000
0 2 4 8 Miles

The trends in clean fuel adoption are depicted in Fig. 2.1 C. States like Manipur and Nagaland exhibited significant increases of 57.8% and 49.06%, respectively, indicating a solid move towards cleaner energy sources. However, Mizoram has faced a decline of -26.15% in clean fuel usage. Although the adoption of clean fuel differs across different regions, there has been an overall increase of about 6.98%. It highlights the progress in adopting cleaner fuel usage, influenced by government policies and awareness campaigns, among other pertinent factors.

Dirty Fuel Transitions in Rural Households: Results from a Multinomial Logit Model

Fuel transition among rural households across different stages of transition. Expenditure on kerosene and LPG emerges as critical determinants: higher spending on kerosene perpetuates reliance on dirty fuels. It poses obstacles to transitioning towards mixed and clean fuels, possibly due to financial barriers and existing subsidies. Conversely, increased spending on LPG facilitates transitions towards cleaner options, encouraging shifts to mixed and clean fuels. Improved chulha usage significantly influences transitions, reducing reliance on dirty fuels and facilitating smoother transitions to mixed and cleaner fuel options. Household income plays a pivotal role, catalyzing transitions to cleaner fuels, indicating the income-energy ladder relationship. Additionally, caste dynamics reveal socio-cultural impacts on fuel choices, influencing transitions to mixed fuels. These findings underscore the multifaceted nature of influencing factors, highlighting the need for tailored interventions addressing financial, infrastructural, socioeconomic, and cultural aspects to foster sustainable energy transitions in rural areas.

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[Abstract:0170] OP-318 [Accepted:Oral Presentation] [Renewables » Other]

Ocean Thermal Energy Conversion Technology for Sustainable Tourism in Small Island Developing States through Carbon Taxing: The Context of Maldives

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Overview:Tourism is a significantly growing sector in Small Island Developing States (SIDS). SIDS has a competitive advantage in tourism because of its exceptional natural and cultural resources. It brings in job opportunities and income from foreign exchange earnings.
Figure 1: Tourism in SIDS. Anguilla, Nothern Mariana Islands, Cook Islands, Guadeloupe, Martinique, Montserrat, New Caledonia, Niue, and Sint Maarten are not included due to the unavailability of data. Singapore is omitted as the country has a high GDP compared to other SIDS. Data is obtained from [1], [2], [3], [4]
SIDS vary significantly in their economic and social performance and their level of international visitor arrivals. However, many demonstrate a high level of dependence on tourism in terms of exports and

contribution to GDP, as seen in Figure 1. They present three critical characteristics in terms of tourism: small size, with implications for pressure on resources and limited economic diversity; remoteness and isolation, leading to challenges for trading but also to a unique biodiversity and cultural richness; and a maritime environment, leading to solid tourism assets but vulnerability to climate change. The burgeoning tourism sector causes SIDS to face challenges in meeting the sector's electricity, cooling, and water demands. Currently, most of these demands are met using fossil fuels, increasing carbon emissions, and decreasing sustainability. At present sustainable tourism is a growing concept with more countries aligned towards the goal of decreasing carbon emissions to hold the increase in the global average temperature to well below 2°C above pre-industrial levels as per the Paris Agreement.

Ocean Thermal Energy Conversion (OTEC) technology can act as a viable renewable energy alternative to these resource limitations in SIDS. OTEC systems utilize the temperature difference between the ocean's surface and deep layers to generate electrical power, which must be more than 20 degrees difference to generate electricity [5]. Additionally, in a cascade effect, the same water flow can be utilized for a central cooling air conditioner. With many SIDS located in temperate zones and having a higher cooling demand this is beneficial. The OTEC plant can also generate fresh water during the Rankine cycle process, and hence the water can be used to meet these demands. Therefore, OTEC plants have the potential to increase the sustainability of the tourism industry in SIDS. One of the main challenges to OTEC systems is the high capital cost associated with these plants. Although most of the SIDS are in the developing countries and the least developed countries aspects such as carbon taxing are currently not in use in these nation states. Carbon taxing could help with bringing in this renewable energy source to the tourism sector of SIDS.

Methods:Figure 2: Block diagram of proposed system including OTEC power generation, cooling, and freshwater production.

The combined system of OTEC power generation, freshwater production and district cooling as seen in Figure 2 will be modeled numerically and the simulation will be used to calculate the cost effectiveness of the system under carbon taxing conditions.

Results:Expected Outcomes

1. Estimation of temperature drop from OTEC cycle to SWAC cycle.
2. Computation of total CAPEX of the system and it’s viability in a resort environment.

Conclusions:The research is still in progress and preliminary rough results are only available right now

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Keywords: ocean thermal energy conversion, sea water air conditioning, sustainable tourism, small island developing states

AuthorToEditor: The research is ongoing right now and there are no specific results yet.

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[Abstract:0237] OP-319 [Accepted:Oral Presentation] [Renewables » Solar]

A Meta-Analysis of Solar Forecasting Based on Skill Score

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Overview:The global solar energy generation has increased significantly within the last decade and contributes substantially to the goal of net zero emissions. Such rapid growth in the solar power may increase uncertainty concerning the feed-in of renewable energy. Managing this uncertainty is crucial for reliable power system operation and solar forecasting emerges as a particularly efficient solution. More accurate forecasts enable the system to plan power generation more efficiently and match it with consumption at lower operational cost. This also allows the integration of a higher share of solar energy into the system. Furthermore, desired levels of reliability in the grid can be achieved at lower cost, for example by balancing power procurement. As a result of these potential benefits, hundreds of papers on solar power forecasting have been published. The large volume of research in the field and rapid expansion of methodologies leads to a need for systematizing the scientific knowledge. However, the task is complicated by the diversity of the datasets and forecast setups. Many studies show that factors such as weather conditions, forecast horizon, and the quality of the input data can significantly influence forecast accuracy. These factors should be accounted for when conducting inter-model comparisons. In addition, variability in forecast validation approaches also causes difficulties in comparing results. The best method to address such differences when comparing forecasts is through meta-analysis. A meta-analysis is a statistical approach to extract findings from individual studies using quantitative methods. For example, a regression can be conducted on the forecast accuracy data and the effects of all relevant variables controlled. From the output of this regression, different forecast methods can be compared and the impacts of different factors on forecast accuracy are analysed. Such insights are important for both industry and academia to adopt the best practices in forecasting. This paper provides the first meta-analysis of solar forecasting based on the skill score metric. Skill score is recommended by many scholars as a standard metric to measure forecasts' performance due to its relative measurement approach. This metric reduces the impact of inherent difficulties in different forecasting situations and renders forecasts across studies more easily comparable. While this property of SS makes a meta-analysis of solar forecasting more convenient, an in-depth analysis of forecasts and an extensive inter-model comparison based on the metric is almost unknown.
Methods:To provide a meta-analysis of solar forecasting based on skill score, a comprehensive search has been conducted on Google Scholar for all literature in the field published from 2006 to 2022. A total of 2,335 search results have been screened, among which the full texts of 320 papers are thoroughly reviewed for data extraction. A database of 4,687 observations from the solar forecasting literature, represented by 11 variables, has been built. Regression methods were employed for the data analysis because they allow examining the impact of one variable while controlling for the impacts of the other variables, thus producing statistically significant results that can be applied globally. In the first place, multivariate adaptive regression spline modelling and partial dependence plots were applied to examine the interactions and capture the non-linearity of variables in the database. Based on this, the database was then split into partitions based on the most influential non-linear term. For these subsets, we performed linear regressions and quantified variables' marginal impacts on skill score.
Results:First, the multivariate adaptive regression spline modelling revealed key insights on non-

linearity and complex interaction terms in the database:
• Forecast horizon was identified as a key variable showing non-linear impacts on forecast accuracy. This implies that what works for intra-hour forecasts does not necessarily work for intra-day or day-ahead forecasts. Therefore, the analysis of solar forecasts should be done separately for each forecast horizon.
• There have been substantial improvements in solar forecast accuracy over time, especially in recent years. These improvements are higher for intra-hour and intra-day than for day-ahead forecasts. This is good news both for researchers in the field who have made this development possible as well as for energy system planning, as solar power will become easier to integrate into electricity systems with better forecasts.
• More training data can improve models' performance. However, the amount of training data should be controlled so that there is no over-fitting. The database shows that the training data of around 2000 days achieve the highest forecast accuracy.
Second, a follow-up linear regression quantified the marginal impact of important variables on skill score. Key findings are:
• Location-related variables such as climate zones show statistically significant correlation with skill score. Hence, the relative measurement approach of skill score is not sufficient to allow a direct comparison of forecasts. A meta-analysis that can account for different effects is therefore important for knowledge transfer between regions. This result is important for future research as past research has mostly focused on developed countries (e.g., the US), while developing countries (which often have great solar potential) have been under-researched. Researchers should be careful when transferring insights on optimality of methodologies from one climate zone to another. Furthermore, front runner papers on new regions and climate zones should not be expected to immediately outperform skill score derived from studies in better researched zones.
• Input usage should depend on horizon class. For the intra-hour class, historical data and spatial temporal information of power system and its neighbours are highly helpful. For intra-day, sky and satellite images play the most important role, which can be combined with any other inputs. For day-ahead, NWP variables and locally measured meteorological data are key.
• Regarding the inter-model comparison, ensemble–hybrid models achieve the most accurate forecasts. Many methods do not show a robust superiority to time series methods. Therefore, it is recommended to consider improving the performance of simple models through using different techniques and processing input data before moving on to complex models.
Conclusions:These findings are important for future solar power forecasters to improve forecast accuracy. Highly applicable recommendations regarding the forecast methodologies and input usage are made separately for each forecast horizon. This is crucially important for regions where a tremendous growth in solar power generation is expected, but the research on solar forecasting is not as robust. For example, Northern Africa and the Middle East might enhance their investments in solar power in the medium-term, considering their very good solar irradiation conditions. Transferring knowledge gained from previous studies to these regions can provide a significant benefit to solar power forecasting.
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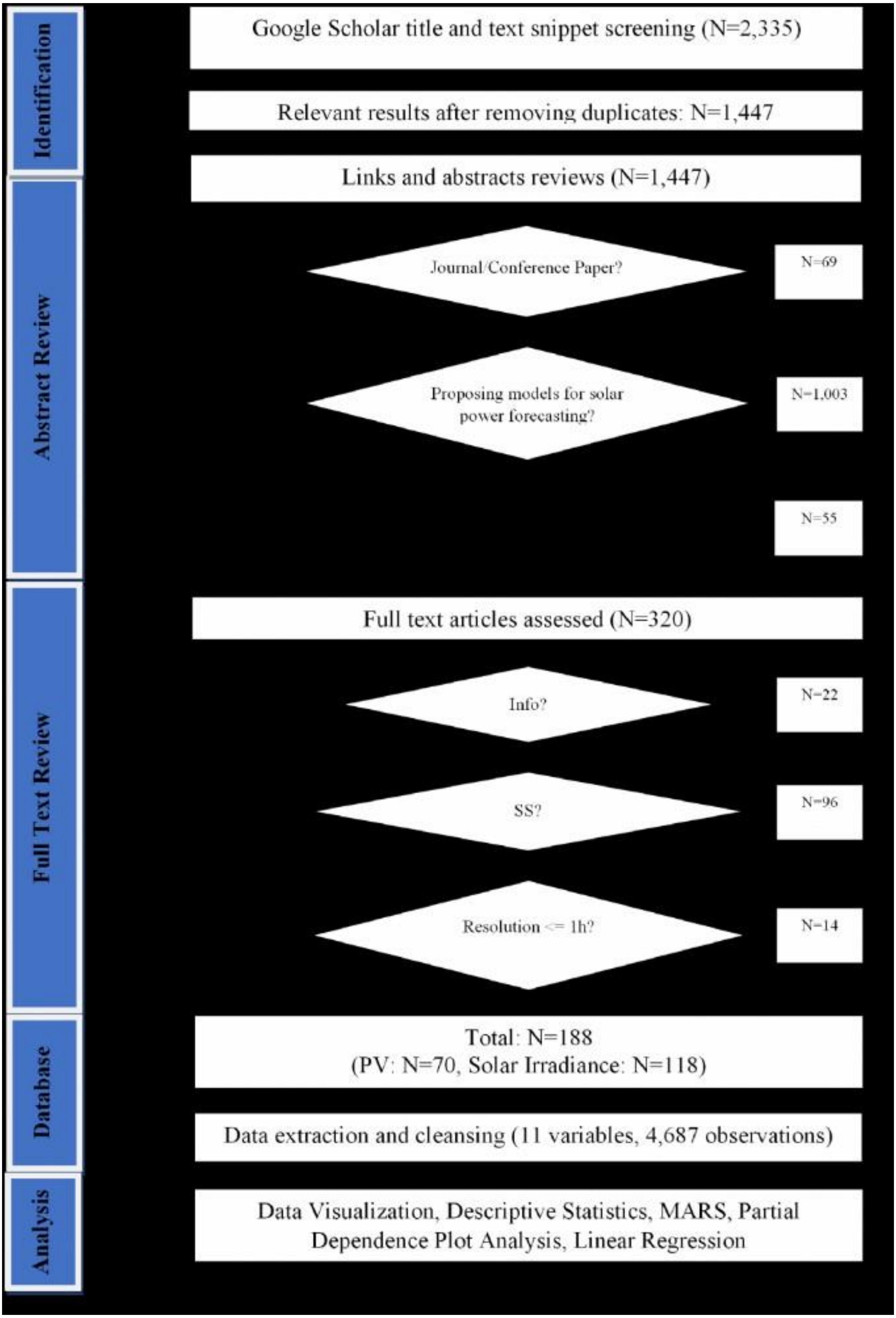
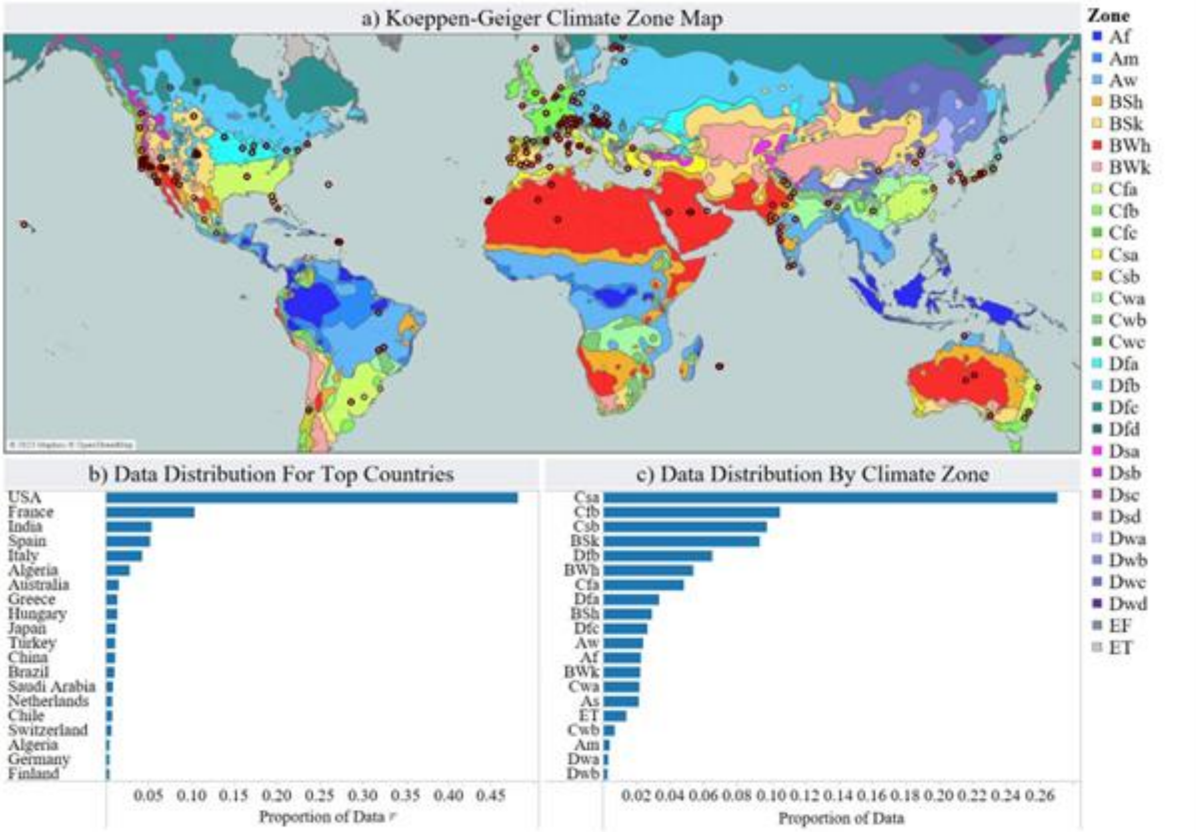
Keywords: meta-analysis, solar forecasting, photovoltaics forecasting, forecast verification, skill score, empirical review

Figure 1: The meta-analysis process illustrated in five steps. SS = skill score, N = total number.


Identification
Abstract Review
Full Text Review
Database
Analysis
Google Scholar title and text snippet screening (N=2,335)
Relevant results after removing duplicates: N=1,447
Links and abstracts reviews (N=1,447)
Journal/Conference Paper?
N=69
Proposing models for solar power forecasting?
N=1,003
N=55
Full text articles assessed (N=320)
Info?
N=22
SS?
N=96
Resolution <= 1h?
N=14
Total: N=188
(PV: N=70, Solar Irradiance: N=118)
Data extraction and cleansing (11 variables, 4,687 observations)
Data Visualization, Descriptive Statistics, MARS, Partial Dependence Plot Analysis, Linear Regression

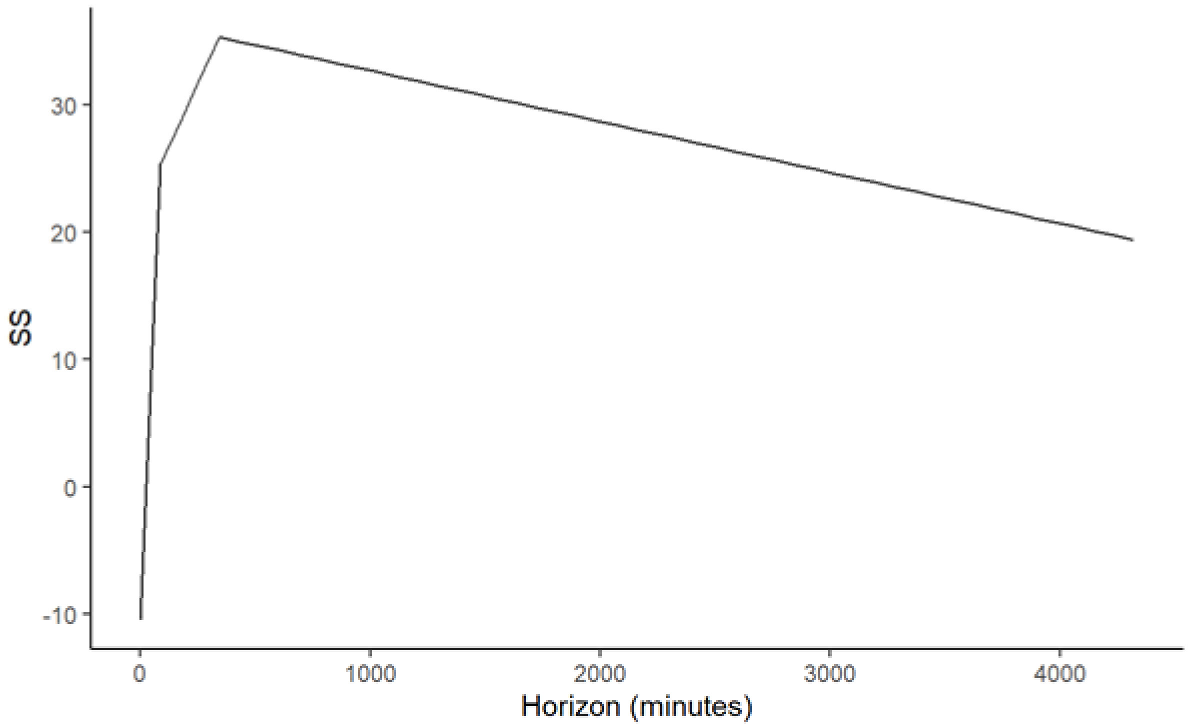
The meta-analysis was conducted in five steps as illustrated in Figure 1. The first three steps, from identification to full text review, describe the literature selection process. The fourth step presents the extraction and cleaning of the database. The final step presents the data analysis.

Figure 2: Data distribution by climate zones and countries.



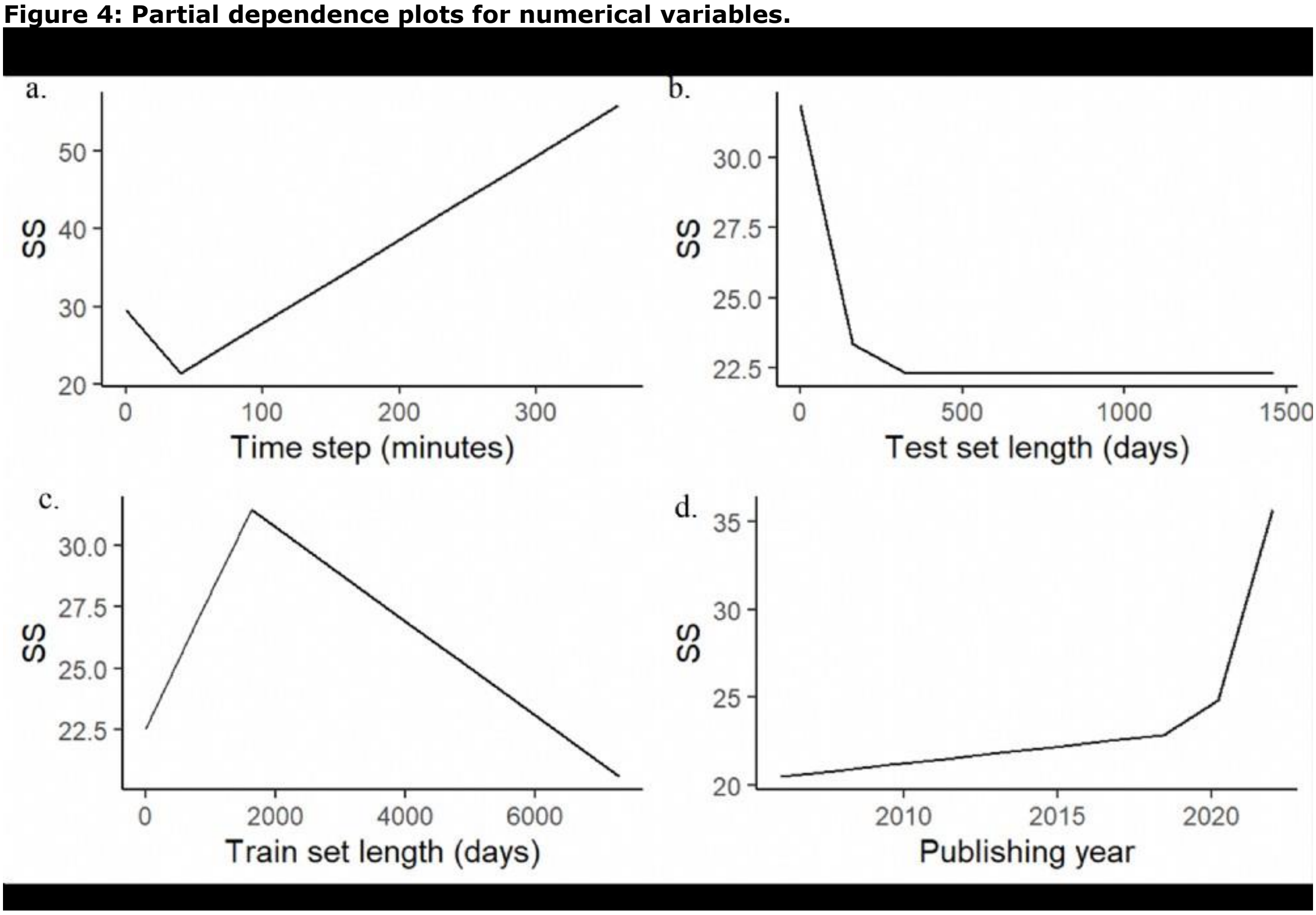
Panel a shows the observations as black circles on the Köppen-Geiger climate zone map. The colours and shades used to represent the zones are those used by Peel, Finlayson, and McMahon (2007) [19]. Panel b presents the share of the data for the top countries. Panel c shows the data distribution by climate zone. An overview of the data distribution is illustrated in Figure 2. In terms of the Köppen-Geiger climate zone classification, more than half the database belongs to climate zones C. Climate zone B covers around 20% of the data. The remaining data (around 22%) comprises the other climate zones. Among countries, the number of observations in the USA seems to dominate the other regions. It might be wondered whether what the best model in climate zone C or the USA also works best in other areas. The possibility of transferring insights between regions to improve forecast accuracy is crucial, especially for those whose research on solar forecasting has not been advanced. By accounting for the impacts of different factors simultaneously, the meta-analysis in this paper enables this transfer of knowledge.

Figure 3: Partial dependence plots (PDPs) for horizon variable.



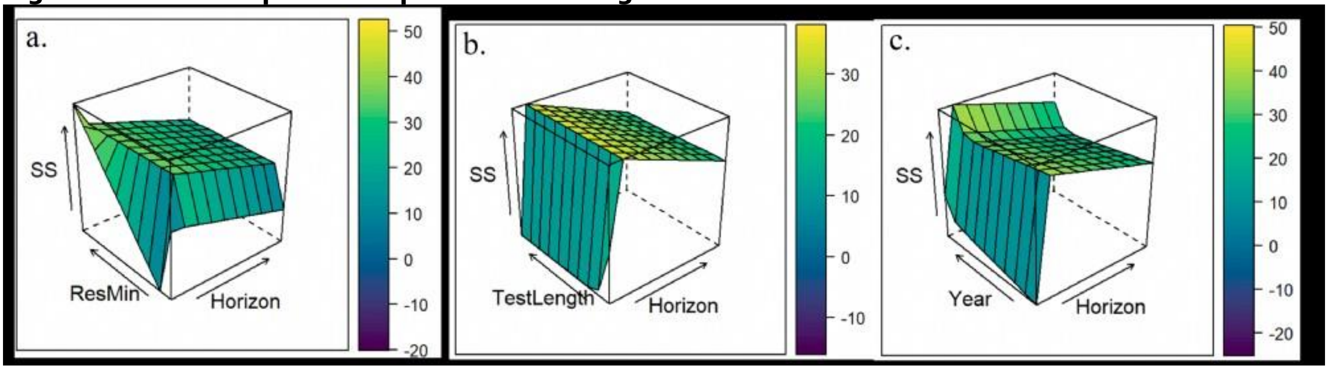
The figure shows the partial dependence of the skill score values (SS) on horizon, accounting for the effects of all the other variables in the multivariate adaptive regression spline modelling (MARS). Non-linearities are observed and distinct pattern can be seen for horizon < 75 minutes, 75–345 minutes, and > 345 minutes. These cut points approximate the thresholds for intra-hour, intra-day, and day-ahead forecasts, respectively. Note that the PDP visualizes the MARS regression results, which already control for the impact of reference models. Therefore, the skill score value can be interpreted irrespective of reference models. This applies to all other PDPs in this paper.

Figure 4: Partial dependence plots for numerical variables.



The figure shows the partial dependence of skill score (SS) on each variable, accounting for the effects of all the other variables in the multivariate adaptive regression spline regression.

Figure 5: Partial dependence plots for two-degree interactions of numerical variables.



The figure illustrates the partial dependence of skill score (SS) on the interaction of different numerical variables. The direction of the arrow indicates the increasing direction of the value.

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[Abstract:0318] OP-320 [Accepted:Oral Presentation] [Renewables » Wind]

The plant-side grid parity analysis of subsidy-free offshore wind power in China

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Overview:The 2060 carbon-neutral target has thrust the low-carbon transition of China's electric system into the frontline as a priority for the upcoming decades. To diversify the energy mix and reduce the reliance on fossil fuels, abundant offshore wind resources in the coastal provinces are increasingly recognized and utilized as valuable generation sources. Owing to technological progress and the economies of scale, offshore wind capacity installation and its electricity generation have experienced substantial growth in China over the 2010-2022 period. The cumulative offshore wind capacity has surged from 147 MW to 30,510 MW, with its share over the total renewable capacity rising from 0.06% to 2.63%. Moreover, the annual electricity generation from the commissioned offshore wind power plants has climbed from 166 GWh to 113,961 GWh, resulting in a notable increase of its share from 0.02% to 4.22% over the total annual renewable energy generation. Its rapid expansion has been largely supported by substantial government subsidies. However, it is not a long-term solution. To wean the industry off abiding subsidy reliance, the subsidy abolition from the central government came into view in 2021 and has begun to be implemented since 2022, symbolizing its transition to the market competition stage, which is an inevitable law of renewables development [1]. At the juncture of subsidy withdrawal, the following question arises: is the subsidy-free offshore wind power plant in China already equipped with conditions for grid parity? Methods:The plant-side grid parity analysis of offshore wind power essentially lies in whether it reaches the economic-equivalent point of coal-fired power and is therefore economically viable to displace it in the electric system. Levelized Cost of Electricity (LCOE) is widely-used to estimate the break-even cost of power plants and is theoretically defined as the present value of the lifecycle cost (LCC) levelized by the lifecycle electricity generation (LCEG) [2, 3]. However, LCOE metric fails to capture the changes in the electric system and the electricity market [4, 5]. As a complementary

metric to LCOE, Levelized Avoid Cost of Electricity (LACE) was developed by EIA [6] to account for the electric system value and the available generation revenue of a power plant over its lifespan [3]. Through comparing with the "base case", LACE can be further explained as the costs that would be incurred to provide the electricity displaced by the outputs from the offshore wind power plant [7]. Based on LACE in conjunction with LCOE, the Net Value (NV) can be used to measure the economic viability of power plants.

Nevertheless, it is noteworthy that NV has certain weaknesses in not considering the external environmental benefits of offshore wind power plants, especially under the context of Tradable Green Certificate (TGC) policy implementation. Unlike the fiscal subsidy, the TGC policy operates as a market-oriented mechanism that has prominence in improving the profitability of offshore wind power plants by establishing the TGC market for green certificate trading [8]. Inside the TGC market, the introduction of a carbon price as a tool can not only recognize the carbon-abatement benefits of offshore wind power plants but also provide them with a new profit source in place of subsidies. Accordingly, we attempt to estimate the Lifecycle Carbon Abatement Revenue (LCAR) of offshore wind power plants under the current carbon price and introduce it as a supplement for the existing NV metric. Based on designing the grid parity index (GPI) framework with LCOE, LACE and LCAR incorporated, we can provide a deeper insight into the grid parity capability of China's 107 offshore wind power plants commissioned over the 2010-2022 period under a subsidy-free situation. Furthermore, we intend to conduct the dominance analysis and sensitivity analysis to investigate the major techno-economic conditions that impact their GPIs.
Results:Through comparing LACE with LCOE, the NV of offshore wind power plants displays a "from slow to swift" upward trend over their commissioned time. This trend signifies the economic viability of subsidy-free offshore wind power to be acceleratingly amplified. Particularly, the advanced scenario unveils the most favorable situation for the economic performance of offshore wind power plants, with the number of economically viable power plants at 5 under the benchmark electricity price and varies within 2-11 when the electricity price fluctuates by 20%. The moderate scenario also uncovers some potential for offshore wind power plants to be economically viable, albeit with only 2 specific plants commissioned at the end of 2022 demonstrating positive NV contingent upon a 20% increase in the benchmark electricity price. Comparatively, the conservative scenario paints a bleak picture, where all commissioned offshore wind power plants are deemed economically inviable. The economic viability of offshore wind power plants differs not only within a given scenario but also across three scenarios, that respectively underline the significance of electricity prices and the techno-economic conditions in determining the plant-side economic performance.

Compared with NV, the GPI is observed to be higher. This proves the introduction of a carbon price in a robust TGC market is advantageous for improving the plant-side economic performance of offshore wind power, as LCAR can offset a portion of LCOE and thereby shorten the payback period. However, it is evident that the current carbon price in China remains insufficient to drive significant change. In the conservative scenario, the 107 commissioned offshore wind power plants remain economically inviable even with their carbon-abatement effect monetized as a new profit source. The situation is slightly improved in the moderate scenario, where one additional power plant can be facilitated to reach grid parity. The most pronounced role of the current carbon price is observed in the advanced scenario, where it can promote the grid parity of 2-7 more power plants under the electricity price fluctuating by 20%. Generally, the current carbon price is too low to accurately reflect the carbon emissions cost, and under such a situation, its effectiveness in aiding the plant-side grid parity of subsidy-free offshore wind power is limited.

According to the dominance analysis, it is found that the improved plant-side grid parity capability of offshore wind power can be attributed to the enhanced cost-effectiveness per megawatt primarily and secondly the increased generation efficiency. Furthermore, the sensitivity analysis provide evidence that some techno-economic factors impact GPI significantly. The discount rate with its ± 2% fluctuations exhibits the most notable non-symmetric impact on the GPI, owing to the highest sensitivity of both LCOE and LCAR to it. Additionally, symmetric assumptions regarding the annual degradation rate of cable infrastructure and the operational lifespan of power plants yield considerable non-symmetric changes in GPI, due to their strong influence on generation efficiency, a dominant component of GPI. Apart from the non-symmetrical impact, the symmetrical parametric assumptions of factors can also exert symmetrical impacts on GPI. The assumption about the shares of annualized OPEX over CAPEX incurs the most significant symmetrical changes in LCOE and thereby in GPI. Besides, 20% fluctuations in electricity prices directly impact the LACE and eventually lead to substantial symmetrical alternations in the GPI.
Conclusions:Based on establishing the GPI framework, we assess the grid parity capability of China's 107 offshore wind power plants commissioned from 2010 to 2022 and find out that offshore wind power is on the way to approaching the plant-side grid parity under the subsidy-free situation,

attributed to the improved cost-effectiveness per megawatt primarily and secondly the enhanced generation efficiency. However, the plant-side grid parity capability exhibit difference under varying electricity prices and techno-economic conditions. The scenario results prove that low electricity prices for coal-fired power would obstruct the grid parity attainment of offshore wind power plants, whereas the sensitivity analysis uncovers the importance of ongoing technological advancement, especially in maintenance techniques, cable materials, and turbine longevity. Additionally, the results indicate that the current carbon price introduced in the TGC market can improve the grid parity capability of offshore wind power plants at certain level by forming a new profit source as an alternative to subsidies, even though it remains too low to effectively reconcile the divergent interests of coal-fired power and offshore wind power. Thus, it is pivotal to refine the carbon pricing mechanism to ensure that the carbon price is at an appropriate higher level to reflect the carbon emissions cost more accurately.

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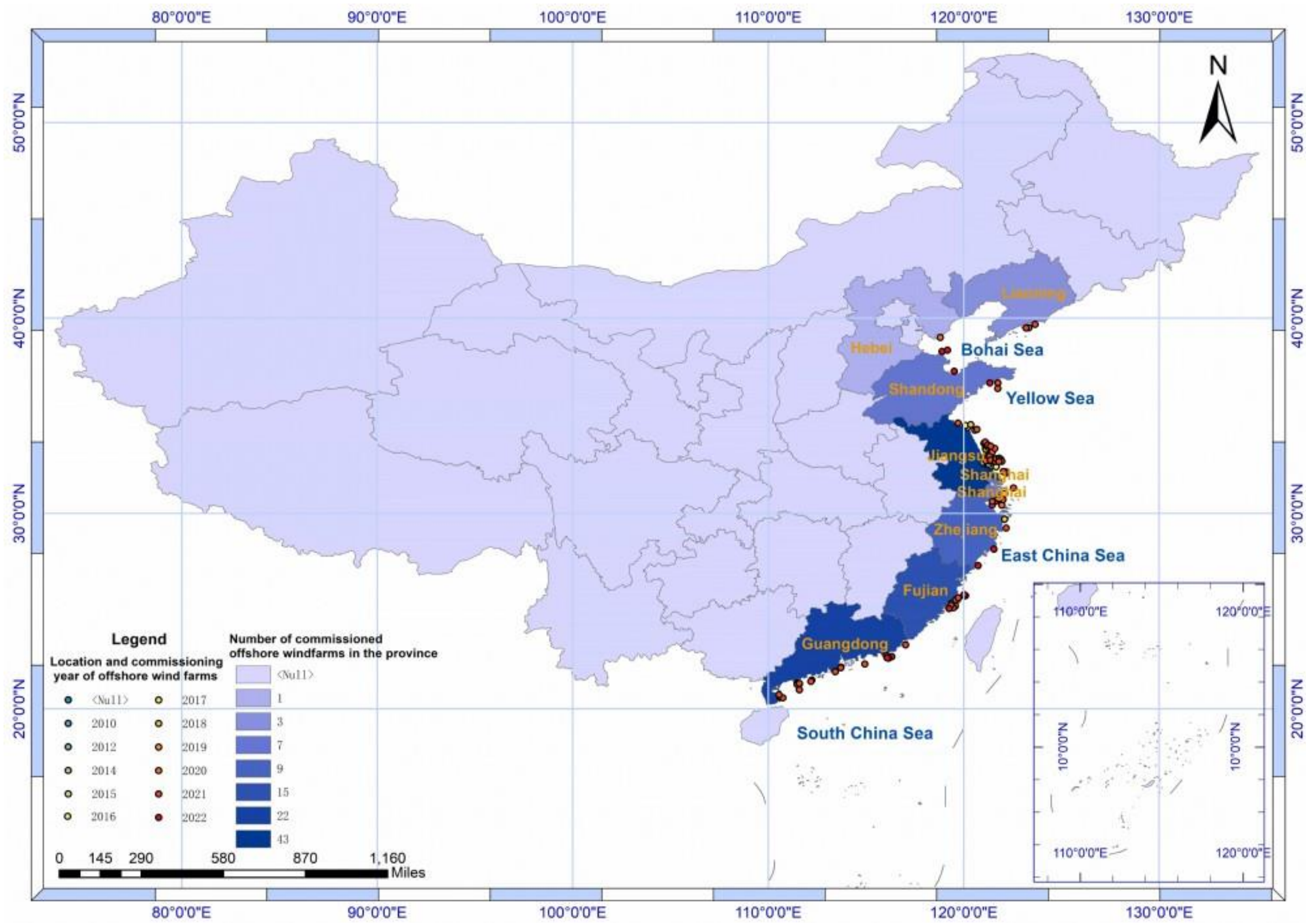
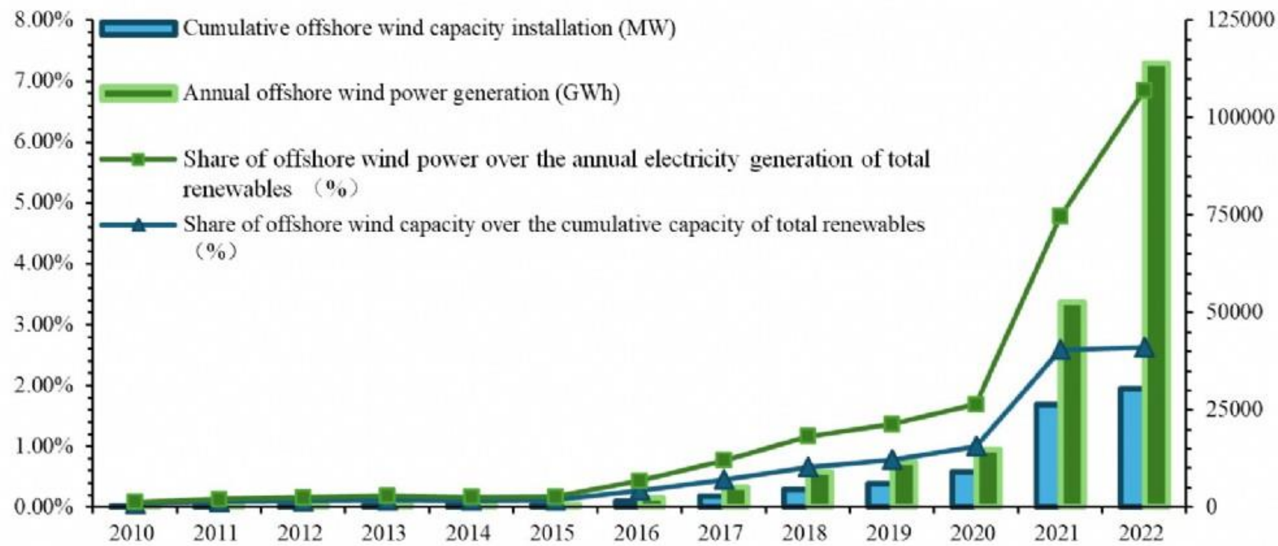
Keywords: Grid parity, Offshore wind power, Subsidy-free, Levelized cost of electricity, Levelized avoided cost of electricity, Carbon price

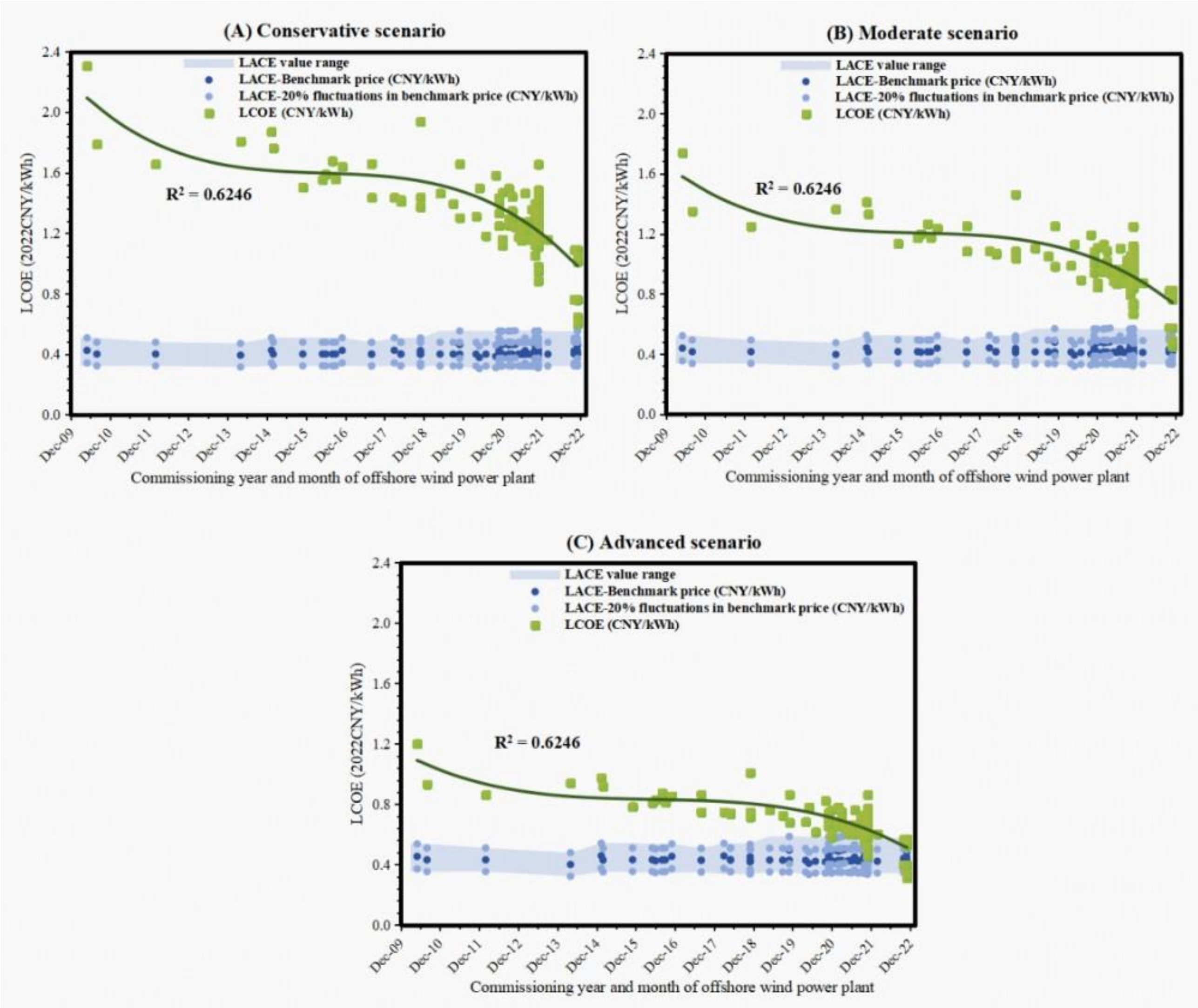
Location and commissioning year of 107 offshore wind power plants.



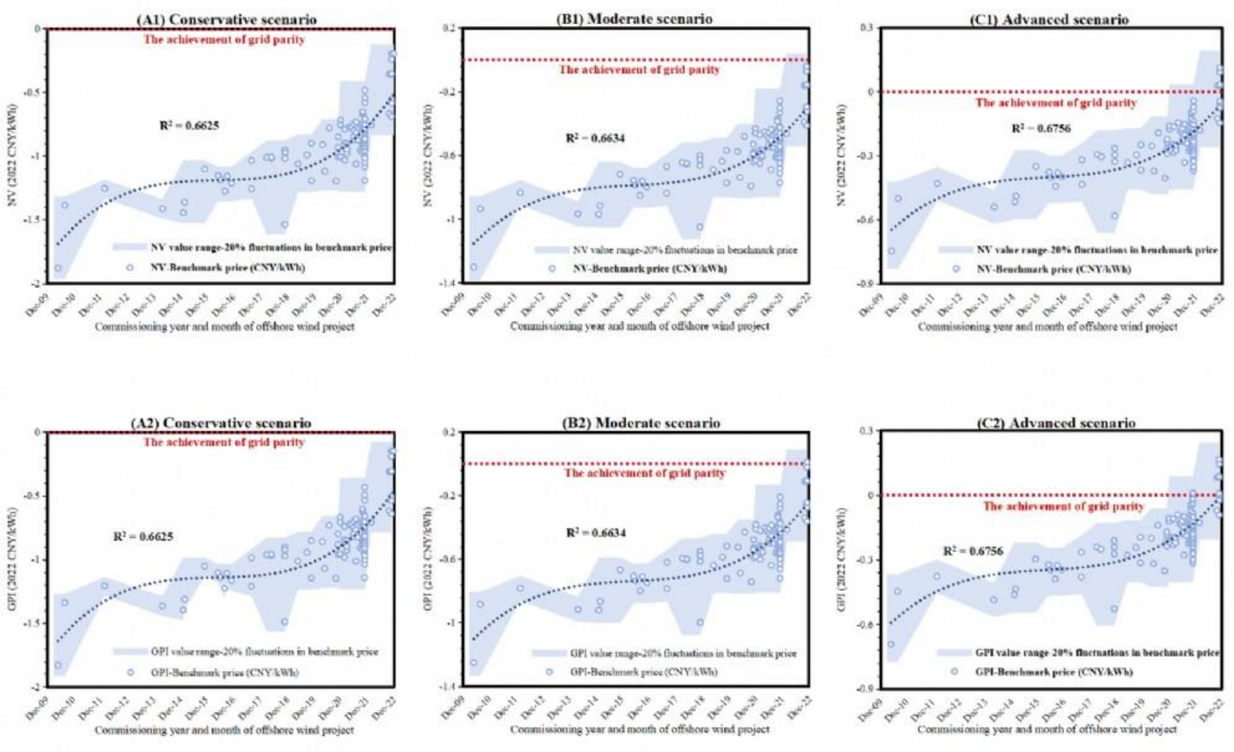
Offshore wind cumulative capacity installation and annual power generation in China from 2010 to 2022.



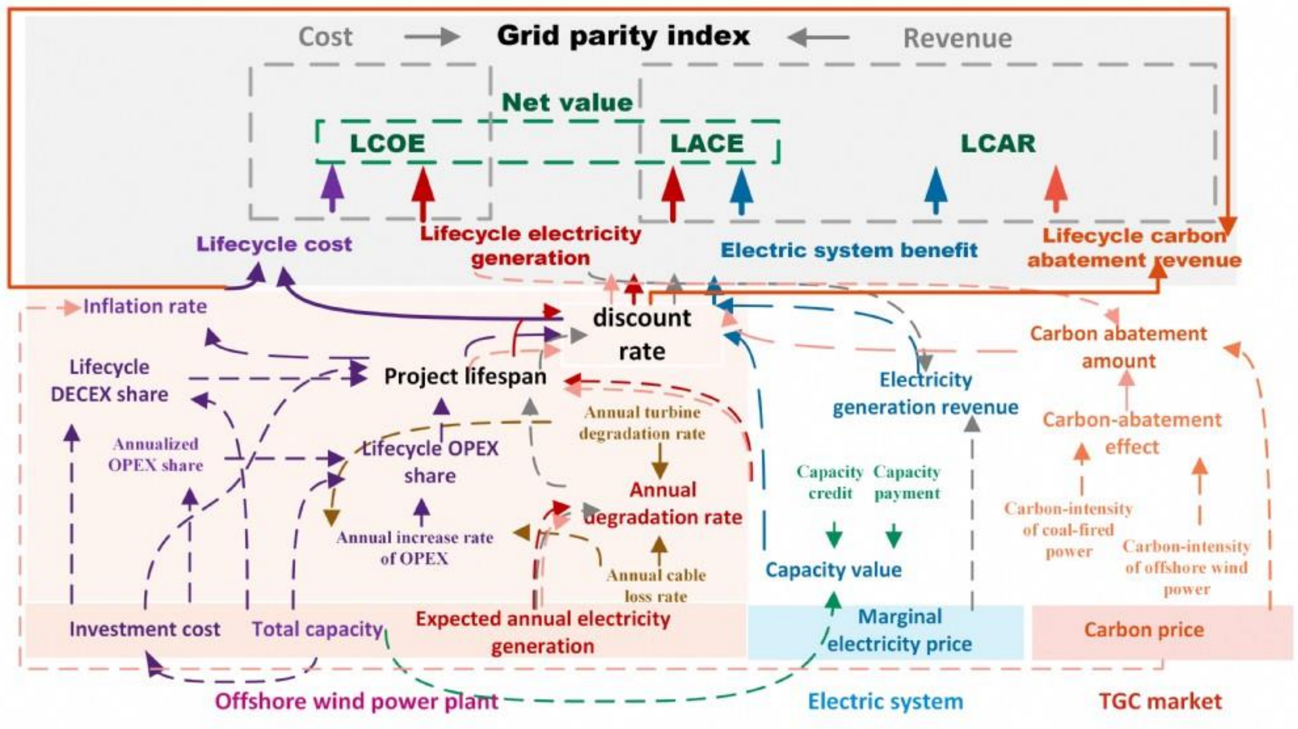
Scenario results of the LCOE and LACE for 107 offshore wind power plants commissioned from 2010 to 2022.



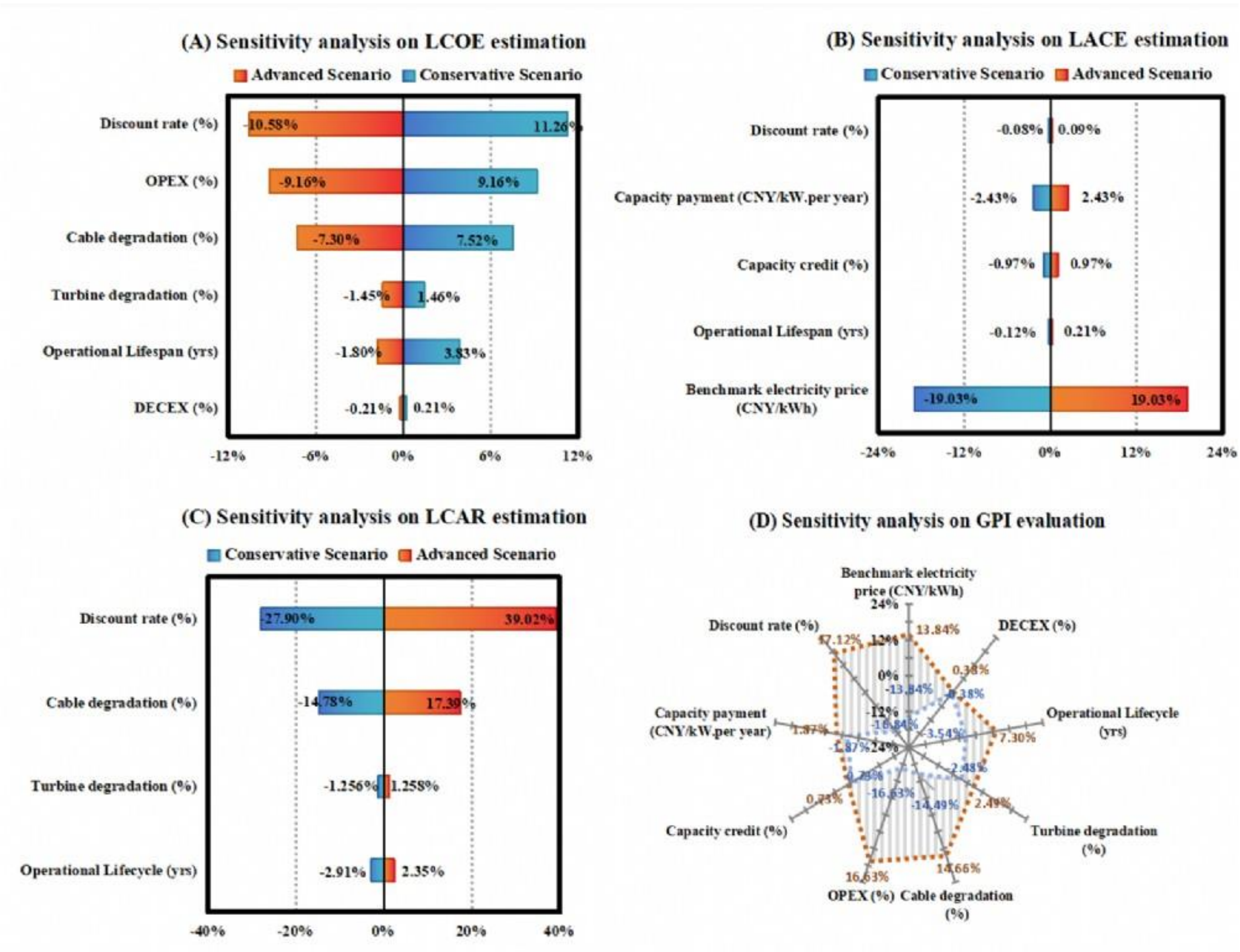
Scenario results of the NV and GPI for 107 offshore wind power plants commissioned from 2010 to 2022.



The flow graph of the GPI analysis framework.



The sensitivity of LCOE, LACE, LCAR and GPI to key factors.



[Page: 321]

[Abstract:0612] OP-321 [Accepted:Oral Presentation] [Renewables » Other]

Can we go beyond 100% renewable race? Evidence from a French urban heating network

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Overview:On 30th March 2023, the European Union has sent a very strong signal for its energy policy, planning to double the share of renewable energies by 2030s in the energy mix of the 27 countries (EU, 2023). Among other strategies, this acceleration from the current level (around 22% (Eurostat (2023)) to 42.5 % of renewables in consumption will necessarily have to go through the massive deployment of additional renewable heat sources, as a tool for the energy transition. In

Europe, there is a diversity of heating sources for reasons related to the historical context, to the choices of energy policy or to the climatic conditions conditioning the amount of heat consumed. When the conditions are favorable, the heating systems can have important benefits by using local renewable energies and by contributing to the energy transition of territories in the long term.
In our paper,we provide examples of heating technologies that have proven their usefulness and benefits for the community. More particularly, our research will provide a better understanding of such system in terms of optimal control of the available resources. With a real options approach we explore how the optimal planning of the energy resources potentially available in the Grenoble area (the second biggest heating network in France,) can be carried out over the long term. In this sense, the methodological approach (decision trees, scenarios) simultaneously incorporates the short-term uncertainties related to the operation issues, and long-term uncertainties associated with changes in market prices or financing costs influencing investments.
Methods:The landscape of district heating (DH) has been evolving rapidly, influenced by diverse factors ranging from environmental policies to market dynamics and technological advancements. A comparative analysis of recent works reveals a multifaceted picture of the challenges and opportunities within the DH sector across different geographical contexts. In terms of environmental and economic implications, Broberg, Dijkgraaf, and Meens-Erikson (2022) illuminate the environmental and economic benefits of utilizing imported waste as fuel in Swedish combined heat and power plants. This approach not only enhances energy efficiency but also aligns with broader waste management and sustainability goals, suggesting a paradigm shift from traditional biofuel use. The study underscores the importance of integrating waste-to-energy solutions within DH systems, especially in cold climate countries where heating demands are significant. Conversely, in China, Guo and Xiao (2022) explore the complexities of pricing strategies within the residential heating market. Their simulation-based analysis points towards the potential of marginal-cost pricing over cost-plus pricing, due to existing market barriers. This finding is crucial for policy formulation, as it highlights the need for adaptable pricing mechanisms that can foster the expansion of cleaner heating solutions in a rapidly urbanizing context. The study by Bonev, Glachant, and Söderberg (2022) on Sweden's implicit yardstick competition introduces an intriguing aspect of customer behavior in DH markets. Customers' price comparisons across different monopolies introduce a form of market discipline, hinting at the complex interplay between consumer perceptions and pricing strategies. This phenomenon indicates the potential for regulatory frameworks to harness market forces in shaping fair pricing behaviors without direct intervention. Wang et al. (2023)'s examination of China's largest heating system post-marketization reform reveals significant improvements in total factor productivity among heating companies. This quasi-experimental analysis highlights the critical role of market reforms in enhancing operational efficiencies, which is vital for sustainable development under stringent environmental constraints. The elasticity of residential heating demand in Denmark, as investigated by Trotta, Hansen, and Sommer (2022), introduces an important consideration for policy makers: the variability of price responsiveness among households. The effectiveness of carbon taxes as a tool to reduce emissions is contingent upon a nuanced understanding of such elasticities, emphasizing the need for a mix of policies that ensure equitable outcomes. In a broader European context, Billerbeck et al. (2023) provide an in-depth overview of DH regulations across 23 countries, revealing a significant variance in the regulatory depth. This variance suggests that the effectiveness of DH systems is not merely a function of comprehensive regulation but also depends on how well these policies align with local market conditions and consumer needs. The comparative study by Bull and Eadson (2023) on DH in the UK and Sweden sheds light on the level of citizen involvement in local heat infrastructure decision-making. The findings suggest a lag in public engagement within the DH sector compared to the broader energy sector, calling for enhanced participatory approaches in DH planning and implementation. Fernqvist et al. (2023) delve into the potential of DH systems in Sweden as flexibility services for the electricity grid. Despite the inherent potential, economic, legal, and societal barriers currently hinder the exploitation of DH for grid flexibility. This insight is crucial for future infrastructure planning, suggesting a need for integrated energy systems approaches that consider both technological and non-technological factors.
We contribute to the literature by assessing the inherent uncertainties and their impact on the district heating network of the city of Grenoble. More precisely, our methodological approach will be based on decision trees, scenarios (incorporation of short-term uncertainties related to the operation issues and long-term uncertainties associated with changes in market prices or financing costs influencing investments).
Results:The assumptions and findings from a real options analysis can offer valuable insights for policymakers and regulators. Understanding the value of flexibility and the impact of regulatory changes on investment decisions can inform the design of policies that support sustainable and resilient DH systems. The Grenoble Urban Heating Utility has an existing portfolio of five assets with associated sources of production and is considering its extension to other types of sources to address the fluctuating demand and the environmental constraints. The model presented has been applied to various scenarios regarding the use of wood as one main source to the heating network in

Grenoble. The results show that among the three scenarios presented, the most realistic would be the one with 25% of wood pellets and 75% of wood consumption. Instead, the construction of a new plant is not useful, as this plant would only operate half of the designed time, because of its important capacity. The walnut shell option is interesting for this area but as the industry of walnut shells is not developed, replacing fuel oil by walnut shells does not seem doable, and the low availability of this resource makes it impossible to replace all fossil fuels. However, the use of this material must not be sidelined as its characteristics are interesting. Furthermore, Grenoble possesses a valuable resource: an abundant aquifer exploited to supply energy to new constructions. An ingenious geothermal system on the aquifer is employed to provide heating, hot water production, and building cooling.

Conclusions:As district heating systems continue to play a pivotal role in the transition towards more sustainable and efficient energy systems, it is important that the urban heating network use all the available tools to support the decision making. In this sense, a real options approach is appropriate to assist decisions and to consider the opportunity cost of investments related to the use of new types of resources or the increase the amount of existing ones.

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Keywords: real options, district heating, uncertainty, investment

[Abstract:0618] OP-322 [Accepted:Oral Presentation] [Renewables » Solar]

Household Reponses to the Tax Treatment of Income from Solar PV Feed-in in Germany

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Overview: We examine possible adverse side effects of feed-in remuneration schemes caused by tax compliance costs. Specifically, for the case of Germany, we study how private households respond to a tax policy instruction issued by the German Federal Ministry of Finance in June 2021, enabling to evade tax compliance obligations if the installed capacity is ≤ 10 kWp. A decision model and two different empirical models are employed to show how such compliance costs distort both deployment decisions and capacity choices. We find that the tax instruction led to a change of the capacity distribution of newly built PV systems towards 50-65% intensified excess bunching slightly below 10 kWp, leading to an inefficient use of rooftop space. The lacking cross-sectional variation in the data and a large number of con-founding events in the observation period calls for further research to corroborate our findings. Using methodical approaches taken from the bunching literature and discontinuity analysis, we estimate potential changes in the average capacity choice.
Methods: We use a simplified decision model, based on which we theoretically investigate under which circumstances tax compliance costs become relevant for the decision-making of prospective PV adopters and where the BMF tax policy instruction may distort the decision. To estimate the influence of compliance costs induced by income tax obligations, we examine the response of residential PV adopters to the BMF tax instruction from June 2021. For that purpose, we exploit on the fact that the publication of the instruction constitutes a quasi-experiment where households who commissioned their system before June 2021 are the control group, and households who deployed the system after the instruction came into effect depict the treatment group (time series analysis). Furthermore, the policy instruction only applies to systems < 10 kWp, which suggests an analysis of the distribution of system capacities around the threshold before and after the instruction came into effect (distribution analysis). The collected data from the Marktstammdaten-Register (MaStR), representing repeated cross-sectional data, enables the use of both approaches. We use bunching estimation and regression discontinuity design (RDD) as suitable approaches to identify excess bunching. A subsequent difference-in-bunching (DiB) analysis further provides evidence for time-delayed responses. In a second step, we adapt these findings to specify a model for a RDD approach, enabling us to include control variables to better analyze quantitative effect sizes for the impact of bunching on the average system capacity. For the empirical analysis, we use administrative data from a public energy producers registry (Marktstammdatenregister, MaStR) maintained by the German Federal Network Agency, for the period Jan 2017 - Jul 2022. This registry contains core data of all actors and power generation units on the German electricity and gas market and, as of August 2022, lists around 2.3 million PV systems commissioned since 2000. The on hand anonymized version of the MaStR provides individual data on the location of a system (postal code, county and state), the exact date of commissioning, PV power capacity, and operator type (natural or legal person). After filtering out systems commissioned before 2007 and such with capacities > 30 kWp and < 1 kWp, we make use of 704,551 observations.
Results: Significant bunching of PV system capacities slightly below the cut-off level of 10 kWp is present in all observed months and across all subsets of different population density. The extent of bunching, though, declines greatly in the first half of 2021. Between July and September 2021, the dynamic reverses, and the excess mass increases by 50-65% compared to the minimum value until the end of the observation period. This behavior is consistent across all subgroups. The general intensity of bunching, while still very pronounced, is found to be less distinct for areas with higher population density than for less densely populated areas. Furthermore, the initial decrease of the bunching measure is greater in areas with high population density, as compared to areas with fewer inhabitants per square kilometer.
Conclusions: Our findings provide evidence for the assumption that the population density indeed is an appropriate proxy for the rooftop size, and, that households with smaller average roof sizes are, on average, less affected by regulations that feature discontinuous treatment at the 10 kWp threshold. Overall, we find that strong evidence for substantial bunching slightly below 10 kWp, which very likely is induced by the BMF tax instruction. Furthermore, the results indicate that this effect goes beyond the natural impact of bunching alone. While the preliminary considerations predict this behavior, the empirical results are insufficient to unambiguously confirm the theory.
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Keywords: Solar photovoltaics, Private households, Prosumers, Tax compliance costs, Excess bunching, Germany

[Abstract:0036] OP-323 [Accepted:Oral Presentation] [Coal » Other]

Coal Fired Power Plant Decarbonization with Cofiring Implementation (Case Study Lontar Coal Fired Power Plant)

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Overview:The technology of the cofiring method in Coal Fired Power Plant (CFPP) divided into 3 (three), there are:
a. Direct method, where coal and biomass are directly mixed and fed into the boiler through the same or different mills.
b. Indirect methods, where one of the fuels, coal or biomasses, pass a gasification process first before being mixed into the boiler.
c. Parallel cofiring, where fuels, coal and biomass, are burned in different burners and the steam produced by two boilers combined for use in the next process.
Methods:Preparation initial data as a reference for cofiring test consists of:
a. Key equipment specification data.
b. Calibration data of instrument equipment, where the latest data used during inspection activities (overhauled).
c. Plant performance or commissioning data, and
d. Plant performance data monthly.
Results:a. Operational equipment evaluation. Based on monitoring data of equipment such as furnace temperature boiler, pulverizes outlet temperature and fans ampere, shows normal limits operating parameters of the equipment.
b. Slagging and fouling potential resulted sulfur content rose to 0.48wt% higher than the commissioning value, which is 0.18wt%.
c. Net Plant Heat Rate (NPHR) during cofiring testing is 5.79% higher than coal firing with the same SFC value, which is 0.56 kg / kWh. Analysis of heat rate differences occurred sawdust humidity that reduced coal mixed calorific value used into pulverizes.
d. Cofiring test data obtained duration for 25 days with 184.42 hours and average daily operation 7 hours a day of unit operation, with use of sawdust of 2,549,080 kg, resulted total green kWh 2,195,118.
Conclusions:Based on the evaluation of the operational parameters above, boiler reheat temperature parameter right outlet side has maximum value 581.61 ºC, 1.61 ºC higher than permissible operating limit. This higher analyzed due to spray control valve interference that set point reheat temperature not achieved. Sulfur content deviation during the cofiring test 0.3wt% higher than the commissioning value, that analyzed due to coal mixing which the percentage Low Rank Coal (LRC) more than Medium Rank Coal (MRC).
Evaluation of production costs shows a fuel cost savings Rp128,225,473 / MWh. This carried out by looking for coal price approaches per kilogram (kg) and cofiring (coal + sawdust) that included in the calculation.
For environment evaluation, the daily average emission parameters with 100% cofiring and coal firing tests do not show significant differences, that can be seen value of Sox and NOx is still below the maximum value, 550 ppm, based on the Minister of Environment Regulation No15/2019 that

concerning the limit of emission quality standards for Sox and NOx Coal Fired Power Plant.
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Keywords: Decarbonization, cofiring, operational evaluation, economic evaluation, environmental evaluation

Picture Abstract

COAL FIRED POWER PLANT DECARBONIZATION WITH COFIRING IMPLEMENTATION (CASE STUDY LONTAR COAL FIRED POWER PLANT)

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Overview

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b. Indirect methods, where one of the fuels, coal or biomass, pass a gasification process first before being mixed into the boiler.
c. Parallel cofiring, where fuels, coal and biomass, are burned in different burners and the steam produced by two boilers combined for use in the next process.

Methods

Preparation initial data as a reference for cofiring test consists of:
a. Key equipment specification data.
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c. Plant performance or commissioning data, and
d. Plant performance data monthly.

Results

a. Operational equipment evaluation. Based on monitoring data of equipment such as furnace temperature boiler, pulverizers outlet temperature and fans ampere, shows normal limits operating parameters of the equipment.

b. Slagging and fouling potential, resulted sulfur content rose to 0.48 wt% higher than the commissioning value, which is 0.18 wt%.
c. Net Plant Heat Rate (NPHR) during cofiring testing is 5.79% higher than coal firing with the same SFC value, which is 0.56 kg / kWh. Analysis of heat rate differences occured sawdust humidity that reduced coal mixed calorific value used into pulverizer.
d. Cofiring test data obtained duration for 25 days with 184.42 hours and average daily operation 7 hours a day of unit operation, with use of sawdust of 2,549,080 kg, resulted total green kWh 2,195,118.

Conclusions

Based on the evaluation of the operational parameters above, boiler reheat temperature parameter right outlet side has maximum value 581.61 •C, 1.61 •C higher than permissible operating limit. This higher analysed due to spray control valve interference that set point reheat temperature not achieved. Sulfur content deviation during the cofiring test 0.3 wt% higher than the commissioning value, that analyzed due to coal mixing which the percentage Low Rank Coal (LRC) more than Medium Rank Coal (MRC).

Evaluation of production costs shows a fuel cost savings Rp128,225,473 / MWh. This carried out by looking for coal price approaches per kilogram (kg) and cofiring (coal + sawdust) that included in the calculation.
For environment evaluation, the daily average emission parameters with 100% cofiring and coal firing tests do not show significant differences, that can be seen value of SOx and NOx is still below the maximum value, 550 ppm, based on the Minister of Environment Regulation No15/2019 that concerning the limit of emission quality standards for SOx and NOx Coal Fired Power Plant.

AuthorToEditor: We declare that the material send has correct data based on field test data

[Abstract:0205] OP-324 [Accepted:Oral Presentation] [Coal » Other]

APEC Coal Demand and Supply Perspective to 2050

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Overview:The 21 economies that comprise the Asia Pacific Economic Cooperation (APEC) forum are home to almost three billion people and account for 60% of global GDP. APEC is reliant on immense levels of energy supply, with a large trade component, required to enable continued strong economic growth in the region. The forum's purpose is to promote regional economic integration and trade. Understanding long-term energy market trends is fundamental to achieving this and has become increasingly important in the context of the global push toward decarbonisation.
For the 8th edition of the APEC Energy Demand and Supply Outlook, the Asia Pacific Energy Research Centre has constructed two potential energy futures out to 2050. The 8th edition contains two scenarios. The Reference scenario analyses recent trends in APEC energy consumption, production, and trade, to deliver one potential energy future. The Carbon Neutrality explores hypothetical pathways for each of the 21 APEC member economies to reach carbon neutral energy sectors. The Carbon Neutrality scenario (CN) explores additional energy sector transformations such as increased levels of energy efficiency, behavioural changes, fuel switching, and CCS deployment. The pathways are constructed based on the unique characteristics, policy objectives, and starting points of each economy.
While APEC members are courting stronger decarbonisation goals, the recent energy security crisis is shifting the focus of policymakers to ensuring the security of coal supply. However, there is value in understanding what the trajectory of coal demand and supply in the APEC region means in a world that is embracing carbon neutrality. Producers and consumers alike can use these results to help illuminate their risk to stranded assets if they invest in coal assets today and a carbon neutral world unfolds over the coming decades.
Although renewable energy generation has risen enormously in recent years, coal-fired power plants can provide reliable baseload power to the national generation grid. The results highlight how coal can continue to play a role in the APEC energy system, provided that they are developed in a way that is in line with carbon neutrality.
Methods:The 8th Outlook modelling involves decomposing the APEC energy system into multiple subcomponents spanning demand sectors (such as industry, transport, and buildings), transformation (power, heat, and refining), and supply (production and trade). Demand sector modelling relies on estimates of output, energy efficiency, fuel switching rates, activity rates, technology diffusion, and multiple other variables. Calibration occurs via knowledge-based iteration, particularly with economy-level experts. When demand is finalised, the power, heat, refining and supply, sector models deliver the required energy based on assumptions about fuel cost trajectories, and policy/market intervention. In the case of the power sector, a least cost model is deployed. However, cost-based decisions and assumptions are overridden if there is political backing for certain technologies or fuels that enhances their relative economic viability. There is frequent iteration of results, with extensive review and input from economy and energy experts to arrive at final energy demand, transformation, and supply results.
Characteristics that distinguish the Reference scenario results from the Carbon Neutrality scenario are energy efficiency rates that follow historic trends; gradual rates of fuel switching; and relatively slow diffusion of new technologies in demand and power sectors. Assumed macroeconomic activity is the same in both 8th Outlook scenarios.
Results:3.1 Coal consumption
Due to environmental and climate change pressures, coal consumption in the APEC region is expected to fall by almost 80% in CN, with a more than 90% fall in the power sector. Higher rates of fuel switching and more stringent coal phase-out policies contribute to this decline (Figure 1).

Figure 1: Coal consumption by sector in CN, 2000-2050 (PJ)

At COP26, nine APEC economies signed the Global Coal to Clean Power Transition Statement, wherein they committed to not building any new coal-fired power plants from the 2030s or 2040s, depending on their economic situation. Assumptions in CN lead to an even lower level of consumption than these commitments imply. However, coal-fired power generation still increases in southeast Asia, albeit at a lower level than in REF.
Coal consumption in the industry sector declines by almost half in CN. Electrification and other fuel switching are the main drivers of this reduction. Greater prominence of electric arc furnaces and hydrogen-based technologies partly displace metallurgical coal in steel making towards the end of the projection period. However, approximately 13 000 PJ of coal consumption remains by 2050, underlining the challenge of eliminating coal from the industry.

The development of a global hydrogen market in CN supports additional coal use to produce the emerging energy carrier. However, coal use to produce hydrogen remains relatively low in the context of total APEC coal consumption, peaking under 1 000 PJ. This occurs solely in China and Australia, the two economies producing hydrogen from coal, and reflects their desire to leverage domestic resources to support the development of the nascent hydrogen industry.

3.2 Coal supply
APEC coal supply falls shy of three-quarters in the CN, as nearly all APEC regions strive to significantly switch away from the high-emitting fuel enroute to carbon neutrality (Figure 2). Every region reduces its coal supply by at least three-quarters, except for southeast Asia, where coal use increases to fuel the industrialisation of the region and some economies, including Indonesia and Viet Nam, opt to continue to burn coal but reduce its emissions with the utilisation of carbon capture and storage (CCS) technology. China and southeast Asia together make up over 90% of all coal use in APEC by 2050 in CN.
A further reduction of coal use by power plants, particularly in China and southeast Asia, and increased fuel switching by heavy industry, particularly in cement and iron and steel production, is required to reduce APEC coal supply further.

Figure 2: Coal supply by region in CN, 2000-2050 (PJ).

Coal production falls by 77% from around 130 000 PJ in 2018 to about 30 000 PJ in 2050 (Figure 3). The reduction is due to declining coal demand in APEC and the world, which sees coal trade (imports and exports) fall by two-thirds through to 2050. The APEC region continues to remain an important source of coal supply in this scenario.

Figure 3: Coal production, imports, and exports in CN, 2000-2050 (PJ).
Conclusions:Despite the strong growth in renewable energy generation in recent years in the APEC region, coal still plays a crucial role in providing baseload power and is an essential ingredient for steelmaking.
Natural gas prices surged in late 2021, leading several economies in APEC to use more coal in coal-fired power plants. As a result, APEC coal consumption rose by approximately 5% in 2021, driven by the five largest coal consumption economies, which accounted for almost 90% of APEC coal consumption.
Based on the CN scenario, the pace of decline in thermal coal consumption is expected to be faster than metallurgical coal consumption because metallurgical coal is a vital ingredient in the steelmaking process, which is not easy to substitute with other fuels.
Coal consumption in APEC is still significant in CN, especially in the power and industry sectors. It will continue to play a crucial role even during the transitional period in coal-reliant APEC economies, particularly in China and Southeast Asia. APEC coal consumption is expected to account for approximately 10% of the APEC total primary energy supply by 2030.
This projection highlights the risk of stranding recent investment in coal infrastructure as a world embraces carbon neutrality. Investment in new coal mines, import and export infrastructure, which are meeting current demand requirements, could all face stranded asset risk in CN.
References:APEC (2022), APEC Energy Demand and Supply Outlook 8th Edition.
APERC (2023, APERC Coal Report 2023.

Keywords: Coal demand, coal production, coal import, coal export

[Abstract:0042] OP-325 [Accepted:Oral Presentation] [Petroleum » Refining and Products]

Maintaining good organizational reputation for operational efficiency in mitigating petroleum shortages in the Nigerian deregulated downstream supply industry

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Overview:Refined petroleum products are the life line of the Nigerian economy. Nigeria is an oil producing nation, ranked 6th by the organization of oil producing exporting countries (OPEC). Despite the abundance of oil resources, Nigeria continually suffers from petroleum products shortages. Every organization or enterprise in Nigeria depends on petroleum products for survival in generating electricity, transportation or for heat production.

The continual shortages of petroleum products in Nigeria cripples business activities, resulting to underdevelopment of the economy. The purpose of this multiple case study was to identify the strategic role of organizational reputation by downstream petroleum supply companies in mitigating petroleum shortages in the petroleum supply chain and to sustain business development in Nigeria.
Methods:The sample for the study included 10 senior leaders from two private-sector Nigerian downstream petroleum supply companies located in the Niger Delta region, who had successfully implemented strategies for petroleum supply. The resource based view theory served as the conceptual framework for the study. Data collection included semistructured face-to-face interviews and review of operational and policy documents from the supply companies. The data for the study went through qualitative rigors of validity and reliability such as dependability, reliability, confirmability, credibility, and transferability. Data were transcribed, analyzed, and validated through member checking and triangulation.
Results:Data were obtained from 10 experts in the field of study. All participants affirmed that one of the strategies for mitigating petroleum product shortages in Nigeria is for business leaders to maintain good organizational reputation in the downstream sector of the industry.

Participants noted that petroleum firms should engage in management practices that emphasize on responsible business practices, and have capacity to manage critical social and environmental situations. Good business practices across the supply value chain includes; importation of quality products, non-adulteration of products, avoid illicit activities such as hoarding or products, overpricing of products, diversion of products, and other sharp practices in the retail outlets. Firms should develop high business integrity among customers, competitors, and host communities of operations. Organizations should be involved in Corporate Social Responsibility (CSR) within host community. Products should adhere to quality standards as stipulated by regulatory authorities.

The findings indicate that petroleum business leaders should be involved in developing acceptable business ethics, enshrine integrity in the supply chain process, engage host communities positively including implementing CSR activities, and ensure excellent customer service delivery.
Conclusions:Refined petroleum product is the backbone of the Nigeria economy. Every sector of the economy; Business, Health, Agriculture, Transportation, Manufacturing, Education, Banking etc. rely on petroleum products for transportation, heat, or power generation. The continual petroleum product shortages in Nigeria cripples economic and business activities, thereby undermining the development of the country. The Nigerian downstream petroleum sector was partially deregulated to user in private investors or business leaders to mitigate shortages of petroleum products, to enhance economic growth.

Firms with good reputation reduces industrial actions such as “strike” which are synonymous with petroleum companies in Nigeria, leading to product availability. Firms with good reputation that engages in CSR avoid situations of petroleum pipeline vandalism, youth restiveness, stealing of products, which eventually lead to improved supply positions. Maintaining good reputation among internal and external customers, regulatory agencies, the environment, and host communities enhances petroleum product availability as affirmed by triangulated sources of the study.

Findings may be used by petroleum business leaders and investors to create effective and efficient

organization’s reputational strategies in the supply chain, leading to product availability, sustainability, poverty reduction, and economic development.
References:None in Abstract

Keywords: Petroleum, Shortages,Organizational reputation, Economic development.

AuthorToEditor: My submission is a finding in my doctoral study from Walden University, USA.

[Page: 326]

[Abstract:0121] OP-326 [Accepted:Oral Presentation] [Petroleum » Markets and Prices]

Managing the Oil Market Under Misinformation: A Reasonable Quest?

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Overview:In this paper, we examine the type and quality of information required by OPEC to stabilize the oil market. We expanded our previous structural model that looked at the possibility of OPEC making mistakes in judging the size of market shocks. The new model now includes the possibility of OPEC misjudging how the market price would respond to any given adjustment to its production level. Thus, we present a model that incorporates both observational errors regarding physical market developments as well as potentially erroneous judgments regarding the elasticities of supply and demand. We use the model to determine the counterfactual (unstabilized) prices that would have prevailed if OPEC, acting under a broad range of misinformation, had not attempted to stabilize the price. We find that misestimation of the demand and supply elasticities generally increases the computed counterfactual price volatility. When compared to historical volatility, these higher counterfactual volatilities strengthen our previous finding that OPEC has substantially decreased price volatility by regulating production from its buffer of spare capacity. This finding holds true for both the OPEC+ period and before.
Methods:Pierru, Smith, and Zamrik (2018) and Almutairi, Pierru, and Smith (APS, 2023) previously demonstrated that OPEC, and more recently OPEC+, have managed to significantly reduce crude oil price volatility by using spare capacity to offset short-term shocks to the demand and supply of crude oil. This was achieved despite OPEC’s presumed inability to accurately predict these shocks. However, the analysis, counterfactual calculations, and conclusions in each of the foregoing studies were based on the assumption that OPEC always held perfect knowledge of the elasticity of demand for its oil. In other words, OPEC can correctly anticipate the precise price impact of any particular change to its own production.
In this paper, we relax the assumption of our earlier papers and consider the possibility that OPEC may misjudge the elasticity of demand for its oil. Combined with OPEC’s presumed inability to precisely estimate the size of shocks, the question becomes whether this more comprehensive analysis that encompasses greater scope for error and misjudgment still supports our previous conclusion that, by attempting to offset shocks to the market, OPEC has the ability, and has indeed been able, to significantly reduce price volatility.
Using monthly data (September 2001 – August 2021), this paper fits a structural model to the behaviour of OPEC’s spare capacity and conducts new counterfactual analyses that reveal whether OPEC’s potential lack of knowledge regarding the true elasticity of residual demand is a problem.
Results:We constructed several counterfactual scenarios and compared the observed volatility of historical oil prices with what the volatility would have been if OPEC had not attempted to stabilize

prices. Our results reinforce previous conclusions and, indeed, somewhat increase the degree to which OPEC's actions appear to have stabilized the price. We find that, even if misinformed, OPEC substantially decreased the price volatility by regulating production from its buffer of spare capacity. Whereas APS (2023) found that price volatility would have been about 50% higher than actually observed if OPEC had not attempted to offset shocks during the Commodity Boom period, we estimate that volatility would have been roughly 55% higher than actually observed—depending on the assumed degree and direction of OPEC's potential misestimation of the elasticities. Regarding the OPEC+ period, APS (2023) found that the counterfactual volatility would have been 86% greater than actually observed. Our estimate tends to be somewhat higher—between 100% to 120% greater than historical volatility, depending on the assumed degree and direction of OPEC's potential misestimation.

Conclusions:In this paper, we develop an extension of our previous models to address both theoretically and empirically the type and quality of information that is required to effectively stabilize the price. Our main question is to see how OPEC's potential misperception of elasticities impacts its ability to stabilize prices. We conducted new counterfactual analyses, which reveal that even if OPEC is misinformed, it has managed to reduce volatility through its attempts to stabilize the price.

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Keywords: OPEC+, Price Stabilization, Misestimation, Spare Capacity, Elasticity

[Abstract:0369] OP-327 [Accepted:Oral Presentation] [Petroleum » Policy and Regulation]

Fuel adulteration issues in Brazil: an economical and behavioral approach

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Overview:Although it is desirable, consumers are not always fully informed about the quality of a product before purchasing it. Often, the true quality of a product only becomes apparent after consumption. In markets with asymmetric information, only the firms know all the attributes of their products. In this case, there are suitable conditions for fraud (Darby and Karni, 1973; Shapiro, 1982; Huck et al, 2016).
A market with a high level of asymmetric information, and consequently susceptible to fraud, is the fuel retail. The prevalent forms of fraud in this market are adulteration and quantity manipulation. Adulteration involves deviations from quality standards set by regulatory agencies, particularly in terms of physical-chemical specifications. Quantity manipulation, on the other hand, occurs when a gas station tamper with the fuel pump, resulting in the injection of less fuel into the car tank than indicated on the pump's meter.
The main motivation for fuel or pump adulteration is the possibility for gas stations to increase their profits. In quantity fraud, the gain comes from the amount of fuel paid for by the consumer, but not delivered. Adulteration involves the addition of cheaper substances, such as solvents, to the fuel. These issues are more common in countries that have not yet reached high levels of economic development, such as Brazil. Generally, these countries have limited budget for enforcement policies.
The consequences of fraud in the fuel retail sector are extensive. For consumers, there is the loss of the paid but not received fuel in the case of quantity fraud. Fuel adulteration may compromise the performance of the vehicle's engine. For the government, the addition of solvents can result in

financial losses due to tax evasion. Additionally, solvents emit more greenhouse gases, accelerating climate change. It can also cause distortions in emission accounting within environmental policies. From an economic perspective, gas stations that charge higher prices for fuel tend to engage in less fraud. According to the literature, there is a positive relationship between price and quality. Sellers who prioritize and deliver quality in their products are often rewarded with a monetary premium (White, 1972). Moreover, many brands do not desire to be associated with fraud (Dranove and Jin, 2010) making branded gas stations less likely to engage in illicit activities. Finally, if a station has many nearby competitors, the tendency is to avoid adulteration, as it may lose customers to competitors if caught by enforcement. Thus, from an economic perspective, there are benefits to offering quality products: financial gains through higher prices, maintenance of brand reputation, and not losing demand to competitors.

However, in a behavioral approach, peer influence can act as an inducer for adulteration. If competitors experience financial gains through quantity manipulation and/or the use of cheaper solvents, a station may be incentivized to also engage in similar illicit practices. In this case, there is an interdependence between agents' decisions, generating a negative contagion effect (Jost, 2001). This phenomenon has been observed in Mexico (Guerrero, 2012; Liu et al, 2018).

The objective of the study is to analyze the role of economic and behavioral factors in the decision to adulterate fuel and to scam fuel quantity in Brazil. The justification is that, despite increased enforcement actions, fraud remains a significant issue. Between 2018 and 2022, 3.5% of gasoline samples collected showed adulterations, while 5.3% of gas stations had pumps with measurement problems. In total, almost 9% of Brazilian gas stations were detected engaging in illegal activities during this period.

Methods:In order to examine how economic factors and behavioral effects influence the decision of gas stations to engage in illicit activities, two probit models were estimated. The first model, in Equation (1), analyzes fuel adulteration. In the second model, the focus is on quantity fraud (Equation (2)). The analyzed period spans from the years 2018 to 2022.

$$Adulteration_{it} = \beta_0 + \beta_1 Price_{it} + \beta_2 Branded_{it} + \beta_3 Competitors_{it} + \beta_4 PeerEffect_{it} + \varepsilon_{it} \quad (1)$$

$$QuantityBias_{it} = \beta_0 + \beta_1 Price_{it} + \beta_2 Branded_{it} + \beta_3 Competitors_{it} + \beta_4 PeerEffect_{it} + \varepsilon_{it} \quad (2)$$

The dependent variables, *Adulteration* and *QuantityBias*, are binary and take the value 1 if gas station *i* in period *t* has committed fraud and was caught by regulatory authority, and 0 otherwise. As for the independent variables, *Price* is the average price charged by the gas station; *Branded* is a binary variable taking the value 1 if the gas station is branded, and 0 otherwise; *Competitors* represent the number of competitors a gas station has in a specific neighborhood. These three variables capture the economic effect of fraud in the retail sector. On the other hand, *PeerEffect* indicates the proportion of gas stations that are not in compliance with regulatory standards within a neighborhood. Therefore, it takes a value between 0 and 1 and captures the behavioral effect of fuel and pump adulteration. Finally, ε represents the error term.

It is important to note that the $\beta_i, i=1,2,3,4$ coefficients should be used solely to determine whether the probability of adulteration or quantity fraud increases or decreases as the dependent variables vary. Therefore, it is also necessary to report the values of marginal effects in means – that is, the effect of economic and behavioral variables on the probability of a gas station offering a fraudulent product or quantity.

The data was collected from the website of the Brazilian regulatory agency, the National Petroleum Agency (ANP). Annually, the ANP publishes the Fuel Supply Inspection Bulletin. In it, the main results of the inspection actions for each gas station visited by the ANP are synthesized. Data from the Fuel Price History Series were also used, which includes information about the prices, as well as other details such as the address (used to calculate the number of competitors and peer effect) and whether the gas station is branded or not. For this work, we combined data from the Fuel Supply Inspection Bulletin and the Fuel Price History Series.

Results:The results corroborate the theoretical postulates of the literature. Indeed, gas stations that charge higher prices for fuel are less likely to engage in both adulteration and quantity fraud. Furthermore, firms care about their reputation, as branded stations are less likely to commit illicit acts. Finally, in the economic context, the number of competitors matters. The greater the number of competitors a gas station has, the lower the probability of that station committing fraud. The main motivation is the fear of being caught by regulatory authority and losing demand to other gas stations in the neighborhood.

Nevertheless, the importance of the peer effect was also highlighted. Having neighbors who are not in compliance with regulation is a factor that affects the likelihood of a station acting unlawfully. The higher the proportion of fraudulent neighbors, the more likely a station becomes to engage in fuel

adulteration or quantity fraud. All presented results are statistically significant at the 10% level. Conclusions:Our analysis identified which gas stations are more likely to adulterate fuel and manipulate pump readings. In general, these are stations that charge lower prices for the fuel they sell, have few competitors, and are not affiliated with any brand. Additionally, there is a higher probability of finding a station engaging in illicit practices if neighbors nearby are identified as non-compliant with regulation standards.
Considering that countries with lower levels of socio-economic development face limitations in resources to expand regulatory oversight, this study carries significant implications for public policies. The first implication is to guide the regulatory agency on where to direct the greatest efforts in enforcement actions. The second is to adopt policies that mitigate asymmetric information, the main cause of fraud. In Mexico, when a station complies with regulations, it receives a green seal. Therefore, for consumers, it becomes easier to choose where to refuel their cars without worrying about the possibility of buying adulterated fuel or incurring financial losses due to quantity fraud. This policy has proven effective in reducing local fraud issues.
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Keywords: Fuel Adulteration, Peer Effect, Fuel Prices, Fraud, Brand

[Abstract:0308] OP-328 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Geopolitics of Energy]

The Impact of the 2022 Oil Embargo and Price Cap

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Overview:The Russian invasion of Ukraine in February 2022 prompted widespread voluntary restrictions on imports of Russian crude oil, which were replaced by a formal oil embargo in December 2022 and a cap on the fob price of Russian crude oil sold to countries not participating in the embargo. The embargo, led by the U.S. and the European Union, dramatically reduced demand for Russian oil from traditional buyers, and caused global oil trade flows to be redirected. The main effects of the

voluntary restrictions and formal embargo were twofold. First, by segmenting the market into buyers and non-buyers of Russian oil it increased the distance Russian oil was required to travel to reach the market. This, in turn, created scarcity in the tanker market that raised the cost of shipping oil by sea for a given distance. Second, the embargo conferred a high degree of bargaining power on India and China, the two remaining large buyers of Russian oil.

The price cap that was added by the G7 countries allows countries not participating in the oil embargo to purchase Russian oil, but makes it more difficult for those countries to import Russian crude valued above the price cap by restricting access to shipping insurance and related financial services. One objective of this price cap was to prevent Russia from benefiting from the surge in the global price of oil that took place in 2022 and to make it more difficult for Russia to finance its war through oil export earnings. The other objective was to prevent the EU oil embargo from sharply reducing the global supply of crude. While the initial price cap of $60 per barrel was intended to be adjusted periodically, as of December 2023, the cap has remained at $60, even as the global price of oil retreated from its high in mid-2022.

A question of obvious policy interest is whether the embargo and/or price cap have been effective, how much they have reduced Russian oil export revenues, and how this outcome was achieved. In this paper, we provide the first quantitative analysis of the economic channels through which these sanctions operate. Our analysis distinguishes between the effects of the import restrictions and the price cap.

Methods:We develop and calibrate a simple model that allows us to analyze and compare data from January 2022 and March 2023. March 2023 is a natural point of comparison as the sanctions on Russian crude and product exports imposed in December 2022 had taken full effect by March. We seek to quantify four effects in sequence. First, the ``supply and demand effects'' reflect changing business cycle conditions in the global market for crude oil as well as exogenous changes in the supply of oil from other producers. Second, given the segmentation of the crude oil market after the invasion of Ukraine and the rerouting of Russian crude exports, we allow a ``transportation cost effect'' to increase the cost of insurance and freight due to more crude oil being shipped by tankers rather than by pipeline, longer shipping routes, and the Black sea port Novorossiysk being close to a war zone. Fourth, the ``market power effect'' allows India and China to exercise partial monopsonistic market power in their respective segmented markets for Russian crude oil.

To this end, we calibrate our model to market data in January 2022 and March 2023, which allows us to recover several unobservables. These include the counterfactual prices and quantities with and without the four effects in question, the social surplus created with and without these effects, their appropriation by various market participants, and a measure of the market power of the major buyers in the Urals and ESPO markets in March 2023. The main assumptions of the model are 1) a competitive and globally integrated market for crude oil before the sanctions; 2) a segmented market for crude oil after the curtailment of Western demand for Russian crude oil; and, 3) (piece-wise) linear demand and supply functions.

Results:We document four key facts. First, the decline in Russian oil export revenues since January 2022 was achieved by reducing the Russian fob price of oil rather than the volume of Russian oil exports. Second, we demonstrate that the price cap was either non-binding or binding but unenforced, and thus cannot explain the Russian price discount. Third, we estimate that roughly half of the Russian price discount arises from having to redirect Russian oil exports to more distant destinations. We find no evidence that the tanker insurance premium arising from the Ukraine war and possibly the G7 price cap has been quantitatively important. Finally, we calibrate a model of global oil supply and demand to demonstrate that the remainder of the Russian price discount can be explained by the increase in Indian and Chinese market power.

Conclusions:Our results are somewhat at odds with common perceptions about the efficacy of the price cap in reducing Russian oil revenues. The price cap policy was heralded by officials at the U.S. Department of the Treasury as ``a new tool of economic statecraft designed to apply economic pressure to an actor who has egregiously violated international law, while preserving the effective functioning of worldwide energy markets and the global economy'' (Rosenberg & Van Nostrand 2023). Conditions under which the price cap would achieve its stated objectives are outlined in Johnson et al. 2023. These include the presence of an effective enforcement regime to ensure compliance by the Western tanker fleet, and the absence of a so-called ``dark fleet'' of tanker ships that can operate at scale outside of the scope of the price cap. We present evidence that, to date, these conditions have not been met. In contrast, our analysis highlights and quantifies two mechanisms by which the embargo on oil imports from Russia would likely have succeeded at reducing Russian oil revenues even as a stand-alone sanctions policy. These are increasing transportation costs (that were borne primarily by Russia) and shifting bargaining power towards India and China, Russia's only remaining potential large-scale buyers, as import restrictions reshuffled global oil trade flows.

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Keywords: Global oil market, Russian Sanctions, Embargo, Price Cap

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[Page: 329]

[Abstract:0470] OP-329 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Fair burden-sharing for climate change mitigation: a cooperative game theoretic approach

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Overview:The Paris Agreement acknowledges that countries bear "common, but differentiated responsibilities" in addressing climate change. A significant challenge in climate change negotiations, therefore, consists in establishing a burden-sharing scheme (or effort-sharing scheme) that all or most governments find fair (Barrett, 1992; Ringius et al., 2002; van den Berg et al., 2020). Two key fairness principles are usually emphasized in allocating mitigation efforts: the Polluter-Pays (or Responsibility) principle, suggesting that countries contributing most to greenhouse gas emissions should contribute more, and the Ability-to-Pay (or Capability) principle, suggesting that economically advantaged countries should contribute more. In this paper, we propose a new methodology grounded in recent advances from cooperative game theory to devise a fair burden-sharing method that integrates both the Polluter Pays principle and the Ability-to-Pay principle.

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Methods:We employ concepts from Transferable Utility (TU) games, a priori unions, and hierarchical structures to formulate a new burden-sharing method. Consider a finite set of countries. Each country is endowed with an environmental cost (e.g., cumulated national greenhouse gas emissions). We introduce a TU-game that assigns to each coalition of countries the sum of their environmental costs. Then, countries are grouped into unions based on development levels, forming a linear hierarchy. This structure reflects the varying developmental stages of the countries, with each country being more developed than those ranked lower and less developed than those ranked higher. Our burden-sharing problem is modeled in a cooperative game fashion, considering various constraints on the player set: the a priori unions and their hierarchical ranking. The class of such models is called the burden-sharing games.

The challenge now is to identify a relevant solution concept to such games, providing a systematic method for sharing the burden of mitigating climate change. Following a two-step procedure similar to Owen (1977), we propose a solution using the Permission value (van den Brink and Gilles, 1996) in the first step (for the game played by unions) and the Shapley value (Shapley, 1953) in the second step (within each union).

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Results:Our normative study introduces axioms, or ethically desirable properties, for solutions of burden-sharing games. We propose three axioms aligned with the Polluter Pays and Ability to Pay principles. The first ensures no obligation for a country to ease the burden of more developed or similarly developed countries. The second advocates equitable contributions among countries at a similar development level to help less developed nations. The third axiom requires equal responsibility from unions of countries towards less developed countries. We demonstrate that our solution uniquely satisfies these three axioms, making it a favorable choice for decision-makers who agree with these principles.

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Conclusions:Article 2.2 of the Paris Agreement states that it “will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities” (UNFCCC, 2015). However, the principles of Responsabity (or Polluter-Pays) and Capability (or Ability-to-Pay) do not necessarily align. Our proposed solution relies on cooperative game theory concepts to integrate both principle in a burden-sharing scheme. In upcoming work, we will perform a numerical application based on world emissions and economic data to compare our solution to other burden-sharing schemes.

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Keywords: climate change mitigation, burden-sharing, effort-sharing, emissions allocations, cooperative game theory, axiomatic approach

[Abstract:0658] OP-330 [Accepted:Oral Presentation] [Energy and the Environment » Policy and Regulation]

Adaptation of small and medium sized enterprises to green transition in Türkiye: SWOT analysis based on expert opinions

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Overview:The adaptation of Small and Medium-sized Enterprises (SMEs) to the green transition is of paramount importance in fostering sustainable and environmentally conscious business practices [1]. While larger corporations often have the resources to navigate the complexities of green transition seamlessly, SMEs encounter distinctive challenges, particularly in the realms of technology, legality, and digitalization. These businesses may grapple with the financial constraints of implementing eco-friendly technologies and complying with evolving environmental regulations. Additionally, the technical expertise required for adopting green practices can be a hurdle for SMEs with limited access to specialized knowledge [2]. Overcoming these challenges necessitates targeted support, such as government incentives, capacity-building initiatives, and accessible digital tools, ensuring that SMEs not only survive but thrive in an increasingly eco-conscious business landscape. Addressing the unique difficulties faced by SMEs in the green transition is crucial for fostering widespread sustainability and promoting a resilient, environmentally responsible business ecosystem. This issue is even more critical in the context of Türkiye, where according to the definition used by KOSGEB (Small and Medium Enterprises Development Organization of Turkey), the share of SMEs (Small and Medium-sized Enterprises) in exports is 35%, while according to the employment-based definition used by the OECD (Organization for Economic Co-operation and Development), the contribution of SMEs to exports is around 60%. Thus, green transition, and especially Carbon Border Adjustment Mechanism, bears significant risks to Türkiye's SMEs and providing training and incentive mechanisms that would speed up this adaptation process is highly critical.
To that end, a joint effort by KOSGEB, which is a state office, and Izmir University of Economics was initiated to develop specialized programs addressing the technical, legal, and digital challenges faced by SMEs in the context of green transition. These programs aim to equip SMEs with the necessary knowledge and resources, fostering a smoother integration into environmentally sustainable practices and mitigating potential adverse effects on their competitiveness in the global market. The first part of this program is to develop a tool that would not only measure the readiness of Turkish SMEs to green transition, but also help them compare their status against companies of similar nature in an anonymous manner.
Methods:The first step was the preparation of a set questions that would test the readiness level of Turkish SMEs to green transition in terms of economic, environmental, governance, and social sustainability themes. The indicators within each theme can be found below:
Economic sustainability indicators:
ECS1: Access to Green Finance
ECS 2: Sustainability Budget
ECS 3: Innovation Policy
ECS 4: Digitalization
ECS 5: Risks/Risk Management Arising from Green Transformation

Environmental sustainability indicators:
ENS1: Footprint Measurements
ENS 2: Energy Consumption
ENS 3: Water Consumption
ENS 4: Waste Management / Industrial Symbiosis
ENS 5: Recycled Resource Utilization

Social sustainability indicators:
SS1: Employee Satisfaction / Employee Training
SS2: Employee Diversity
SS3: Occupational Health and Safety
SS4: Social Responsibility Projects
SS5: Consumer and Customer Satisfaction

Governance sustainability indicators:
GS1: Transparent Information Sharing with Stakeholders
GS2: Supply Chain Management
GS3: Sustainability Strategy
GS4: Sustainability Awareness

GS5: Internal / External Auditing
GS6: Non-commercial Collaborations
Each indicator will be assessed via a Likert scale approach from 1 to 5.

The second step is prioritizing the themes and indicators above by using an expert opinion analysis via an online survey. The survey remained active for a period of one month from Dec. 15, 2023 to Jan. 15, 2024. The results of this survey can be found in the next section.

Last step will be the development of an online tool that will use a multi-criteria decision making approach based on TOPSIS method [3] to calculate an overall score for each company and enable them to compare their score against other companies that use the same tool. This work is expected to be completed by early summer of 2024.
Results:As of Feb 2nd, 2024, an esteemed group of experts filled out the survey. More than 50% of the participants have doctorate degrees. 40% of them are academics, 33% work at governmental organizations and the remaining are private sector employees. Based on the preliminary results of the survey, economic sustainability indicators are considered the most important, with a weight of 0.327, followed in close proximity by environmental sustainability indicators with a weight of 0.313. Social and governance sustainability indicators have weights of 0.207 and 0.153, respectively. As far as each theme is concerned, the most important and the least important indicators turned out to be as follows:
Economic sustainability indicators:
Most important indicator: ECS 2 (weight score: 0.249)
Least important indicator: ECS 5 (weight score: 0.160)

Environmental sustainability indicators:
Most important indicator: ENS 2 (weight score: 0.276)
Least important indicator: ENS 5 (weight score: 0.129)

Social sustainability indicators:
Most important indicator: SS 1 (weight score: 0.262)
Least important indicator: SS 4 (weight score: 0.124)

Governance sustainability indicators:
Most important indicator: GS 4 (weight score: 0.229)
Least important indicator: GS 6 (weight score: 0.092)
Conclusions:The preliminary survey results, with input from experts representing diverse sectors, underscore the significance of economic sustainability indicators, especially in the context of green transition readiness for Turkish SMEs. The prioritization analysis reveals ECS 2 (Sustainability Budget) as the most crucial economic indicator. Furthermore, environmental sustainability, social sustainability, and governance sustainability exhibit distinct weightings, emphasizing the need for a holistic approach. The ongoing expert survey and forthcoming development of the online tool using the TOPSIS method are anticipated to provide valuable insights for SMEs aiming to enhance their green transition preparedness, fostering a sustainable and competitive business landscape in Türkiye. Future work involves refining the tool, incorporating additional expert opinions, and disseminating its application for wider industry impact.
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Keywords: green transition, SMEs, policy development, readiness analysis

[Abstract:0462] OP-331 [Accepted:Oral Presentation] [Energy and the Environment » Environmental Markets and Taxes]

On the implications of carbon removal & emission trading system designs

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Overview:While carbon pricing for emission compensation is mature in many countries, strategies for carbon removals are still in their infancy. Then again, there exists a clear need for negative emission pricing to efficiently comply with climate targets. Many authorities apply market-based approaches to price emissions, i.e. cap-and-trade or Emission Trading Systems (ETS). These price carbon emissions by turning it into a scarce resource, that is, by imposing an emission limit that typically decreases over time. As this cap approaches zero, such carbon markets may face liquidity issues and hard-to-abate industries may face serious difficulties. Integrating negative emissions into an ETS can provide a solution by (i) injecting liquidity into the market and (ii) allowing hard-to-abate processes to offset their emissions with removals.

There currently exist different approaches in terms of integrating emission trading and removal frameworks. This also follows from Tab. I that includes regions with an existing ETS and (proposed) removal frameworks. We distinguish direct coupling, disconnected markets and hybrid systems. Different scholars have been discussing similar interactions between ETS and carbon removal market mechanisms.Theuer et al. proposed four different levels of integration ranging from disconnected removal and allowance markets to one fully connected system. Fully integrated markets tend to reduce allowance prices because the allowance supply increases through removal offsets. This could, however, cause high-carbon lock-ins and potentially less ambitious reduction efforts. Entirely disconnected markets – potentially financed by allowance revenues – do not face this lock-in problem albeit with a risk of severe liquidity issues [1]. Intermediate systems, e.g. a certain number of carbon offset credits can be used to create a single emission allowance, have been proposed by M ¨ollersten and Zetterberg. These may provide a trade-off between the benefits and drawbacks mentioned above, and could additionally be corrected for non-permanent removals as discussed by Edenhofer et al. [3].

Currently, the discussion on integrating carbon removals in cap-and-trade systems has been mostly qualitative. We aim to contribute by providing an analytical assessment via a market equilibrium framework. In particular, this research aims to investigate the effect of different levels of ETS-removal integration on the level of emission abatement, total emissions, carbon prices, and welfare implications.

Methods:We use a stylistic model that allows analysing the effect of different designs of ETS and removal frameworks on the functioning and outcomes of these carbon markets. That is, we develop a model that mimics market outcomes based on the different integration options. This yields a mixed complementarity problem which we solve with the Alternating Direction Method of Multipliers (ADMM) approach following [6, 7]. The model set-up is detailed in Fig. 1 and comprises two main actors. First, a hydrocarbon process industry (HPI) can invest and produce in a conventional (fossil) way, apply CCS or invest in a bio-based production installation whether or not equipped with BioCCS. The latter option allows the generation of removal credits.

Second, an emission fringe (EMF) aims to optimise its emission costs through abatement and the purchase of emission allowances or removal certificates (depending on the design). Different cases then reflect different policy options in terms of integrating carbon emission and removal markets.

Those cases comprise (i) no removal compensation (base case), (ii) fully disconnected markets, (iii) fully interconnected markets, (iv) an allowance market with a cap adjustment based on removal certificates entering the market and (v) an allowance market that allowance the inflow of removal credits for which one allowance certificate should correspond to x removal credits (with x larger than one).

Results:The results allow us to describe the price trajectory of the emission allowance price, a possible removal offset price, the amount of total net emissions and the investments by the hydrocarbon process industry. Fig. 2 shows the emission allowances (EA) both bought and banked by the HPI and EMF over time as well as the resulting allowance price for the fully integrated market case. This combined market case allows selling removal credits from BioCCS as emission allowances, stimulating investments in BioCCS and resulting in a significant EA price drop as can be seen in Fig. 2. This leads to more emissions and less abatement efforts on the EMF side.

The results of the other modelled cases indicate different levels of emissions abated, net emissions, ETS price trajectories and different investments by the hydrocarbon process industry. A policymaker might like to consider related impacts such as changing state revenues and expenses, deviations from net or negative emission targets, environmental integrity concerns and ensuring fair competition between BioCCS and biomass utilisation.

Conclusions:This study analytically shows that the design of a potential removal framework could have important implications on CCS-related investments as well as on resulting emissions and abatement efforts. This results in different levels of net emissions and emission allowance price trajectories. Ultimately, deviations from the social optimal can be expected as well as additional influences on public spending, biomass competition and environmental integrity.

Hereafter, we try to better qualify and quantify the pros and cons of the different carbon pricing mechanisms. An assessment of the optimality of the different removal pricing schemes will by calculating the total production and abatement cost in relation to the total emissions abated. Those insights can help policymakers in deciding on appropriate carbon removal frameworks.

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Keywords: Carbon Capture with Storage (CCS), Carbon removal certification framework, Emission Trading System (ETS), Economic evaluation, Market equilibrium modelling

Fig. 1: Illustration of the emission and removal trading framework connecting the 2 main actors.

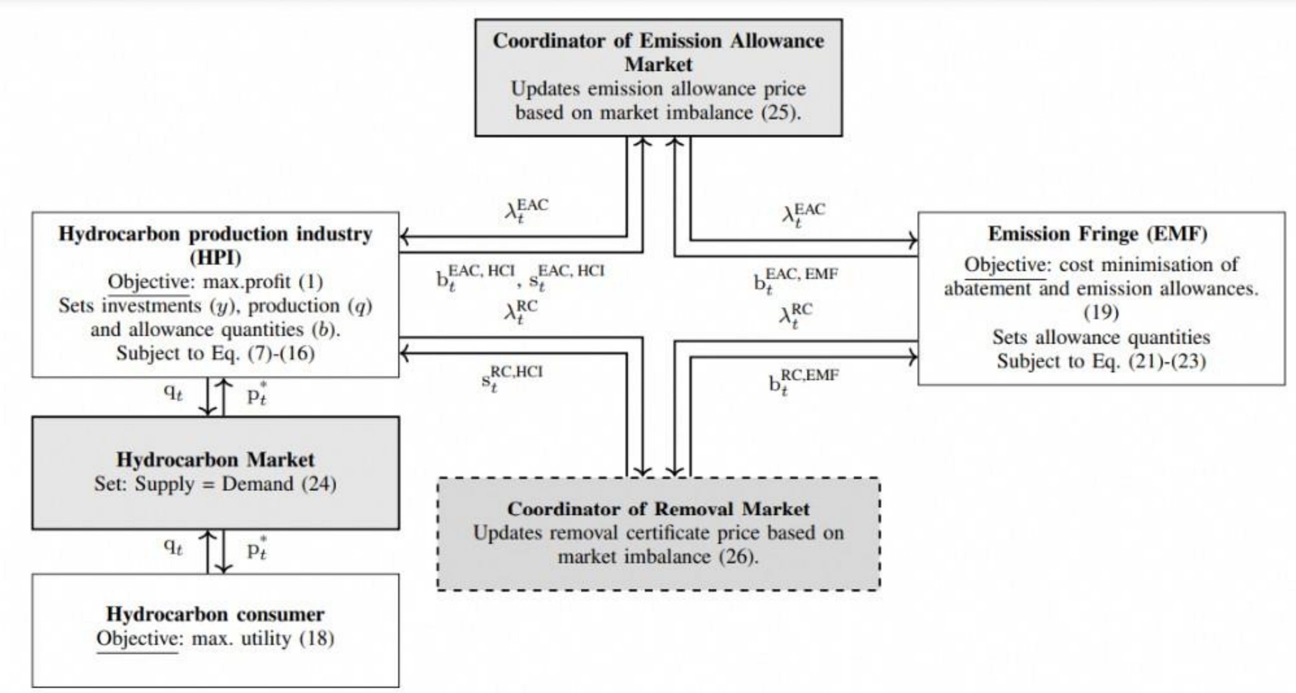

Fig. 2: Amount of emission allowances (EA) bought and sold by the market players.

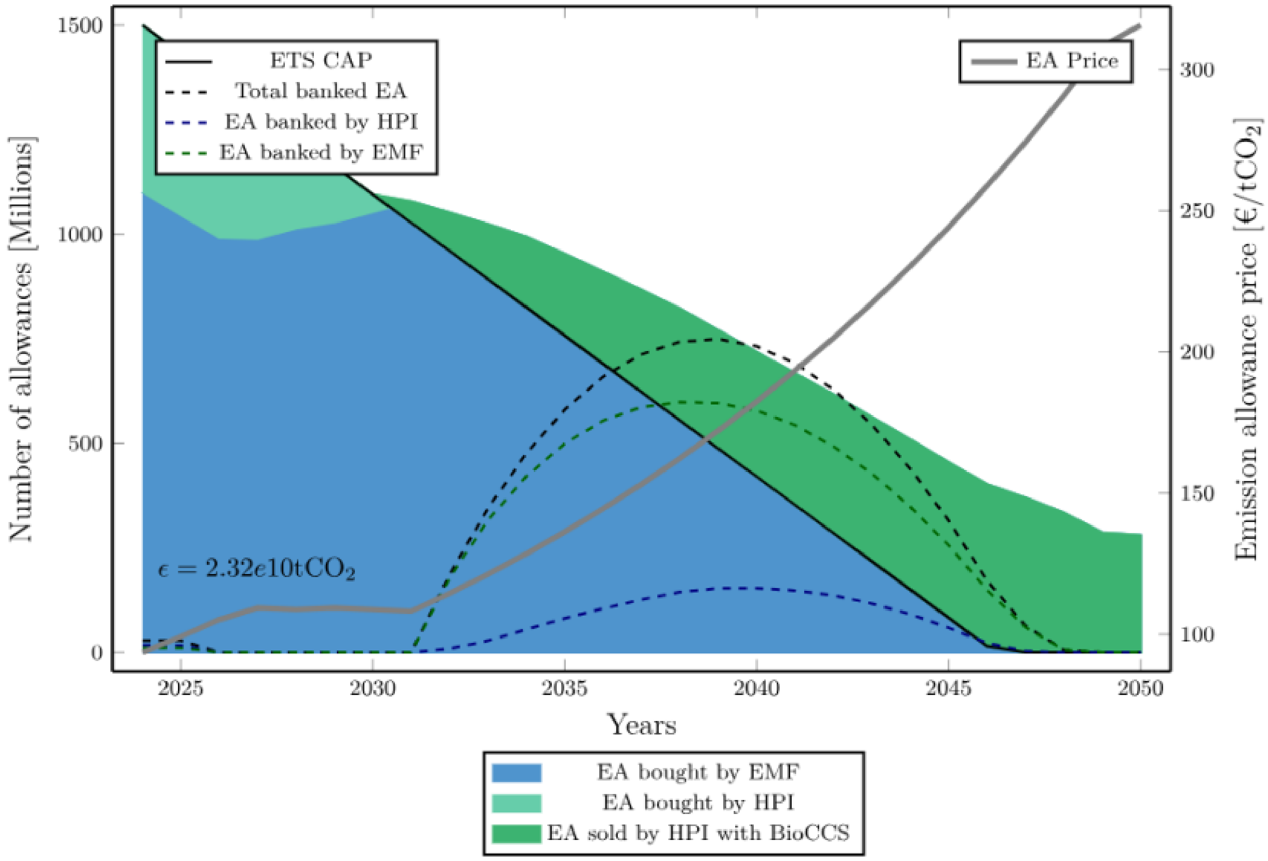

TABLE I: Carbon removal strategies of countries with an implemented emission trading scheme [4, 5]

Country/ Region	Scope ETS sectors	Direct linkage ETS - removals	Seperate removal frameworks
Canada - Québec	77% coverage: transport, buildings, industry, power	/	Voluntary offset credit system for removals and GHG reductions: DACCS, nature-based solutions (in discussion)
European Union	EU ETS I - 38% emission coverage: power, energy-intensive industry, aviation, maritime. EU ETS II - : buildings, road transport and smaller industries.	(in discussion)	Voluntary carbon credit market for nature-based and technology-based solutions (in progress)
Japan	+-20% emission coverage: buildings, industry	/	Voluntary carbon credit market: natural-based solution: credits sold to companies, local governments (implemented & in review)
New Zealand	49% emission coverage: Power, industry, buildings, transport, domestic aviation, waste, forestry	Biochar (implemented & in review)	/
UK	25% emission coverage: domestic aviation, industry, power	Engineering & nature-based (in discussion)	Negative emission CfD as additional support: BECCS, DACCS (in discussion)
USA - California	75% coverage: power, industry, buildings, transport	/	- Regulated carbon credit market: nature and technology based. Obligation to emitters to offset certain percentage of emissions with removals additional to cap-and-trade program. (proposed) - Voluntary carbon credit market (agreed, in implementation) - Tax credit for DACCS & BECCS via inflation reduction act (implemented)
USA-Washington	70% coverage: power, industry, buildings, transport	DACCS, BECCS (technology-based) with target: at least 5% of ETS allowances from CDR (in implementation)	- Tax credit for DACCS & BECCS via inflation reduction act (implemented)

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A literature review of economic incentives to upscale Carbon Dioxide Removal

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Overview:The Paris Agreement signed at COP21 set the target of limiting global warming lower than 2°C by 2100. This implies reaching net-zero CO2 and greenhouse gas emissions at global and national levels. Reducing greenhouse gas emissions is the first lever to activate, but Carbon Dioxide Removal (CDR) will also be required to ensure the world meets its objectives (IPCC, 2022). CDR methods include technologies and processes that remove CO2 from the atmosphere and durably store it.

Despite the urgency of addressing climate change, the development of commercial CDR has been slow, prompting the need for a closer examination of the constraints on market development and CDR investment (Bednar et al., 2021, 2019; Honegger et al., 2021; Tamme and Beck, 2021). Furthermore, the regulatory tools implemented to control greenhouse gas emissions, such as carbon taxes (Pigou, 1920), or emission quota systems (Coase, 1960; Convery, 2003; Ellerman et al., 2010) are not yet adapted to the integration of CDR (Kalkuhl et al., 2022; Rickels et al., 2022, 2021).

This indicates a gap in the market, from private and public initiatives, that needs to be addressed to facilitate the development and implementation of CDR technologies. As the world strives to meet ambitious climate goals, it becomes crucial to adapt markets and policies to create new mechanisms that can effectively support and incentivize the deployment of Carbon Dioxide Removal methods. The aim of this paper is to identify proposed and/or implemented economic incentives for the upscaling of CDR. The main issues identified is the unclear and/or unstable private and public economic incentive initiatives, and the links between them. This paper provides an innovative framework to improve clarity and transparency for these required new incentives schemes.

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Methods:We reviewed the literature to map the propositions for economic incentives for the upscaling of CDR. Once we identified the papers, we classified the economic incentives by characterizing how each proposition addresses CDR market failures. These market failures, for example, include externalities and the heterogeneity of CDR methods. Additionally, emission quota systems do not include CDR (Kalkuhl et al., 2022; Rickels et al., 2022, 2021), while voluntary carbon markets considers emission reduction and CDR as similar products (Hickey et al., 2023).

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Results:The main types of CDR market failures have been identified and associated with propositions in the literature. This classification provides a novel framework to improve clarity and transparency for these required new incentives schemes for CDR. It sheds a light on the objectives achievable through each type of economic incentive for the deployment of CDR along with drawbacks they face.

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Conclusions:The classification outlined limitations and gaps in these propositions for future work, including elements on potential additional incentives and objectives missing incentives to scale up CDR.

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Keywords: Carbon Dioxide Removal, negative emissions, economic incentives, market failure, carbon markets

[Abstract:0713] OP-333 [Accepted:Oral Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

Assessing the effectiveness of the carbon border adjustment mechanism for reducing emissions in different product categories and the role of energy transition in emission reduction

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Overview:The growing urgency of climate change mitigation has spurred international efforts to reduce greenhouse gas (GHG) emissions. The Carbon Border Adjustment Mechanism (CBAM), which began to be implemented by the European Union (EU) in 2023, is a key policy tool aimed at addressing the issue of carbon leakage. CBAM functions by imposing a carbon price on imported goods from countries with less stringent climate policies. While CBAM aims to incentivize decarbonization efforts in exporting countries and level the playing field for EU producers, its effectiveness in achieving real-world emission reductions remains a topic of ongoing debate. This study investigates the potential of CBAM to promote emission reductions across different product categories. Our analysis focuses on five key sectors with the selected products written in parentheses: machinery (trailer), textiles (cotton fabric), packaged food product (fruit juice), plastics (trash bag), and personal care products (shampoo). By examining the emission profiles of these products and the role of embodied energy throughout their life cycles, we aim to shed light on the potential effectiveness of CBAM for each category.
The research presented here contributes to the ongoing discussion on CBAM's role in achieving broader climate goals. By delving into specific product categories, we aim to move beyond a generalized understanding of CBAM's impact and provide a more nuanced perspective on its potential for driving decarbonization across various industries.
Methods:This study employs a life cycle assessment (LCA) methodology to evaluate the environmental impact of the chosen product categories. LCA is a standardized approach that quantifies the environmental burdens associated with a product or service throughout its entire life cycle, from "cradle to grave" (extraction of raw materials to final disposal). This holistic approach allows us to identify the critical stages within each product's life cycle that contribute the most to its overall environmental footprint, including GHG emissions.
Specifically, this study utilizes the "cradle-to-gate" LCA approach, focusing on the environmental impacts from raw material extraction and processing up to the point of factory gate. This focus goes beyond the scope of CBAM by including Scope 3 emissions, whereas CBAM targets emissions associated mainly with the production stage (Scope 1 and Scope 2 emissions). All the data were obtained from real-life manufacturing companies located in Adana,Türkiye..
We utilize the CML 2001 impact assessment method within the LCA framework. CML 2001 is a widely recognized method that assesses environmental impacts across various categories, including climate change, acidification, and human toxicity potential. By applying this method, we can translate the quantified GHG emissions into a broader environmental context. The Ecoinvent 3.0 database serves as this study's primary source of life cycle inventory data. Ecoinvent is a comprehensive life cycle inventory database that provides data on the environmental impacts of various processes and materials. By utilizing it, we ensure consistency and transparency in our LCA calculations.
The analysis further investigates the share of energy-related emissions within the total emission footprint of each product category. This allows us to understand the relative contribution of production processes (primarily targeted by CBAM) to overall emissions. By identifying energy-intensive processes within each product category, we can assess the potential impact of CBAM on the target emissions and, subsequently, its overall effectiveness in promoting decarbonization.
Results:As shown in Table 1 below, Scope 3 emissions dominate all products, with an average share of 86.2%. Scope 1 emissions merely contribute to the overall emissions with an average share of 1.0%. This analysis shows that, at least for the selected product categories, ignoring Scope 3 emissions fails to effectively reduce life-cycle emissions.
Table 1. Distribution of emissions for different product category types

Product Type	Scope 1	Scope 2	Scope 3
Shampoo	0.6%	2.4%	97.0%
Fruit Juice	0.3%	3.8%	95.9%
Trash Bag	0.1%	23.6%	76.3%
Cotton fabric	14.2%	18.1%	67.7%
Trailer	1.0%	4.9%	94.1%

Table 2 below presents the results of a scenario analysis in which all the electricity required for the manufacturing processes is obtained from photovoltaic panels.

Table 2. Distribution of emissions for different product categories with all the electricity generation from photovoltaic panels.

Product Type	Scope 1	Scope 2	Scope 3
Shampoo	0.6%	0.3%	99.1%
Fruit Juice	0.3%	0.8%	98.9%
Trash Bag	0.1%	3.6%	96.3%
Cotton fabric	17.3%	0.9%	81.8%
Trailer	1.0%	0.6%	98.4%

As the Scope 2 emissions did not have a high share, replacing the grid electricity with photovoltaic electricity only seems to be a reasonable solution in the case of plastics and cotton fabric. Under this scenario, the average shares of Scope 1, 2, and 3 emissions are 3.9%, 1.2%, and 94.9%, respectively.

Conclusions:Our analysis shows that Scope 3 emissions should not be ignored if an effective reduction in global GHG emissions is desired. Having said that, we acknowledge that measuring and managing these emissions is easier said than done. Measuring Scope 3 emissions, encompassing a company's entire value chain, presents significant challenges. Data availability can be difficult, especially when relying on suppliers and partners with complex supply networks. The lack of a single standardized methodology can lead to inconsistencies and inaccuracies [1]. Additionally, allocating emissions fairly across products or services can be subjective and complex. Finally, the resource intensity of data collection and analysis can strain company resources. Companies can improve Scope 3 measurement by fostering data transparency through collaboration with stakeholders, utilizing industry-specific databases and life cycle assessment tools for better estimates, setting clear boundaries for their area of responsibility, and exploring technological solutions for streamlined data management. By overcoming these challenges, companies gain a more comprehensive view of their environmental footprint, allowing them to make informed decisions for a sustainable future.

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Keywords: carbon border adjustment mechanism, GHG emissions, life cycle assessment, scope 1-2-3

[Abstract:0442] OP-334 [Accepted:Oral Presentation] [Electricity » Markets and Prices]

European carbon prices: what impact on electricity prices in France?

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Overview:Standards, taxes and markets: economists put forward a variety of instruments to fight against climate warming. In 1997, the Kyoto Protocol institutionalized market instruments to tackle climate change. A market for emissions permits would offer several advantages. It would provide a price signal to economic agents, which would be the best way to ensure effective decentralized decision-making for the energy transition. In a quantitatively constrained system of quotas, it would

also enable pollution control efforts to be shared out, minimizing the collective costs of reducing emissions

In 2005, the European Commission created the first binding carbon market. The European Emission Trading System (EU-ETS) is a market for tradable emissions permits that sets national caps on CO_2 emissions, divided between different installations. For each, carbon quota holders must arbitrate between investing in clean production modes, buying quotas on the EU ETS to ensure compliance, or holding them for a later period.

From the outset, the power generation sector received the majority of allocations. This production emits a significant amount of CO_2, which varies according to the quantity produced and the fuel used. We also note that electricity prices now include European capacities, which are part of the interconnected grid. In this context, European prices are still largely dependent on the price of fossil fuels, which play a major role in national power mixes, but also on the price of carbon.

French electricity prices are linked to the European electricity market, and therefore to the electricity mixes of the other countries in the zone. This is why, despite a highly decarbonized energy mix, the question of its potential sensitivity to the EU ETS price signal is open. With European interconnection, the price of allowances on the EU-ETS market could be reflected in the price of French electricity, and in its expectations on futures markets. If this were the case, then the highly institutional nature of the electricity and carbon markets would have enabled price formation, capable of supporting the decarbonization of European electricity mixes, wherever the electrons are consumed.

Methods:In order to address the importance of the carbon price in determining the wholesale price of electricity in France, this proposal analyzes the impact of the carbon price on the instantaneous and anticipated price of electricity in France, in relation to various reforms of the EU-ETS market in a given economic context. The period from 1/01/2017 to 12/31/2022 we use combines i) a sharp increase in the price of French electricity and European carbon from 2021 onwards ii) the introduction of the Market Stability Reserve in 2019 which, by significantly reducing the supply of allowances, has led to an increase in their price iii) a rapid and unprecedented increase in the price of gas due to Russia's invasion of Ukraine iv) an atypical period of electricity imports for France from European countries. The end of the reference period marks the turnaround in gas prices and a return to normal for electricity production in France.

We use daily data on spot electricity prices in France, electricity production in France from different technologies (hydro, intermittent renewables (wind and solar),...) and French electricity demand. To take expectations into account, we will use market data on electricity futures contracts in Germany, the TTF gas price and the price of emissions permits (EU ETS).

Our empirical model is written as follows:

$$(elec.France)_t = \alpha\_0 + \alpha\_1 Carbon_t + \alpha\_2 Gas_t + \alpha\_3 Hydrau_t + \alpha\_4 Nuclear + \alpha\_5 Wind + \alpha\_6 Solar_t + \alpha\_7\ elec.\ Germany_t + elec\ Demand\ France + \varepsilon_t \quad (1)$$

In order to test the dynamics of the relationships that may exist between our variable of interest (spot price of electricity in France) and the other variables mentioned, we use cointegration theory and VAR modeling.

Results:Based on a brief overview of the literature on the effects of carbon prices on electricity prices (I) and a review of the various EU ETS reforms to analyze the evolution of their links (II), we suggest that the literature struggles to specify the effects of European carbon prices on electricity prices. These reviews, however, enables us to select an appropriate approach for modeling the impact of carbon prices on electricity prices, as well as well as on futures (III). In the context studied, the influence of the carbon price on the electricity price in France constitutes our main result (IV): with the implementation of the stability reserve from 2019, the increase in the permits prices caused a priority call for gas power plants over coal power plants in the merit order curve. As a result, we saw a much higher equilibrium price of electricity. This upward impact of the TTF gas price on the spot price of electricity was exacerbated following Russia's invasion of Ukraine in February 2022.

Conclusions:As long as gas remains the equilibrium energy resource in the formation of the price of electricity, the price of carbon seems to have become a suitable vehicle for decarbonizing electricity. However, it is crucial to acknowledge that substantial alterations in the energy price dynamics, particularly those affecting the competitiveness of gas relative to alternatives like coal, could diminish the role of the carbon price in driving effective decarbonization strategies

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Keywords: Electricity price, Carbon Price, Pass-trough

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[Abstract:0055] OP-335 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Energy Security]

Challenges and Opportunities in Turkey's Renewable Energy Sector: A Comprehensive Overview

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Overview:This summary provides a comprehensive analysis of the potential and difficulties influencing Turkey's renewable energy environment. In the context of worldwide endeavors towards sustainable development, Turkey finds itself at a pivotal point in its quest for a more varied and cleaner energy mix. The review explores Turkey's present situation with regard to renewable energy, highlighting the country's distinct geographic advantages as well as its existing governmental frameworks. The approach entails examining the obstacles impeding the extensive integration of renewable energy sources and investigating the promising prospects that accompany this shift. Important discoveries highlight the difficulties associated with grid integration, the intricacies of regulations, and the financial limitations, but they also highlight the enormous potential for the development of jobs, energy independence, and environmental stewardship. The results underline the significance of a strong policy framework and purposeful public-private partnership, using lessons from successful foreign models. The advantages to society and the environment are discussed, with a focus on how important it is to be flexible in responding to changing market conditions. The abstract attempts to provide a comprehensive viewpoint on the various obstacles and exciting prospects facing Turkey's renewable energy path, in order to provide significant insights to the conversation.
Methods:The comprehensive overview of Challenges and Opportunities in Turkey's Renewable Energy Sector employed a multifaceted research approach. Primary data was gathered through an extensive review of governmental reports, industry publications, and academic research, providing a comprehensive understanding of the current state of the renewable energy landscape in Turkey. Collaborative efforts were undertaken in consultation with subject matter experts, stakeholders, and relevant institutions to enhance the depth and accuracy of the analysis. This collaborative approach ensured a holistic perspective and enriched the qualitative insights.
Results:A detailed grasp of the present dynamics within the Turkish renewable energy environment is anticipated to be revealed by the thorough assessment of Challenges and Opportunities in Turkey's Renewable Energy Sector. The study attempts to identify significant obstacles and promising prospects in the business by the careful examination of original data obtained from government papers, industry publications, and scholarly research. It is envisaged that the cooperative efforts with experts and stakeholders would produce qualitative insights, offering a comprehensive viewpoint. Data-driven findings will be developed with the use of sophisticated modeling and analytical tools, with important ramifications for researchers, industry practitioners, and policymakers. The findings are intended to assist in making strategic decisions and promote long-

term progress in Turkey's renewable energy sector.
Conclusions:The thorough assessment of Opportunities and Challenges in Turkey's Renewable Energy Sector, which was produced through a thorough examination of a variety of data sources, concludes by providing a nuanced picture of the current situation. The results have the potential to clarify the complex issues that the industry faces, such as legal restrictions and technology limitations. In addition, the identification of opportunities—whether in the form of technology advancements or governmental interventions—offers stakeholders a strategic road map for maximizing the nation's potential for renewable energy.

Furthermore, including experts, stakeholders, and institutions in a collaborative approach not only adds a diversity of viewpoints to the research but also cultivates a feeling of shared responsibility for the sustainable growth of Turkey's energy sector. The anticipated outcomes of this partnership are anticipated to provide new and practical solutions to successfully address the difficulties that have been identified.

The study's findings are intended to act as a catalyst for educated decision-making, promoting positive change and creating an atmosphere that will support the expansion of renewable energy sources as Turkey sets off on its path to a more robust and sustainable energy future. The report is positioned as a significant resource for policymakers, industry leaders, and scholars interested in the sustainable growth of Turkey's energy sector due to its comprehensive approach and practical suggestions.

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7-

Keywords: Turkey, Energy Security, 2030, Renewable, energy transition, climate change

AuthorToEditor: Dr. Umud Shokri is a distinguished authority in energy strategy and foreign policy, boasting a Ph.D. in International Relations that underpins his unparalleled expertise in global energy dynamics, climate change, clean energy technologies, energy security, and complex geopolitics. With over two decades of experience in energy security and Geopolitical Risk Intelligence, he has contributed significantly to international relations. As the author of "US Energy Diplomacy in the Caspian Sea Basin: Changing Trends Since 2001," his contributions are substantial. Dr. Shokri's extensive knowledge encompasses diverse areas. He conducts pioneering research on the energy transition landscape, examining policies, technologies, and market dynamics driving the shift toward clean and renewable energy sources. Additionally, he focuses on the role of critical minerals in renewable energy technologies and the associated geopolitics and supply chain challenges. At George Mason University, he serves as a senior visiting fellow, sharing his wisdom with future energy and foreign policy leaders. Driven by his passion for renewable energy, he advocates for its transformative potential in addressing climate change. His research also extends to electric vehicles (EVs), where he explores policies, infrastructure, and market dynamics crucial for global EV adoption and sustainable transportation. Beyond energy and climate, Dr. Shokri delves into geopolitics. He analyzes Iranian regional and foreign policy, trade, security, military relations with neighbors, and regional rivalries in the Middle East, offering valuable insights into the impacts of these rivalries across the region.

[Abstract:0072] OP-336 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Geopolitics of Energy]

The Geopolitics of Oil Disruptions: An Industrial Level Analysis of Oil Sanctions on Global Oil Markets

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Overview: Falling somewhere between a diplomatic slap on the wrist and a full-scale use of militarized force, the threat and imposition of economic sanctions have been increasingly employed to coerce the targeted state to change contested policy. Deepening globalization and cross-border economic relations following the end of the Cold War have increasingly enabled developed countries the chance to leverage their economic prowess in foreign policy, either via bilateral relations, multilateral engagements, or through international organizations such as the UN.
Disrupting energy exports of targeted states, oil in particular, has been a recurring theme in over the past quarter of a century of sanctions. The threat and imposition of oil export sanctions have frequently been levied against major producers such as Iran, Iraq, Libya, Venezuela, and Russia, making sanctions a keystone in global geopolitics of energy. Recent geopolitical tensions on the Venezuela – Guyana border and northern Iraq further suggest controlling flows of international oil continue to be a major as a means of enacting foreign policy.
Despite the salience sanctions carry in global oil markets, our knowledge on how sanctions specifically affect oil markets remains limited. While some excellent studies frame the relationship between sanctions and oil price (e.g., Omar and Lambe 2022), or the spillover effects between oil sanctions and macroeconomic indicators (e.g., Hatipoglu et al. 2023), few studies have presented empirical evidence on how sanctions on a specific oil supplier can affect oil industries in its respective customers and across the global market at large. This is an important part of the equation as an industry level analysis of customer responses is essential in understanding how global oil markets respond to a sanction on aggregate, and, in turn, whether the response will coerce the sanctioned country to change contested policy.
Methods: By identifying the various occasions of sanction enactments on the five exporters mentioned earlier, between 1970 to 2022, we investigate the impact downstream of the supply and value chains of the oil industry using the KAPSARC Oil Value-Chain Analyzer (KOVA) model. KOVA is a global oil value-chain model that represents flows of global oil and refined products from production to consumption (Umeozor, 2023). The model represents the dynamics of global crude oil flows and refinery operations using a machine learning approach which is integrated with a global optimization model. Impact of sanctions are captured through disruptions of flows to established product supply destinations, refinery retrofits to accommodate emergent crude flow patterns, constraints on high demand refined oil products supplies, and impact on downstream refinery margin performance including the potential transfer of margin losses to final product consumers. KOVA poses the effects of sanctions as an optimization problem considering two likely objective criteria of least cost evolution of the oil products supply and refining landscape post sanction imposition or refining margin maximization problem on net cash cost basis. Supply and value chain changes following sanction imposition such as limited product supply availability from a sanctioned party to other non-aligned countries are parameterized in the modeling constraints.
Results: Our analyses of oil products sanctions on Russia, Iran and Venezuela indicate that negative global supply shocks on in demand products such as gasoline and diesel are palpable. We also observe that, while sanctions drive significant margin losses in most aligned (pro western world) countries, non-aligned countries which now receive the sanctioned supplies experience over 25% increase in refined products margins. There is also evidence that these losses or gains are transferred to some extent to the final consumers, albeit not proportionately.
Conclusions: This paper contributes to the literature by:
1. Developing the first-in-its-kind global refinery programming model to assess how specific shocks to oil supply reverberates through global oil value chains.
2. In relation, differentiating how sanctions on various oil producers will affect specific consumer states and regions.

3. And in doing so, developing a wholistic/global perspective in understanding how global oil markets respond to specific oil sanctions.
4. Moving beyond energy economics, this paper also presents a novel contribution to the current scholarly debate on unintended consequences of economic sanctions. It does so by presenting a solid causal framework of how third parties can react to sanctions by modelling the actions of players at a granular (industry/firm/consumer) level, rather than looking at countries as amalgamated players.
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Keywords: Oil markets, Sanctions, Economics, Spillovers, Consumers, Investments

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[Abstract:0279] OP-337 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Energy Security]

Supply chain risks of critical metals: sources and propagation

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Overview:Critical metals play irreplaceable and significant roles in new energy industries—from solar photovoltaic and wind turbines to electric vehicles and battery storage (Zhai et al., 2019; IEA, 2021a). With the massive and increasing deployment of low-carbon technologies for a net zero emission society, demands for these metals have been increasing significantly and the world is moving from fuel-intensive systems to more material-intensive systems (IEA, 2021b). Nonetheless, the geographically concentrated supply makes reliable access to critical metals more of a strategic concern. In addition, industries of critical metals are organized through the global supply chain. The disrupted global supply chain since 2020 by the outbreak of COVID-19 and a series of geopolitical crises highlight the importance of studying the supply chain risks of critical metals. However, we currently lack a picture of the progress on the supply chain risks of critical metals. The absence of such study impedes our comprehensive understanding of supply chain resilience of critical metals, which in turn could possibly mislead the policy-decision makings for clean energy transitions. This paper, different from others, focuses on the supply chain risk sources and propagation of the risks, thus making a contribution to building a resilient supply chain of critical metals.
Methods:1. Define the supply chain of critical metals
2. Construct the framework of supply chain risks
3. Build trade network model
4. Establish propagation model
Results:1. The single-layer network analysis of cobalt shows that (1) D. R. Congo, Mainland of China, United Kingdom, and Germany have systemic impacts in the global cobalt trade network, and their collapses will reach to more than 20 economies in the scenario of r = 8.
2. The multi-layer network analysis of cobalt industrial chain shows that: (1) trade complexity in upstream network is the lowest compared with middle-stream network and downstream network; (2) Mainland of China, USA, Germany, United Kingdom, and Spain are the systemic importance nodes for the global cobalt industry chain.
Conclusions:To better address the supply chain challenges of critical metals in the era of frequent disturbance, this article investigates the sources and propagation of supply chain risks of critical

metals, using cobalt as an example. Based on the results, we conclude that there are more to be done on the supply chain risks from a holistic perspective. The new potential framework to assess the supply chain risks should not only focus on the specific risks in the upstream, middle-stream, and downstream but also on general risks along the whole supply chain. Related to this conclusion, to respond effectively to the supply chain challenges, besides the short-term measures like stockpiling and price hedging, policy makers should work on the long-term approaches like recycling and diversification strategy that focus on the supply chain diversification rather than diversification of one stage.

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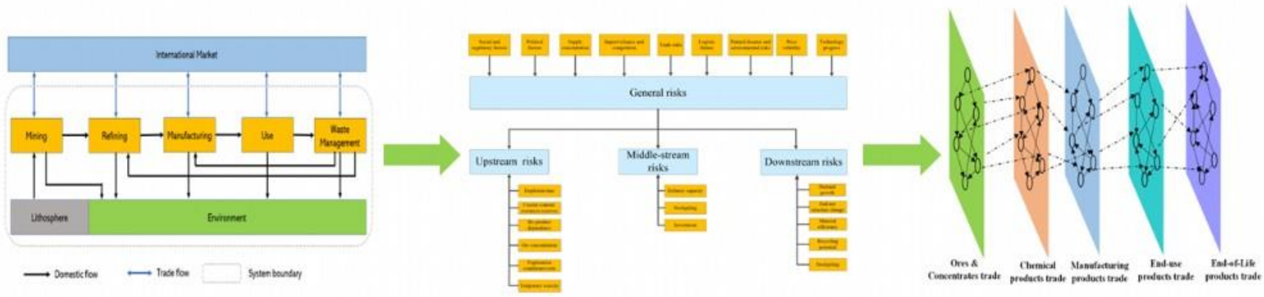
Keywords: Supply chain, critical metal, complex network, propagation, energy transition

Model framework



[Abstract:0565] OP-338 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Energy Security]

Enhancing Energy Security: A Techno-Economic Model for Assessing Tanzania’s Diverse Energy Potential

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Overview:Similar to many fast growing economies in East Africa, Tanzania historically relied heavily on hydropower until recent droughts caused significant disruptions to the system. In response, Tanzania has increased its use of natural gas to mitigate the impacts of droughts. However, a supply mix primarily composed of hydro and natural gas exposes the electricity system to vulnerabilities arising from global price volatility of fossil fuels or recurring droughts.
Methods:As part of its ongoing national development policies, Tanzania has set objectives to deliver secure, affordable and reliable electricity. To achieve these national goals, the country emphasizes importance of energy security, and aims to diversify its electricity supply by tapping into its abundant renewable and non-renewable energy sources. This paper presents a techno-economic model of Tanzania's electricity system using PLEXOS. It explores both the Business as Usual scenario and high renewable scenarios, aiming to assess the impact of generation diversification while accounting for the seasonality of hydroelectric power plants.
Results:Developing a diversified electricity generation from various generation sources alleviates the risk of hydro seasonality, and increases energy security.
Conclusions:The findings underscore that, to mitigate the risks associated with seasonality and costs in hydro and fossil power plants, a diversified electricity generation is crucial for ensuring energy security in a growing economy and population such as Tanzania.
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Keywords: East Africa, Tanzania, Energy Security.

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[Abstract:0358] OP-339 [Accepted:Oral Presentation] [Energy Security and Geopolitics » Other]

Research on the Resilience of the Global New Energy Mineral Lithium Supply Network Under the Background of Frequent Risks

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Overview:As the global climate crisis becomes more prominent, preventing global warming has garnered broad consensus among major economies worldwide. The global shift to green and low-carbon energy has led to a substantial increase in demand for new energy products like electric vehicles, lithium batteries, and solar cells. New energy minerals form the foundational materials for the new energy industry, critical for achieving sustainable development goals (SDGs) such as green and low-carbon energy transformation and global climate protection. Ensuring the supply security of mineral resources, including new energy minerals, has evolved into a focal point of energy and foreign policies, becoming a significant aspect of geopolitics and the power play among nations.Lithium, a key new energy mineral, boasts the highest specific capacity among all metals, making it an ideal material for battery manufacturing due to its remarkable electron gain and loss capabilities. The global significance of lithium resources has risen steadily, with major economies like Japan, China, the United States, and the European Union designating it as a national strategic or

critical mineral. In 2020, the United Nations Environmental Protection Agency classified lithium as a "Green Rare Metal." The increasing trends in global renewable energy and electrification have fueled a growing demand for lithium. The International Energy Agency (IEA) predicts that global demand for lithium in 2040 will surpass 40 times that of 2020. However, the distribution of global lithium resources is concentrated, leading to a spatial mismatch between major suppliers and consumer countries. International trade becomes crucial for countries to secure lithium resources. Yet, in the current landscape of frequent risks, the global lithium supply network faces significant uncertainty. If a major supplier encounters supply interruption risks due to factors like natural disasters or geopolitical conflicts, it could trigger a cascade effect, leading to a global lithium resource supply crisis. This not only jeopardizes lithium resource supply security but also hampers the progress of global low-carbon energy transition.Enhancing the resilience of the global new energy mineral lithium supply network is crucial for the development of the global new energy industry, the promotion of low-carbon energy transformation, and the achievement of carbon peak and carbon neutrality.
Methods:Evaluating the structural resilience of the global lithium supply network from the dimensions of Hierarchy, Matching, Transmission, and Aggregation, the indicators and their explanations are as follows:

1. Hierarchy: Degree Distribution.Reflects the hierarchical characteristics and distribution of the global lithium supply network.
2. Matching: Degree Correlation.Indicator Explanation:Explains the matching characteristics of the global lithium supply network and the trade preferences of node countries.
3.Transmission: Average Path Length.Indicator Explanation:Represents the transmission efficiency and trade circulation of the global lithium supply network.
4. Aggregation: Clustering Coefficient.Indicator Explanation:Reflects the aggregation characteristics of the global lithium supply network. A higher clustering coefficient indicates a higher level of integration in the global lithium supply network.

Using computer simulation methods and selecting six network characteristic indicators: average path length, clustering coefficient, network efficiency, average degree, proportion of isolated nodes, and relative size of the largest connected subgraph, random attacks and deliberate attacks on countries in the global lithium supply network were conducted. The study analyzed the changes in network characteristic indicators under these two attack states and explored the dynamic characteristics of the resilience of the global lithium supply network. The evaluation indicators and descriptions for the dynamic characteristics of the global lithium supply network are as follows(The same indicators are not introduced repeatedly):

1.Network Efficiency:This indicator represents the operational status of the global lithium supply network. A higher network efficiency indicates better connectivity and accessibility in the global lithium supply network.
2.Average Degree of the Network:This indicator represents the average degree value of nodes in the global lithium supply network. The greater the variation in the average degree, the lower the network resilience.
3.Proportion of Isolated Nodes:This indicator reflects the proportion of nodes in the global lithium supply network that, after an attack, have no trade connections with other countries.
4.Relative Size of the Largest Connected Subgraph:This indicator represents the relative size of the largest connected subgraph during the fragmentation process of the global lithium supply network under attack. A smaller value indicates a higher degree of network disruption.

Results:Firstly, the article conducts an in-depth analysis of the structural resilience of the global lithium supply network.Both the midstream and upstream supply networks and the downstream supply network have obvious hierarchical structures.But there are some differences.Firstly, the global lithium downstream supply network involves not only more node countries than the mid-to-upstream supply network but also more trade activities between countries in the supply network. Secondly, downstream lithium products differ from midstream and upstream lithium products in that their supply is not entirely dependent on a few lithium-supplying countries. The in-degree and out-degree distributions of the global downstream lithium supply network are more uniform than those of the mid- and upstream lithium supply networks.the degree correlation index of the global lithium midstream and upstream supply network is -0.1077. The correlation index of the global lithium downstream supply network is -0.2888.Both the global lithium downstream supply network and the midstream and upstream supply networks exhibit heterogeneous characteristics. Based on the absolute value of the degree correlation index, competition among core trading countries in the global lithium downstream supply network is more intense than in the midstream and upstream supply networks.In terms of connectivity, the global lithium downstream supply network exhibits higher accessibility and diffusion compared to the midstream and upstream supply networks.The average clustering coefficient of the global lithium midstream and upstream supply network is 0.3837.The average clustering coefficient of the global lithium downstream supply network is 0.7257.The downstream supply network exhibits a stronger agglomeration effect.
Subsequently, computer simulations are utilized to investigate dynamic changes in the network's

resilience under both random and deliberate attacks. Further utilize percolation theory to identify the critical threshold and core supply network for the fragmentation of the global new energy mineral lithium supply network. The global lithium downstream supply network exhibits stronger structural and dynamic resilience compared to the midstream and upstream supply network. When the network faces attacks, deliberate attacks have a more significant destructive impact on the global lithium resource supply network than random attacks.When the global lithium supply network faces attacks, significant changes occur in network characteristics. For the midstream and upstream networks, the collapse threshold is reached at an attack proportion of 19%, while for the downstream supply network, the collapse threshold is at an attack proportion of 23%.
Finally, In the state of supply disruption in Chile, Argentina, Bolivia, or the entire "South American Lithium Triangle," although the relative size of the largest connected subgraph decreases by about 45%, the changes in network average degree, average path length, network efficiency, and clustering coefficient are all within 3%. The proportion of isolated nodes is 0. In the state of supply disruption in China, Japan, South Korea, or the entire "Three Major East Asian Economies," although the relative size of the largest connected subgraph decreases by around 44%, the changes in the proportion of isolated nodes, average path length, network efficiency, and clustering coefficient are all within 4%, and the change in network average degree is within 9%. The proportion of isolated nodes is 0, network efficiency is above 0.55, and the clustering coefficient is above 0.7. This indicates that compared to the midstream and upstream supply network, the global lithium downstream supply network exhibits better network operational capabilities and resilience when facing disruptions in crucial nodes and regions.
Conclusions:1. The global new energy mineral lithium downstream supply network exhibits greater strength in terms of development and resistance to risks compared to the midstream and upstream supply networks. Deliberate attacks have a more detrimental impact on the global new energy mineral lithium supply network than random attacks.
2. When the global new energy mineral lithium supply network faces deliberate attacks, significant changes occur in network characteristics. In the midstream and upstream networks, the attack proportion increases from 19% to 43%, surpassing the percolation threshold. The top 19% of nodes constitute the core supply network for the global new energy mineral lithium midstream and upstream, while the top 43% form the overall network. Other node countries assume a relatively marginal position in the midstream and upstream supply networks.Concerning the downstream supply network, the top 23% of nodes constitute the core supply network for the global new energy mineral lithium downstream, with the top 38% forming the overall network. Other node countries hold a relatively marginal status in the downstream supply network.
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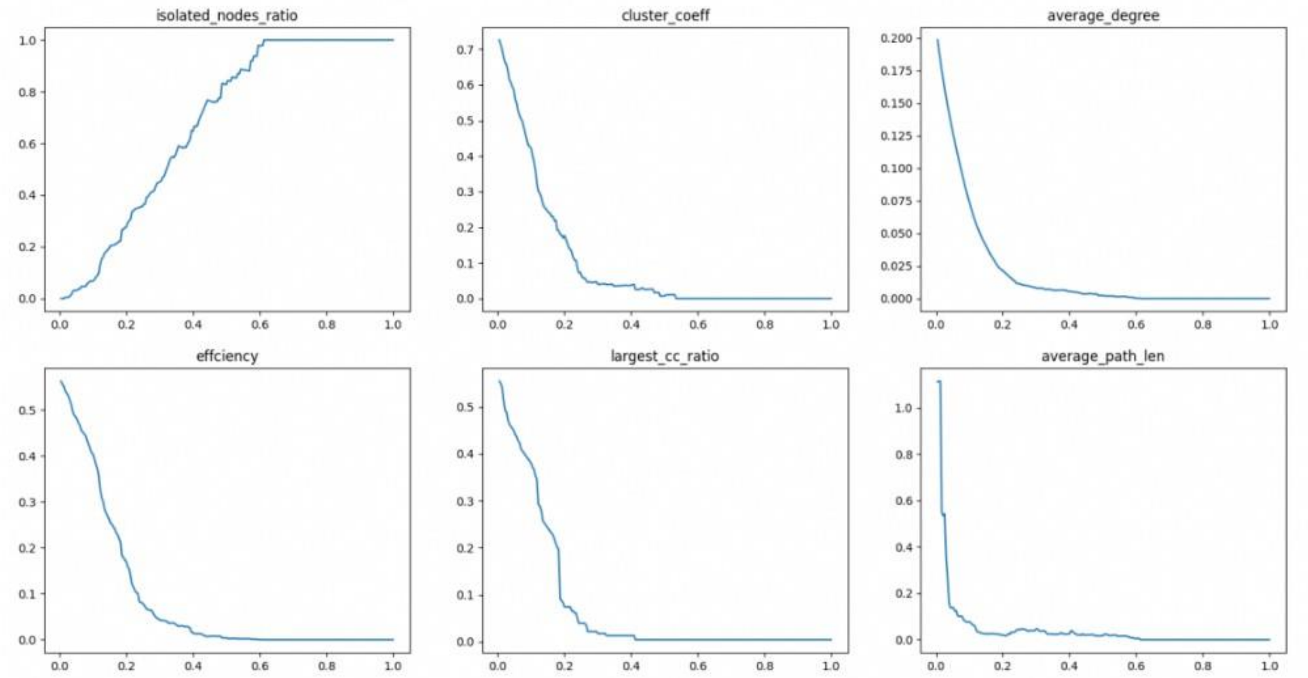
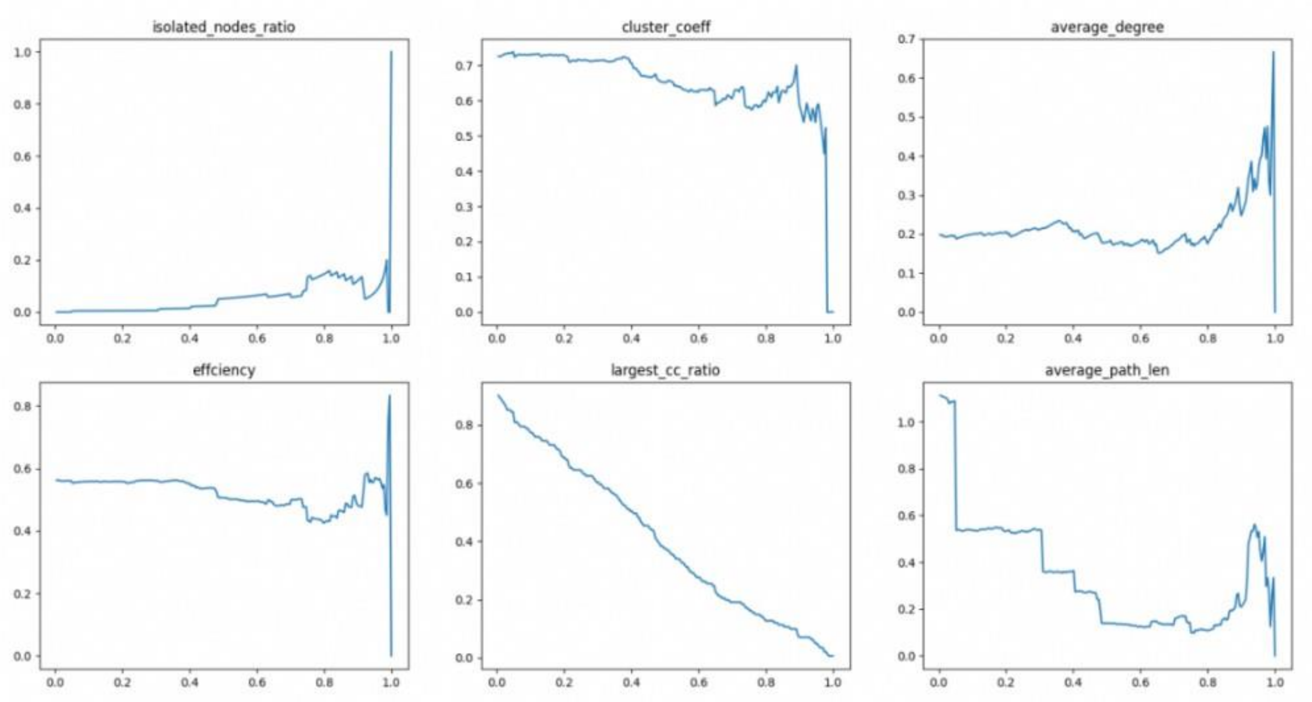
Keywords: Resilience, Complex Networks, New Energy Minerals, Lithium, Risk

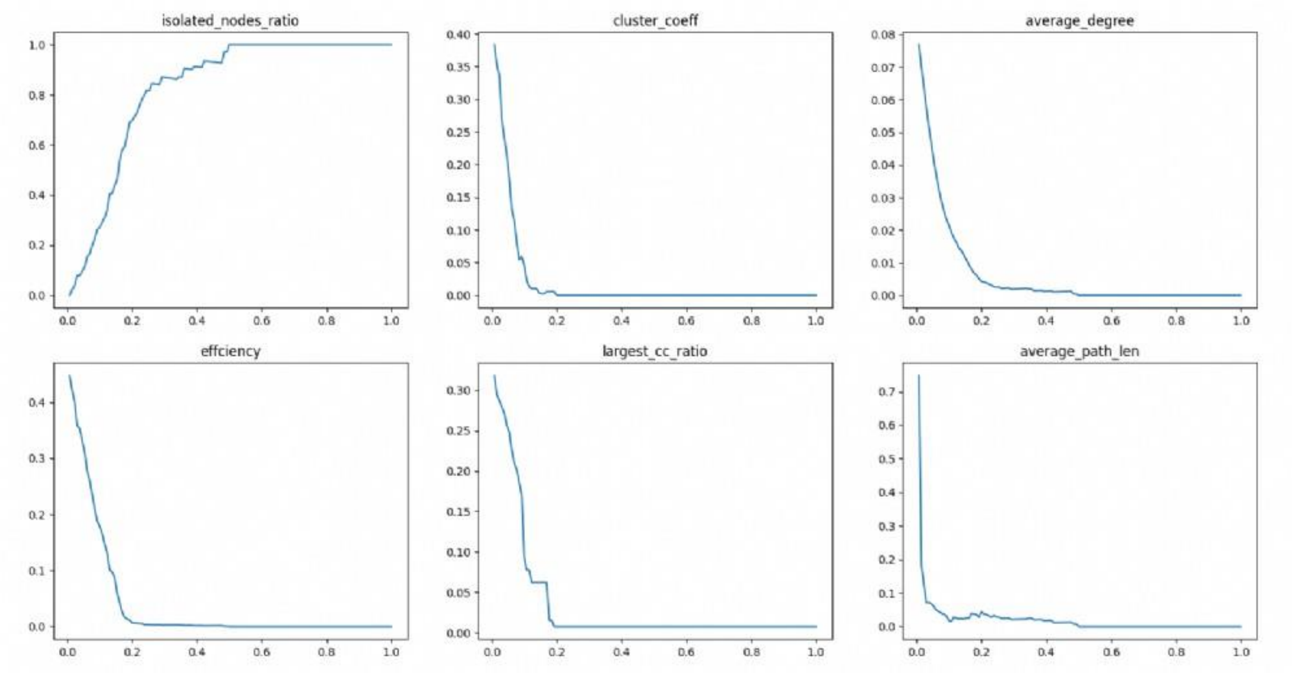
Changes in the resilience characteristic value of the downstream supply network of global lithium under deliberate attacks



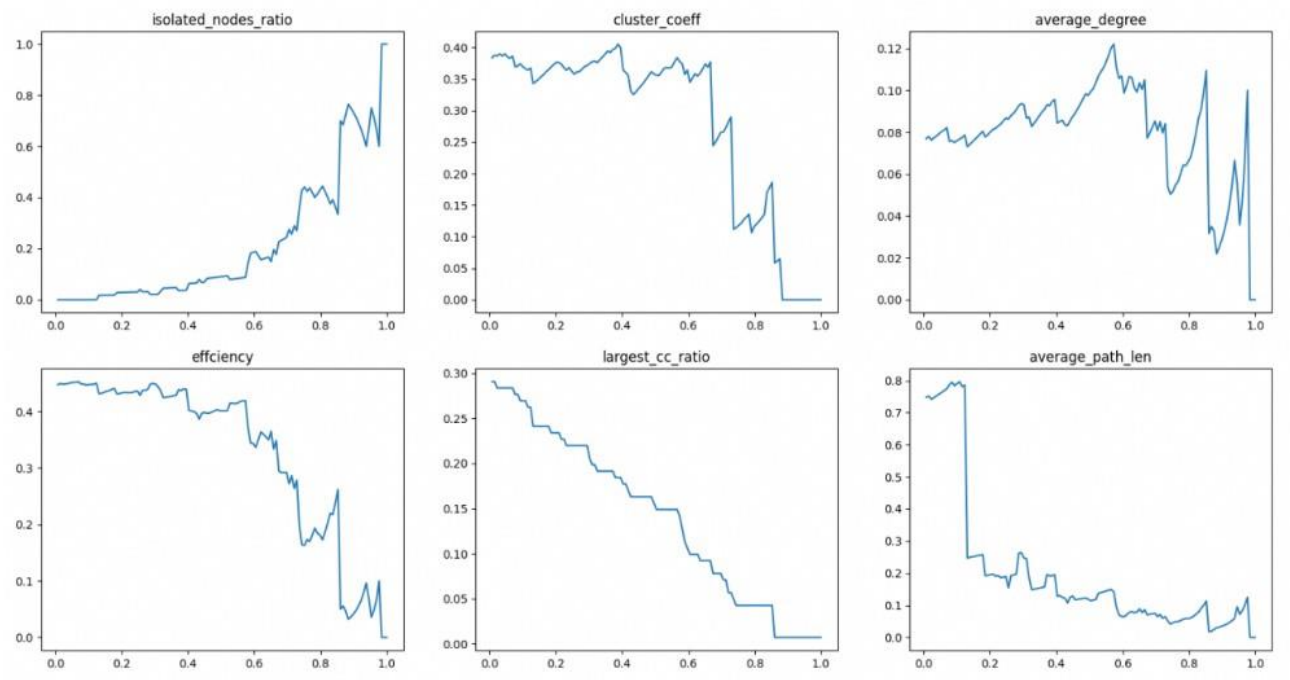
Changes in the resilience characteristic value of the downstream supply network of global lithium under random attacks



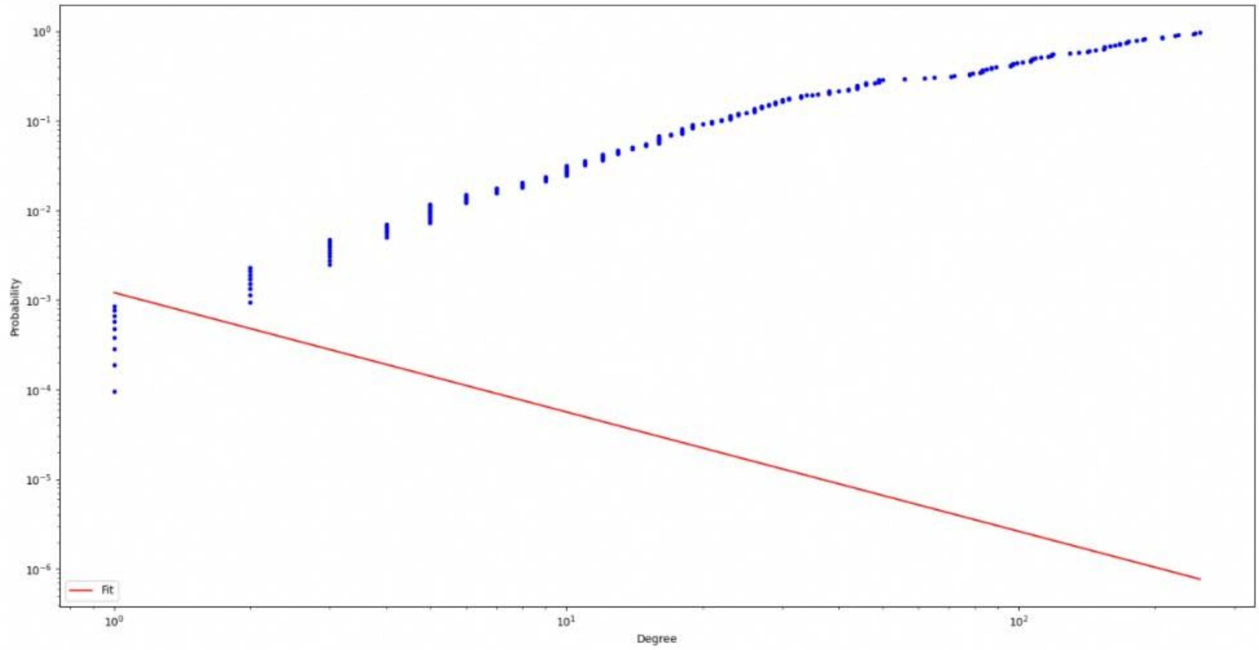
Changes in the resilience characteristic value of the global lithium mid-upstream supply network under deliberate attacks



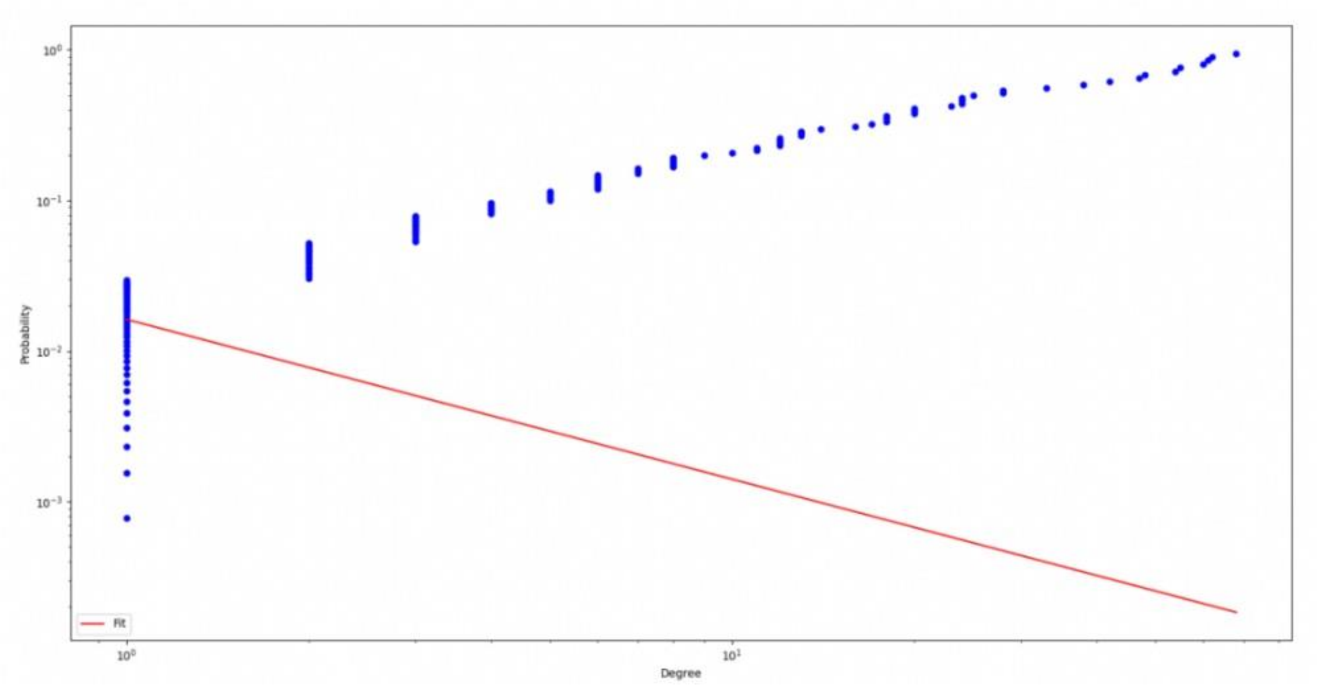
Changes in the resilience characteristic value of the global lithium mid-upstream supply network under random attacks



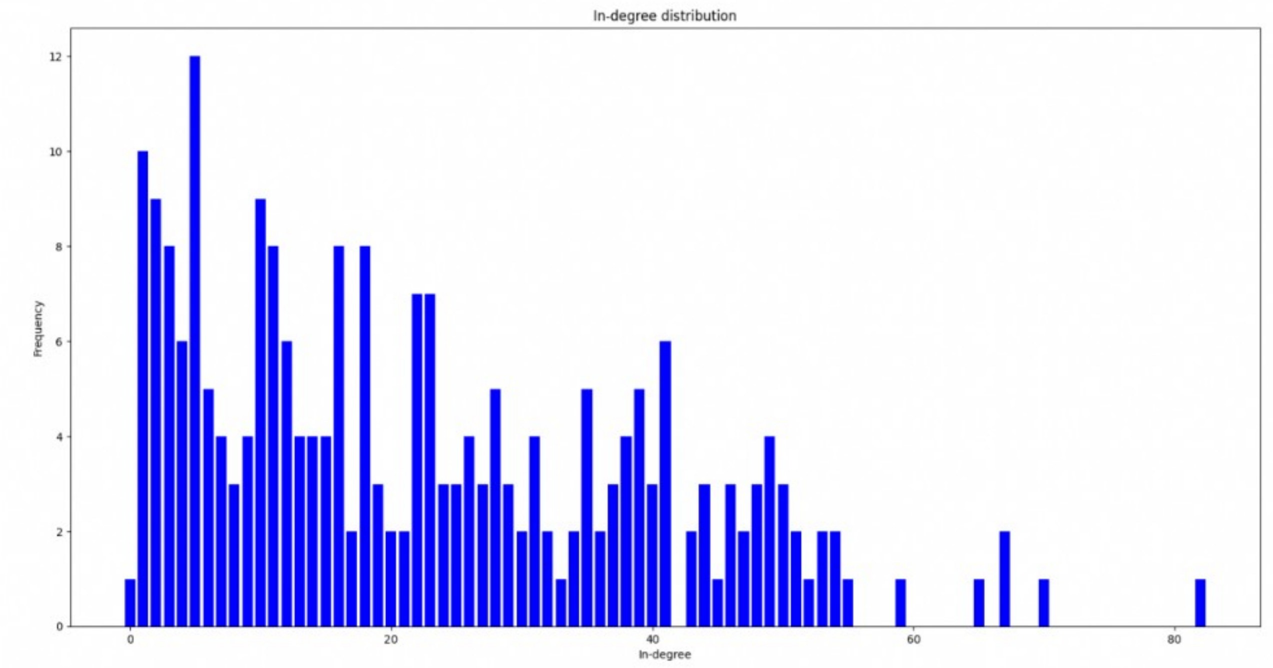
Degree distribution of downstream supply network in log-log coordinates



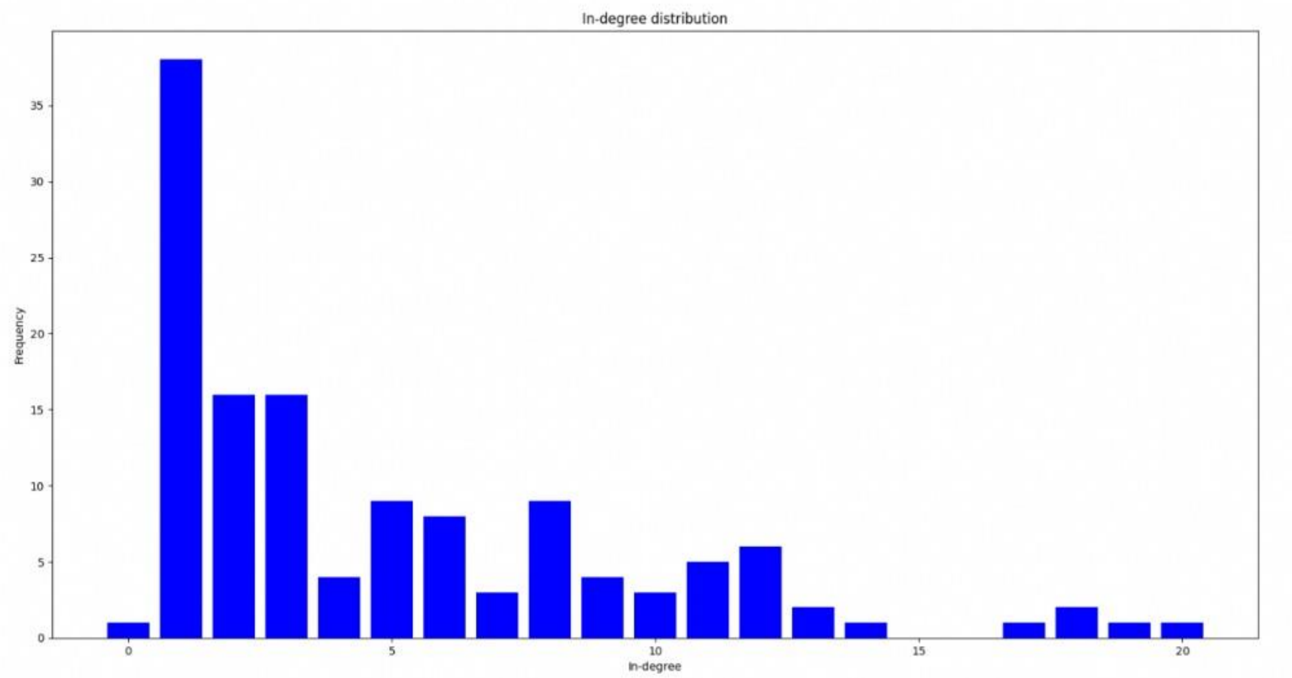
Degree distribution of mid-upstream supply network in log-log coordinates



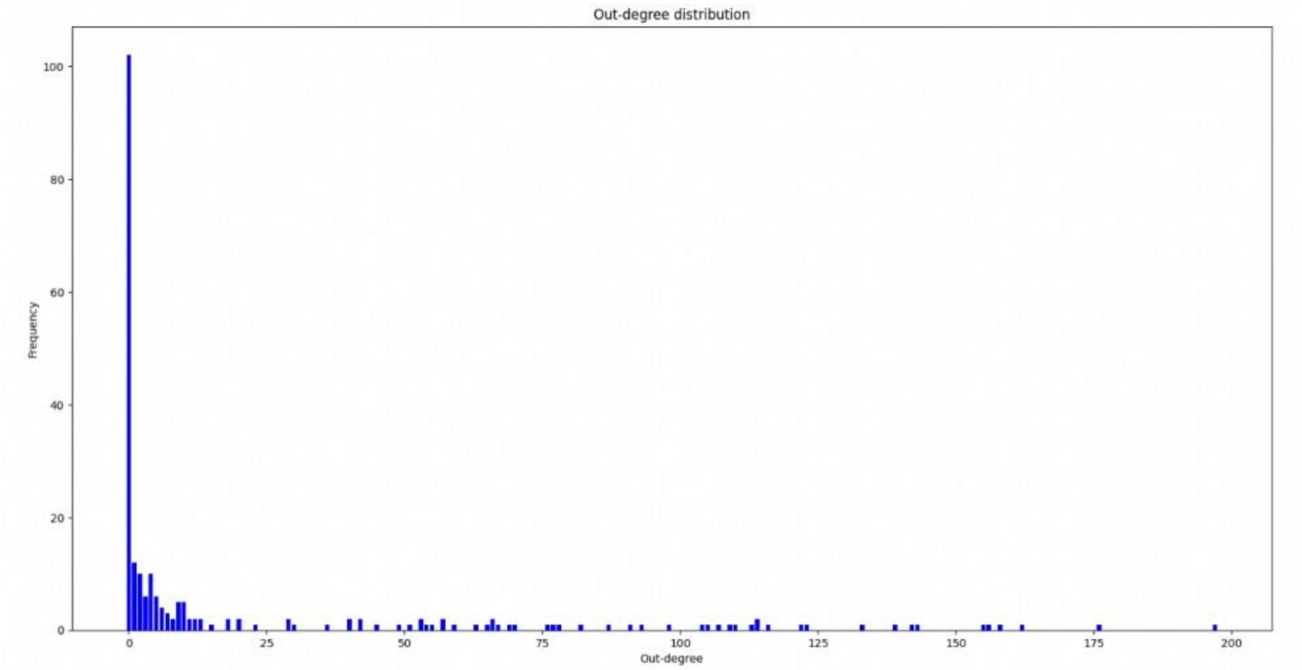
In-Degree distribution of downstream supply network of global lithium



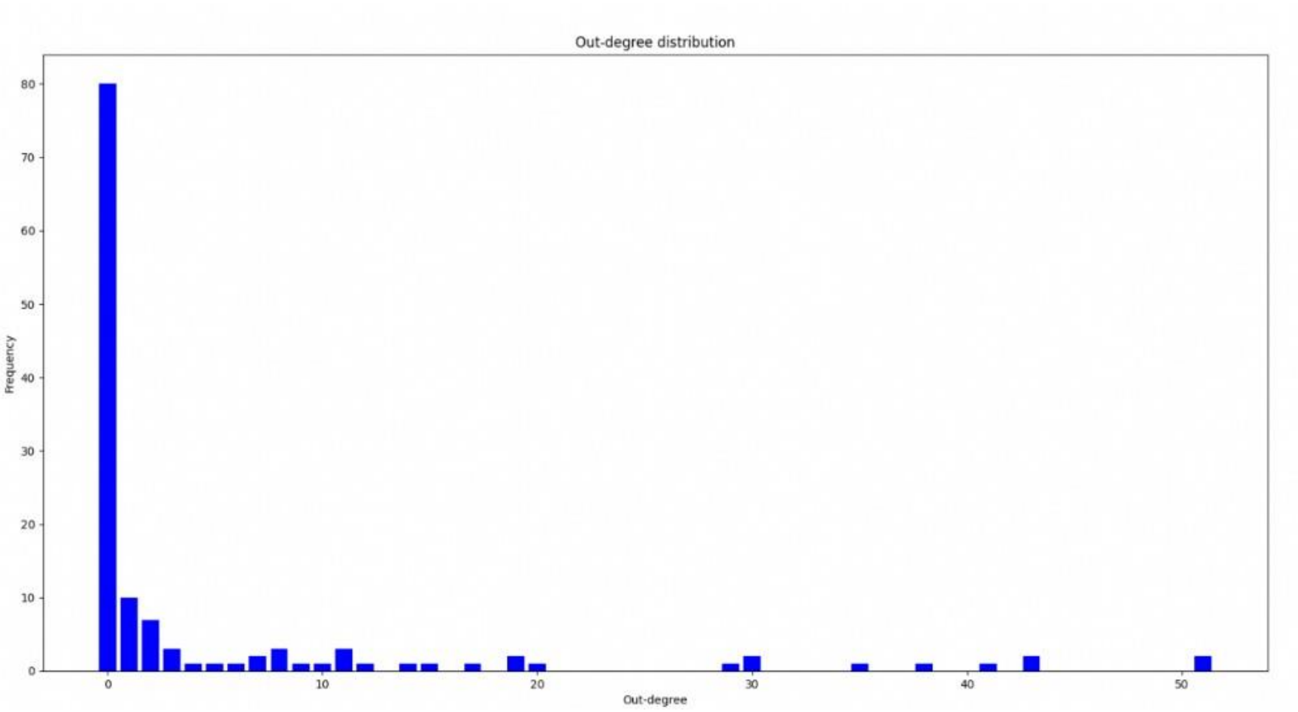
In-Degree distribution of mid-upstream supply network of global lithium



Out-Degree distribution of downstream supply network of global lithium



Out-Degree distribution of mid-upstream supply network of global lithium



Changes in the resilience characteristic value of the downstream supply network of global lithium under the node failure state

Scenario	Average Degree	Average Path Length	Network Efficiency	Clustering Coefficient	Relative Size of the Largest Connected Subgraph	Proportion of Isolated Nodes(%)
Original Network	0.1986	1.1119	0.5624	0.7257	0.9845	0.0000
Supply Disruption in China	0.1906	1.1150	0.5555	0.7136	0.5502	0.0000
Supply Disruption in Japan	0.1951	1.1109	0.5613	0.7242	0.5502	0.0000
Supply Disruption in South Korea	0.1944	1.1111	0.5608	0.7199	0.5502	0.0000
Supply Disruption in "Three Major East Asian Economies"	0.1822	1.1131	0.5522	0.7020	0.5415	0.0000

Changes in the resilience characteristic value of the global lithium mid-upstream supply network under the node failure state

Scenario	Average Degree	Average Path Length	Network Efficiency	Clustering Coefficient	Relative Size of the Largest Connected Subgraph	Proportion of Isolated Nodes
Original Network	0.0769	0.7473	0.4474	0.3837	0.3178	0.0000
Supply Disruption in Chile	0.0752	0.7388	0.4457	0.3864	0.1747	0.0000
Supply Disruption in Argentina	0.0770	0.7339	0.4468	0.3815	0.1747	0.0000
Supply Disruption in Bolivia	0.0780	0.7518	0.4493	0.3874	0.1790	0.0000

upply Disruption in the "South American Lithium Triangle"	0.0765	0.7295	0.4470	0.3875	0.1703	0.0000

Resilience characteristic values of global lithium mid-upstream supply network under different proportions of deliberate attacks

Attack Proportion	Average Degree	Average Path Length	Network Efficiency	Clustering Coefficient	Relative Size of the Largest Connected Subgraph	Proportion of Isolated Nodes
0	0.0769	0.7473	0.4474	0.3837	0.3178	0
19	0.0052	0.0279	0.0117	0.0058	0.0078	0.6887
43	0.0010	0.0116	0.0013	0	0.0078	0.9333

Resilience characteristic values of global lithium mid-upstream supply network under different proportions of deliberate attacks

Attack Proportion	Average Degree	Average Path Length	Network Efficiency	Clustering Coefficient	Relative Size of the Largest Connected Subgraph	Proportion of Isolated Nodes
0	0.0769	0.7473	0.4474	0.3837	0.3178	0
19	0.0052	0.0279	0.0117	0.0058	0.0078	0.6887
43	0.0010	0.0116	0.0013	0	0.0078	0.9333

Resilience characteristic values of the downstream supply network of global lithium under different proportions of deliberate attacks

Attack Proportion	Average Degree	Average Path Length	Network Efficiency	Clustering Coefficient	Relative Size of the Largest Connected Subgraph	Proportion of Isolated Nodes
0	0.1986	1.1119	0.5624	0.7257	0.9845	0
23	0.0142	0.0319	0.1024	0.1075	0.1085	0.3483
38	0.0065	0.0319	0.1024	0.0365	0.1085	0.5833

The downstream supply network path of global lithium resources

Type	Path Count	Percentage
Direct	5229	18.0%
1 Transfer	18437	63.4%
2 Transfers	5217	17.9%
3 Transfers	203	0.7%

The supply network path of the upper and middle reaches of the global lithium resources

Type	Path Count	Percentage
Direct	645	12.2%
1 Transfer	2400	45.5%
2 Transfers	1857	35.2%
3 Transfers	363	6.9%
4 Transfers	13	0.2%

[Abstract:0679] PHD-001 [Accepted] [Energy System Transition » Policy]

Diffusion forecast for grid-tied rooftop solar photovoltaic technology under store-on grid scheme model in Sub-Saharan Africa: Government role assessment

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Overview:This paper builds on the previous research conducted by the authors on the Store-on Grid Scheme model for rooftop solar photovoltaic systems, particularly looking at the industrial and commercial building. The Store-on Grid Scheme model is extensively discussed in (Mukisa, Zamora et al. 2020, Mukisa, Zamora et al. 2021a, Mukisa, Zamora et al. 2021b). For this particular paper, the lead author will discuss the results in paper (Mukisa, Zamora et al. 2021c). Below is the paper abstract.

Government support is crucial for the competitiveness and success of renewable energy market policies. As an advancement to the previously developed store-on grid (SoG) scheme, this study considered 14 countries to examine the government's role in facilitating the battery energy storage systems (BESS) under the SoG scheme. A methodology for evaluating the total government expenditure on the BESS to achieve the solar photovoltaic cumulative capacity forecasted by the Bass model and possible total greenhouse gases (GHG) emissions avoided was presented. Using a 15 years' timeline and cumulative capacity target of 500 MW, the Bass model forecasting results revealed that over 480 MW cumulative capacity would be achieved under the SoG scheme. The average present value of the total government expenditure on the BESS across the selected countries was about $ 47,154,052. Eswatini at $ 61,304,636 and Zimbabwe at $ 30,924,616 recorded the highest and lowest total government expenditure on the BESS, respectively. This is attributed mainly to the country's forecasted diffusion capacity at the peak point and duration to the inflection points. Furthermore, Zimbabwe with 19.99 MtCO2eq and Uganda with 2.79 MtCO2eq recorded the highest and least total GHG emissions avoided, respectively, attributed mainly to the country's grid emission factor.

Methods:The methods section is divided into four subsections. First subsection presents the methodology for forecasting the diffusion of solar PV technology under the SoG scheme based on Bass Model. The second subsection presents the verification and validation of the Bass Model based on root mean square error (RMSE) and mean absolute percentage error (MAPE). Third subsection presents the methodology for evaluating the government expenditure on the BESS under the SoG scheme. Fourth subsection presents the methodology for evaluating the total GHG emissions avoided under the SoG scheme to achieve the forecasted cumulative solar PV installation.

Results:The values of the Bass Model parameters (p and q) for all the selected SSA countries agree with the literature assertion that the innovation coefficient should always be greater than the diffusion coefficient (q> >p) for technological or product innovation diffusion processes.
The RMSE, and MAPE for the predicted values of 2020 solar PV cumulative capacities are in the range of 5:6 x10^(-4) - 13.86 MW and 0.06 - 16.80%, respectively, for the selected SSA countries. Based on the literature assertion about the values of RMSE and MAPE, that the smaller these values are, the better the predicting performance of a model is, then, the Bass Model in this study is suitable for

use to forecast the diffusion of solar PV technology in the selected SSA countries. The results agree with the assertion that the rate of diffusion for an innovation is represented by a bell-shaped curve, while the cumulative diffusion of an innovation is represented by an S-shaped curve.

Results reveal that different patterns of solar PV annual installations would be experienced in the different countries considered in this study. For instance, Uganda, Cote d'Ivoire, Mali, Eswatini and Cameroon could record notable installations in the first year of enacting the SoG scheme, while all the other considered countries record negligible installations in the first year. Also, although most of the selected SSA countries are predicted to have a spike in the solar PV annual installation, countries such as Uganda, Cote d'Ivoire, Zimbabwe, and Cameroon would record a gradual rise and fall in the annual installation capacity.

By the end of the 15 years of the SoG scheme, all the selected SSA countries would have a total cumulative installation of over 497 MW, except for Uganda that would have only 482 MW. The low cumulative installation capacity in Uganda could be attributed to the fact that Uganda records the lowest value of the imitation (diffusion) coefficient q.

reveals that the highest present value of the total government expenditure on the BESS under the SoG scheme model would be recorded in Eswatini at $ 61,087,336, followed by Mali, Cote d'Ivoire, and Cameroon, in that order. Likewise, the least present value of the total government expenditure on the under the SoG scheme model would be recorded in Zimbabwe at $ 30,777,562, followed by Kenya, Niger, Uganda, Burkina Faso, and Madagascar, in that order. Although both Eswatini and Zimbabwe approximately have the same cumulative capacities, 499.99 MW and 497.81 MW, respectively, the present value of the total government expenditure on the BESS under the SoG scheme model for Eswatini is almost double that of Zimbabwe. This discrepancy in the expenditures is due to the time at which the technology diffusion reaches the inflection points.

Namibia would record the highest total solar PV energy generated of about 18,767.83 GWh under the SoG scheme, which is attributed to its high solar yield potential of 1709.18 kWh/kW. Kenya and Namibia have a wide difference in the total solar PV energy generated of about 3950.70 GWh even though they have the same forecasted total solar PV capacity installed of about 499.20 MW. Furthermore, although Cote d'Ivoire has a higher forecasted total solar PV capacity installed of 488.20 MW compared to that of Uganda of 482.34 MW, Cote d'Ivoire records the least total solar PV energy generated of about 13,219.11 GWh, mainly due to its low solar yield potential.

Uganda records the least total GHG emissions avoided by adopting solar PV under the SoG scheme of about 2.79 MtCO2eq, followed by Namibia with about 3.66 MtCO2eq. Uganda's low total GHG emissions avoided is attributed to both its low grid emission factor of 201 gCO2eqkWh and d the fact that Uganda records the least total solar PV capacity installed of about 482.34 MW. Thus, although Namibia has the least grid emission factor of 195 gCO2eqkWh, because it records one of the highest forecasted total solar PV capacity installed of about 499.20 MW, the difference of 16.86 MW in comparison to Uganda results in a significant amount of total GHG emissions avoided.

On the other hand, Zimbabwe records the highest total GHG emissions avoided by adopting solar PV under the SoG scheme of about 19.99 MtCO2eq. Zimbabwe has the highest amount of GHG emissions avoided by adopting solar PV under the SoG scheme mainly because it has a high grid emissions factor of 1302 gCO2eqkWh resulting from its overreliance on coal and oil-based thermal power plants.

Conclusions:Based on the historical cumulative installation data for solar PV, innovation coefficient p and imitation coefficient q were found to be in the range 0.002 - 0.0389 and 0.4262 - 1.0486, respectively, across the selected SSA countries. The testing process revealed that the cumulative installation capacity predictions of the BM have values for the RMSE, and MAPE in the range of 5.6x 10^(-4) - 13.86 MW and 0.06 -16.80%, respectively, for the selected SSA countries. This is an indication that the BM is suitable for forecasting solar PV technology diffusion.

At the end of 15 years of the SoG scheme, all the selected SSA countries could have a cumulative installation capacity of over 497 MW, except for Uganda that could have 482 MW. The low cumulative installation capacity in Uganda is attributed to the fact that Uganda recorded the lower imitation coefficient value of all the selected SSA countries.

At the peak point of innovation diffusion, Togo records the highest annual installation capacity of 132 MW, while Uganda records the least annual installation capacity of 58 MW. Except for Uganda, Cote d'Ivoire, Mali, Eswatini and Cameroon, the cumulative installation capacity peak point is about 250 MW, and Cote d'Ivoire records the least cumulative installation capacity at the peak point of 231 MW. Other than Mali, Eswatini, Cote d'Ivoire, Togo and Cameroon, the rest of the selected countries would take about seven years to get to the peak point of technology diffusion in the community. Mali and Eswatini reach the lower inflection point in two years, while most of the selected countries take about six years to the lower inflection point.

For all the selected countries, 11 out of 14 could have their highest share of the forecasted cumulative installation capacity in 5e10 years, which represents the early majority and late majority of the innovation by the community. Only cote d'Ivoire, Mali and Eswatini would have their highest share

of the forecasted cumulative installation capacity by the end of the 5th year of the SoG scheme enactment.
The average present value of the total government expenditure on the BESS under the SoG scheme across the selected SSA countries is about $ 47,154,052. The highest present value of the total government expenditure on the BESS under the SoG scheme was recorded in Eswatini at $ 61,304,636, while the least value was recorded in Zimbabwe at $ 30,924,616. Overall, the sooner the technology diffusion in the society reaches its inflection points, the higher the present value of the total government expenditure on the BESS under the SoG scheme will be.
The evaluation of the possible total GHG emissions avoided by adopting solar PV technology under the SoG scheme revealed that Uganda would record the least amount of about 2.79 MtCO2eq, while Zimbabwe would record the highest amount of about 19.99 MtCO2eq.
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Keywords: Innovation diffusion, Bass model, Government expenditure, Store-on grid scheme, Sub-Saharan Africa, GHG emissions

AuthorToEditor: I look forward to hearing from the committee about my submission.

[Page: 341]

[Abstract:0680] PHD-002 [Accepted] [Energy and the Macroeconomy » Economic Growth and Energy Demand]

Energy Consumption Forecasting using ARIMA Models: An Empirical Study for a small island developing state

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University of Mauritius

Overview:Global warming has been internationally debated and significant importance has been laid on the link between energy conservation policies and economic growth. Studies on the energy consumption-growth nexus has been widely discussed but such studies have not reached a consensus. In addition to that this topic has not been widely investigated for the case of the small island developing states of Mauritius. The Mauritian government energy policy encourages the use of renewable and clean energy to reduce the country's dependence on fossil fuels and decrease greenhouse gas emissions. Official statistics for 2020 indicated that the percentage of renewables used for electricity generation was 23.9 percent, compared to 21.7 percent in 2019. In its 2021-2022 budget speech, the government announced plans to increase the use of renewable sources of energy for electricity generation to 60 percent, phase out the use of coal, and increase energy efficiency by 10 percent, all by 2030. The government also reviewed the Renewable Energy Roadmap 2030, initially published in 2019, to reflect Mauritius's strategy to achieve the goals announced in the latest budget speech. It aims to do this through wind farms, solar energy, biomass, wave, and waste-to-energy projects. Bagasse (sugarcane waste) is currently the leading source of renewable

energy (13.3 percent). Mauritius derives its other renewable electricity generation from hydro, wind, landfill gas, and solar.
Methods:The present study aims at investigating the link between energy consumption and Economic growth for Mauritius as well as investigating the existence of non-linearities in the energy consumption and economic growth nexus. The ARIMA model is being used for this purpose. ARIMA are theoretically the most frequently used models for the forecasting of short run forecasts of time series. ARIMA models became popular from Box and Jenkins (1976) and predict the future values of a time series as a linear combination of its past values and the lags of forecast errors named innovations. An ARIMA (p, d, q) model has three parameters. AR parameter (p) represents the order of autoregressive procedure, parameter (d) represents the order of difference on the time series and MA parameter (q) represents the order of moving average process. The ARIMA forecasting equation for a stationary time series is a linear equation like regression where the predictors consist of the lags of dependent variable as well as the lags of forecast errors.
Results:Forecasting was attained with static and dynamic procedure in and out-of-sample using all the forecasting criteria. The results forecast a rise in energy consumption in the following years. Research implications and policies are discussed as well.
Conclusions:Forecasting was attained with static and dynamic procedure in and out-of-sample using all the forecasting criteria. The results forecast a rise in energy consumption in the following years. Research implications and policies are discussed as well.
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Keywords: Energy consumption, Economic growth, ARIMA, Small island developing State.

AuthorToEditor: Dear Scientific Committee I have already completed my phd. I want to participate in the conference.

[Page: 342]

[Abstract:0685] PHD-003 [Accepted] [Electricity » Demand]

Unveiling the Economic Shadow of COVID-19: A Study of Electricity Consumption Trends in Tehran

Mohammad Fallah
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Overview:This research investigates the economic impacts of the COVID-19 pandemic on Tehran Province, Iran, through the lens of commercial electricity consumption. Utilizing a difference-in-differences (DID) model, it quantifies the pandemic's economic costs, revealing the relationship between a significant decrease in electricity usage and economic downturns. The study underscores the viability of electricity consumption data as a real-time indicator of economic activity, offering insights crucial for informed policy-making and recovery strategies in a post-pandemic landscape.
Methods:The research employs a counterfactual DID model to compare electricity consumption in Tehran's commercial sectors before and after the onset of COVID-19, using data from 2019 as a control. This model accounts for seasonal variations and includes fixed effects for regions and months to control for unobservable heterogeneity. The dataset encompasses bi-monthly electricity consumption data from 14,638 commercial units in Tehran Province, spanning from 2019 to 2021.

Regression analyses are conducted to estimate the pandemic's impact on electricity usage, serving as a proxy for economic activity.
Results:The empirical analysis reveals a marked decline in electricity consumption post-COVID-19, indicating a significant economic slowdown. The regression models, both with and without fixed effects, show statistically significant negative coefficients for the interaction term of treatment and post-treatment indicators. This confirms the hypothesis that COVID-19 led to a considerable reduction in economic activities within Tehran's commercial sectors. The inclusion of fixed effects enhances the model's robustness, isolating the pandemic's specific impact from other factors.
Conclusions:The findings suggest that the COVID-19 pandemic exerted a profound economic toll on Tehran Province, as evidenced by decreased electricity consumption in the commercial sector. The study advocates for targeted governmental support and digital transformation initiatives to facilitate economic recovery, emphasizing the importance of flexible economic policies in response to future crises. It also highlights the potential of electricity consumption data as an effective tool for real-time economic monitoring and policy formulation.
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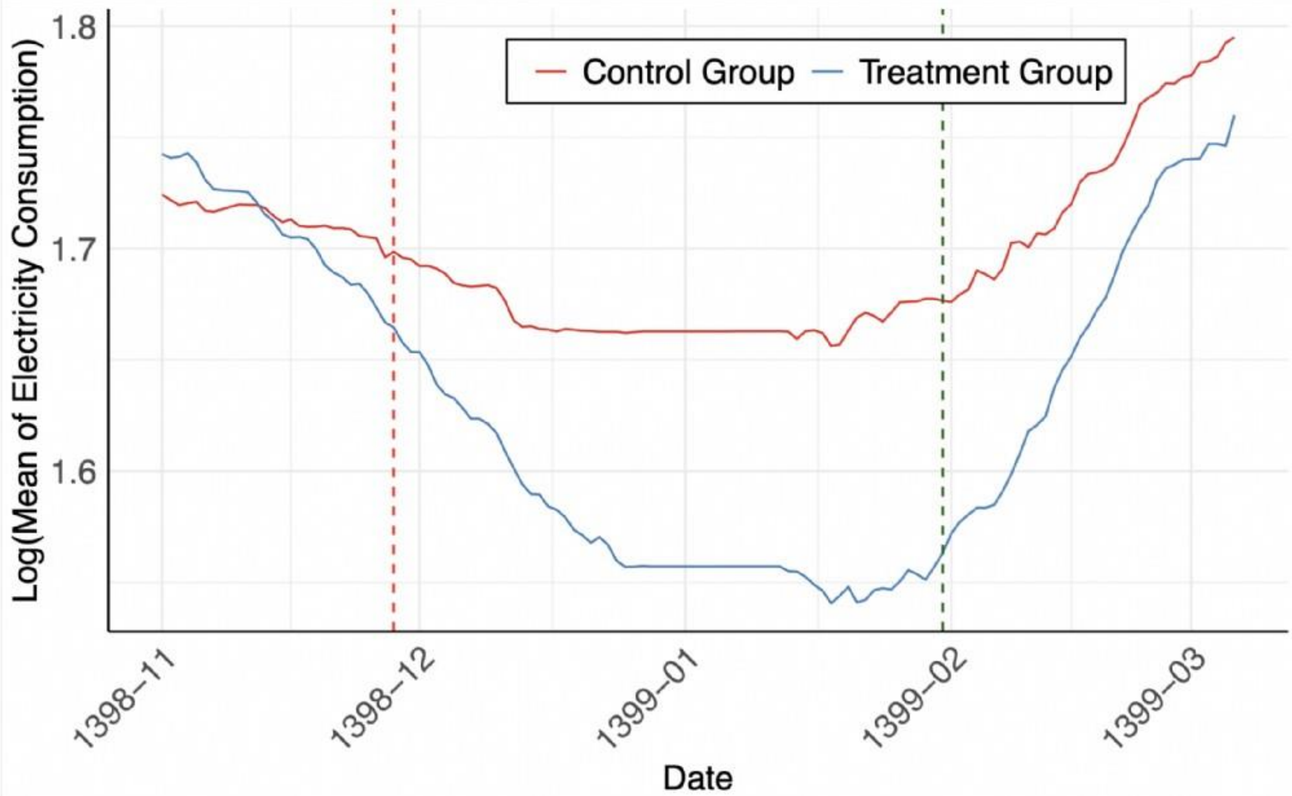
Keywords: COVID-19, Electricity Consumption, Economic Impact, Tehran, Difference-in-Differences (DID) Model, Policy Response

Electricity consumption trends for the treatment and control groups.



Regression Results

	(1)	(2)
post	-0.345^{***}	-0.010
	(0.017)	(0.038)
treat	-0.126^{***}	-0.125^{***}
	(0.020)	(0.020)
treat × post	-0.562^{***}	-0.563^{***}
	(0.024)	(0.023)
Constant	7.106^{***}	7.974^{***}
	(0.015)	(0.055)
Region FE	No	Yes
Month FE	No	Yes
Observations	2,423,347	2,423,347
R^2	0.002	0.043
Adjusted R^2	0.002	0.043

Note: *p<0.1; **p<0.05; ***p<0.01

Summary statistics

Table 2: Summary statistics

	count	mean	min	max	sd
Control Group					
id	1162369	7900.275	2	15732	4506.569
year	1162369	1397.34	1397	1398	.4736757
treat × post	1162369	0	0	0	0
treat	1162369	0	0	0	0
post	1162369	.7149305	0	1	.4514478
electricityconsumption	1162369	6.859393	0	45.83333	8.650187
LnElectricityConsumption	957190	1.423722	-4.882802	3.825011	1.484576
Treatment Group					
id	1260978	7891.84	1	15732	4510.759
year	1260978	1398.322	1398	1399	.4671628
treat × post	1260978	.6856194	0	1	.4642689
treat	1260978	1	1	1	0
post	1260978	.6856194	0	1	.4642689
electricityconsumption	1260978	6.358611	0	45.78688	8.301629
LnElectricityConsumption	1029512	1.356911	-5.236442	3.823998	1.452429
Total					
id	2423347	7895.886	1	15732	4508.75
year	2423347	1397.851	1397	1399	.6795638
treat × post	2423347	.3567591	0	1	.4790429
treat	2423347	.5203456	0	1	.499586
post	2423347	.6996786	0	1	.4583978
electricityconsumption	2423347	6.598814	0	45.83333	8.474298
LnElectricityConsumption	1986702	1.389101	-5.236442	3.825011	1.468384
N	2423347				

[Abstract:0686] PHD-004 [Accepted] [Energy and the Environment » Climate Change and Greenhouse Gases]

Reconcile air pollutants mitigation and CO2 emission reduction brings new opportunities for the abatement potential and cost

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Overview:The CO2 abatement cost for different sectors is investegated by many scholars. However, many emission reduction technologies can reduce carbon dioxide and air pollutants at the same time. Thus, under the perspective of synergistic reducton of pollution and carbon emissions, marginal emission reduction costs of technologies will be overestimated, which will affect the economics of emission reduction activities. This paper selects seven key industries and three pollutants (NOx, VOCs, and CO2) of China's air pollutants and carbon dioxide emissions, constructs the list of emission reduction technologies in key industries and the cost curve of collaborative emission reduction, analyzes the impact of carbon neutralization on the marginal abatement cost of China's air pollutants emission reduction, and explores the dynamic changes of emission reduction potential and cost based on uncertainty analysis, Finally, policy suggestions on the synergy of pollution reduction and carbon reduction are put forward from the perspective of technology.
Methods:(1) This paper uses the expert-based MAC curve to rank the abatement technologies and measures according to their abatement cost.

(2) We employ MCA to incorporate uncertainty analysis into the bottom-up emission reduction cost curve.

(3) In general, the cost reduction of abatement technologies is achieved through learning-by-doing, which enhances efficiency and improves work specialization. For simplicity, we adopt a one-factor learning-by-doing curve in this paper.

(4) We evaluate the synergistic abatement cost by measuring the equivalent emission of carbon emission and air pollutants.
Results:(1) Examining the MAC curve for CO2 emissions, it's evident that the fire power, iron and steel, and cement industries possess significant potential for CO2 emission reduction. In addition, we also note the NOx curve. From this, we observe that the fire power and transportation industries exhibit significant NOx emission reduction potential.

(2) Considering reconcile air pollutants mitigation and CO2 emission reduction, the cumulative emission reduction potential across various industries has increased significantly. Notably, the thermal power industry has seen the most notable growth in emission reduction potential, leaping from 9 billion equivalent tons before collaboration to 18.6 billion equivalent tons afterwards. On the cost side, when considering the cost of reducing emissions by 98% in the iron and steel industry, the total cost was 492.00 billion yuan. However, when considering synergy, the total cost was reduced to 485.81 billion yuan, representing a decrease of 6.19 billion yuan.

(3) In the iron and steel industry, assuming a reduction of 618 million tons in carbon emissions and a reduction of 222.8 thousand tons in NOx. For CO2, before the collaboration, the technical ranking is as follows: recovery of blast furnace gas, heating and regenerative combustion of steel rolling, energy monitoring and management, sintering waste heat power generation, recovery of blast furnace slag waste heat, dry quenching coke, and carbon capture and storage (CCS). After the collaboration, the updated technical ranking is as follows: heating and regenerative combustion of steel rolling, energy monitoring and management, recovery of blast furnace gas, recovery of blast furnace slag waste heat, sintering waste heat power generation, CCS, and dry quenching coke.

(4) Carbon price and emission reduction coefficients have a significant impact on the fluctuations of cost reduction. To ensure greater cost reduction, it is essential to prioritize these two factors. Conclusions:Our study quantitatively evaluates the opportunities presented by China's pollution reduction and carbon reduction efforts in the context of carbon neutrality, as well as the cost savings and potential enhancement of emission reduction in various industries. We posit that the adoption of collaborative emission reduction technologies is paramount if China is to tackle both climate change and air pollution issues simultaneously.

Our findings suggest that China's efforts to enhance air quality and mitigate climate change should be intertwined and mutually reinforcing, as reconcile air pollutants mitigation and CO2 emission reduction offers significant cost savings and high emission reduction potential. This shift in perspective is particularly essential for other developing regions grappling with severe air pollution and carbon emissions, such as India. This differs significantly from the situation in many developed regions (such as the United States and the European Union), which have largely solved the air pollution problem.
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Keywords: synergistic reduction, marginal abatement cost, CO2, air pollutant

AuthorToEditor: Because of some reasons of information difference, I have missed the Abstract submission deadline. Our paper is supposed to give an oral presentation (not PhD day) in Turkey. But the system can only choose PhD day. If possible, can you help us to change the type to oral presentation? Our full paper will be submitted befor the deadline of 4.19. Thank you for your time.

[Abstract:0687] PHD-005 [Accepted] [Renewables » Policy and Regulation]

Sustainable financing options for entrepreneurs in Post-insurgency Northeast Nigeria

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Overview:This study investigated sustainable financing options for business entrepreneurs in Post-Insurgency Northeast Nigeria. It adopted survey research design. The study population covers all business entrepreneurs within Northeast Nigeria. Krejcie and Morgan (1970) sample and sampling size determination table was used to arrive at a 384-sample size. Data for the study were primarily sourced with the aid of a structured questionnaire on a five-point Likert scale. Data collected for the study were regressed, using SPSS21. Questionnaire was used as the instrument for data collection. The Ordinary Least Square (OLS) regression method was adopted to determine the linear relationship between the variables. Findings from the study showed that green debt financing had a significant effect on business entrepreneurs in Post-insurgency Northeast Nigeria. The results revealed that green equity financing also had a significant effect on business entrepreneurs in Post-insurgency Northeast Nigeria. Finally, further findings revealed that the option of using carbon credits financial instruments had a negative and significant effect on business entrepreneurs in Post-insurgency Northeast Nigeria. Based on the findings aforementioned, recommendations were made that the use of both green debt and green equity financing be encouraged among business entrepreneurs in Post-Insurgency Northeast Nigeria, and that government, policy makers and stake holders should create awareness on the immense benefits available in the usage of carbon credits for Sustainable business development.

Methods:METHODOLOGY

The study adopted survey research design. The study population covers all business entrepreneurs within northeast Nigeria. Krejcie and Morgan (1970) sample and sampling size determination table was used to arrive at a 384-sample size. Data for the study were primarily sourced, with the aid of a structured questionnaire on a five-point likert scale. Data collected for the study were regressed, using SPSS21. Questionnaire was used as the instrument for data collection and most of the questions were defined in simple format to arouse respondent interest to read carefully and answer each question to ensure easy completion.

Results:Test of Hypotheses One:

H01: Green Debt Financing has no significant effect on Business Entrepreneurs in Post-Insurgency Northeast Nigeria. From the regression result in table 1, it was observed that the calculated t-value for GDF is 3.08 and whilst the tabulated value is 1.96. Since the t-calculated is greater than the t-tabulated (3.08 > 1.96) it thus falls in the rejection region and hence, we reject the first null hypothesis (H01). The conclusion here is that Green Debt Financing has a significant effect on Business Entrepreneurs in Post-Insurgency Northeast Nigeria.

Test of Hypotheses Two:

H02: Green Equity Financing has no significant effect on Business Entrepreneurs in Post-Insurgency Northeast Nigeria. From the regression result in table 1, it was observed that the calculated t-value for GEF is 4.74 and whilst the tabulated value is 1.96. Since the t-calculated is greater than the t-tabulated (4.74 > 1.96) it thus falls in the rejection region and hence, we reject the second null hypothesis (H02). The conclusion here is that Green Equity Financing has a significant effect on Business Entrepreneurs in Post-Insurgency Northeast Nigeria.

Test of Hypotheses Three:

H03: Carbon Credit Financial Instruments have no significant effect on Business Entrepreneurs in Post-Insurgency Northeast Nigeria. From the regression result in table 1 the calculated t-value for CCFI is 1.57 and the critical value is 1.96 under 95% confidence level. Since the critical value is greater than t-calculated (1.96 > 1.57) it therefore falls in the acceptance region and hence, we accept the third null hypothesis (H03). The conclusion here is that: Carbon Credit Financial Instruments have no significant effect on Business Entrepreneurs in Post-Insurgency Northeast

Nigeria.

Discussion of Findings

Findings from the study showed that Green debt financing has a significant effect on Business entrepreneurs in Post-Insurgency Northeast Nigeria. This may not be unconnected with the drive towards renewable energy installations and migration from the expensive power generators to the much easier-to maintain solar power marketing by businesses in the region. The devastation caused by the insurgency, coupled with the recent hike in fuel prices as a result of the removal of the decades long subsidy by the government, has contributed a lot in the pursuit of green debt financing by both companies and financial institutions.

More, the results revealed that Green Equity Financing has a significant effect on Business Entrepreneurs in Post-Insurgency Northeast Nigeria. Closely related to Green debt financing is Green Equity financing where business entrepreneurs opt for green assets and stocks to finance their business ventures. The effect of green equity on business ventures is that it serves the dual purpose of resuscitating the devastated community while at the same time bringing in steady income to the entrepreneur.

Finally, further findings revealed that Carbon credit Financial Instruments have a negative and significant effect on business entrepreneurs in Post-insurgency Northeast Nigeria. This finding disagrees with Nkusi, Habtezghi and Dolles (2013) whose finding revealed the positive and significant impact of Carbon credits to Entrepreneurship financing. One of the most rational explanation to this may be the fact that the concept of carbon credits is relatively new in the region and requires a lot of orientation and awareness as to how the entrepreneurs can take advantage of it.

Conclusions:Conclusion and Recommendation

Based on the findings aforementioned, recommendations were made that the use of both green debt and green equity financing be encouraged among business entrepreneurs in Post-Insurgency Northeast Nigeria, and that government, policy makers and stake holders should create awareness on the immense benefits available in the usage of carbon credits financial Instruments for Sustainable business development.

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Keywords: Sustainable financing, Green debt, Green equity, Carbon credits

[Abstract:0688] PHD-006 [Accepted] [Energy System Transition » Policy]

Towards low-carbon development pathways for Ethiopia's transport sector

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Overview:This study outlines the creation of baseline and mitigation scenarios to foster a sustainable, low-carbon future for Ethiopia's transport sector. Leveraging the Low Energy Analysis Platform and informed by governmental policies, three net-zero scenarios—NDC-aligned, maximum ambition, and late action—are assessed from 2020 to 2050. The analysis presents emissions and energy consumption projections for each scenario, showcasing distinct pathways toward sustainability. Mitigation strategies, such as electrification, energy efficiency enhancements, and rail transport expansion, demonstrate significant emission reductions. Particularly, electrification initiatives, notably in the road freight sector, exhibit promising declines by 2050. The study emphasizes the pivotal role of rail transport and energy-efficient measures in realizing Ethiopia's low-carbon ambitions. These insights provide essential guidance for the Government of Ethiopia in prioritizing and implementing effective policies, stressing the importance of a holistic approach encompassing electrification, energy efficiency, and sustainable mass transit. Future research should refine policy combinations and
Methods:This section details the methods utilized in crafting low-carbon development pathways within Ethiopia's transport sector. The primary steps employed are illustrated in Figure 3. A key focus of the discourse lies in the development of the mitigation or net-zero pathways.
Results:The Business-As-Usual (BAU) scenario serves as the foundation for establishing the baseline of the Transport sector's Long-Term Low-Emission Development Strategy (LT-LEDS). This scenario forecasts the trajectory of energy demand and emissions in the transport sector under the assumption that existing policies and practices remain unchanged. The BAU scenario depicts a projection
of greenhouse gas (GHG) emissions in the absence of policy interventions or advancements in technologies such as renewable energy. It operates on the premise that current energy demand patterns within the transportation sector persist without significant alterations. As a result, transportation emissions are expected to continue increasing due to rising mobility demand and continued reliance on conventional, carbon-intensive fuels. The modelling exercise projects emissions from 2020 to 2050, providing insights into the sector's 100-Year Global Warming Potential (GWP). In the base year (2020), the total emissions from the Ethiopian transport sector are estimated at 4.81 million tons of CO2e.
Conclusions:The analysis of mitigation scenarios for Ethiopia's transport sector underscores the critical role of A-S-I policy interventions in achieving a low-carbon development pathway. Examining net-zero scenarios, including NDC-aligned, maximum ambition, and late action scenarios, highlights the importance of timely and ambitious actions in curbing greenhouse gas emissions and reducing energy
consumption. The obtained results indicate that interventions focused on improving energy efficiency, expanding the rail transport sector, and electrifying vehicles offer the most significant potential for emission reductions. Electrification, particularly in the road freight sector, emerges as a promising strategy, with substantial projected reductions compared to the Business-As-Usual scenario.
Furthermore, enhancements in non-motorized transport, congestion reduction, and limiting vehicle age are identified as complementary measures to decrease emissions and energy consumption in the transport sector. Looking ahead, future research should focus on several key areas. Firstly, continued analysis and refinement of mitigation policies are necessary to identify the optimal combination of interventions and their implementation timelines. Additionally, assessing these policies' socio-economic impacts and feasibility, including their effects on employment, accessibility, and equity, is crucial for ensuring a holistic and sustainable transition. Furthermore, investigating the potential synergies and trade-offs between different mitigation measures will provide valuable insights for policymakers. Moreover, research on innovative technologies, alternative fuels, and sustainable transportation infrastructure can contribute to accelerating the transition towards a low-carbon transport sector.
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Confining g-C3N4 Nanosheets in TiO2 Hollow spheres for solar hydrogen evolution

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Overview:Hydrogen is a versatile clean fuel and can be used in various industries, such as automobiles and power plants. 1 The idea of hydrogen economy or net-zero CO2 society becomes rational by utilizing sustainable energy sources for the deployment of hydrogen-based technology. One of the most sustainable methods for hydrogen production is photocatalytic water-splitting, where the photocatalytic particulate suspension decomposes water into hydrogen and oxygen with sunlight.2 Non-toxic, earth-abundant materials and green chemical methods should be utilized to synthesize an efficient catalyst.3 Material chemists believe that the integration of multi-functional inorganic and organic components is promising for solar cells or photovoltaic devices. Also, the synthesis of such catalysis is green, because multiple reactions are combined in a single synthetic operation and yield a product without purifying or separating the intermediates.4 Another example is a particulate catalyst, where the spatial organization of each catalytic component plays different roles in photochemical reactions.5
Metal oxides such as crystalline titanium dioxide (TiO2) is stable, and inexpensive particulate photocatalysts for water splitting reactions but suffer from low hole mobility and life. Impressively, the sluggish reaction kinectics of TiO2 have been addressed by the spatial distribution of mixed metal oxides such as Fe2TiO5/Fe2O3 in shell/shell, Fe2TiO5/TiO2 in shell/core hollow spheres.6-8 However, a general plan for managing the spread of inorganic/organic interfaces like TiO2 and graphitic carbon nitride (g-C3N4) in shell/shell and shell/core has not been shared yet, and these materials are being thought of as the next generation of sensors. 9 Such metal oxides/g-C3N4 interfaces in shell/shell and shell/core is advantageous as it allow the absorption of different wavelengths of light. However, for solar photons with > 90% absorbance, the thickness of metal oxide shell should be > 270 nm. This is too thick for the efficient collection of photogenetrated electrons and holes at the surface. Another strategy to achieve maximum light harvesting is the integration of different photoabsorbers in tandem configuration. In addition, control over the MO shell-thickness and pore-structure engineering ensures high performance.
Herein, I propose that sugars, e.g., glucose or sucrose, in water at low temperatures form carbon spheres (CSs) with rich (C=O, C-OH) negative ions. In water, CSs (C=O, C-OH) negative ions attract to metals (Mn+) of positive ions, e.g., Mn+ = Mn2+, Fe3+, Co2+, Ni2+, Cu2+, Zn2+, Al3+, Ti4+, Ce4+, etc. When CSs-Mn+ is heated in air, the carbon reacts with oxygen and transforms to CO2 gas, and the metal ions react with oxygen to form MO hollow shells. The proposed work gives control to produce different MO in shells with predetermined shell distances and shell thicknesses. The starting materials for conducting the proposed research are economical and green. For example, sugar is the most abundant disaccharide in nature, whereas in the earth’s crust, oxygen is the most common element (46.6 %), and titanium is the ninth most common element (0.44%). It is worth noting that the solvents utilized in the proposed research are green, such as water. In Fig. 1, the synthesis scheme illustrates three main steps: i) glucose-water solution is heated in a Teflon line autoclave to construct the carbon spheres having abundant functional groups such as (C=O, C-OH), ii) the (=O, -OH) acts as a host for guests positive charge ions such as Ti4+ ions and is electrostatically attached to each other, followed by heating in air to obtain TiO2 hollow spheres, iii) urea-water solution is infiltrated into the pores of TiO2 hollow spheres and, upon heating, obtained interfaces of nitrogen-doped TiO2 (N@TiO2) and g-C3N4. The designed work provides control over different structural parameters, such as MO shell composition, numbers, and thickness.
Methods:The synthesis of catalysis was achieved via the hydrothermal method, followed by

annealing. Staring with carbon spheres (Mn+), sequential loading of guest ions via coulomb interaction followed by one-step annealing in air yields the desired catalyst. The chemical composition and reaction fronts of integrated elements would be evaluated by X-ray diffraction, various spectroscopes, and electron microscopes. Whereas, the hydrogen photoactivity setup is as follows: a quartz reactor containing tandem catalyst suspension irradiated by simulated Xenon lamp and connected with online gas chromatography for monitoring hydrogen evaluation rate
Results:In Figure 1, the Fourier transform infrared spectroscopy (FT-IR) spectra of carbon spheres showed the presence of abundant (C=O, C-OH) functional groups. In Figures 2a–b, the scanning electron microscopy (SEM) and transmission electron microscope (TEM) images of carbon spheres showed that particles are uniformed and well dispersed. Figures c–d show that the SEM and TEM showed that heating in air removed the carbon, and uniformed TiO_2 hollow spheres were obtained. In figure 2e, the SEM-elemental mapping suggests the uniform dispersion of titanium and oxygen elements in hollow spheres. In Figure 2f, the X-ray diffraction pattern confirms that the pure anatase phase of TiO_2 is obtained. The SEM image in Figure 2g shows that adding g-C_3N_4 units to the TiO_2 matrix made the surface much rougher. This is clear proof that an interface formed between the TiO_2 and g-C_3N_4 layers. Figure. 3 illustrates the tentative photo-induced electron-hole migration pathway for N@TiO_2/g-C_3N_4 hollow spheres. Upon photon irradiation, both the N@TiO_2 and g-C_3N_4 entities generate electron-hole pairs. Because the g-C_3N_4 CB is in a good place, the electrons are moved to the TiO_2 CB and the water reduction reaction works well. At the same time, holes are moved from TiO_2 VB to g-C_3N_4 VB to stop the photoinduced recombination of electron-hole pairs. In Figure. 4a, the N@TiO_2/g-C_3N_4 hollow spheres produced H_2 with a rate of 91 μmol.g-1.h-1 and stability of 5 cycles, each lasting 6 hours. This makes sure that the H_2 photoactivity stays the same and that the N@TiO_2/g-C_3N_4 hollow spheres work well as catalysts.
Conclusions:In summary, g-C_3N_4 nanosheets are confined in TiO_2 hollow spheres, which drastically enhances H_2 photoactivity. The synthesis strategy is simple; the starting materials are green, such as glucose and water. The adapted synthesis protocol gives us control over several parameters, such as the metal oxide shell thickness and layer thickness of g-C_3N_4. The heterogeneous intricate shells having strongly coupled TiO_2 and 2D-subunits of g-C_3N_4 boost the H_2 photoactivity due to their large surface area, exposed crystal facets, and excellent photo-induced excitons separation. In light of this, we envision that the described features motivate the photocatalysis community to develop intricate shell-like hollow materials which selectively drive water oxidation-reduction reactions for photoelectrochemical water splitting
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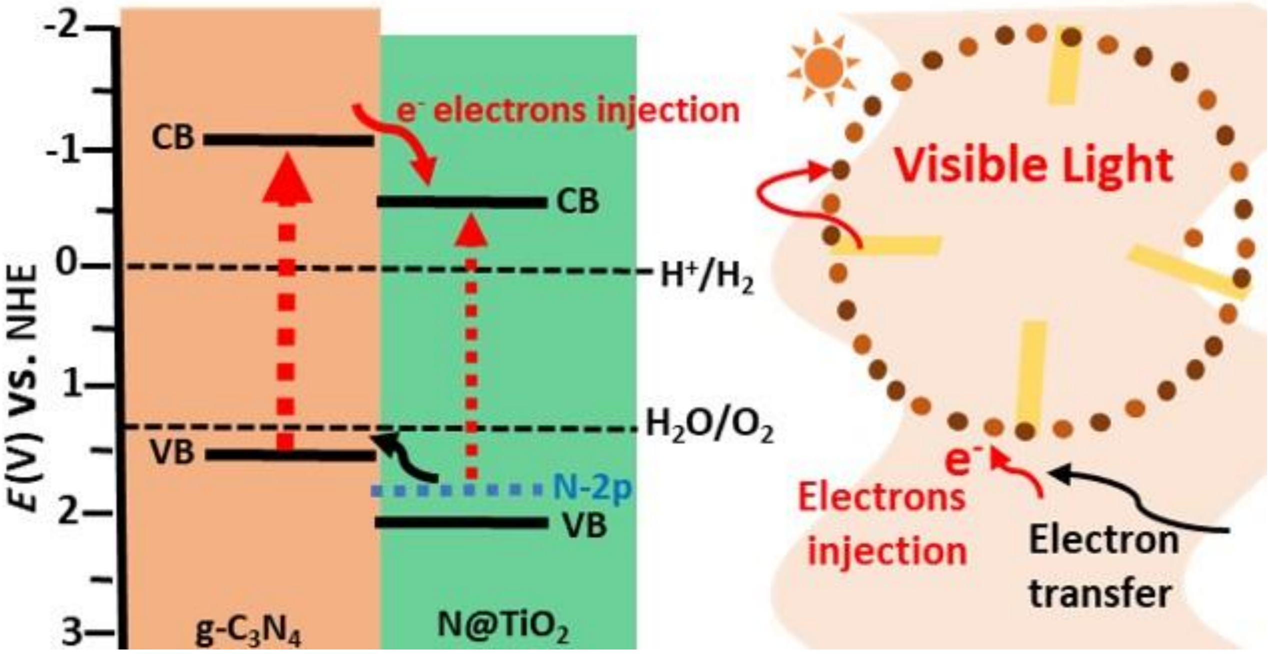
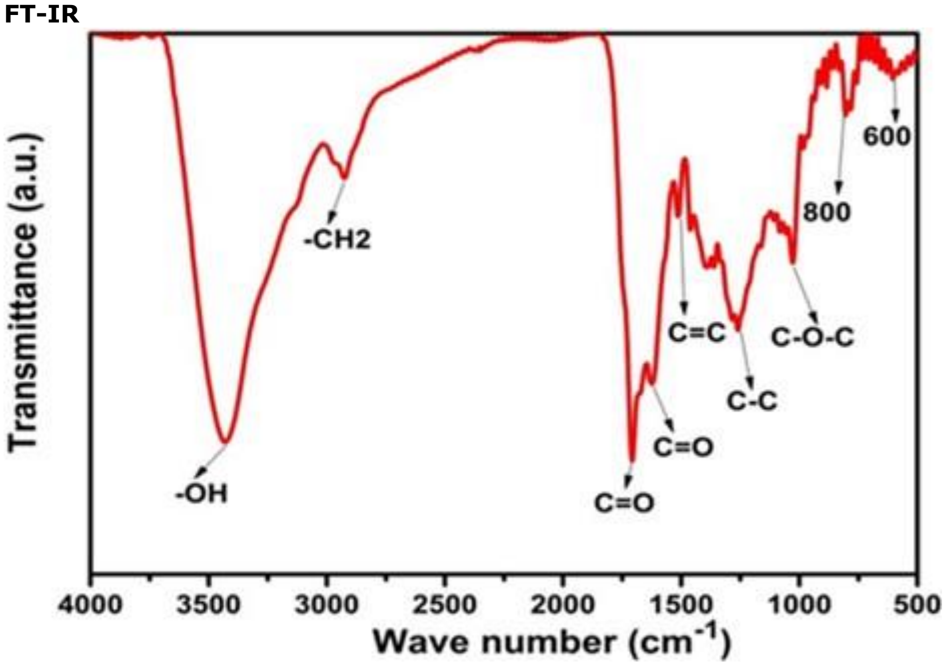
Keywords: earth abundant, hollow structure, solar energy, hydrogen production

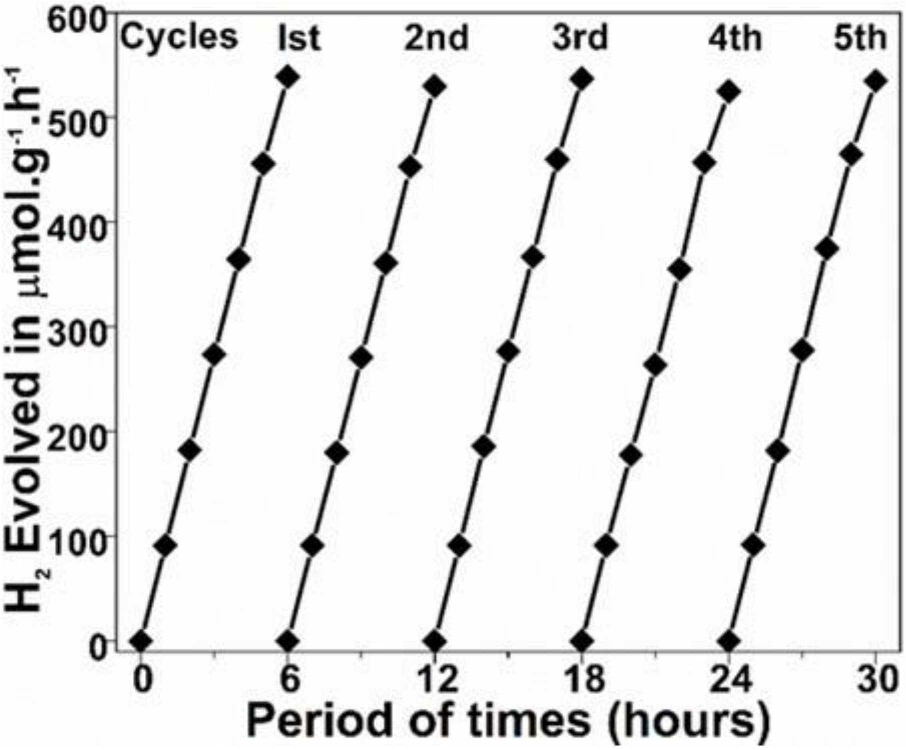
Electron Transfer pathway



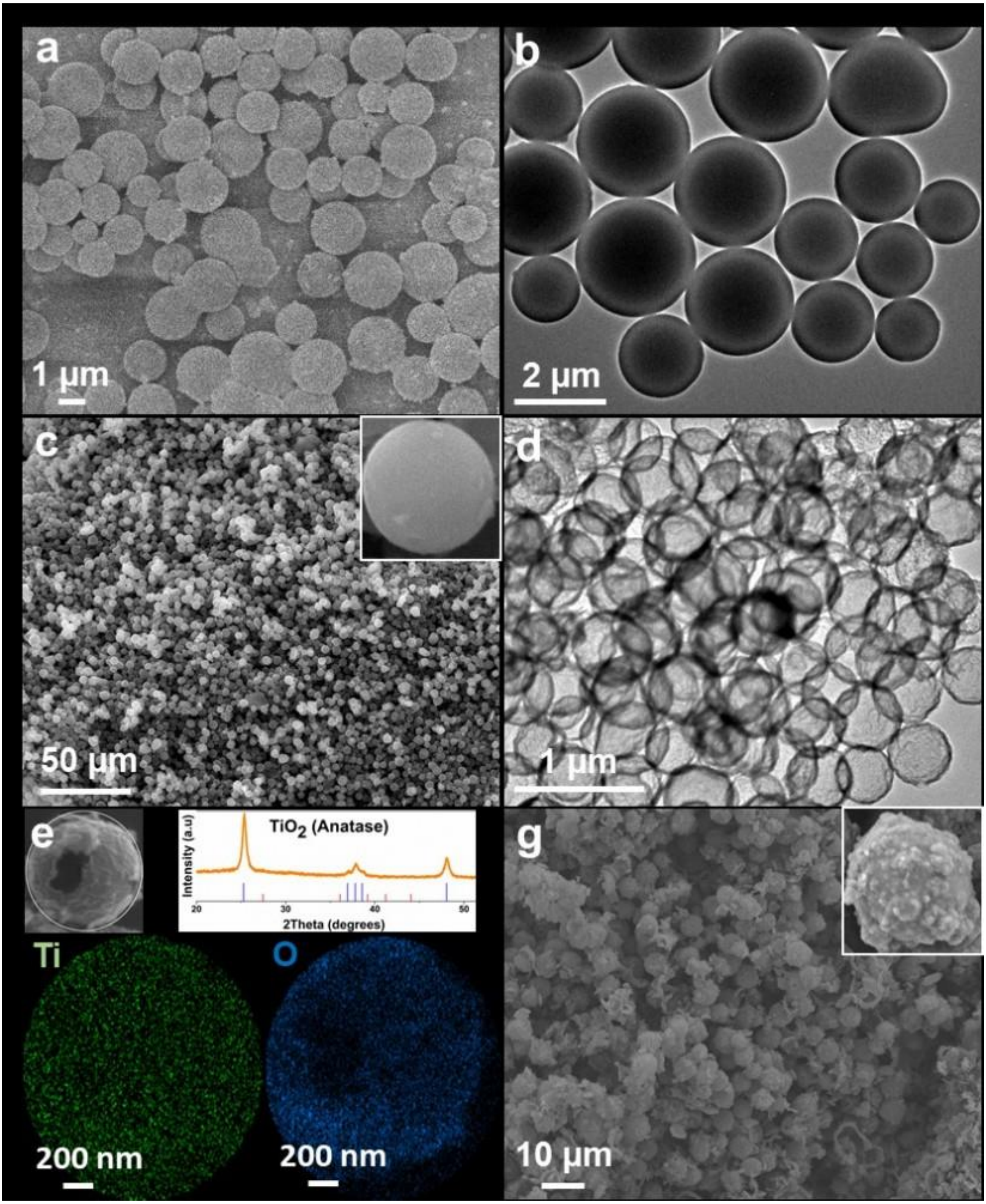
FT-IR



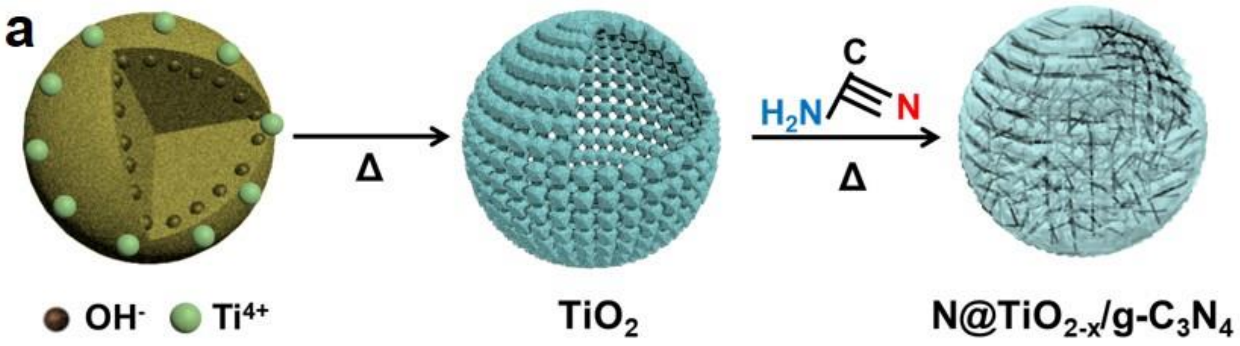
Recycling


600
500
400
300
200
100
0
Cycles
Ist
2nd
3rd
4th
5th
H_2 Evolved in μmol.g^{-1}.h^{-1}
0
6
12
18
24
30
Period of times (hours)

SEM-TEM



Synthesis Scheme



[Abstract:0691] PHD-008 [Accepted] [Energy and the Environment » Climate Change and Greenhouse Gases]

Factors Influencing the Decline of Manufacturing Pollution in the European Union: A Study of Productivity, Environmental Regulations, Expenditure, and Trade Costs

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Overview:Despite ongoing industrial production, pollution levels in the European Union have shown a consistent decline since the 1990s. This is due to several factors, such as the implementation of environmental regulations and pollution taxes, boosted productivity through the use of low carbon technologies and environmentally friendly equipment, relocation of high-carbon industries to countries with more favorable trade costs, and changing consumer behavior to prioritize sustainable products and services.
The study also reveals that reducing pollution emissions occurs due to diminished pollution per unit of output in specific industrial sectors rather than changes in overall manufacturing output or production shifts. Increased production leads to a corresponding increase in pollution emissions, and the impact of production composition on pollution varies according to the pollutant. The most effective way to reduce pollution is by increasing environmental regulations by 20%, often resulting in the complete elimination of pollution in highly polluted manufacturing industries.
This study contributes to the existing literature on EU manufacturing sectoral pollution in several ways. Firstly, we decompose air pollution emissions from EU manufacturing into scale, composition, and technical effects. Secondly, We calculate the elasticity of pollution and the elasticity of trade for the European industry. Thirdly, we conduct counterfactual scenarios with 20% increases and decreases in environmental regulations, productivity, trade costs, and expenditure share. Finally, we provide quantitative evaluations of environmental policy. Accurately interpreting the results of this research can provide more reliable insights into the importance of reducing manufacturing pollution in the EU.
Methods:This study employs a quantitative trade model integrating key factors influencing global trade, including pollution and abatement measures. It aims to understand the complex relationship between international trade and environmental sustainability, focusing on input-output analyses of

trade and the environment. The production process involves complying with environmental standards while minimizing costs and maximizing profit through enhanced technology or abatement measures. Intermediate-good producers optimize profits while considering environmental impact, resulting in pollution emissions subject to an environmental tax. The model comprehensively explores the interplay between international trade, environmental sustainability, and producers' economic choices. This section analyzes the composition effect on the manufacturing industry across 27 European nations and 35 sectors, focusing on international trade while controlling for temporal alterations. We examined the period 1995-2009, extending the literature of (copeland2003,grossman1991) to assess changes in emission intensity from manufacturing production, considering scale, composition, and technique effects.
Results:This study explored the environmental impact of economic sector changes, including emissions associated with total output, shifts in the proportion of environmentally friendly goods, and variations in pollution intensity. Increased production correlated with higher pollution intensity, indicating positive scale effects. Composition effects varied by pollutant, being positive for CO_2, NOX, N_2O, NMVOC, and NH_3, and negative for CH_4 and CO. Technique effects showed a consistent decrease in emission intensity for all pollutants. The study found that the reduction in manufacturing pollution is mainly due to changes in production techniques rather than the types of goods produced. However, the diminishing impact of techniques on this trend and the lasting influence of composition suggest evolving dynamics. Factors such as increasing abatement costs, regulatory responses, and smaller technology increments over time may contribute to the observed decline in technique efficacy in mitigating pollution. Changes in energy prices may also play a role in this reduction.
Conclusions:The paper investigates the reasons behind the decrease in pollution levels and improvement in air quality during the period of increased industrial production in Europe from 1995 to 2009. The study found that the decline in pollution levels could be attributed to the implementation of environmental regulations, increased production of carbon-intensive goods in developing or less developed countries, lower input costs, and increased productivity in low-carbon industries. Additionally, the decline in pollution emissions is attributed to a reduction in pollution per unit output within specific sectors and categories of industries, rather than a shift in production or changes in the overall manufacturing output.
Based on the findings, the paper recommends that policymakers prioritize productivity-enhancing policies that also take environmental concerns into account. Policies that support the adoption of cleaner technologies, the use of skilled labor, and the production of low-carbon goods should be encouraged. Furthermore, investments in environmentally-friendly equipment and incentives for research and development of low-carbon production methods can also be effective measures to improve both productivity and environmental outcomes. It is also recommended that policymakers prioritize stringent environmental regulations and enforce emissions standards, promote the use of cleaner technologies and renewable energy sources, and impose penalties for non-compliance to reduce emissions in Europe.
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Keywords: Environmental Account and Accounting, Environmental Taxes, General Equilibrium Model, Productivity, Quantitative Model, Technological Innovation

[Abstract:0696] PHD-009 [Accepted] [Energy Security and Geopolitics » International Energy Organizations]

How far does OECD countries’ environmental policy stringency curve their reliance on Russian energy? A dose response analysis

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Overview:The prevalence of the dependency theory on a global scale can be ascribed to the significance of redistributing resources from countries abundant in resources to nations devoid of such resources (Adams et al., 2019). Within this context, the reliance on energy resources via trade assumes a pivotal role in sustaining industries based on non-renewable energy, encompassing manufacturing and agriculture (Ramzan et al., 2022). Despite this, certain countries have undertaken proactive measures to introduce rigorous environmental policies, aiming to veer towards the path of sustainability. These policies serve the purpose of conserving the natural environment, curbing pollution, and mitigating the ramifications of climate change. Remarkably, such policies encompass a wide array of initiatives, including emissions standards, pollution control measures, renewable energy targets, and conservation endeavors change (Afshan et al., 2022). However, dependent on Russian energy supplies, OECD countries confront distinct challenges when it comes to implementing and enforcing stringent environmental policies (Smith, 2010). Given this backdrop, we investigate whether OECD's environmental policy stringency has contributed to a reduction in member countries' energy dependence on Russian fossil fuels (including gas, coal, and oil).
Methods:Our study utilizes the Dose-Response causal inference function to examine the extent to which OECD member countries depend on aggregated and disaggregated Russian energy supply, including oil, gas, and coal imports. We consider various co-variants, such as economic conditions, innovation, renewable energy production, and labor force, to ensure the validity of our analysis.
Results:Our findings reveal a significant dose response in relation to the reliance on Russian energy and the different levels of environmental policy stringency. Specifically, when it comes to oil, our analysis demonstrates that the implementation of Environmental Policy Stringency (EPS) effectively reduces the dependence on Russian oil imports. This suggests that stricter environmental policies encourage the diversification of energy sources among OECD countries, thereby decreasing their reliance on Russian oil. Interestingly, our analysis shows that the dependence on gas imports from Russia decreases up to a moderate level of environmental policy stringency. However, paradoxically, as policy stringency reaches higher levels and transitional energy sources are emphasized, the reliance on Russian gas imports increases. This finding highlights the complex relationship between environmental policies and energy dependence, indicating the need for careful consideration when implementing policies to transition to cleaner energy sources. Furthermore, it is worth noting that despite the implementation of environmental policies, some countries continue to import coal from Russia, and this reliance remains relatively stable. This implies that coal, as a transitional energy source, still plays a significant role in the energy mix of certain OECD member countries, even in the face of environmental concerns.
Conclusions:Our study reveals that EPS plays a significant role in reducing dependence on Russian oil. Additionally, it decreases reliance on gas imports up to a moderate EPS level but exhibits a paradoxical increase in dependence at higher EPS levels, where transitional energy sources come into play. Intriguingly, despite the implementation of environmental policies, certain OECD countries persist in importing coal from Russia, and this dependency remains relatively constant.
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Keywords: OECD environmental policy stringency, Russian energy supply, Dose response function

AuthorToEditor: Hi, I am late but I am submitting the full paper for your kind consideration. Thank you

[Abstract:0699] PHD-010 [Accepted] [Energy Modeling » Integrated Assessment Modeling]

Macro Model for Microgrid connections in Morocco: Implications for Water-Energy-Food Nexus

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Overview:This paper presents a macro model that aims to connect farms using microgrids in Morocco, with a focus on mapping different regions of the country. The purpose of the model is to explore the

potential benefits of integrating microgrids into the agricultural sector, specifically in terms of electricity generation, water usage, food production, livestock, and overall sustainable development. Methods:The research methodology includes a comprehensive analysis of the energy load, agricultural practices, and water management systems of a case study farm, building upon a previous micro model developed by Agadi et al. (2023) within the ongoing project MG-Farm. Julia and AnyMoD are utilized as critical analytical tools for economic and energy modeling, providing a framework to assess the financial feasibility of adopting microgrids. Additionally, the open-source modeling framework AnyMOD and the decision support tool by the Land and Water Development Division of FAO, CropWat (Version 8.0), are employed. The study proposes several scenarios to assess the impact of connecting farms via microgrids. The base scenario includes two reference farms for each region, with variations in agricultural practices and energy needs. The first scenario assumes that farms in each region are connected via a microgrid, allowing farms in each region to exchange unused energy. The second scenario assumes that half of the farms are connected to the national grid, allowing them to inject surplus solar PV generation into the grid and purchase directly from the grid. The third scenario includes additional electricity demand using electric vehicles on the farm. Results:The study's results are expected to showcase the significant potential of connecting farms using microgrids in Morocco. Implementing microgrids can enhance the efficiency of electricity usage, reduce reliance on fossil fuels, and increase the utilization of renewable energy sources. Furthermore, integrating microgrids can improve water usage by providing reliable and sustainable energy for irrigation systems, addressing water scarcity, and enhancing agricultural productivity. The research findings will contribute to the existing literature on sustainable development and offer valuable insights for policymakers, energy planners, and agricultural stakeholders in Morocco. The macro model developed in this study will serve as a roadmap for successfully integrating microgrids into the agricultural sector, fostering a resilient and sustainable water-energy-food nexus in the country. Conclusions:The developed macro model in this study is expected to serve as a roadmap for effectively integrating microgrids into the agricultural sector in Morocco, fostering a resilient and sustainable water-energy-food nexus in the country. The proposed scenarios aim to evaluate the impact of connecting farms via microgrids, integrating with the national grid, and accommodating electric vehicle usage, providing valuable insights for future implementation strategies.
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Keywords: Energy Modelling, Macro Model, Morocco, Water-Energy-Food-Livestock Nexus, Renewable energy, Resource Optimization.

[Page: 350]

[Abstract:0700] PHD-011 [Accepted] [Energy and the Macroeconomy » Other]

The Effect of Education on Direct and Indirect Household Energy Consumption in Urban and Rural China

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Overview:This study explores the impact of education on direct and indirect household energy consumption (HEC) in China, using 2017 data and distinguishing between urban and rural areas. In

2017, Chinese households used a total of 1192 million tons of coal equivalent (Mtce) energy, with 554 Mtce from direct energy use and 638 Mtce from indirect sources (i.e., embodied in consumption of goods and services). Higher education correlates with increased direct HEC per capita in both areas. Urban households with higher education tend to increase use of petroleum products, natural gas, and heat energy, while rural households still rely on coal due to accessibility challenges. Indirect HEC, 54% of the total, is influenced by income gaps with urban households contributing more due to better affordability. Meanwhile, Urban households display stronger indirect HEC pattern variations with rising education levels compared to rural ones. The findings highlight the intricate role of education in shaping China's HEC.
Methods:Energy Input-output Model
Results:a. In 2017, Chinese households used a total of 1192 million tons of coal equivalent (Mtce) energy, with 554 Mtce from direct energy use and 638 Mtce from indirect sources (i.e., embodied in consumption of goods and services).
b. Higher education correlates with increased direct HEC per capita in both areas.
c. Urban households with higher education tend to increase use of petroleum products, natural gas, and heat energy, while rural households still rely on coal due to accessibility challenges.
d. Urban households display stronger indirect HEC pattern variations with rising education levels compared to rural ones.
Conclusions:Education significantly influences China's HEC landscape, with urban households showing higher consumption and education amplifying variations in consumption patterns.
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Keywords: Education, Direct and indirect household energy consumption, Energy products

AuthorToEditor: Thank you!

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[Abstract:0701] PHD-012 [Accepted] [Petroleum » Policy and Regulation]

Evaluating the Current Fiscal Regime in the Kuwaiti Petroleum Sector: What are the Alternatives?

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Overview:Kuwait's plan to diversify the economy away from Petroleum exports must consider the current state of the industry. In order to achieve successful economic diversification, the government will have to reorganize its commitments and participation with the Petroleum industry since it consumes a large portion of the general budget. Partnering with international oil companies can reserve the liquidity needed for the diversification plans and also enhance the performance of the Petroleum industry. On the other hand, the oil fields in Kuwait demand immediate development, additionally Kuwait needs to increase the production from new assets that are technically challenging to develop, the operator "Kuwait Oil Company" lacks the expertise, technology and know-how to undertake such complex projects.
Methods:By using financial modeling, the economic output of KPSA can be measured. Financial models will provide the economic metrics on which governments and international oil companies alike will evaluate the project. Metrics such as government take, front-loaded index, IRR and MEREI are essential for the investor's decision-making process. Since the financial models used are tailor

made for this thesis, the influence of volatility of oil price, production levels and cost on the mentioned metrics above could be calculated. A well-designed fiscal regime should remain efficient for both parties under different scenarios.
Results:The output of the proposed fiscal regime proved to be acceptable by global metrics by the IOC. By additionally taking into consideration non-financial factors such as the political stability and low geological risks, KPSA can prove its competitiveness with other fiscal regimes globally
Conclusions:On the other hand, the Kuwaiti government will achieve many goals by adopting this arrangement, the government will be able to relocate more than $45 Billion in the first three years to pursue its diversification plans that would have been spent on the industry, additionally the technical tasks can be executed more efficiently with this partnership due to the international company’s global experience and cutting edge technology.
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Keywords: Fiscal regimes, Petroleum Economy, Fiscal regime attractiveness, Royalties

[Abstract:0702] PHD-013 [Accepted] [Electricity » Customer/Grid Interactions]

Smart Grids, Smart Pricing: Employing Reinforcement Learning for Prosumer-Responsive Critical Peak Pricing

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Overview:The research evaluates the efficacy of CPP strategies in incentivizing electricity consumers to shift their usage patterns during peak demand periods to flatten the demand curve. This demand response strategy aims at peak load shaving, which is critical for reducing the stress on electricity infrastructure, lowering electricity costs, and decreasing carbon emissions. The novelty of the study lies in integrating prosumer behavior, incorporating distributed energy resources (DERs) like photovoltaic (PV) panels, batteries, and electric vehicles (EVs), into the CPP model. Through simulations and the application of reinforcement learning algorithms, the paper assesses the impact of CPP in both broad and targeted offering scenarios, uncovering the complexities introduced by varying levels of prosumer integration.
Methods:The methods section of the paper outlines a sophisticated approach combining mathematical modeling and reinforcement learning (RL) algorithms to evaluate the effectiveness of Critical Peak Pricing (CPP) strategies in a smart grid environment, particularly focusing on the integration of prosumer behavior. This detailed methodology is aimed at understanding and optimizing CPP programs for both mass and targeted offerings, accounting for the dynamic interplay between the electricity distributor and prosumers equipped with distributed energy resources (DERs) such as photovoltaic (PV) panels, batteries, and electric vehicles (EVs). Here's an extended overview

of the methods employed:

Mathematical Modeling
The paper constructs a comprehensive mathematical model that represents the interactions between the electricity distributor (the utility company) and various prosumer profiles within the grid. This model encapsulates the decision-making processes of both the distributor and the prosumers under CPP schemes, considering the following key components:

Prosumer Profiles: The model distinguishes between different prosumer profiles based on their capability to generate, store, and manage electricity. These profiles are defined by the presence or absence of DERs, including PV panels, batteries, EVs, and demand response (DR) tools. The study considers a spectrum of prosumer types, from those with no DERs to those fully equipped with a combination of DERs, creating a nuanced analysis of prosumer behavior under CPP.

Distributor OBJECTIVES: The distributor's primary objective is modeled as a dual aim of maximizing revenue from electricity sales while minimizing the peak load to reduce capacity-related costs. The model incorporates the distributor's strategies for CPP announcements, considering both penalty-based and rebate-based CPP mechanisms, and evaluates the impact of these strategies on the grid's overall load profile and the distributor's financial performance.

Prosumer Response: The prosumers' response to CPP announcements is modeled through their decision-making processes regarding electricity consumption, generation, and storage. The model accounts for the prosumers' ability to adjust their load profiles in response to CPP signals, including charging or discharging batteries, modulating EV charging, and utilizing PV generation, with the goal of minimizing their electricity costs while adhering to operational constraints.

Reinforcement Learning Algorithms
To analyze and optimize the CPP programs, the study employs RL algorithms, leveraging the mathematical model to simulate the grid and prosumer dynamics. The RL framework is designed to identify optimal CPP announcement strategies for the distributor by learning from simulated interactions within the grid. Key aspects of the RL approach include:

State Space: The RL model defines the state space to encapsulate relevant information about the grid and prosumer status, including current load profiles, DER states, CPP announcements, and environmental conditions such as weather forecasts affecting PV generation and electricity demand.

Action Space: The action space for the RL model consists of possible CPP announcements the distributor can make, ranging from no CPP to announcing CPP during specific peak periods. This allows the RL algorithm to explore different CPP strategies and their impacts on the grid.

Reward Function: The reward function is formulated to reflect the distributor's objectives, rewarding actions that lead to higher revenue and lower peak loads. This function guides the RL algorithm's learning process, steering it towards strategies that optimize the distributor's performance under CPP.

Algorithm Implementation: The paper details the application of specific RL algorithms, such as Double Dueling Deep Q Network (D3QN), Soft Actor Critic (SAC) for discrete actions (SACD), and Proximal Policy Optimization for discrete actions (PPOD), to solve the optimization problem. These algorithms are selected for their ability to handle the complexity of the model and the high-dimensional state and action spaces.

Through the integration of mathematical modeling and RL algorithms, the methods section of the paper presents a rigorous approach to analyzing and optimizing CPP strategies in smart grids. This methodology not only allows for a detailed examination of the interactions between the distributor and prosumers under dynamic pricing schemes but also offers insights into developing targeted dynamic pricing strategies that can effectively manage peak load demands in the presence of an increasing number of prosumers.
Results:Efficacy of CPP in Demand Response
The analysis reveals nuanced insights into the efficacy of CPP as a demand response strategy:

Load Shifting and Peak Load Reduction: CPP successfully incentivizes load shifting among consumers and prosumers, leading to notable reductions in peak load. Initially, as prosumer participation is low, CPP effectively flattens the demand curve, demonstrating its potential in peak load shaving.
Diminishing Returns with Increased Prosumer Participation: The effectiveness of CPP diminishes with

higher levels of prosumer participation. Simulations show that as the proportion of prosumers in the grid increases, the initial reductions in peak load are offset by new peak demands created by the shifted loads, particularly during off-peak hours when prosumers charge batteries or EVs in anticipation of CPP events.
Targeted Dynamic Pricing Strategies
The study introduces and evaluates targeted dynamic pricing strategies as an alternative to mass CPP offerings, yielding significant FINDINGS:

Improved Load Management: Targeted dynamic pricing, which tailors CPP announcements to specific prosumer profiles and grid conditions, demonstrates superior performance in managing the grid's load distribution. This approach allows for more nuanced load adjustments, preventing the formation of new peak demands.
Extended Viability of CPP Programs: By preventing new peak formations and optimizing the grid's overall load profile, targeted dynamic pricing strategies extend the viability of CPP programs. They offer a sustainable solution to integrating increasing numbers of prosumers without compromising the grid's stability.
Role of Batteries and Electric Vehicles
The study highlights the instrumental role of DERs, particularly batteries and EVs, in peak load reduction:

Strategic Storage and Discharge: Prosumers with batteries and EVs can strategically store energy during off-peak periods and discharge during peak times, contributing significantly to peak load shaving efforts. This dynamic plays a crucial role in enhancing the effectiveness of both mass and targeted CPP programs.
Challenges in Load Forecasting and Management: However, the integration of batteries and EVs introduces additional complexity in forecasting peak load events and managing the grid. The variable charging and discharging behaviors of prosumers equipped with these technologies pose challenges to optimizing CPP strategies.
Financial Implications for Distributor and Prosumers
The financial analysis underscores the economic impacts of CPP and targeted dynamic pricing strategies:

Increased Distributor Profits in Targeted Scenarios: The implementation of targeted dynamic pricing strategies results in increased profits for the electricity distributor. By reducing peak loads more efficiently and avoiding the costs associated with new peak formation, the distributor can achieve higher cost savings and revenue gains.
Prosumer Savings and Participation Incentives: Prosumers benefit financially from participating in CPP programs, especially under targeted dynamic pricing strategies. The potential for cost savings and rebates incentivizes prosumer participation, contributing to the broader adoption of DERs and demand response behaviors.
Conclusions:The investigation into CPP and targeted dynamic pricing strategies within Quebec's electricity grid illustrates a promising pathway toward managing peak loads more efficiently. The nuanced approach of integrating prosumer behavior, reinforced by the strategic application of reinforcement learning algorithms, offers valuable insights into optimizing energy consumption patterns across the grid. This research advocates for a balanced approach to designing demand response programs, emphasizing the importance of equitable benefits distribution among all network participants. As we pivot towards a more sustainable and efficient energy consumption paradigm, the insights garnered from this study could inform policymakers, grid operators, and consumers alike, paving the way for a resilient and adaptable energy infrastructure.
References:Please find the comprehensive literature review and references list in the attached paper.

Keywords: Critical Peak Pricing, Demand Response, Distributed Energy Resources, Reinforcement Learning, Peak Load Shaving, Targeted Pricing

AuthorToEditor: Please find the full paper and implementation detail in the following links: Full paper: https://drive.google.com/file/d/1Ju1fU5QQ2hSpMYaifVcyV4oyQhIX0h7q/view implementation: https://github.com/srmadani/Targeted_Critical_Peak_Pricing

[Abstract:0707] PHD-014 [Accepted] [Energy and the Environment » Other]

The Impact of Modern Renewable Energy Consumption on the Green Energy Transition in the East African Community

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Overview:The need for reducing the carbon dioxide emissions (CO2) has gained great attention by scholars and policy makers across the globe, seen as an effective response to climate change. This paper investigated the impact of Green Energy Consumption on Green Energy Transition proxied by CO2 emissions in the East African Community. Green energy in this study refers to renewable energy sources except the use of solid or traditional biomass.
Methods:The authors controlled for the effects of economic growth, population growth, government effectiveness and regulatory quality. The examination of these relationships is grounded on the concept of the Multi-Level Perspective hypothesis. This study utilized panel data of the five EAC countries of Uganda, Kenya, Tanzania, Rwanda and Burundi for the period of 2000 to 2022. The analysis adopted the use of the Autoregressive Distributed Lag and Johansen Fisher Cointegration tests, and the data were sourced from the International Energy Agency and the World Bank Development Indicators (WDI).
Results:The study found that Green Energy Consumption (gec) has a statistically significant negative impact on CO2 emissions. For every 1% increase in green energy consumption, there is a 0.02% decrease in CO2 emissions in the long run. However, it was found that gec is statistically insignificant in influencing CO2 emissions in the short run.
Conclusions:Overall, the study suggests that an increase in green energy consumption has the potential to lead to a decrease in CO2 emissions.
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Keywords: Green Energy Transition, Green Energy Consumption, ARDL, EAC

AuthorToEditor: Dear scientific committee, kindly receive and accept my abstract and full paper. I will continue to improve it. I will be grateful for the opportunity to present on the PhD day. Thank you in advance for your positive response. Warm regards Muhire

[Abstract:0708] PHD-015 [Accepted] [Energy Efficiency » Energy Production and Transformation]

Coal Fired Power Plant (CFPP) Decarbonization With Co-Firing Implementation (Case Study Lontar Coal Fired Power Plant)

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Overview:The technology of the cofiring method in Coal Fired Power Plant (CFPP) divided into 3 (three), there are:
a. Direct method, where coal and biomass are directly mixed and fed into the boiler through the same or different mills.
b. Indirect methods, where one of the fuels, coal or biomass, pass a gasification process first before being mixed into the boiler.
c. Parallel cofiring, where fuels, coal and biomass, are burned in different burners and the steam produced by two boilers combined for use in the next process.
Methods:Preparation initial data as a reference for cofiring test consists of:
a. Key equipment specification data.
b. Calibration data of instrument equipment, where the latest data used during inspection activities (overhaule).
c. Plant performance or commissioning data, and
d. Plant performance data monthly.
Results:a. Operational equipment evaluation. Based on monitoring data of equipment such as furnace temperature boiler, mill outlet temperature and fans ampere, shows normal limits operating parameters of the equipment.
b. Slagging and fouling potential, resulted sulfur content rose to 0.48 wt% higher than the commissioning value, which is 0.18 wt%.
c. Net Plant Heat Rate (NPHR) during cofiring testing is 5.79% higher than coal firing with the same SFC value, which is 0.56 kg / kWh. Analysis of heat rate differences occur sawdust humidity that reduced coal mixed calorific value used into mill.
d. Co-firing test data obtained duration for 25 days with 184.42 hours and average daily operation 7 hours a day of unit operation, with use of sawdust of 2,549,080 kg, resulted total green kWh 2,195,118.
Conclusions:Based on the evaluation of the operational parameters above, boiler reheat temperature parameter right outlet side has maximum value 581.61 ºC, 1.61 ºC higher than permissible operating limit. This higher analysed due to spray control valve interference that set point reheat temperature not achieved. Sulfur content deviation during the cofiring test 0.3 wt% higher than the commissioning value, that analyzed due to coal mixing which the percentage Low Rank Coal (LRC) more than Medium Rank Coal (MRC).
For environment evaluation, the daily average emission parameters with 100% cofiring and coal firing tests do not show significant differences, that can be seen value of SOx and NOx is still below the maximum value, 550 ppm, based on the Minister of Environment Regulation No15/2019 that concerning the limit of emission quality standards for SOx and NOx Coal Fired Power Plant. Evaluation from economic result evaluation, by doing improvement co-firing method saving for fuel cost heavy equipment $137.765 (Rp2.160.115.200)/ years by using 2 excavator as heavy equipment.
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Keywords: Decarbonization, co-firing, evaluation, improvement method

[Page: 355]

[Abstract:0709] PHD-016 [Accepted] [Energy and the Environment » Climate Change and Greenhouse Gases]

Exploring the Dynamics of Climate Change Perceptions on Energy Technology Preferences in Sub-Saharan Africa and MENA regions

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Overview:In the aftermath of climate change and environmental disasters, the global transition to renewable energy sources is key for mitigating greenhouse gas emissions and ensuring sustainable development. Energy transition is a crucial priority for Africa (UNDP, 2023), a continent characterized by rapid economic growth, increasing energy demand, and a significant vulnerability to climate change (UNCC, 2020). While renewable energy technologies offer promising solutions to these challenges, their adoption is influenced by a complex interplay of factors, including economic, social, demographical characteristics of the respondent (Kizilcec et al., 2022). Pro-environmental behaviours towards climate change also revealed key in shaping individual and collective attitudes towards renewable energy technologies (von Borgstede et al., 2013). Understanding the determinants of climate engagement and how it influences preferences for renewable energy is essential for designing effective policies and interventions aimed at promoting sustainable energy transitions. However, research exploring this relationship, particularly within the context of Sub-Saharan Africa (SSA) and Middle East and North Africa (MENA) regions, remains limited.
This study aims to fill this gap by investigating the relationship between climate engagement and energy technology preferences in 10 countries (6 in SSA and 4 in MENA). By integrating perspectives on climate engagement and socio-demographic factors influencing energy choices, this research attempts to provide a comprehensive understanding of the drivers behind renewable energy preferences in these regions. Specifically, the study examines how perceptions of climate change as a global priority, beliefs about countries' responsibilities for climate change, and perceptions of climate change risks contribute to shaping public preferences for energy technologies. To capture the nuanced concept of climate engagement, this research employs Structural Equation Modeling

(SEM), a statistical technique that is particularly useful in analyzing complex relationships between observed and latent variables (Kaplan, 2008). SEM allows us to model climate engagement as a multifaceted latent construct that is reflected through various indicators such as the perceived global priority of climate change, beliefs about the responsibility for climate change, and the perceived risks of climate change.

Despite the growing body of research in the field of global climate change beliefs, the literature exploring the role of climate behaviours in shaping energy technology preferences remains scarce. This gap is particularly noticeable in the context of developing regions, where the interplay between individual actions toward climate change and the adoption of renewable energy technologies is crucial for achieving SDG7. Research conducted by Oluoch et al. (2021, 2022), Wassie et al. (2021), and Menyeh (2021) delves into the factors shaping public preferences for renewable energy in Africa. These studies highlight the multifaceted determinants of energy choices, including socio-economic conditions, environmental awareness, policy environments, and technological accessibility. Von Borgstede et al. (2013) illustrates how pro-environmental attitudes toward global warming significantly favour the increased use of renewable energy technologies and the adoption of energy-efficient behaviours. This evidence underscores the importance of environmental attitudes in influencing energy preferences, suggesting a direct correlation between ecological concern and support for renewable energy.

Methods:Data for the study comes from the EIB Climate Survey 2022. The EIB Climate Survey was conducted online by the market research firm BVA for the European Investment Bank in August 2022 in SSA and MENA reigons. Respondents were randomly selected among nationally representative panels. Panellists participated via self-administered web surveys. The total sample includes 6,105 people composed of 10 representative samples of the population aged 15 and over in each country. The representativity of samples was ensured through the quota method and samples in each country were weighted according to gender, age and region.

The structural model used in examining the impact of climate engagement (CE) on renewable energies preferences is presented in Figure 1. The structural equation model (SEM) is used in examining the impact of climate engagement on energy technology preferences. SEM is chosen for its ability to model complex relationships involving both observed and unobserved (latent) variables, making it well-suited for analysing how behavioural concepts like climate engagement influence concrete outcomes like energy technology preferences (Bollen and Noble, 2011).

In our study, climate engagement includes individuals' awareness, concerns, and attitudes toward climate change (Schuldt et al., 2018). In the context of SSA and MENA regions, where the urgency for policy-relevant indicators is critical, measuring climate engagement becomes particularly relevant. Specifically, CE was captured as a latent variable using the following observed information: i) recognition of climate change as a pressing issue; ii) acknowledgment of human responsibility for climate change; iii) climate risks perceptions encompassing several aspects that together indicate an individual's perceived threat from climate change.

Results:The descriptive statistics reveal that the majority of the respondents (75%) recognize climate change as a human-caused phenomenon, with around half (51%) considering it among the top five challenges facing their country. This indicates a significant level of awareness and concern about climate change and its impacts. Furthermore, a notable proportion of respondents have experienced direct impacts of climate change on their everyday life, income, or time spent acquiring resources, with 62% taking actions to adapt to these impacts. These insights underscore the pervasive nature of climate change in respondents' lives and their willingness to engage in adaptive behaviors.

Our empirical results reveal a significant positive relationship between climate engagement and preferences for renewable energy technologies. This aligns with the growing body of literature that suggests a strong link between environmental awareness, beliefs about climate change, The findings suggest that policies aimed at increasing public awareness and understanding of climate change could be effective in fostering greater acceptance and adoption of renewable energy technologies. Education campaigns that enhance climate literacy, emphasizing the human contribution to climate change and the risks posed by inaction, may increase public support for renewable energy policies and investments.

Moreover, the negative association observed between gender and renewable energy preferences, where females showed a lower preference for renewable energy compared to males, indicates that gender-targeted interventions might be necessary. Policies and programs that specifically address male perceptions and attitudes towards renewable energy could help in broadening support across demographics. Regional factors also played a significant role, with respondents in SSA less likely to prioritize renewable energy. This finding is particularly salient, given the region's vulnerability to climate change and the critical need for sustainable energy solutions to support its development trajectory.

Conclusions:This study aims investigate the relationship between climate engagement and preferences for renewable energy technologies in SSA and MENA regions, incorporating a variety of control variables at both individual and country levels. The findings from our Structural Equation

Modeling (SEM) analysis underscore the pivotal role of climate engagement in shaping attitudes towards renewable energy technologies.
For practitioners, especially those working in the renewable energy sector in SSA, understanding the significance of climate engagement offers a clear directive: communication strategies should not only inform but also engage the public in a dialogue about climate change and its solutions. Tailored communication that connects the benefits of renewable energy to individual and community well-being, economic development, and climate resilience could enhance engagement and support for renewable energy projects.
While this study contributes valuable insights into the dynamics of climate engagement and renewable energy preferences in SSA and MENA regions, further research is needed to deepen our understanding of these relationships. Future studies could explore the long-term impact of climate engagement initiatives on renewable energy adoption and examine the interplay between global climate policies and local energy choices. Additionally, qualitative research could elucidate the contextual factors and individual experiences shaping climate engagement and energy preferences in SSA, offering a more nuanced perspective on sustainable energy transitions.
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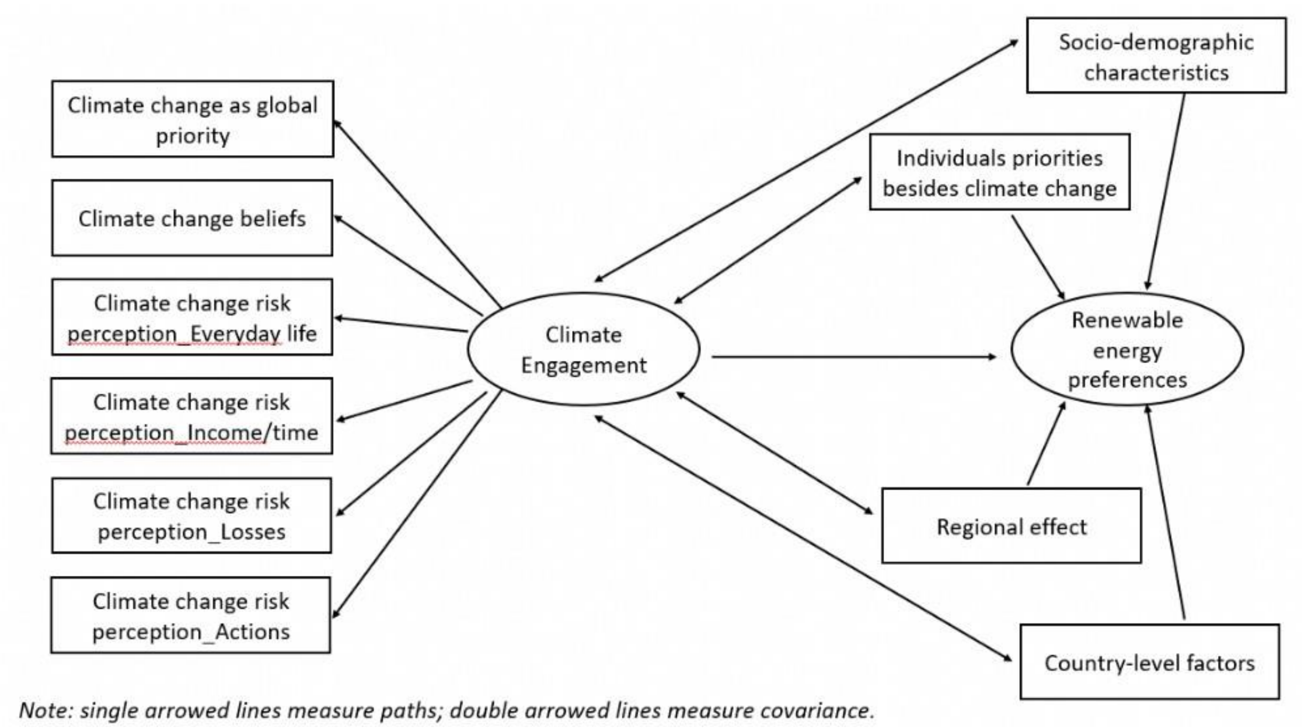
Wassie, Y. T., Rannestad, M. M., & Adaramola, M. S. (2021). Determinants of household energy choices in rural sub-Saharan Africa: An example from southern Ethiopia. Energy, 221, 119785.

Keywords: Climate-change perceptions, Renewable energy technologies, Sub-Saharan Africa, Middle East and North Africa

Figure 1. Structural model framework



[Abstract:0064] PP-001 [Accepted:Poster Presentation] [Energy and the Environment » Non-Greenhouse Gas Emissions]

A Grey Forecasting Approach to Evaluate Non-fossil Energy Potential in Carbon-neutral China

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Overview:Climate change is a major challenge facing human society in the 21st century. In response to this crisis, carbon neutrality has been proposed in recent years. Carbon neutrality refers to the total amount of greenhouse gas directly or indirectly generated by human production and life, will be offset through afforestation, energy conservation and emission reduction, and the final goal is to achieve zero emissions of carbon dioxide. More than 150 countries have proposed carbon neutrality targets, covering 92% of global GDP, 89% of the population, and 88% of emissions. China is one of the largest energy consumers and importers, as well as the world's largest carbon emitter because of its large population and booming industrial demand. To reduce the carbon emissions, China has taken many measures to develop non-fossil energy such as solar, wind, hydropower and biomass. By 2023, China has become the largest non-fossil energy market, ranking first in the installed capacity of hydropower, wind power, photovoltaic, biomass power generation and nuclear power under construction. According to the International Energy Agency (IEA), global clean energy investment has reached 1.5 trillion dollars by 2023, China's clean energy investment accounted for more than 30%. In order to further reduce carbon emissions and enhance energy sustainability, the dual carbon targets of peaking carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060 are proposed by Chinese government in 2020. To realize the ambitious target of dual carbon goals, a comprehensive analysis of non-fossil energy in China is essential. The intension of this study

is to evaluate the non-fossil energy potential and polices in China, and make some beneficial suggestions.
Methods:Grey forecasting approach was applied to non-fossil energy potential assessment in China. This study conducted an empirical evaluation of non-fossil energy resources. By analyzing the energy consumption data from government database, this study reviewed the evolving trajectory of non-fossil energy consumption over the period of 2013-2021, and made use of grey model to predict non-fossil energy consumption scale in 2030.
Results:According to the prediction results by grey model, the total national energy consumption will reach 7.2 billion tonnes of coal equivalent in 2030, and non-fossil energy account for 31%, which is a vast improvement. But more sustained efforts are needed to achieve the carbon neutrality in 2060.
Conclusions:This study conducted non-fossil energy potential in China. China have formulated a long-term program for non-fossil energy in 2022. More new energy industries are developed to increase the proportion of wind power, solar energy, biomass energy and geothermal energy in rural areas. However, China's non-fossil energy industries are more dependent on government investment. As the economic growth slows, continued government investment is confronted with great challenge in China.
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Keywords: Carbon-neutral, Grey Forecasting, Non-fossil Energy.

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[Abstract:0065] PP-002 [Accepted:Poster Presentation] [Energy and the Environment » Policy and Regulation]

Regulation, Policy and its Impact on Net Zero Emission Transition Programs

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Overview:Government enact regulations and policies to pursue energy transition towards net zero emission goal. These regulations and policies are crucial for the following action items and programs both in state-owned enterprises and private enterprises.
Methods:To assess the impact on these regulations and policies, several aspects are considered such as corporate blue print, financial investment and quick wins (programs/projects). Those data will be gathered through company latest publications such as their annual report, news and company's website.
Sampling companies are mainly picked from top 5 up to 10 companies in the region.
Results:By using samples we can recognize which institution who are making most endeavor to comply regulations and policies toward net zero emission, investing more in sustainable goals and presenting the real quick wins projects.
By average we can find most of the institution are putting net zero emission goal in their annual

report or front page website.
However, only by analyzing their investment budget and realization of projects/programs, quick wins, we can conclude which institution is capable in implementing those regulation and policies. Big projects such as floating solar power plant, electric vehicle ecosystem, B 35 or green fuels are among those projects in the highlights.
Conclusions:The novelty of impact analysis provides lesson learnt, emphasizes key business drivers that should be considered in designing effective regulation and policies in the future.
Using these lesson learnt, policy maker is able to recognize challenges and enablers to achieve net zero emission long-term goal.
References:Government regulations and policies
Examples from government agencies, state-owned enterprises and public corporation

Keywords: net zero emission, regulation, policy, investment, greenfuel

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[Abstract:0084] PP-003 [Accepted:Poster Presentation] [Renewables » Policy and Regulation]

Energy communities as the key to the heating transition: A case study on overcoming regulatory hurdles in Germany

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Overview:The urgent need to counteract global climate change has highlighted the importance of a comprehensive energy transition in recent years. To drive forward the necessary transformation, public acceptance is crucial. To promote this, concepts such as energy communities can be helpful. But regulatory obstacles stand in the way of the successful implementation of energy communities in Germany. This paper therefore quantifies the economic advantages of energy communities compared to the status quo using the example of the Hassel district park (Gelsenkirchen, Germany). A techno-economic optimization model is used for the study. The study thus discusses the effects of regulatory complexity on the optimal use of the energy system and highlights the economic advantages of energy communities: the energy is now also consumed economically where it is generated.
Methods:The energy system model is based on the approach of Hoffmann et al. (2023) and therefore builds on the FINE framework of Gross et al. (2023). The model represents a multi-node energy system with the demand sectors electricity and heat as a mathematical system of equations and is therefore a powerful tool for calculating optimized energy systems for districts. The input data includes the energy requirements for heat, hot water and electricity for each individual single and multi-family house, the available potential of renewable energies such as solar energy and geothermal energy. In addition, possible supply technologies and their technical and economic parameters are taken into account, as the model is designed as a techno-economic bottom-up model. The optimization calculations are carried out in hourly resolution, i.e. the energy balances for 8,760 hours are optimized simultaneously.
As part of this work, the energy system model (see: Energy_Model_Status_Quo) was adapted specifically to the regulatory framework considered in the Hassel district park. The regulatory obstacles are as follows:
a. The central heat pump in the technical center can only be operated using electricity from the grid.
b. The decentralized heat pumps in the single-family homes can only be operated using electricity from the grid.
c. The apartment buildings can only meet their demand for electricity via the grid.

d. The free exchange of electricity between all single-family homes and apartment buildings in the district is not possible.

These restrictions hinder the optimal use of the energy system. In order to quantify the advantages of an energy community, these restrictions are removed from the model and the differences to the status quo are examined. Therefore, the energy system (see: Energy_Model_Energy_Community) is rearranged as follows:
a. The central heat pump in the technical center can now also be operated by the PV systems installed on the single and multi-family houses.
b. The decentralized heat pumps in the single-family houses can be operated by the electricity produced on the single-family houses by means of PV systems.
c. The electricity demand of the multi-family houses can be met not only via the grid, but also via the installed PV systems (the decentralized heat pumps in the multi-family houses can already benefit from PV).
d. The free exchange of electricity is possible between all single and multi-family houses in the district.
Results:As part of this paper, the economic advantages of energy communities compared to the status quo were quantified using the example of the Hassel district. The total annual costs for setting up and operating the energy system to meet the demand for electricity, heat and hot water for the energy community fall by 29.54% from 556,112 euros/a to 391,850 euros/a compared to the status quo (see: Results_Comparison). The differences are mainly driven by the different costs of the demand for electricity from the grid (322,293 euros/a vs. 158,112 euros/a). The capacities for electrical storage (688 kW vs. 685 kW) and thermal storage (11029 kW vs. 10939 kW) decrease for the Energy Community compared to the status quo. Full utilization of the PV capacities of 535 kW is achieved in both cases.
The Energy Community's degree of self-sufficiency rises sharply from 26.69% to 43.62% compared to the status quo. The degree of self-consumption increases less sharply from 83.22% to 86.79%.
Conclusions:The study delves into the economic advantages derived from overcoming regulatory hurdles within the context of the Hassel district park in Gelsenkirchen, Germany. It unveils that establishing an energy community as a means to surmount these barriers results in a noteworthy 29.54% reduction in the overall annual costs of the energy system when compared to the existing status quo. The primary drivers of this difference lie in the diminished demand for electricity from the public grid.
This shift is notably mirrored in the heightened levels of self-sufficiency and self-consumption exhibited by the energy community in contrast to the status quo. The creation of energy communities, coupled with a reduction in regulatory constraints, emerges as an appealing prospect from the perspective of the districts.
It's important to note that this study does not account for the impacts of energy communities on distribution grid operators. This aspect necessitates further exploration in subsequent research endeavors. On one hand, the energy communities may be obligated to remit payments to the distribution grid operator, given that the electricity generated circulates among the community members through the distribution grid without incurring grid fees. On the other hand, the energy community might offer additional flexibility options that can be commercialized to support the grid, potentially mitigating the required payments from the energy community to distribution grid operators.
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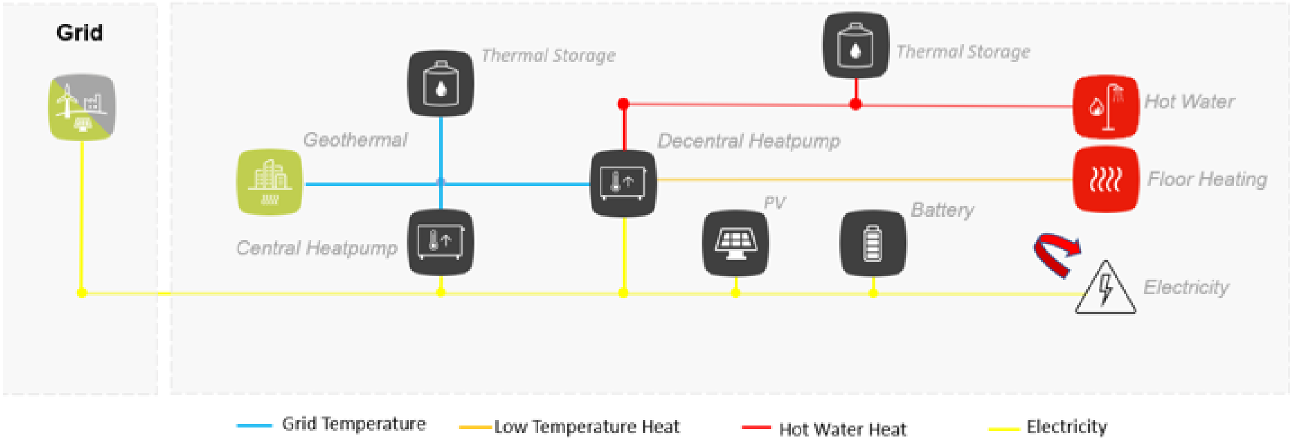
Keywords: Energy transition, energy community, acceptance of population, regulatory complexity, techno-economic optimization model

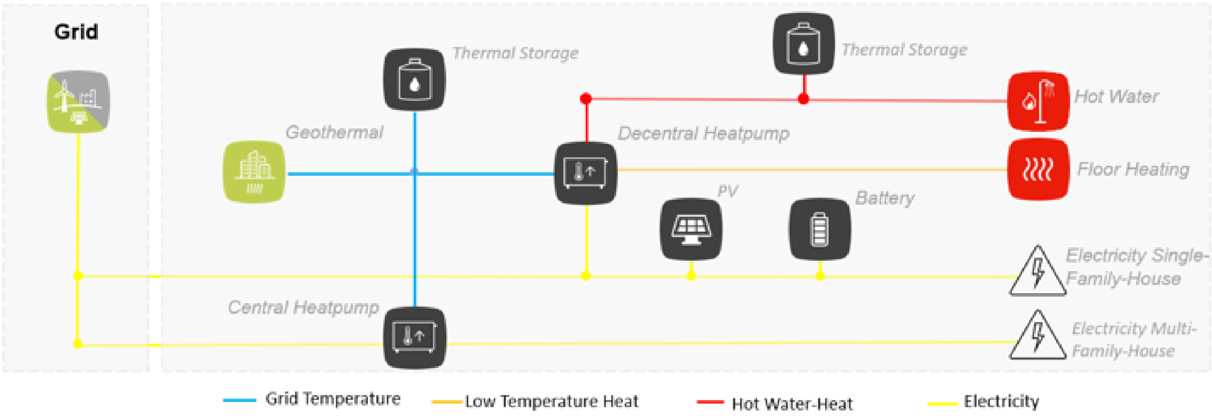
Energy_Model_Energy_Community

Figure 2: Energy System under Energy Community



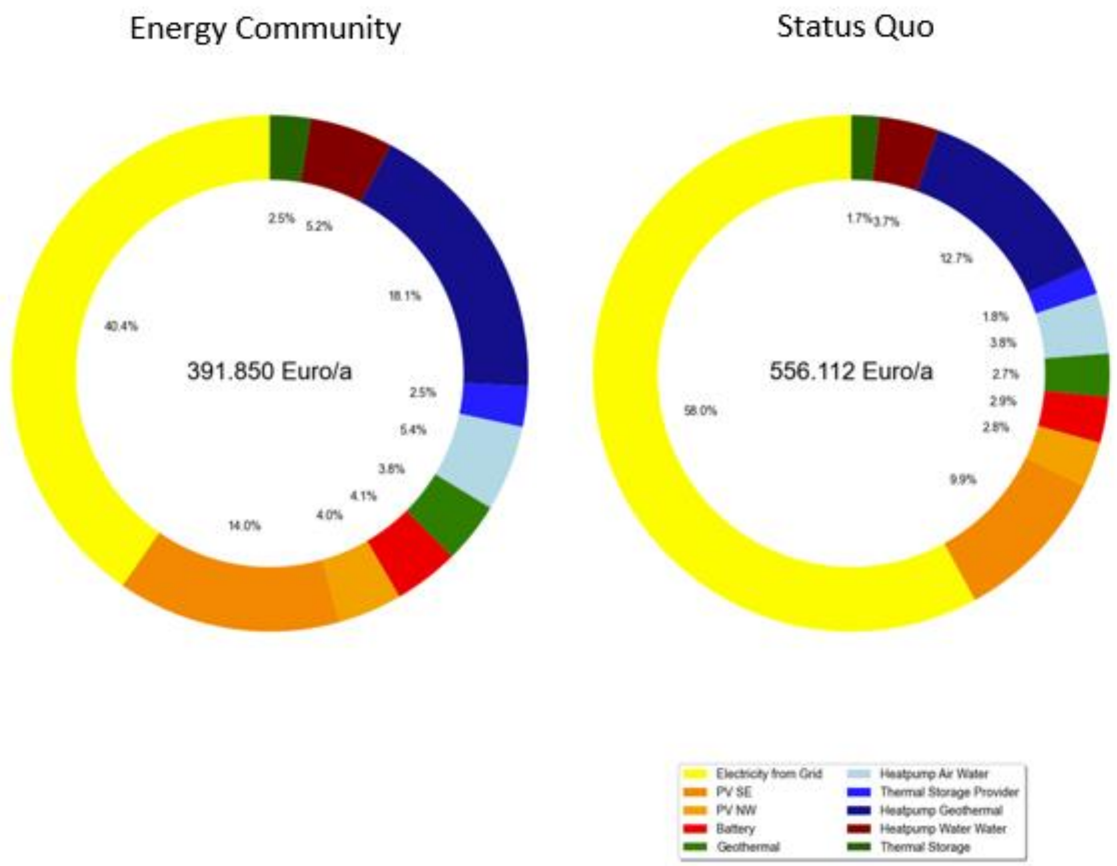
Energy_Model_Status_Quo

Figure 1: Energy System under status quo



Results_Comparison

Figure 3: Comparison of Energy System Cost



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[Abstract:0099] PP-004 [Accepted:Poster Presentation] [Energy Finance and Trading » Corporate Strategy and Investor Oversight]

Sovereign-related Risks and Market Capitalization: A Study of Two Oil Companies in Emerging Markets

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Overview:
The study draws on the pre-COVID data to analyze the business models, economic performance, and risks of two vertically integrated oil companies from emerging markets, Rosneft (Russia) and Petrobras (Brazil), which, as of mid-2020, had almost identical market capitalization while being operationally, technologically, and financially significantly distinct. It examines the challenges faced

by both companies related to their business and technological strategies, including offshore drilling and new field development, as well as sovereign-related risks that influence their market value. The author also discusses the importance of corporate governance, market-oriented industry-level reforms, and foreign investment in unlocking the potential of these companies and boosting their market capitalization.

Methods:

This study employs data gathered from corporate reports and domestic statistical databases at both the company and industry levels. Both qualitative and quantitative methods have been implemented. Qualitatively, the study examines and analyzes the business models, economic performance, and economic risks of Rosneft and Petrobras, while linking them to market capitalization. Quantitatively, the study employs financial ratios, market data, industry benchmarks, and statistical methods to extract relevant insights and establish a robust analytical framework. The analysis encompasses a review of financial and economic data, as well as an assessment of industry- and company-specific factors.

Results:

Market capitalization and ownership structure: the study highlights the similarities in market capitalization between the two companies as of mid-2020 despite differences in their economic fundamentals, attributing this phenomenon to the influence of sovereign-related risks. The impact of corruption scandals, such as the "Car Wash" scandal in Brazil on Petrobras, and "High Profile Bribery Case" in Russia on Rosneft, is explored, emphasizing the significance of governance and transparency in shaping companies' market value. Additionally, it discusses the ownership structures of Rosneft and Petrobras, shedding light on how these structures contribute to companies' overall market perception and valuation.

Oil deposits and breakeven cost estimates: the study emphasizes that both companies command a substantial share of their respective countries' oil deposits, with Rosneft possessing four times more oil reserves than Petrobras. The capital-intensive nature of tapping into these reserves, particularly in the case of Petrobras' "pre-salt oil" reserves, which require deep-water drilling and pose technical challenges, is underscored. Similarly, Rosneft faces the challenge of substituting its aging onshore fields with new onshore fields in Northern Russia and offshore on the Arctic shelf, which also demands significant technological and capital investments. The paper acknowledges the heightened oil price volatility and long-term uncertainty in global energy demand, which renders large capital investments in tapping offshore potential risky. Additionally, it provides representative estimates of the oil production costs in Brazil and Russia, shedding light on the economic considerations associated with tapping into these significant offshore resources.

Business models: the study explores Petrobras and Rosneft's business models, highlighting their unique approaches to address challenges and pursue growth. It specifically examines the capital intensity of their business strategies by comparing Petrobras's more capital- and asset-intensive models with Rosneft's. It also analyzes the net income volatility of both companies, emphasizing Petrobras' successful deleveraging efforts and their impact on the company's financial performance. Additionally, it delves into revenue, CAPEX, and EBITDA by comparing the financial metrics and operational strategies of these two companies.

Economic analysis: the study argues that Petrobras, with significantly lower volumes of production, higher debt, and a more capital-intensive business model, managed to improve its financial and operational performance in 2018-2019 and was rewarded by the market. In terms of market valuation, both P/E ratios and TEV/EBITDA multiples were strikingly similar as of mid-2020, supporting our hypothesis that Mr. Market considered these companies as twins from a balance of risks and value-generation point view.

Strategic challenges through companies' strengths and weaknesses: the study delves into the strategic responses of Petrobras and Rosneft to the challenges they face. It discusses the contrasting approaches taken by two companies in confronting these challenges, highlighting Petrobras' ambitious turnaround strategy towards a more focused, agile, and ecologically conscious business model. The chapter also addresses Rosneft's continued vertical integration through acquisitions and its potential impact on governance and operational management. Furthermore, it emphasizes the alignment of these strategic directions with the government-level policies in Brazil and Russia.

Conclusions:

The paper concludes that sovereign-related risks influence the market value of both Rosneft and Petrobras, overshadowing industry- and company-specific factors. This highlights the strategic challenges faced by both companies, including their strengths and weaknesses. While Petrobras has demonstrated its ability to adjust production costs and de-leverage, making significant turnaround efforts, Rosneft pursued extensive expansion tapping its large domestic resource base, but the agility and adaptability of its business model is yet to be tested. This study estimates the impact of oil prices on companies' offshore drilling and new field development, concluding that a price range of US $50-$60 per boe is necessary for their economic viability. Further improvements in governance and broader market-oriented reforms in the Russian energy sector are prerequisites for unlocking

Rosneft's potential and for ensuring that its advantages are sustainable. Opening Brazil's oil and gas industry to foreign investors could stimulate growth by promoting competition, fostering international collaboration, and facilitating technology transfers. Additionally, Petrobras's absence from volume-based targets, as part of the OPEC+ balancing mechanism, provides it with a competitive advantage.

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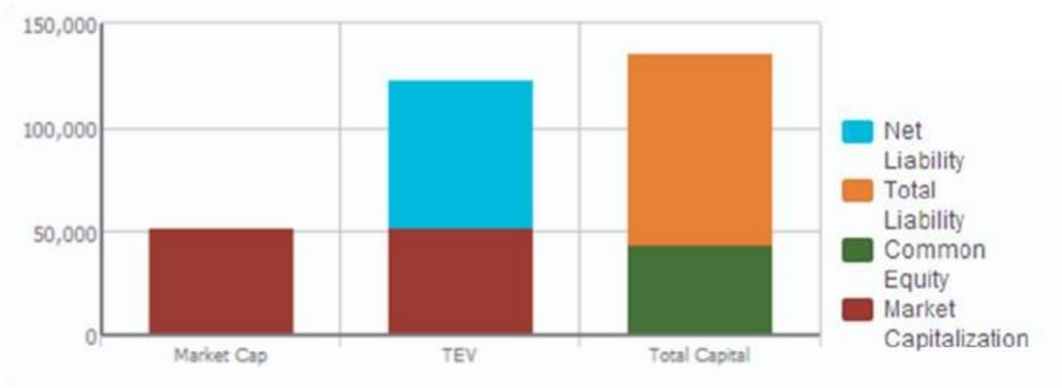
Keywords: oil companies, emerging markets, sovereign risks, market capitalization, business models

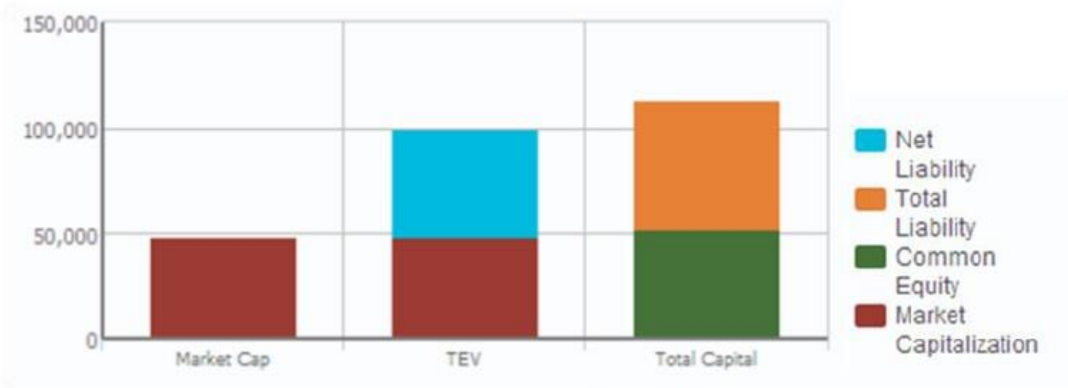
Market Capitalization

Exhibit 1: Market Capitalization (Millions of USD), August 2020



Petrobras

Market Capitalization, Total Enterprise Value (TEV), and Total Capital, US$ million



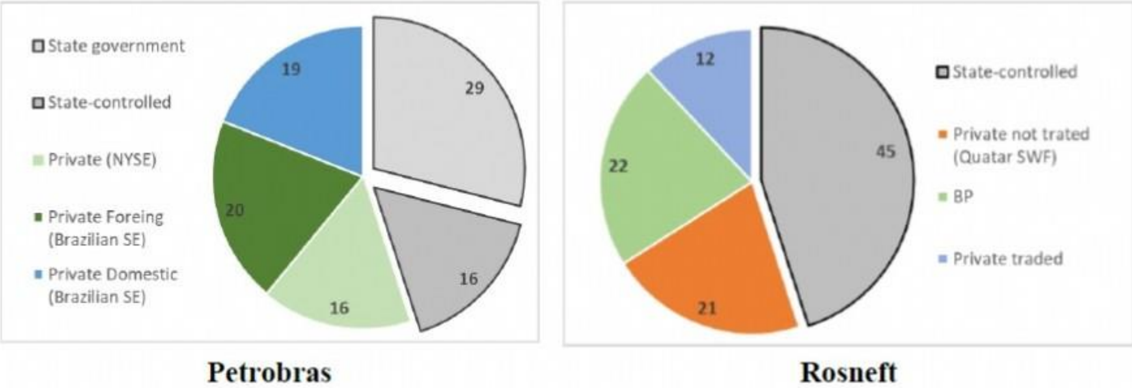
Rosneft

Market Capitalization, Total Enterprise Value (TEV), and Total Capital, US$ million

Source: Capital IQ, companies' filings, author's own calculations.

Ownership Structure

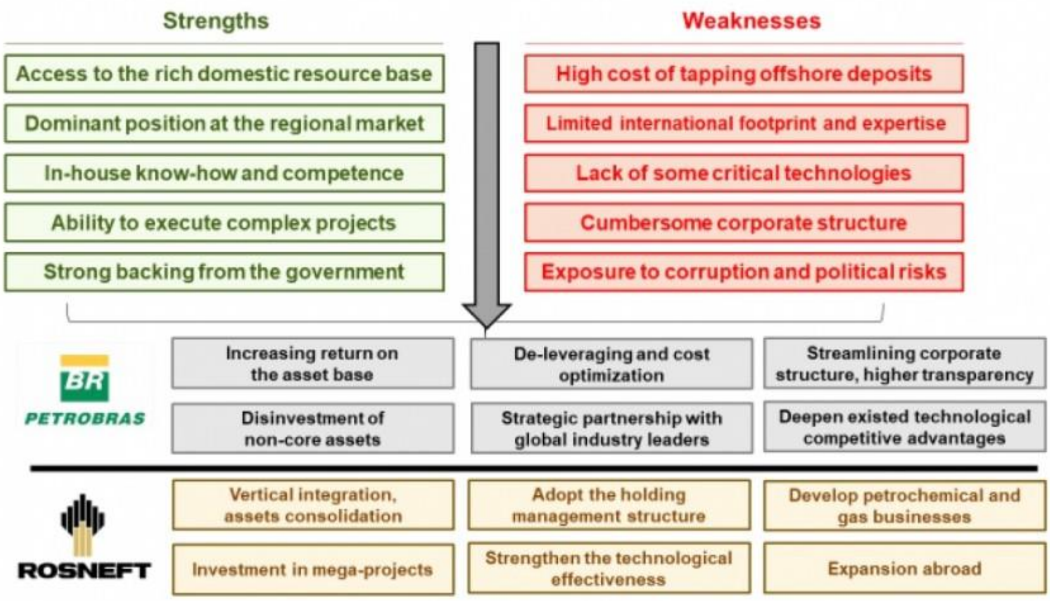
Exhibit 2: Ownership Structure, 2020



Source: S&P Global Market Intelligence, companies' websites, author's own calculations.

Strategic Priorities

Exhibit 3: Strategic priorities of Petrobras and Rosneft against Strengths and Weaknesses



Source: companies' websites, author's assessment

Estimated breakeven cost of oil production, US$/boe

Breakeven costs	Petrobras (offshore), $	Petrobras (offshore), %	Rosneft (onshore), $	Rosneft (onshore), %
Capital spending	$16.09	46.0%	$5.10	26.5%
Production costs	$9.45	27.0%	$2.98	15.5%

Admin/transport	$2.80	8.0%	$2.69	14.0%
Gross taxes	$6.66	19.0%	$8.44	43.9%
Total	$35.00	100.0%	$19.21	100.0%

[Page: 360]

[Abstract:0104] PP-005 [Accepted:Poster Presentation] [Renewables » Geothermal]

Numerical study of a new Earth-Air Heat Exchanger configuration in cool regions of Algeria

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Overview:In this article, the numerical results of the study on a geothermal-air heat exchanger system in cold areas of Algeria (Constantine region) were presented. This system consists of a new configuration of the earth–air heat exchanger (EAHE). In these conditions, a good agreement between our simulation results and those from the literature was found. A parametric analysis of the new geometry of the EAHE was carried out with the aim of investigating the effect of the pipe length, diameter, pitch and the air velocity on the outlet air temperature and the EAHE's mean efficiency. The simulation results showed that the EAHE was capable of increasing the cold ambient air temperature by 10°C. In addition to this, a maximum effectiveness of 0.61 was observed at 2 m/s for the smallest diameter pipe.
Methods:The computational fluid dynamics platform FLUENT was used in the study and employed the finite volume method to convert the governing equations into numerically solvable algebraic equations. The outputs of the numerical calculations were validated with the experimental results.
Results:Based on the numerical results, the following remarks were made:

1- For all selected depths, the critical depth for efficient heat exchange in EAHEs is 6–7 m.
2- The decrease of the pipe diameter causes an increase in the outlet air temperature. Based on the results of this study, it is recommended to use a pipe diameter of 110 mm to cool closed areas in the city of Constantine.
3- The outlet air temperature increased with decreasing air velocity.
4- The increase in the pitch distance in the spiral pipe causes the the outlet air temperature from the EAHE to decrease.
5- The mean efficiency η decreases when the air velocity increases. The maximum decrease was found for a higher pipe diameter of 250 mm and a lower air velocity (V=2 m/s). The maximum decrease in η is about 21%, between pipe diameters 110 mm and 250 mm.
Conclusions:In this study, the thermal performance of a spiral shaped configuration of EAHE was investigated for heating mode in cold regions in Algeria. Numerical simulation was performed using ANSYS FLUENT commercial software. The model has been validated with experimental results found in the literature. The influence of different variables including pipe length, inlet air temperature, diameter pipe, air velocity and pitch spacing on the effectiveness was analyzed during the coldest months of the year 2023.
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Keywords: Earth-air heat exchanger, heating, Geothermal energy, spiral pipe, numerical study

Figure 11. Evolution of the mean efficiency versus the air velocity for different diameters

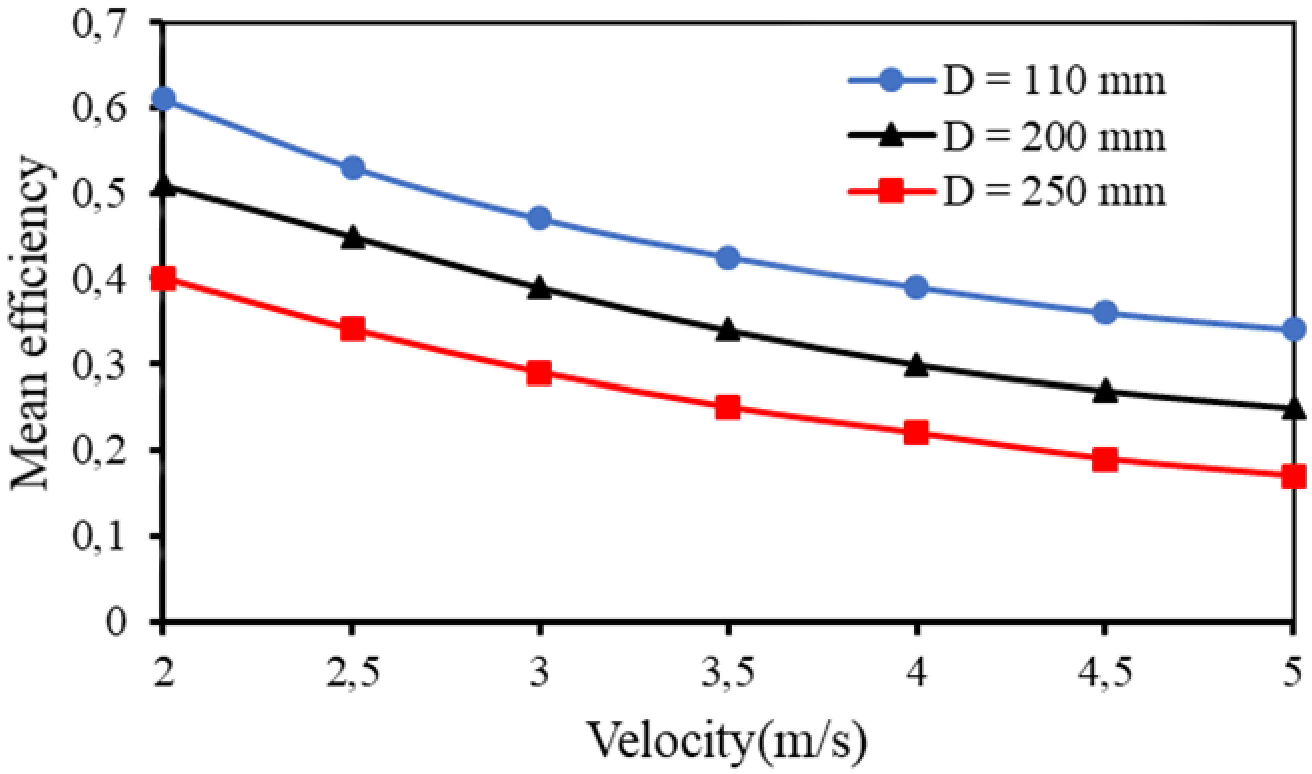
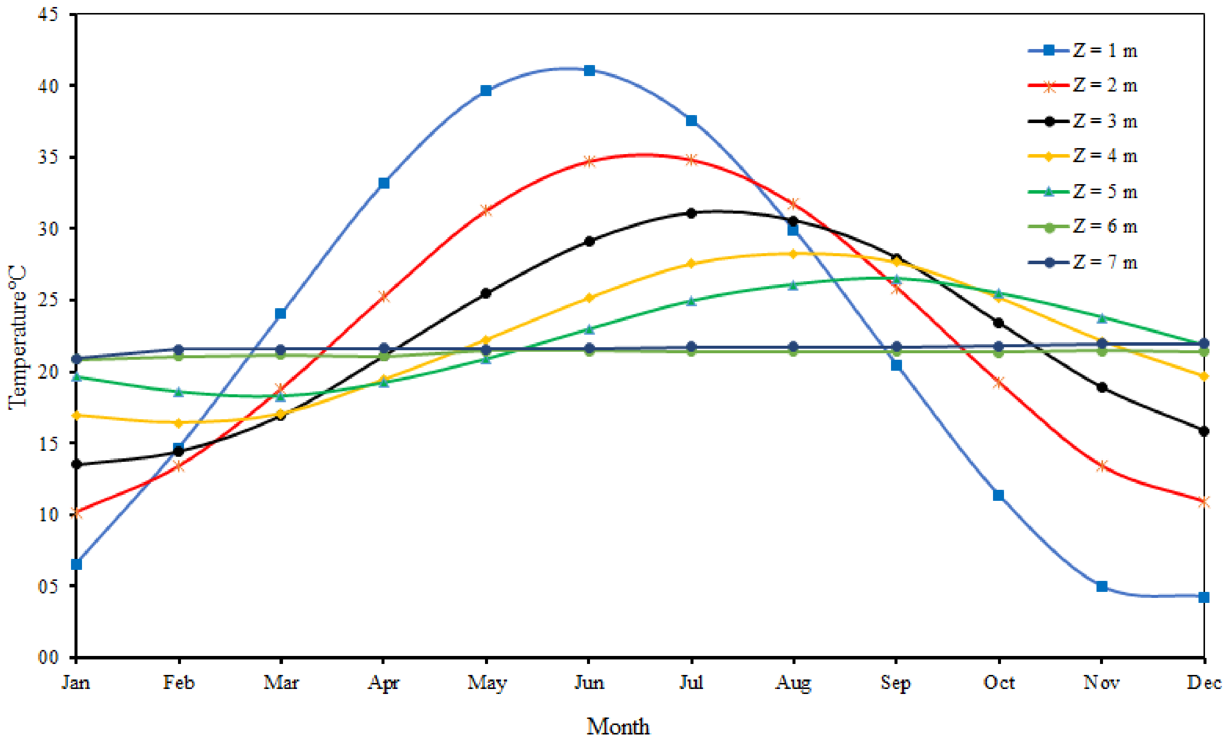


Figure 11. shows the variation of the mean efficiency with respect to the air velocity for pipes of different diameters at a constant ground temperature of 10 °C. It can be observed in this figure that the mean efficiency decreases as the velocity of air increases. The explanation for this is that the increase in the velocity of airflow causes the volumetric flow rate inside the pipe to increase, which in turn reduces the time of flow of air molecules inside the pipe. In consequence, the total rise in temperature inside the pipe is reduced, and thus the effectiveness of the EAHE system decreases. In addition, it is also clear that the mean efficiency of a smaller diameter pipe is greater than that of a larger diameter pipe, because when the pipe diameter decreases the contact surface between the tube and a unit volume of air become greater.

Figure 2. Variation of annual soil temperature in the region of Constantine at different depths



The variation of soil temperature values at different depths in Constantine were calculated using MATLAB. The results are shown in Figure 2. The figure shows that variations in the soil temperature decrease at higher depths, and become essentially unchanged at depths of 6 m or higher. Because significant temperature fluctuations at certain depths attributed to environmental factors can reduce the efficiency of the EAHE, it is important to understand the soil temperature distribution and the critical depth in order to design and operate energy-efficient EAHE.

Figure 4. Geometry and mesh of the soil domain

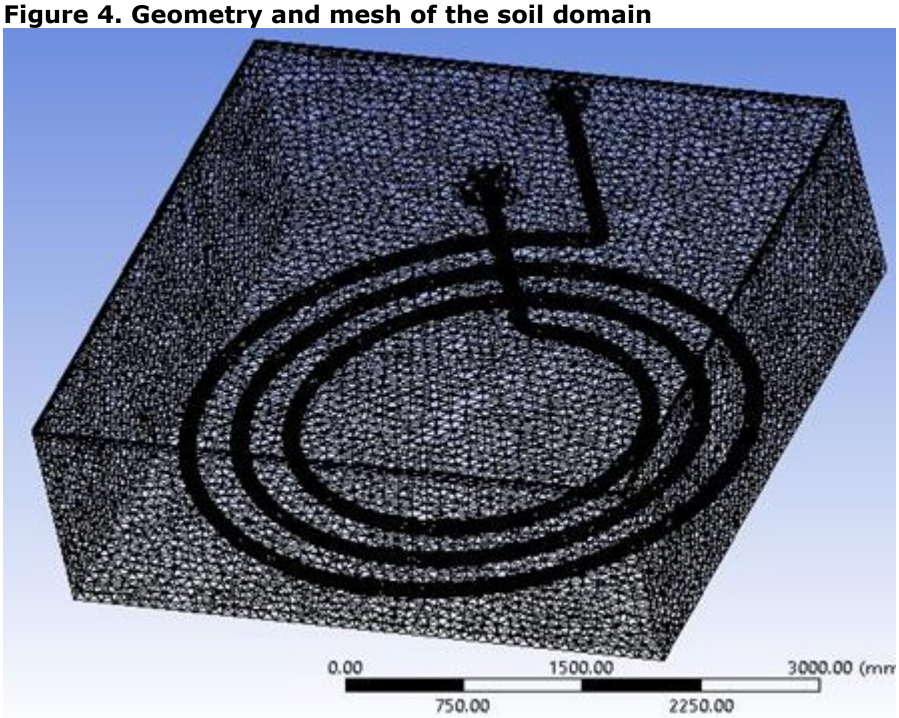


Figure 4. shows the volume dimensions of the soil as a domain of calculations that are: height H = 2 m, and with a square surface. Due to the high insulation of the pipe, we assume that the air temperature inside the vertical pipe does not change due to the difference in soil temperature around it. The lateral boundary conditions are supposed to be adiabatic.

Parameters of the Earth-Air Heat Exchanger used in the simulation

Parameters [m]	Values
Pipe Length	30
Pipe Diameter	0.11
Pipe Depth	6
Pitch Distance	0.4

AuthorToEditor: The city of Constantine has a rather cold climate in winter, this is why we wanted to study the use of a heating method based on a renewable geotherlam energy (EAHE). The study gave encouraging results for the use of this method in the city of Constantine.

[Abstract:0112] PP-006 [Accepted:Poster Presentation] [Energy Security and Geopolitics » Regional Analysis (North America)]

Give me a break, oil companies don't need them: a case study of drilling incentives in Louisiana oil & gas

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Overview:On July 31, 1994, Louisiana halted all taxes on hydrocarbon production from new wells in the state for the initial 23 months post-completion or until well cost payout, whichever occurred first, in efforts to stimulate oil & gas activity and promote economic growth. Methods:To evaluate the impact of the new severance tax provision, I gathered county-level panel data on all the new wells in Texas and Louisiana parsed by county—and parish—before and after the policy change. Using Texas as a control group, pre and post-treatment comparisons of the growth in wells in each state provide estimates of the effect of the tax break on Louisiana's energy industry. I specifically study changes in the same outcome variable, new wells, through a differences-in-differences (DiD) approach in five distinct geographical regions within both states as robustness checks to provide supporting evidence of the causal effect of the law: 1. localities within the Haynesville Shale, 2. all localities of Texas and Louisiana as a whole, 3. localities along the Texas-Louisiana border, 4. comparable localities in specific regions of each state, and 5. and specific localities within Louisiana. Results:Contrary to the intent of the law, I find no indication that the new tax break increased growth in Louisiana. Conclusions:This paper empirically finds that the 1994 New Discovery Well exemption did not lead to new wells in Louisiana, ceteris paribus, compared to its sister state Texas. Study results suggest severance tax breaks act as money transfers, rather than production hurdles which cause deadweight loss. While there are no current studies regarding the tax loss from this drilling incentive, the Louisiana Legislative Auditor reported that the state had loss upwards up $1.1 billion in a four-year period from a similar drilling incentive, indicating that the loss in revenue could be substantial, assuming these incentives had similar effects (Purpera, 2015). Nevertheless, this study does not suggest that higher severance taxes compose a "free lunch," since every penny into a state's tax bucket must come from a company's shareholders, its customers, or its employees. While this study provides evidence of broader implications in tax policy in the energy industry, it is neither my conclusion nor my intention to suggest that all tax incentives have no statistically significant effects, i.e., are useless. Fair conclusions from this paper should be limited to discussions about the tax policy regimen in the state of Louisiana, and more specifically the 1994 tax break.
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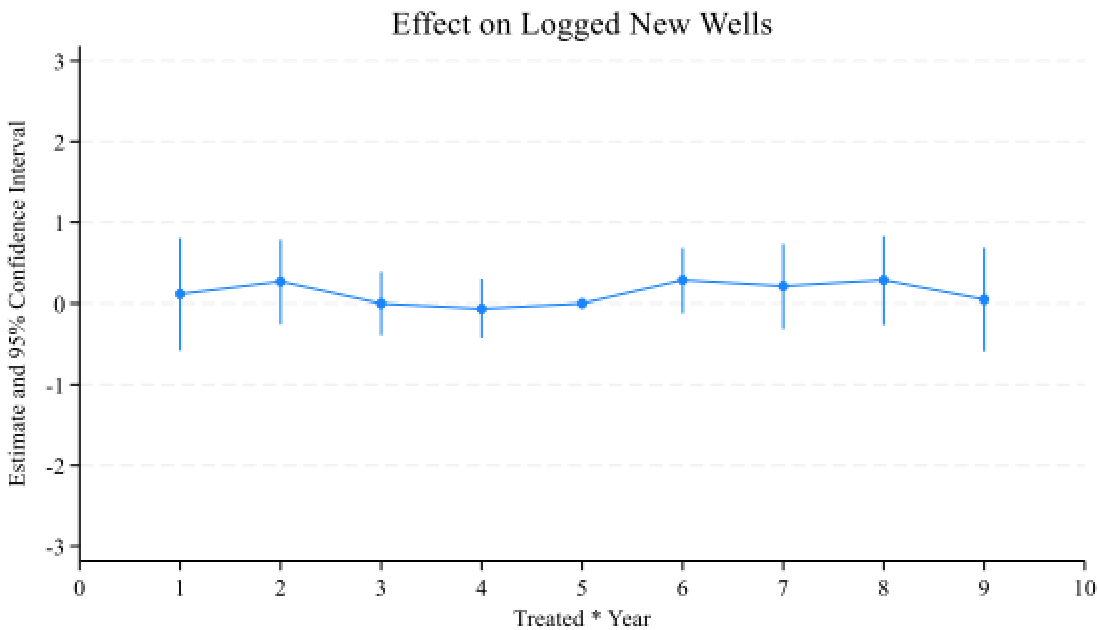
Keywords: Energy Economics, Oil and Gas Production Taxes, Energy Law, Louisiana Severance Tax

Effect on Logged New Wells



Event study (as attached) supports evidence of the parallel trends, the most important assumption of the DiD model. The plotted coefficients are zero for statistical purposes, with all confidence bars before treatment and after treatment being near identical (treatment occurred when x-axis = 6, with the fifth value being set to 0 on purpose).

Baseline DiD Model

treat	-0.081 (0.84)
post	0.236 (0.158)
change1994	-0.231 (0.277)
cons	3.547*** (0.667)

Results show statistical insignificance of the 1994 tax break, providing evidence of the law's failure in spurring growth in Louisiana.

[Abstract:0117] PP-007 [Accepted:Poster Presentation] [Energy Security and Geopolitics » Energy Security]

Energy security and sustainable development of oil and gas sector in Nigeria

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Overview:Energy security is a critical component of a nation's sustainable development, and for an oil and gas-rich country like Nigeria, it is particularly pivotal. This study explores the multifaceted dimensions of energy security in the context of Nigeria, delving into the challenges, opportunities, and policy considerations that shape the sustainable development of its oil and gas sector. Nigeria is one of the largest oil and gas producing country in West Africa Sub region. The country has been striving to attain national and energy security.
Methods:The methodological frame work of the study involves the use of literature review, policy documents and case study. The methodology also involves using a PESTLE (Political, Economic, Social, Technological, Legal and Environmental/ Ecological) analysis. In strategic management a pestle analysis is a common tool for assessing exogenous influences for market prospect and as such it was deemed a transferable tool to analyze the factors influencing energy security in a developing country like Nigeria.
Results:The study finding reveals that for a country like Nigeria which is a mono based economy. Without energy mix, it is very challenging to achieve energy security despite being endowed with fossil fuels. However, Nigeria has the potential to increase its energy security in future by diversifying it energy resources, decarbonizing the oil and gas industry by utilizing its enormous gas resources and integrating with other African country especially in the energy market. Several factors were observed to be influencing energy security in Nigeria among which are political, economic, social, technological, legal/regulatory, environmental and ecological.
Conclusions:The study recommends keying into renewable energy especially in this era of energy transition and adopting energy efficiency principle. In conclusion, the PESTLE analysis of energy security in Nigeria highlights the interplay of several factors. Achieving energy security requires a holistic approach that addresses economic resilience, political stability, social inclusion, technological innovation, legal frameworks, environmental sustainability, and adequate infrastructure. Policymakers and industry stakeholders must navigate these factors to create a secure and sustainable energy future for Nigeria.
References:Nil

Keywords: Mono based economy, energy security, energy transition, diversification, renewable energy and sustainable development.

[Abstract:0153] PP-008 [Accepted:Poster Presentation] [Energy Finance and Trading » Other]

The impact of digital financial inclusion on CO2 emission sub-Saharan Africa Countries

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Overview:Carbonomics has become a popular area of study due to the growing threat posed by climate change and global warming, which are mostly caused by rising greenhouse gas levels. The adverse effects of climate change, including water stress, decreased food production, an increase in the frequency of extreme weather events, and slower economic growth, are already being felt disproportionately in African countries (Cozzi, Daniel, & Bouckaert, 2022). These effects are causing mass migration and regional instability. In addition to being a threat to life, climate change also offers a chance to restructure the global economy. It is appropriate to apply digital technologies and contemporary trends that are currently provided by the digital economy in order to reduce those emissions and their detrimental impacts on the environment (Kovacikova, Janoskova, & Kovacikova, 2021). This shift reflects declining clean technology costs and shifting global investment. More digital financial service deployments are currently taking place in sub-Saharan Africa than in any other region of the world, with 218 million active users over half of the approximately 401 million mobile money accounts individual users worldwide in 2022 (Taylor, 2023). Increased access to financial services encourages and supports manufacturing and industrial activity, which could result in higher CO_2 emissions, which would accelerate global warming. However, digital financial inclusion makes it easier for enterprises and individuals to obtain beneficial and cheap financial plans, which increases the viability of investments in green technologies and reduces the proportion of heavy-polluting industries.

Although Africa is the lowest emitter of GHG today as compared to other regions of the world like Asia, the United States, and Europe, strangely it remains the most vulnerable to the effects of climate change due to the fact that the output from the climate change-sensitive agriculture sector is a major source of income. (Beg, et al., 2002), (Huq, et al., 2011) (Olubusoye, 2020). As a result, increased economic expansion in Africa will also result in increased carbon emissions, which will have an increased impact on climate change in Africa. Based on its insignificant global emission contribution, this study will provide one of the tools on how SSA countries may leapfrog the pollution and environmental degradation stage of their growth.

Methods:Ehrlich (1971) introduced the well-known IPAT model, which states that environmental impact (I) is a function of population expansion, Affluence (A) and Technological advancement (T). The model has been improved due to their static nature and it does not experience variable or factor electricity. Because of these restrictions, we adopt the (Dietz & Rosa, 1997) propose the extend version of IPAT model to the “Stochastic Impacts by Regression on Population, Affluence and Technology” (“STIRPAT”) as follows:

$$I_{it}=\alpha_{it} P_{it}^{\beta_1} A_{it}^{\beta_2} T_{it}^{\beta_3} \varepsilon_{it} \quad (1)$$

Where I represent the impact (I) of human activities and aspect on environment(P), A is presented the Affluence which represents the scales of economy, T refers to technological advances or expenditures for country I at time t. β1, β2 and β3 are elasticities regarding variables P, A, and T. In the logarithm form model (1) is transformed as:

$$\ln I_{it}=\alpha_{it}+\beta_1 \ln P_{it}+\beta_2 \ln A_{it}+\beta_3 \ln T_{it}+\varepsilon_{it} \quad (2)$$

The STIRPAT model has been expanded multiple times to incorporate additional significant environmental influences. The environmental impact is represented as the level of carbon emissions in this study. The present analysis expands upon the fundamental STIRPAT model in (2) by incorporating certain control variables that have been found to have an impact on emissions in the current literature, in addition to DFI. In this study we add other variables such as GDP per capita (Pablo-Romero & Bouznit, 2016), (Mardani, Streimikiene, Cavallaro, Loganathan, & Khoshnoudi, 2019), Energy intensity (Shahbaz, Solarin, Sbia, & Bibi, 2015), (Dogan & Inglesi-Lotz, 2017), FDI (Essandoh, Islam, & Kakinaka, 2020), (Chandran & Tang, 2013), trade openness and industrialization (Li & Lin, 2015). Therefore, to test if DFI could play a potential role in the environment, the environment model to be estimated will be as follows based on the study of Salman et al. (2022)

$$ghg_{it}=\beta_0+\beta_1 ghg_{i,t-1}+\beta_1 dfi_{it}+\beta_2 gdp_{it}+\beta_3 enint_{it}+\beta_4 fdi_{it}+\beta_5 trade_{it}+\beta_6 indus_{it}+\gamma_i+\varepsilon_{it} \quad (3)$$

In Eq. (1) above, ghgit greenhouse gas emission for country i over period t; ghgit-1 is the lagged value of the dependent variable for country i over period t; dfiit is digital financial inclusion for country i over period t, gdpit gross domestic product for country i over period t, enintit energy intensity level of primary energy, indusit is a measure of industrialization, fdiit is the foreign direct investment, tradeit represents trade openness for country i over period t, in the second equation we introduce a interaction term, γ and individual fixed country effects where εit a stochastic error term.
Results:In our case (GMM estimation), depending on the proxies used, it is evident that the lag-dependent variable, GDP per capita, financial inclusion (only number of ATM) conditional to the use of mobile phone, trade openness and mobile phone subscribers have shown consistent outcome in all the models estimated. Compared to the four models, on average if the lag CO2 emission increases by 1 %, the current CO2 emission will increase by almost 0.86% ceteris paribus. For financial inclusion, the number of ATM only has a positive causal relationship with the CO2 emission in all the models. In addition, when we conditional the use of financial inclusion proxies to the use of mobile phones, we find a negative causal relationship between CO2 emission and financial inclusion (only the number of ATM) in all models. On average, 1 % increase in the digital financial inclusion led to 0.064 % increase in the CO2 emission. But when we conditional on the use of mobile phones, a 1 % increase in the digital financial inclusion led to a decrease in CO2 emission by 0.022% on average in all the models. Trade openness also has a positive causal relationship with the CO2 emission in all the models.
Conclusions:The current level of global warming needs to be improved to face the future challenge due to the annual population growth and expected economic growth in SSA countries. The demand for both the clean and dirty fuels is guaranteed to increase as energy is an important input in the production of goods and services. For SSA countries, firms with less environmental policy and rural populations which have a higher population growth would tend to consume dirty energy (Ali, 2021). This excessive demand for dirty energy is expected to produce more CO2 and harm the environment. Based on the result, which shows a negative impact between the number of ATMs conditional to the use of mobile phones and the CO2 emission borrowers from a commercial bank and energy consumption, the role that energy consumption plays on CO2 emission. Therefore, policymakers should encourage the financial sector to promote the so-called "green loan" (Lyu, Da, Ostic, & Yu, 2022) to discourage the growth of energy-intensive and capital-intensive firms that aggravate CO2 emission.
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Keywords: Digital financial inclusion, sub-Saharan Africa, CO2 emission.

[Page: 364]

[Abstract:0155] PP-009 [Accepted:Poster Presentation] [Energy Finance and Trading » Other]

A relational view on the EU ETS: Relational mechanisms as drivers of firm EUA trading behavior

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Overview:The European Union Emission Trading Scheme (EU ETS), designed to lower CO_2 emissions as part of the broader effort towards EU climate neutrality, has recently entered its final phase. Meanwhile, plans for the ETS 2.0 starting in 2027 have been stated, so it is a timely moment to reflect on the functioning of the EU ETS in terms of firm trading behavior.

Much research on the EU ETS has focused on market efficiency and dynamics, with studies reporting, for example, the presence of trading asymmetries (Abrell et al., 2022) and transaction costs (Jaraitė-Kažukauskė & Kažukauskas, 2015). A central research avenue concerned firm trading behavior in terms of their likelihood to engage in emission allowances (EUAs) trading (e.g., Abrell et al., 2022; Jaraitė-Kažukauskė & Kažukauskas, 2015; Zaklan, 2013) and choose certain types of transaction partners (e.g., Cludius & Betz, 2018; Hintermann & Ludwig, 2023).

Relational mechanisms – broadly defined as micro-level social processes guiding the interactions – are recognized as an important factor in selecting transaction partners (Lomi & Bianchi, 2021), but empirical evidence in the context of the EU ETS remains limited to a handful of studies. For example, Karpf et al. (2016) found evidence of triadic closure in the EU ETS trading network, as well as an overall tendency of the firms to exchange EUAs with firms from the same country and those belonging to the same owner. Similarly, next to identifying other factors underlying the choice of transaction partners, such as degree-based preferential attachment, Karpf et al. (2018) showed that the prevalence of relational mechanisms varies over time, which is indicative of the EUA trading network dynamics. Another study by Hintermann and Ludwig (2023) further confirmed some of the earlier findings, showing that firms from the same country are more likely to engage in EUA trading.

In contributing to the growing literature on firm trading behavior in the EU ETS, we use relational event modeling to explore relational mechanisms underlying the transfers of EUAs. Relational event modeling is a statistical method that builds upon survival analysis while also accounting for the presence of local dependencies in longitudinal relational data (Butts, 2008). The results of our exploratory EUA trading network analysis show that trading partner selection is driven by several relational mechanisms: inertia (i.e., transacting with prior transaction partners), reciprocity (i.e., role-switching of EUA receivers and senders), and different triadic network effects (i.e., transacting with firms that share common transaction partners). For the EU ETS market participants and policymakers, these findings provide novel insights into the functioning of the market and its efficiency, suggesting that trading partner selection might be driven by key relational considerations other than a mere minimization of trade-related transaction costs.
Methods:*Empirical setting*
The EU ETS operates on the so-called "cap and trade" basis, whereby the volume of annual greenhouse gas emissions is regulated and reduced with every year of the scheme's operation. Complying firms, that is, firms operating in industries that are subject to emission reduction targets, are held accountable for their annual CO_2 emissions. In the second and third phases of the scheme, EUAs could be bought from the auctions or exchanged, either bilaterally, via over-the-counter (OTC) trades, or organized exchanges. Upon receiving EUAs from the government (if any) for the current year at the end of February, firms need to submit their verified emissions report for the preceding year by the end of March and surrender the corresponding amount of EUAs before the end of April. An overview of the EU ETS compliance cycle is illustrated in Figure 1 (European Commission, 2015, p. 101).

Data
All EUA transfers are recorded in the EU ETS Transaction Log, with data becoming publicly available after a three-year time lag. Given that its first phase was a pilot and that information on the fourth phase transactions is only starting to become available, we focused on the second and third phases of the EU ETS. Instead of directly scrapping data from the Transaction Log website, we used the pre-processed version of the dataset made available by Abrell (2023). In this dataset, accounts are matched to the Orbis Bureau van Dijk database, which simplified the subsequent pooling of the accounts for firms that have more than one account and made it possible to easily obtain firm-level data, such as information on firm size and ownership structure.

As decisions about trading are typically made at the level of firms (Venmans, 2016), we followed prior studies (e.g., Abrell et al., 2022) in using firms as the level of analysis. Since every firm may have multiple (types of) accounts in the EU ETS registry, we consider all transactions across accounts affiliated with a focal firm as those of that firm. The sample we use for analysis includes all firms from the EEA economic area that had at least one active operator holding account (OHA), person holding account (PHA), trading account, or person account in the EU ETS national registry in the period from 2012 until 2020. We further restricted the sample by only considering the external and internal transfers of EUAs between registries, as well as supplementary program transactions, thereby omitting the allocations of EUAs by the government and surrender of EUAs by complying firms. In addition, we only considered the transfers of EUAs, Certified Emission Reduction Units (CERs), and Emission Reduction Units (ERUs). On top of that, we excluded all within-firm transactions. Finally, in case multiple transactions among the same pair firms were recorded as taking place at the exact same moment in time, we only kept the first one of these to prevent overestimation of network effects.

Variables
An operationalization table with an overview of the variables included in the statistical model is presented in Table 1.

Statistical analysis
In preparing transaction data for the analysis, we used the eventnet software (Lerner & Lomi, 2020). Using eventnet, we first constructed a sample of non-events by using case-control sampling with 10 non-events per observed event and dynamic risk set. That is, for every instance of observed EUA transfer (N = 50,950), we randomly sampled 10 transfers involving firms that could have initiated a trade at a given time point but did not do so. Next, we used eventnet to compute the network statistics of interest for all 560,450 relational events. The processed longitudinal dataset was then analyzed with a Cox proportional hazards model using the R survival package (Therneau & Lumley, 2015).
Results:The descriptive statistics and correlations are presented in Table 2, while the output of the Cox proportional hazards models is reported in Table 3. Although several variables are highly

correlated (r > 0.7), the examination of VIF values for the estimated regression coefficients revealed no substantial multicollinearity (see Appendix A).

Model 1, which only included control variables, has a high value of concordance (90 %). In line with prior research, firms from the same registry (b = 2.939, p < 0.001) and those belonging to the same global ultimate owner (b = 5.589, p < 0.001) were more likely to trade EUAs. In contrast, and again mimicking prior findings, firms from the same industry were less likely to engage in EUA trading (b = -0.743, p < 0.001), though this effect was not statistically significant in the full model. In addition, firms were more likely to transfer EUAs to larger firms, as evidenced by the significant negative effect of size assortativity (b = -0.023, p < 0.001). Finally, financial firms were more likely to both send (b = 3.078, p < 0.001) and receive (b = 2.546, p < 0.001) EUAs.

Model 2, which included networks effects, has an even higher concordance value than the controls-only model (99.4 %). Its lower value of the AIC (19,231.940) suggests a better fit to the data than that of Model 1 (AIC = 107,419.500). The findings show that both dyadic and triadic network effects account for the choice of transaction partners. To that end, firms tended to transfer EUAs to those to whom they have transferred them in the past (b = 1.449, p < 0.001) and those from whom they received EUAs in the past (b = 0.283, p < 0.001). In addition, firms were less likely to transfer EUAs to firms that shared more common buyers with them (b = -0.098, p < 0.001) and more likely to transfer EUAs to firms that shared more common sellers with them (b = 0.207, p = 0.004). Despite there being no evidence of transitivity (b = -0.008 p = 0.804), focal firms were less likely to transfer EUAs to those that often sent EUAs to firms from whom focal firms received EUAs themselves, as evidenced by the significant negative effect of cycle closure (b = -0.173, p < 0.001). Finally, firms were more likely to engage in EUA trading if they more often initiated (b = 1.204, p < 0.001) or received (b = 0.910, p < 0.001) EUAs in the past.
Conclusions:The analysis of EUA trading behavior in the second and third phases of the EU ETS revealed that relational mechanisms are at play in how firms select transaction partners. Adding to prior research concerning country-, owner-, and industry-based (dis)assortativity in EUA trading, we find that trading partner selection also relies on important relational mechanisms, namely inertia, reciprocity, as well triadic network effects. These findings yield novel insights into the functioning of the EU ETS. The presence of relational mechanisms in EUA trading is indicative of firms relying on existing networks of trading relations with other firms as a means to overcome trade-related transaction costs. As a result, trading partner selection decisions can be driven by relational considerations, as opposed to economic considerations, as commonly thought.
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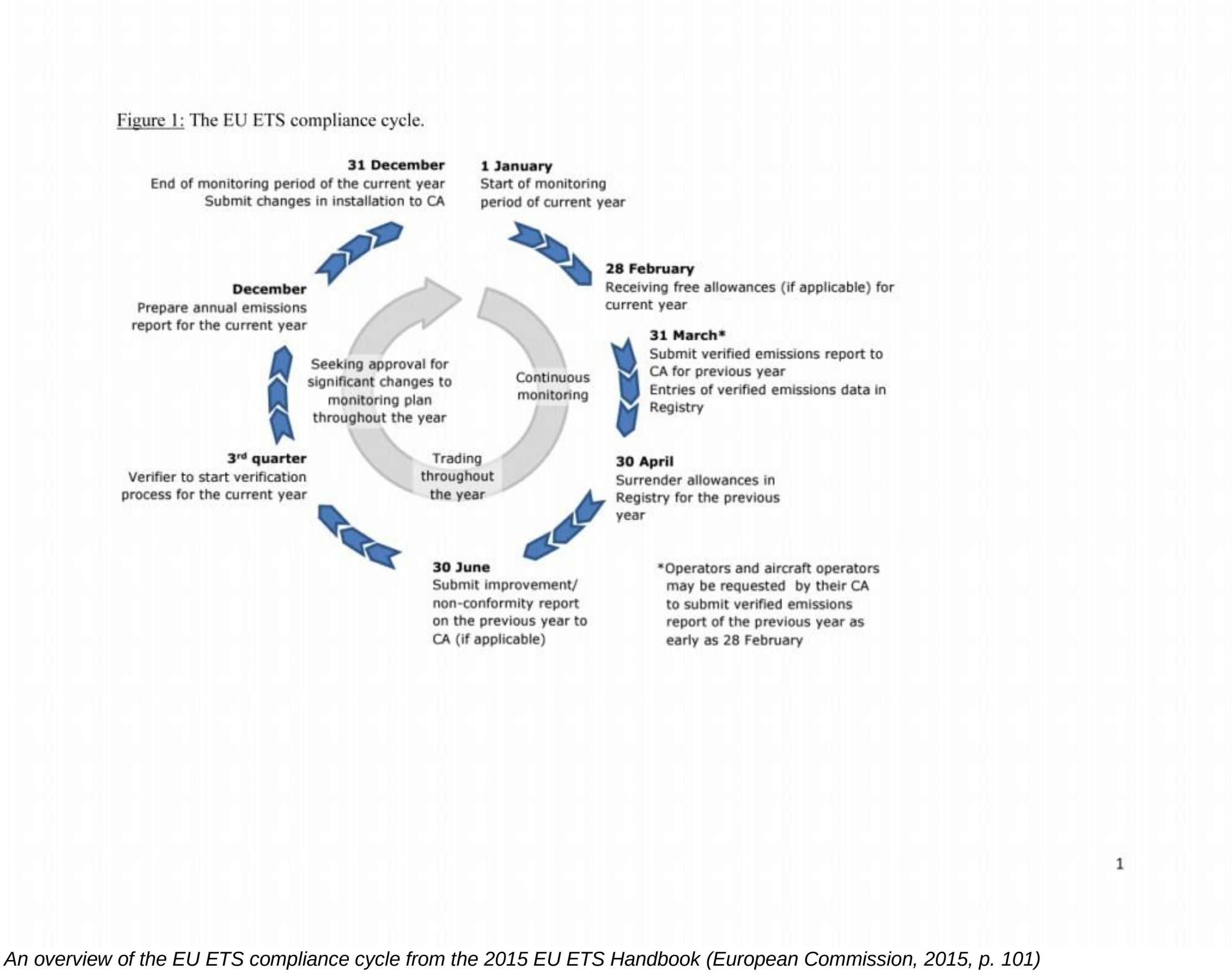
Keywords: EU ETS, EUA trading network, relational event modeling, relational mechanisms

Figure 1: The EU ETS compliance cycle.



An overview of the EU ETS compliance cycle from the 2015 EU ETS Handbook (European Commission, 2015, p. 101)

[Abstract:0192] PP-010 [Accepted:Poster Presentation] [Energy and the Environment » Policy and Regulation]

Adapting to Heatwaves in the elderly population: Behavioral Patterns and Strategies

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Overview:The city of Paris has been identified as a high-risk area for heat-related mortality among individuals over 85, emphasizing the urgency of addressing excess mortality during heatwaves. The severe impact of the 2003 heatwave in France underscores the significance of understanding excess mortality causes, notably heat-related diseases. Climate change exacerbates heatwave frequency, contributing to prolonged implications on public health and economic sectors. Physiological and psychological consequences of heat stress affect worker health, safety, and productivity. Moreover, heat stress correlates with mental health disorders, necessitating proactive strategies to mitigate these effects. Inadequate behavioral responses to heatwaves pose a vulnerability, particularly among the elderly. This study focuses on cognitive functions, perceptions, emotions, beliefs, and digital usage to explore adaptive behaviors' inequality among the elderly.

Existing literature on heatwaves and their impact on vulnerable populations provides a foundation for understanding the complexities involved. The exceptional heat event of 2003 in France serves as a benchmark, revealing stark increases in mortality, particularly among individuals aged 75 and over. The causes of death during this period varied, including heat-related diseases, infectious diseases, accidental falls, and undetermined causes. Notably, excess mortality is differentiated by the place of death, with implications for age distribution. Moreover, climate change is acknowledged as a significant contributor to the increased frequency of heatwaves, necessitating proactive strategies to mitigate their impact on public health, mental well-being, and economic productivity.

The primary objective of this study is to delve into the interplay between cognitive functions, perceptions, emotions, beliefs, and digital usage in shaping adaptive behaviors among the elderly during heatwaves. The research seeks to bridge existing gaps in the literature by employing latent class analysis (LCA) to identify distinct adaptation profiles. Additionally, latent transition analysis (LTA) is applied to explore behavioral transitions in response to varying heatwave severity. By achieving these objectives, the study aims to contribute valuable insights for developing targeted prevention strategies and guiding behavioral responses during heatwaves.
Methods:A comprehensive methodology has been devised to achieve the study's objectives. A survey, administered to 300 participants aged 55 and older, serves as the primary data collection tool. The survey explores various aspects, including cognitive capacities, beliefs, health impact perceptions, and digital usage patterns. The utilization of latent class analysis allows for the identification of distinct adaptation profiles within the population. Furthermore, latent transition analysis is employed to scrutinize behavioral transitions based on preventive measures, shedding light on population attributes transitioning between profiles in response to varying heatwave severity.
Results:The application of latent class analysis reveals three distinct adaptation profiles within the elderly population. Approximately 41% of the population takes no proactive measures, 25% reacts moderately regardless of heatwave severity, and 34% promptly adopts all precautionary measures. These profiles offer valuable insights into the heterogeneity of adaptive behaviors among the elderly during heatwaves. Latent transition analysis further explores the dynamics of behavioral responses, highlighting how populations transition between profiles in response to changing heatwave severity. The results underscore the need for a nuanced understanding of cognitive, emotional, and belief-related determinants shaping these behavioral responses.
The distinctive contribution of this study lies in its segmentation of behaviors, encompassing cognitive

capacities, beliefs, perceptions of health impacts, and digital usage. This comprehensive approach enhances not only the ability to characterize vulnerability among the elderly populations but also deepens the comprehension of the determinants driving behavioral changes. The study's focus on the elderly population recognizes their likelihood to exhibit alterations in cognitive functions, perceptions, emotions, and beliefs, resulting in a distorted perception and disturbed emotion. By identifying and understanding these nuances, the study paves the way for targeted prevention strategies tailored to specific needs.
Conclusions:This study provides a comprehensive analysis of the nexus between cognition and actions in pro-reactive adaptation to heatwaves among the elderly in France. The results, highlighted through latent class analysis, indicate three classes of adaptive behavior related to older people according to the intensity of the heatwaves. Moreover, cognition emerges as a significant driver of adaptation, influencing beliefs, a main driver of adaptive behavior to heatwaves. Additionally, computer skills among the elderly enhance willingness to adopt actions in case of heatwaves. Beyond these insights, the research carries significant implications for informing public health policies and interventions geared towards mitigating the impact of heatwaves on vulnerable populations. Despite the study's contributions, certain limitations, such as sample size and reliance on self-reports, are acknowledged. Future research avenues could explore the predictability of behavioral intention through past behavior and the desire to perform the behavior, further enhancing our understanding of adaptive behaviors during heatwaves.
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Keywords: Heatwaves, adaptation, cognition, beliefs, latent class analysis, health information

AuthorToEditor: Dear Scientific Committee, I am excited to submit my poster titled "Adapting to Heatwaves in the Elderly Population: Behavioral Patterns and Strategies" for your consideration. This visual presentation explores the behavioral responses of the elderly to heatwaves, highlighting crucial adaptation strategies. While presented in poster format, this research offers significant insights for multiple fields, including public health and behavioral sciences. Specifically, it delves into how older individuals adjust their behaviors to cope with high temperatures, impacting their well-being. Additionally, this poster may spark interest in the energy context by examining adaptation strategies, raising relevant questions about energy practices during extreme heat. I am confident that the visual representation of these findings will foster fruitful discussions. I am available for additional information and to address any questions the committee may have regarding this poster. Thank you sincerely for your attention to this submission, and I look forward to contributing to your event.

[Page: 366]

[Abstract:0248] PP-011 [Accepted:Poster Presentation] [Electricity » Local Distribution]

Economic Trades in Energy Communities and Optimal Allocation

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Overview:In the urgent need to create more decarbonised energy systems, distributed energy resources (DERs) have been supported by emerging policy schemes and benefit from increased affordability (IEA, 2022). The integration of intermittent and unpredictable renewable energies into centralised energy systems poses challenges, particularly impacting distribution grids connecting small DERs with end-consumers (Wang et al., 2015). In this context, Local Energy Markets (LEMs) gain increasing interest and constitute a new market approach enabling the real-time pricing and the local balancing of energy supply and demand with the inclusion of DERs and prosumers, i.e. users who both generate and consume electricity in the energy system (Mengelkamp et al., 2018; Parag and Sovacool, 2016). Among several market designs of LEMs, Energy Communities (ECs) are attracting growing interest in the research community. They provide prosumers with a platform to generate, store, and trade energy within their local area and reduce energy costs due to joint-owned DER assets. Hence, local ECs play a pivotal role in the energy transition by fostering local energy generation and consumption, particularly with the use of renewable energy resources (Mantegazzini et al., 2023). While ECs present an innovative approach, questions persist about their financial and technical viability, especially regarding the trading of local energy and the equitable sharing of costs and benefits among community members (Li et al., 2021). Addressing the crucial issue of modelling optimal economic trading for ECs reveals the necessity for adapted trading mechanisms and pricing strategies in emerging decentralised market forms. Yet, the extent to which these trading models influence the allocation of costs and benefits to EC members remains largely unexplored. A critical research gap lies in understanding the effectiveness of trading schemes and their potential implications for the viability of ECs (Abada et al., 2020). A considerable amount of previous work has focused on energy trades inside LEMs. Hence, it is essential to analyse the general framework of LEMs and to derive important implications for community energy trading inside ECs. Therefore, this article provides an up-to-date overview of existing literature, lays down relevant models and derives essential principles for economic trades inside ECs. By examining these concepts, important obstacles and enablers of local energy trading are discussed and related to the framework of ECs.
Methods:A systematic literature review was conducted to identify relevant literature, focusing on different energy trading models for regulating the allocation and distribution between community members and how different models affect the resulting allocation of ECs. The objective of this work is to analyse various trading models that exist in LEMs and identify the key obstacles that impede the progress and adoption of ECs, including economic and political conditions that are essential to provide effective and fair allocation methods. These three interrelated concepts and their associated research questions are visualised in Figure 1. Particular attention is paid to the distinctive features of ECs and Peer-to-Peer (P2P) markets to identify the key theoretical frameworks that justify economic exchanges within these contexts. For this purpose, this work adopts a holistic approach and reviews literature across economic and engineering domains. Then, framework conditions and key aspects of economic trades are identified while stating important insights from industrial economics and game theoretical principles and highlighting relevant allocation schemes. With a well-conceptualised literature review, this work lays down an outlook of possible research areas and aims to improve public's understanding of this topic.
Results:The study highlights the P2P model as a notable market scheme for fair trading options within

communities and neighbourhoods. Among the assessed models, the community-based P2P model demonstrated its adaptability, particularly in ECs, and potential to foster cooperation among prosumers, by integrating a community manager, who provides essential services to community members and helps organising energy trading processes. By comparing different methods and trading mechanisms, cooperative game theory emerges as highly relevant for ECs, ensuring prosumers to collaborate when exchanging local energy while mitigating potential free-riding behaviours. Furthermore, this article delves into vital insights concerning energy sharing mechanisms and their integration within energy trading models and highlights that the implemented trading model will influence the cooperation level between the agents and may impact the choice of cost allocation rules inside the EC, as depicted in Figure 2. The review of various research studies has shown connections and patterns between economic, social, and engineering approaches. The conducted literature review further identifies the need for cost allocation methods that should address variations in costs between different consumption periods. Moreover, the Shapley value method stands out as a promising method that allocates costs and benefits based on a better reflection of economic and social impacts on members, as compared to flat energy pricing methods. However, computationally complex methods can hinder the social acceptance and scalability of ECs. Thus, energy trading processes should incorporate allocation methods that respect the characteristics and preferences of ECs. This work proposes essential conditions and key considerations to determine the optimal energy trading structure for ECs, including the need to find a balance between efficiency, fairness and scalability in the design of allocation methods. In this regard, the allocation of costs and benefits should provide fair outcomes for the users to ensure social acceptability, but also be computationally efficient and comprehensive to provide easily scalable methods for ECs. Moreover, energy sharing models needs to be cost-effective in order to incentivise members to join and stay inside the coalition of the EC. In other words, the scheme must be tailored to the participants' characteristics as well as to the size of the community. Implementing effective cost and benefit allocation schemes not only contributes to the long-term sustainability of ECs but also fosters widespread social acceptance, thereby facilitating a smooth transition to sustainable energy practices. Finally, this work highlights the increasing need for interactions between the prosumer community and the energy system operators, and thus for organised trading mechanisms.

Conclusions:According to several literature findings, ECs seem to be a promising way to decarbonise and decentralise our current energy system. In order to be economically viable and sustainable in the long term, trading and sharing models inside ECs need to be well-defined. The choice of the trading design and the implemented market structure of the EC will influence the design and the rules of the economic sharing methods between members. However, the choice of a trading model and their allocation rules remain challenging, as the adaptability of the schemes largely depends on the characteristics and circumstances of the EC. The self-governance of these communities should be characterised by lower transaction costs and a fair cost-benefit allocation while being framed by simplified legal requirements. Different methods may be suitable for different scenarios, and the decision may involve trade-offs between simplicity, fairness, and efficiency. Future research avenues include viable allocation methods for ECs as well as identifying the optimal size to avoid inefficient and inequitable allocation results. Moreover, technological advancements and strategic considerations are crucial aspects that should be carefully examined. With the further integration of ECs into the electricity grid, more research must be carried out on how trading mechanisms of community-based energy systems affect the network system, as well as their associated changes for the revenues and tariffs of the participating actors. Given a trade-off scenario between the conflicting goals of optimal economic trades, complementary research should evaluate direct and indirect effects on the members and the grid while achieving a balance between the economic goals. It is therefore essential to develop suitable models that involve various interest groups and take a long-term perspective into account.

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Keywords: Local energy trading, Energy Communities, Prosumers, Peer-to-Peer trading, Cost allocation, Optimisation models.

Figure 1. Interconnected Energy Trading Concepts.

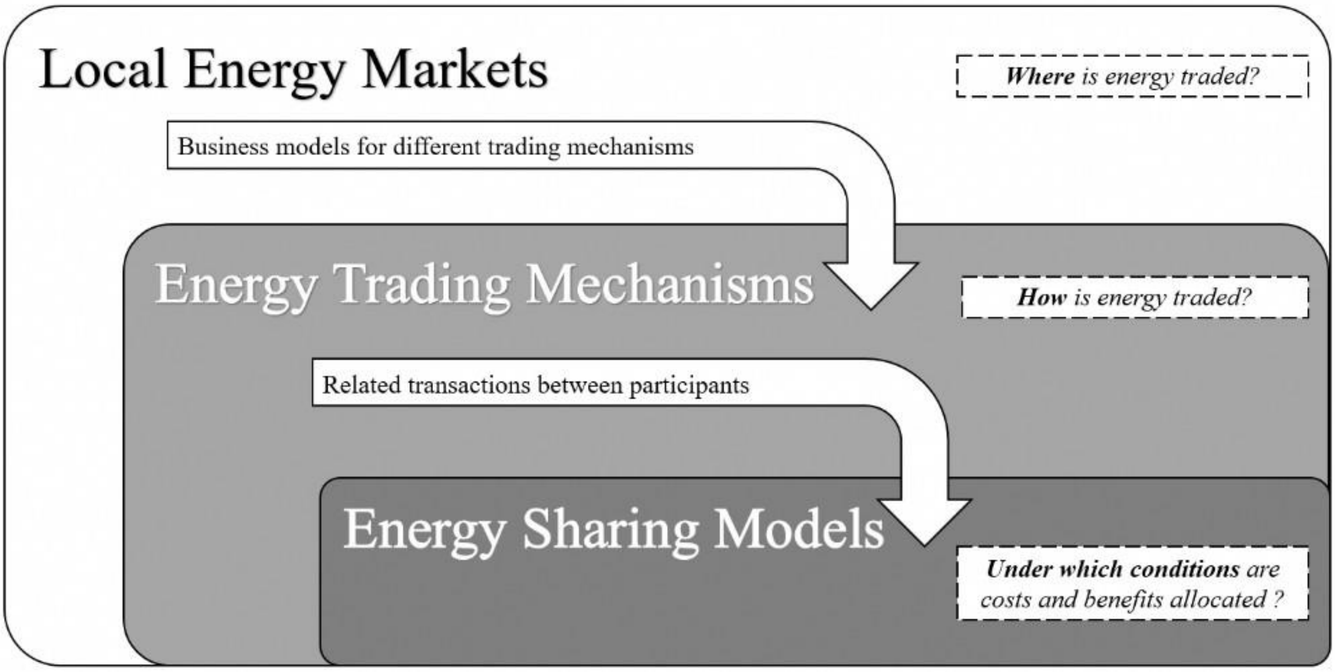
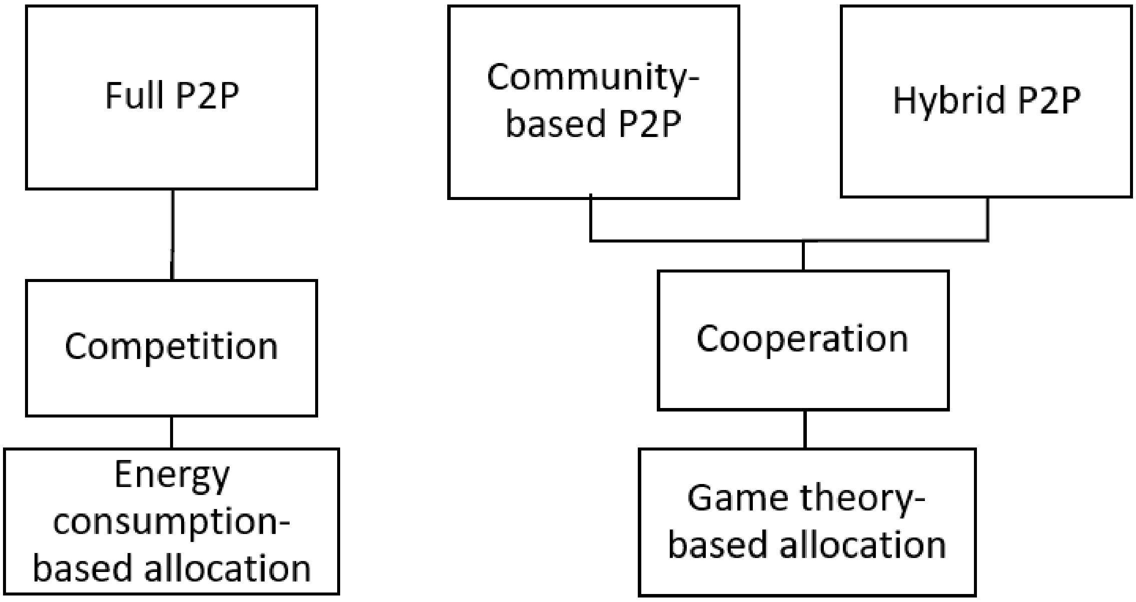


Figure 2. Cost Allocation Methods according to P2P Trading Models.



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[Abstract:0265] PP-012 [Accepted:Poster Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

Carbon border adjustment in the global trade network: measures to reconcile the competitiveness concerns

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Overview:The enforcement of EU carbon border adjustment mechanism (CBAM) marked the first attempt to extend the unilateral climate regulations worldwide. Although it is deemed as a promising tool to reduce carbon leakage and create a 'level playing field' as the climate regulations become tightened, it has been controversial and encountered oppositions from major developing economies for its potential unfair competitiveness outcomes. Looking ahead, however, the bottom-up architecture of the Paris Agreement leads to regionally differentiated climate policies, implying persistent asymmetries among regional policy stringencies and implicit carbon prices. Under such a context, more and more countries may follow the EU's practice and consider their own CBAMs to protect their industrial competitiveness, which, in the meantime, may risk more trade disruptions and unequal impacts to low-income countries. Considering a possible future with more prevalent trade adjustments, this study investigates into a scenario where CBAM is implemented along each bilateral trade flow within a multilateral trade network. Specifically, we mainly focus on three

questions: 1. What are the competitiveness and environmental effects of such a generalized CBAM at the global and regional scale; 2. Does a direct generalization of current EU CBAM design into a multilateral setting result in fair competition between developed and developing countries; and 3. How to design a multilateral CBAM to minimize the competitiveness impacts due to regional asymmetry climate policies. To answer the questions above, we first propose a conceptual model, through which we compare the competitiveness and emission outcomes of two alternative CBAM designs along with a reference no-CBAM scenario in a multilateral framework. Then, by employing a global computable general equilibrium model, we simulate the impacts on industrial competitiveness and trade structures of countries' fulfilling their Paris commitments under three policy regimes, as well as the global economic costs. Results highlight the efficiency-equity trade-off in multilateral CBAM designs, and the importance to deepen global cooperation to avoid the abuse of trade measures.

Methods:This study consists of two interrelated parts: theoretical considerations and numerical simulations. In theoretical part, we proposed an n-region partial equilibrium model to understand the competitiveness and emission implications of carbon pricing and CBAM. It is generalized from Fischer and Fox (2012) and features regional asymmetric carbon prices and heterogenous carbon intensities. In such a transparent partial equilibrium framework, we layout three policy regimes, i.e., a refence no CBAM scenario, a 'standard' CBAM scenario which simply extends the EU CBAM multilaterally, and an alternative CBAM based on 'cost-fairness' principle, which is designed to minimize competitiveness impacts among trade partners. Following Fischer and Fox (2012), we compare the competitiveness of different countries measured by changed output, and the environmental efficiency measured by global emissions (with the same regional carbon prices). To concretize our theoretical insights, we then employ a global multi-region, multi-sector general equilibrium model to simulate countries' fulfilling their national determined contributions (NDCs) in the Paris Agreement. The model is extended from standard global trade analysis project (GTAP) model in GAMS presented by van der Mensbrugghe (2018), with the incorporation of energy production and consumption structures, various climate policies (e.g., carbon prices and border adjustments), and dynamic mechanisms. Results from the general equilibrium model complement the theoretical results by incorporating characteristics from real-world economy, and more complicated general equilibrium effects.

Results:From the conceptual model, it is demonstrated that: 1) Regionally differentiated carbon prices distort relative competitiveness because of unbalanced cost-pressures. 2) The 'standard' CBAM could lower global emissions by narrowing the gap among regional carbon prices, thus could mainly be justified by environmental effectiveness. However, it may result in inequitable burdens for those transitional economies with high carbon-intensity. 3) The alternative 'cost-fair' CBAM leads to smaller but positive emission reductions compared to no-CBAM scenario, but has the main advantage of competitiveness preservation and less output impacts. In numerical simulation, we mainly focus on competitiveness of EITE sectors and compare different metrics, including regional output, net export, domestic and foreign market share. Simulation results from CGE model largely confirm our theoretical conclusions, that are, the 'standard' CBAM regime results in largest emission reduction given the same regional carbon prices, while the 'cost-fair' CBAM regime has the least impacts on regional competitiveness (see Figure 1 for comparison of competitiveness effects). Furthermore, the rich detail of trade and sectoral linkages in CGE model allow us to gain insights from other perspectives, such as change in trade structures and economic costs. It is shown that the 'standard' CBAM regime causes more 'trade diversion' effects than the 'cost-fair' CBAM, because the shift in regional comparative advantages is much more prominent. Regarding the global abatement costs, an interesting finding is that both two CBAM regimes lead to negative cost-saving effects compared to no-CBAM scenario. The main reason is that the efficiency losses from overuse of trade measures outweigh the gains from narrowing the carbon price gap. This result is different to those derived under unilateral CBAM implementations, where they usually provide limited but positive cost-saving effects due to leakage reduction.

Conclusions:Conclusions are laid out to answer the three questions proposed in overview. For question (1), two different CBAM regimes lead to differentiated effects. Both contributes to reducing global emissions, with the 'standard' CBAM being more effective, while 'cost-fair' CBAM being more equitable in competitiveness. As for question (2), a direct generalization of EU CBAM can not ensure competitiveness equity because it actually biases towards low-carbon-intensity regions. Although such a bias seems beneficial to global emission reductions, it places unfair burdens to developing countries and thus has low acceptability. And finally, for question (3), it turns out that neither of the two CBAM regimes is advantageous in both efficiency and equity. We will suggest the 'cost-fair' CBAM to be considered in policy-making, for its higher equity and acceptability. More importantly, however, we suggest that broadening global climate cooperation would be a much more efficient avenue to achieve the Paris Agreement than unilateral actions with border measures.

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Keywords: carbon border adjustment mechanism (CBAM), competitiveness equity, environmental effectiveness, computable general equilibrium (CGE) model

Comparison of the effects of three policy regimes on four competitiveness metrics

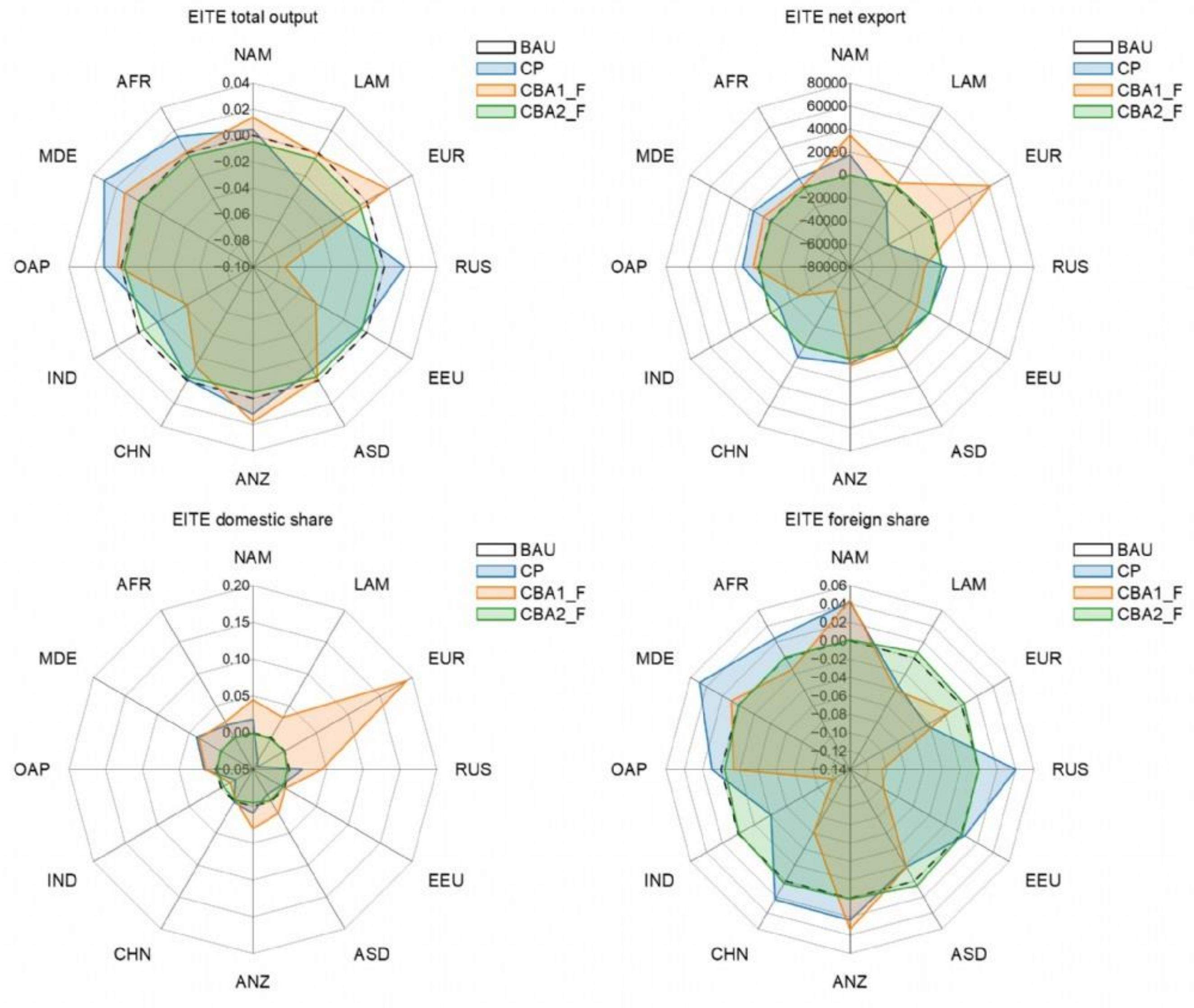

Figure 1. Comparison of the effects of three policy regimes on four competitiveness metrics (w.r.t BAU). CP: carbon pricing alone; CBA1_F: the 'standard' CBAM (with export rebates); CBA2_F: the 'cost-fair' CBAM (with export rebates).

This figure compares the effects of three policy regimes on four competitiveness metrics, w.r.t BAU. Note: CP: carbon pricing alone; CBA1_F: the 'standard' CBAM (with export rebates); CBA2_F: the 'cost-fair' CBAM (with export rebates).

[Abstract:0310] PP-013 [Accepted:Poster Presentation] [Energy Modeling » Energy Supply]

Multi-Time Scale Optimal Scheduling Model of Integrated Energy System with Flexible CCPP under Ladder-Type Carbon Trading

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Overview:Integrated energy system (IES) has achieved the coordinated complementarity of various energy sources such as cooling, heating, and electricity. However, there are inevitable deviations in forecasting wind power, photovoltaic, and load within IES, which increases the difficulty of system scheduling. Thus, an innovative multi-time scale dynamic optimal scheduling model for IES considering demand response speed is proposed. First, the IES structure is introduced and equipment operation models are established, and the principle of comprehensive and flexible operation of carbon capture power plant (CCPP) is analyzed in detail. Second, to fully stimulate the emission reduction characteristics of carbon CCPP, a reward and penalty ladder carbon emission trading mechanism is designed. And a demand response mechanism is implemented on the user side, which can be divided into price-based and incentive-based depending on different driving methods. According to the different response speed, incentive-based demand response can be introduced in different time scales. Third, to address the contradiction between forecast accuracy and scheduling foresight, a multi-time scale optimal scheduling model with day-ahead static, intra-day rolling, and real-time correction is established. Each stage is connected by using the control variables from the previous stage. Finally, the model needs to be linearized and solved layer by layer. The results show that: 1) The rolling optimization method improve the foresight, continuity, accuracy, and economy of scheduling. 2) By integrating load side resources with different response speeds into the multi-time scale optimal framework, the potential of different types of demand response resources in terms of regulation depth and regulation speed is fully explored. 3) The solution storage tank of CCPP strengthens the synergy between electricity flow and carbon flow, while balancing economic and environmental benefits. 4) The reward and penalty ladder-type carbon trading mechanism has a stronger incentive effect on emission reduction than the fixed price carbon trading mechanism.
Methods:(1) Comprehensive and flexible operation of carbon capture power plants modeling method
Unlike the split flow carbon capture power plant, the ethanolamine solution in the comprehensive and flexible operation carbon capture power plant can be cycled between the rich and lean solution storage tanks, which determines the amount of carbon dioxide entering the regeneration tower. The storage tanks achieve the spatial and temporal transfer of carbon capture energy consumption, and indirectly plays a role of storing and releasing electricity energy. In addition, the output regulation range of CHP has been expanded and the flexibility has been improved.
(2) Reward and punishment ladder-type carbon trading modeling method
The reward and punishment ladder-type carbon trading mechanism has different rewards and punishments for users with different carbon emission intensity. The principle is similar to ladder-type electricity price, which further reduces carbon emissions on the basis of conventional carbon emission trading mechanisms. The ladder-type carbon trading mechanism divides carbon emissions into multiple trading ranges, with different ranges corresponding to different carbon trading prices. When IES carbon emissions exceed the carbon quota, it is necessary to purchase carbon emission rights. And the more emissions exceed, the higher the unit cost. When IES carbon emissions are lower than the carbon quota, carbon emission rights can be sold. And the more quota surplus, the more the unit revenue.
(3) Multi-time scale optimization operation modeling method

To address the contradiction between forecast accuracy and scheduling foresight, the model predictive control (MPC) method, an advanced process control method, is introduced in the intra-ahead and real-time stages. First, sampling (wind power, photovoltaic, load) carried out at each moment, and the finite time domain open-loop optimization scheduling problem is solved based on the obtained forecast data (forecast domain). The first plan (control domain) in the obtained control sequence is applied to the controlled object. Then, the forecast domain rolls forward and repeats the process at the next moment by resampling, i.e., refreshing the optimization scheduling problem with new forecast data. Finally, a control strategy with higher accuracy is developed through continuous rolling updates until the end of the scheduling cycle. For the internal of IES, the multi-time scale dynamic optimization scheduling method can reduce the problems of wind power and photovoltaic abandonment and load loss, and improve the security of system operation. For the external of IES, it avoids fluctuations of the power purchase and sale plan and reserve plan, and improves the stability of the external response to the power grid.

Results:(1) During the response to the external power grid, the power purchased and sold by IES and the reserve capacity provided are determined in the day-ahead stage, and no further adjustment is made, which can avoid the interference of IES internal power and load fluctuation on the superior power grid. The operating status of units with poor flexibility, slow regulation speed, and high importance level has been determined in the day-ahead stage, thus the start-up and shut-down cost of the units have been controlled. In addition, the calling amount of Class A incentive-based demand response resources with lower costs and slower speed has been determined, which not only reduces demand response cost but also taps the potential of demand response in regulating depth to the greatest extent. Finally, as the beginning of multi-time scale, the day-ahead stage improves the foresight of scheduling.

(2) The output plans of various units and the operating status of energy storage have been determined in the intra-day stage, effectively controlling the fuel cost required for system adjustment. The amount of Class B incentive-based demand response resources with higher costs and faster speed has been determined in the intra-day stage, which can tap the potential of demand response regulation in the most economical way. Finally, as a transition of multi-time scale, the intra-day stage enhances the continuity of scheduling.

(3) The plan of energy storage, carbon capture solution storage tank, and Class C incentive-based demand response are determined in the real-time stage. The robustness of the integrated energy system is enhanced by continuously correcting the deviation between the intra-day and real-time through feedback. The amount of Class C incentive-based demand response resources has been determined, which can maximize the potential of demand response in regulating rate. Finally, as the end of multi-time scale, the real-time stage improves the refinement level of scheduling.

Conclusions:The three stages of day-ahead, intra-day, and real-time are modeled and solved layer by layer. Through the example analysis, some meaningful conclusions are obtained:

(1) The multi-time scale optimization method improves the foresight, continuity, accuracy, and economy of scheduling. In the scheduling model of day-ahead static, intra-day rolling, real-time correction, the corresponding control domain scheduling scheme can be determined based on the source and load data of different forecast domains. The control viables in the previous stage is used as the determined viables in the next stage, and multi-time scale scheduling has a certain coherence. The purchased and sold power and reserve capacity determined in the day-ahead stage are not used as subsequent adjustment variables, which improves the stability of external response. After solving layer by layer, the minimum operating cost is $ 7803.24, and the energy supply cost and deviation balance cost have been effectively controlled.

(2) The regulation potential of demand response resource has been fully explored. According to different driving modes, price-based demand response resource is called in the day-ahead stage. According to different response speeds, Class A, Class B, and Class C incentive-based demand response resources are called in the day-ahead, intra-day, and real-time stage, respectively. The regulation depth of demand response is fully explored in the day-ahead stage. The calling cost and response speed of demand response are taken into account in the intra-day stage. The regulation speed of demand response is fully explored in real-time stage.

(3) Carbon capture power plant reduces system carbon emissions and improves system flexibility. Carbon capture power plant can expand the minimum output range of CHP, making the optimal decision between providing electricity and capturing carbon. The system's carbon emissions are controlled at 16,254 kg, balancing economic and environmental benefits. The comprehensive and flexible operation of carbon capture power plant realizes the spatial and temporal transfer of carbon capture energy consumption, and has a larger adjustable range than the split flow type. In addition, as the ethanolamine solution circulates between the rich and the poor solution storage tank, there is more decision-making space for the capture of carbon dioxide, and the net output can be flexibly controlled.

(4) The reward and punishment ladder-type carbon trading mechanism has a significant effect on emission reduction incentives. As the benchmark price of carbon trading increases, the carbon

emissions of the integrated energy system decrease. In the process of participating in electricity trading and carbon trading, electricity needs to make the optimal decision between purchasing, selling and capture consumption, realizing the synergy between power trading and carbon trading.

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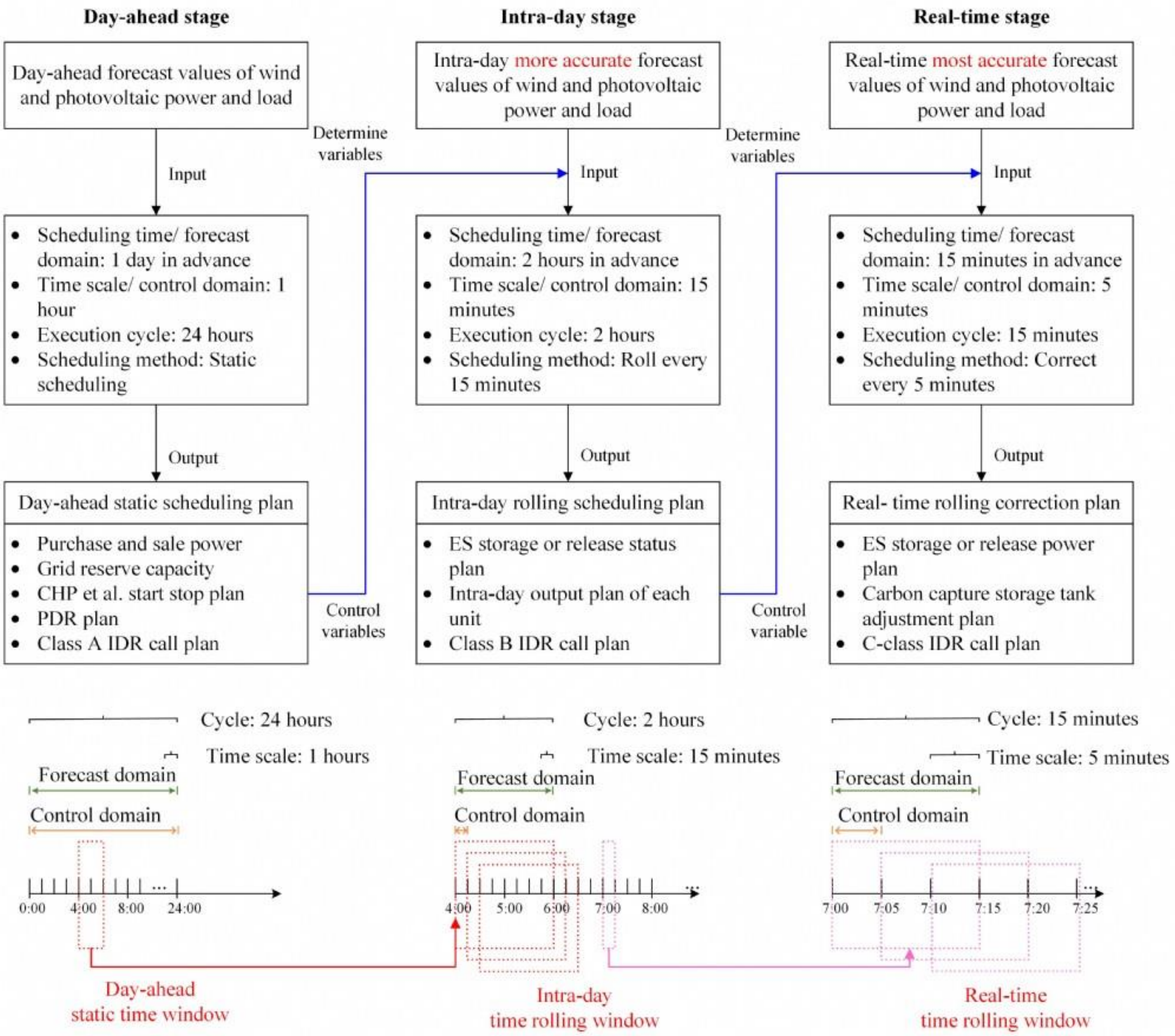
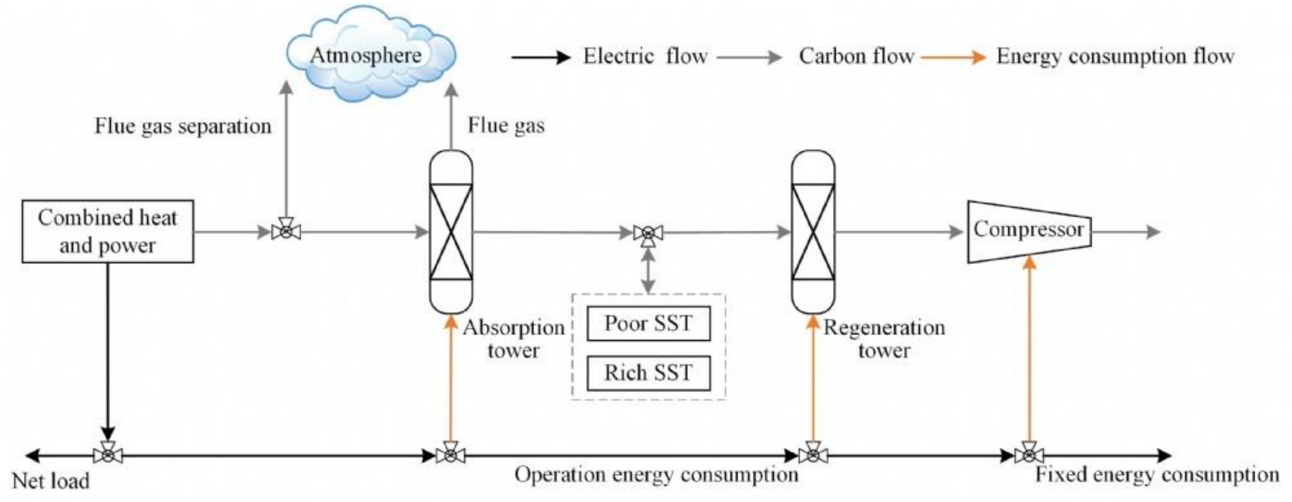
Keywords: Integrated energy system, Multi-time scale, Optimal scheduling, Reward and penalty ladder-type carbon trading, Demand response speed, Carbon capture power plant

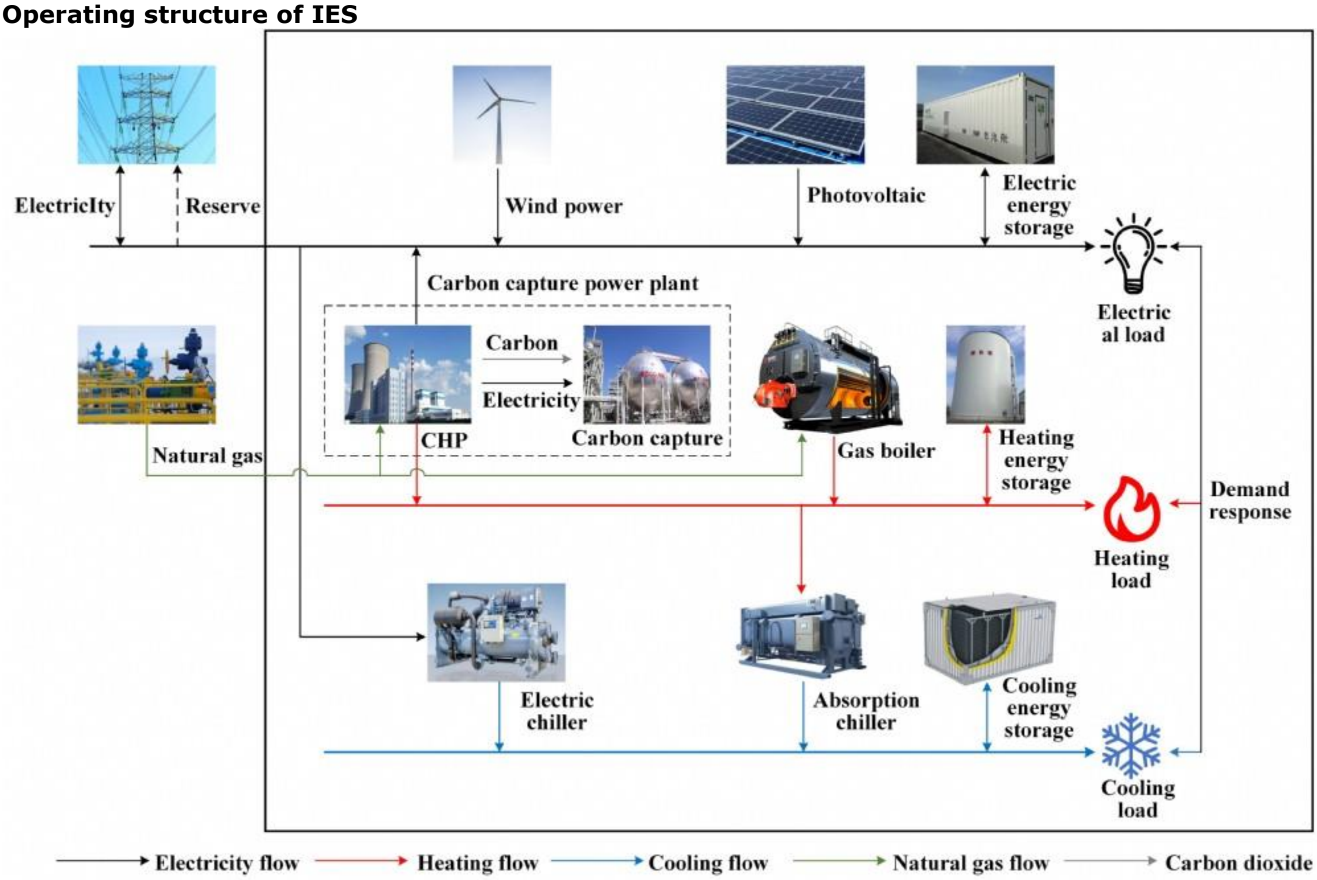
IES multi-time scale dynamic optimization framework



Internal energy flow diagram of CCPP



Operating structure of IES



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[Abstract:0311] PP-014 [Accepted:Poster Presentation] [Energy and the Environment » Policy and Regulation]

The synergistic impact of climate policy and green finance policy on emission reduction and transformation risks

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Overview:We study climate and green finance policies in an economy with financial frictions. Using a dynamic stochastic general equilibrium model featuring both a pollution market failure and a market failure in the financial sector, we explore transition risk – whether ambitious climate policy can lead to macroeconomic instability. but the risk can be alleviated through green finance policies – green targeted reserve requirement reduction policy. In the context of dual carbon goals, in order to encourage the development of clean energy and address the insufficient green investment caused by financial frictions, the country has developed some green financial support tools in the monetary and financial fields, such as green refinancing and green targeted reserve requirement reduction.The green targeted reserve requirement reduction policy is a quantitative easing policy aimed at green enterprises, which directly affects the financial sector and stimulates output and investment in green enterprises by releasing liquidity in the financial sector.We found that the green targeted reserve requirement reduction policy can alleviate some of the transformation risks, but the emission reduction effect of this policy is not significant. Therefore, in the context of the dual carbon goals, in order to achieve emission reduction goals while controlling transformation risks, this article conducted a collaborative study of climate policy and green finance policy. Through the coordination of the two policies, the transformation risks were controlled while achieving emission reduction goals.
Methods:This article constructs an environment dynamic stochastic general equilibrium model, which includes the household sector, financial sector, government sector, green enterprise sector, brown enterprise sector, capital provider, and final product sector. The climate policy is an emission tax imposed on brown enterprises, while the green targeted reserve requirement reduction policy is imposed on the debt side of the financial sector.
Results:1: The carbon tax policy can achieve emission reduction, but it will pose a risk of stranding the net assets of banks.

2: The green targeted reserve requirement reduction policy can optimize the economic structure and make bank assets lean towards green, but its impact on emissions reduction is relatively small.

3: The combination of carbon tax policy and green targeted reserve requirement reduction policy can reduce the risk of bank net assets being stranded while achieving emission reduction.
Conclusions:We found that a carbon tax shock of 200 yuan/ton would lead to a significant decrease in emissions, with a decrease of nearly 40%. However, it can also cause a decline in bank net assets, with a decline of over 50%. After the introduction of reserve requirement reduction policies, the decline in bank net assets has been partially alleviated.The setting of green targeted reserve requirement reduction in this article is that the reserve requirement reduction rate depends on the proportion of green assets in banks. We need to compare the green targeted reserve requirement reduction policy and the reserve requirement reduction policy in the future, and compare the impact of the green targeted reserve requirement reduction policy and the reserve requirement reduction policy on the risk of grounding under the impact of carbon tax policy.
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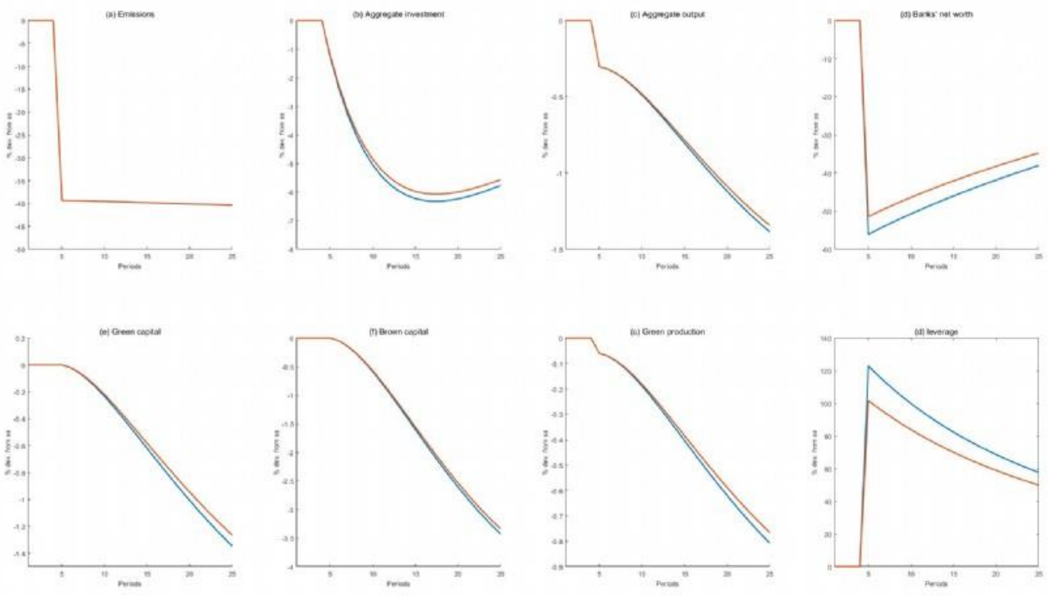
Stefano, C., Garth,H. and Givi,M.:2023,Climate policy, financial frictions, and transition risk,Review of Economic Dynamics 51.778-794.

Keywords: climate policy,green targeted reserve requirement reduction policy,DSGE

model,transition risk

Comparison of macro variables on whether there is a green targeted reserve requirement reduction policy under the impact of carbon tax



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[Abstract:0319] PP-015 [Accepted:Poster Presentation] [Renewables » R&D and Emerging Technologies]

Role of Patents In Renewable Electricity Generation: Statistical Evidences From 18 OECD Countries

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Overview:This study analyzes effects of patents in renewable energy fields as a policy variable to expand renewable electricity generation among 18 OECD countries. We use US patents in renewable energy, especially solar and wind to represent output of a country’s R&D activities. Annual data from 1990 to 2015 of 18 OECD countries were analysed using panel econometrics model. Estimation results show that patents have positive effects on renewable electricity generation and are statistically significant across all 18 countries. Among 18, Germany, Spain, and United Kingdom show the highest effects.
Methods:This study uses a panel econometric model:

$$y_{it} = \alpha + x_{it}\beta + z_{it}\gamma + a_i + e_{it}$$

where y_{it} is renewavle electricity generation of I country in t year, x_{it} is the number of US patents in

rerenewable electricity fields od I country in t year, α_i and e_{it} are error terms. Annual data from 1990 to 2015 of 18 OECD countries were used.
Results:Estimation results show that renewable energy patents have positive effects on renewable electricity generation and are all statistically significant across all 18 countries. We also find that a fixed-effects model is more efficient by the Hausman test. Estimation results show that the size and sign of the coefficients remain constant with different sets of control variables in the model, confirming that the estimation model of this study is solid and stable.
Among 18 countries analysed, Germany, Spain, United Kingdom show the highest effect. These three countries all have high numbers of renewable energy patents. On the other hand, Korea, even with high numbers of patents, shows below-average coefficient values in policy variables, indicating that the relation between R&D policy and renewable energy dissemination policy is still at a low level.
Conclusions:This study shows that technology R&D activities, including patents, have highly positive impacts to enhance renewable energy productionfor most of IECD countries. Among 18 OECD countries examined, Germany, UK and Spain come with the highest effects and those countries all have high numbers of renewable energy patents. Results give policymakers concrete implications that putting budget into renewable energy technology R&D is centainly one of the main policy tools in renewable energy.
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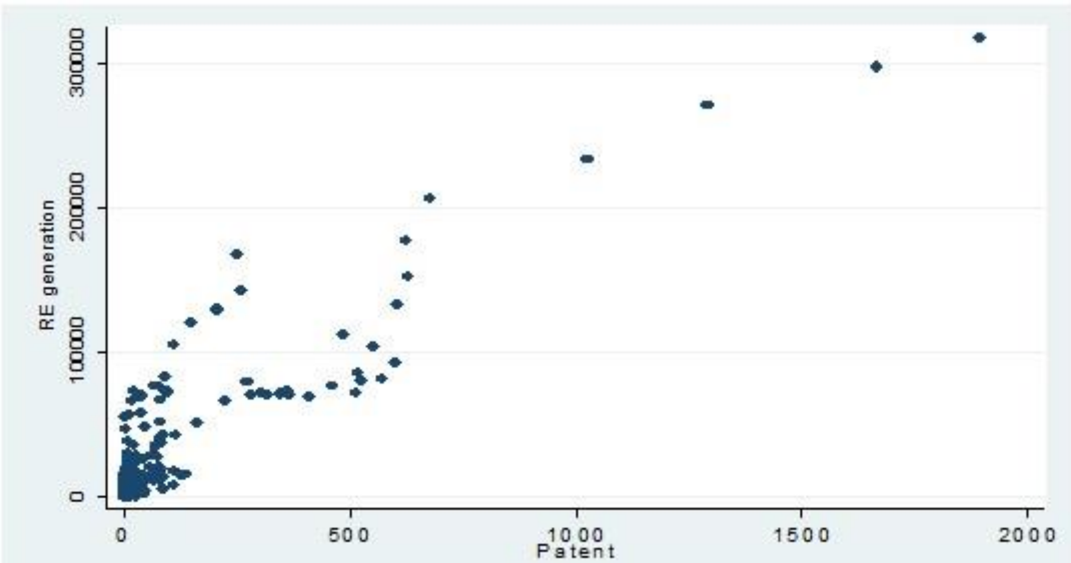
Keywords: *Renewable Energy, Electricity Generation, Patents*

Plots between Renewable Energy Patents and Reneable Electricity Generation



[Abstract:0320] PP-016 [Accepted:Poster Presentation] [Energy and the Macroeconomy » Other]

The nexus between economic growth, CO2 emissions, and healthcare expenditure in Asia-Pacific countries: evidence from a PVAR approach

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Overview:This study aims to adopt an integrative framework to investigate the relationship between economic growth, carbon emissions, and healthcare expenditure in the Asia-Pacific region. Carbon emissions pose global challenges due to their widespread repercussions for human health and the environment (Chaabouni and Saidi 2017; Yu and Qayyum 2022). The Asia-Pacific region, marked by densely populated countries experiencing rapid industrialization and urbanization, has witnessed a consequential surge in carbon emissions. Concurrently, economic growth requires increased healthcare spending to address the population's health needs. However, many countries face challenges related to inadequate healthcare practices and infrastructure. Consequently, examining the nexus between economic growth, healthcare expenditure, and carbon emissions in the Asia-Pacific area is crucial for informing policymaking and addressing real-world challenges in the face of the dual challenges of climate change and economic progress. Although numerous studies have explored the relationships between any two of these variables, a consensus regarding their causality has yet to be reached. Moreover, there is a notable scarcity of research specifically focused on exploring the dynamics between all three variables simultaneously.
Methods:This study employs a panel vector autoregressive (PVAR) model with system generalized method of moments (GMM) estimation to examine the dynamic causalities between economic growth, CO2 emissions, and healthcare expenditure. The PVAR model was proposed by Love and Zicchino (2006), which treats all the variables in the system as endogenous within a panel data construct, introducing fixed effects to allow for unobserved individual heterogeneity (Love and Zicchino 2006; Abrigo and Love 2016). To address this endogeneity issue and ensure consistent estimates, we employ GMM estimation with instrumental variables. We utilize the forward orthogonal deviation or Helmert transformation technique proposed by Arellano and Bover (1995) to eliminate the panel-specific fixed effects. This transformation can effectively remove the influence of unobserved fixed effects and maintain the orthogonality between variables and their instruments. Moreover, the applicability of dynamic panel GMM estimators has been established in "large N, small T" panel data settings (Arellano and Bond 1991; Blundell and Bond 1998), aligning with the data characteristics in this study. Our dataset covers 2000 to 2019, including a total of 30 countries located in the Asia-Pacific region. The data are sourced from the World Bank's World Development Indicators.

Prior to model estimation, the study conducts a pre-estimation diagnostic involving unit root tests to ensure stationarity, followed by cointegration tests to ascertain the long-run equilibrium relationship among the variables. Subsequently, the PVAR estimation is conducted. Granger causality tests are used to examine the direction and strength of the causal relationships. Additionally, impulse response analysis is implemented to assess the temporal evolution of economic shocks, while forecast error variance decompositions are employed to evaluate the relative contributions of various shocks across the system.
Results:Table 1 reports the descriptive statistics for all the variables in our strongly balanced panel dataset comprising 600 observations. In Table 2, the correlation coefficient matrix reveals significant correlations among variables. Table 3 displays the unit root test results, confirming that all the series of the four variables are first-difference stationary. As shown in Table 4, the cointegration tests confirm the existence of long term cointegration relationships among variables of interest. Table 5 reports the outcomes of the selection process for the optimal lag length q in the PVAR model and suggests that selecting a lag length of one is the most appropriate choice when using GMM estimation in this study.

Table 6 presents the coefficients of PVAR analysis and Table 7 shows results of Granger causality test that validates the robustness of our Table 6 results. First, the regression results indicate a statistically significant positive impact of economic growth on both government healthcare expenditure and private healthcare expenditure. These results suggest that healthcare is a necessity in the Asian-Pacific region, as evidenced by the income elasticity of healthcare expenditure. Additionally, there exists a bidirectional relationship between economic growth and private healthcare expenditure. Moreover, GDP has a nonsignificant impact on CO2 emissions, which is consistent with prior empirical studies conducted by Salahuddin and Gow (2014), Soytas et al. (2007), and Zhang and Cheng (2009), indicating that economic growth does not necessarily lead to increased CO2 emissions. Thus, economic growth might be achieved without degrading the environment in the Asia-Pacific region. Conversely, the results indicate that CO2 emissions negatively affect economic growth. This finding aligns with the empirical findings of Azam et al. (2015) and Ejuvbekpokpo (2014), revealing the detrimental effect of carbon emissions on economic prosperity. Therefore, the results indicate a unidirectional causal relationship running from carbon emissions to economic growth, supporting the conservation hypothesis proposed by Acheampong (2018) and Fodha and Zaghdoud (2010). These findings emphasize the economic consequences of pollutant emissions and highlight the necessity of sustainable development strategies in the Asia-Pacific region.

Furthermore, the results show bidirectional causalities between government healthcare expenditure and CO2 emissions and unidirectional causality between private healthcare expenditure and CO2 emissions. Government healthcare expenditure responds positively to CO2 emissions at the 1% level of significance, with a one percent increase in CO2 emissions corresponding to a 0.4% increase in government healthcare expenditure. Notably, an increase in CO2 emissions does not significantly reduce private healthcare spending, possibly due to increased public subsidies for healthcare, which alleviate the burden of individual out-of-pocket healthcare spending.

Figure 1 suggests that our PVAR model is stable, and Figure 2 displays the dynamic causalities among variables of interest. Figure 3 presents impulse response functions. The results suggest a short-term positive impact of carbon emissions on GDP, followed by a negative impact in the long term. Additionally, economic growth has a positive effect on government healthcare expenditure, but no significant long-term relationship is detected. Moreover, these findings indicate a slight short-term decrease in government healthcare expenditure due to CO2 emissions, with no evident long-term relationship.

Table 8 reports the forecast error variance decomposition results. These results suggest that carbon emission fluctuations are mainly influenced by their own shocks and healthcare expenditure dynamics. Additionally, we observe greater impact of private healthcare expenditure and GDP growth on government healthcare expenditure compared to the impact of CO2 emissions. Moreover, the results indicate the significant contribution of government healthcare expenditure to economic growth and private healthcare spending, in addition to the important role of private healthcare spending in economic growth.
Conclusions:This study presents pioneer research on the dynamic causality among economic growth, public and private healthcare expenditure, and carbon emissions. The key findings can be summarized as follows: First, economic growth unidirectionally stimulates government healthcare expenditure while exhibiting bidirectional positive causality with private healthcare expenditure. These results emphasize the role of economic development in bolstering public health and reflect a later weakening of the level of government response as economies expand. Second, emissions negatively affect economic growth in a unidirectional manner and there exists a short-term positive impact of carbon emissions on GDP, followed by a negative impact in the long term. These results emphasize the importance of fostering economic growth alongside implementing carbon reduction measures, aligning with the environmental Kuznets curve hypothesis. Finally, there exists a bidirectional causal relationship between carbon emissions and government healthcare expenditure. This result calls for a dual focus on enhancing healthcare services and reducing emission for health and environmental benefits.

In summary, the findings offer policymakers evidence-based insights to develop strategies for promoting economic growth, sustainable development, and healthcare resource allocation. This research contributes to addressing the nexus between economic development, healthcare delivery, and environmental conservation, facilitating the development of holistic and integrated policies for the Asia-Pacific region.
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Keywords: *Economic growth, CO2 emissions, Healthcare expenditure, PVAR, System-GMM, Asia-Pacific region*

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[Abstract:0326] PP-017 [Accepted:Poster Presentation] [Renewables » Hydroelectricity]

Factor analysis on the integration of renewable energy and hydrogen in rural electrification in Kenya

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Overview:The Kenyan government plans to ensure universal access to electricity by utilizing its renewable energy resources. Renewable energy requires storage due to its intermittent nature, and

hydrogen storage is a key complement to annexing of Kenya's renewable energy resources. As of 2022, 77% of Kenya's population had electricity, comprising 95% of the urban and 68% of the rural population. The remaining 3.3 million rural households lacked reliable electricity. While some studies on integrating renewable energy and hydrogen in Kenya exist, they have yet to specifically focus on powering rural areas. Further, multi-criteria decision-making methodologies have yet to be used. This research uses the analytical hierarchy Process to address two research issues: First, priority considerations for integrating renewable energy and hydrogen in rural electrification are identified and analysed. Secondly, implications to policy are proposed.
Methods:The AHP (Analytical Hierarchy Process) pre-survey consulted13 experts who categorized decision-making factors into five categories: social, environmental, technological, policy and regulations, and economic and financial criteria. The total number of sub-criteria factors was twenty. 34 experts from different fields responded to the AHP survey.
Results:According to the findings, social criteria is Kenya's most significant factor(criterion) in the integrating of renewable energy and hydrogen in rural electrification compared to environmental, technological, economic, and policy issues(Table1.1). Social acceptance, social benefits, and job creation were the most significant in the overall sub-criteria(Table 1.2).
Conclusions:Priority factors for integrating renewable energy and hydrogen in rural electrification were identified and analyzed using the AHP methodology. Social criteria is Kenya's most significant factor in energy supply for rural electrification compared to environmental, technological, economic, and policy issues. Social acceptance, social benefits, and job creation were the most significant in the overall sub-criteria. The study recommends developing of a policy for stakeholder management to ensure social acceptance of energy projects. It is expected that the study analysis will provide a basis for prioritization of important factors for sustainable integration of renewable energy and hydrogen in rural electrification and related decision making as well as impact future policies.
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Keywords: *Renewable Energy Integration, Hydrogen Storage, Analytical Hierarchy Process (AHP)*

Table 1: Overall ranking of the main criteria categories

Main Criteria	% Weight	Rank
Social	34.5%	1
Environmental	23.7%	2
Technical	16.6%	3
Policy and Regulatory	12.8%	4
Economic & Financial	12.4%	5
Consistency Ratio (CR)	7.0%	

Table 2: Overall ranking of the sub-criteria

Main Criteria	Weight of the main criteria	Sub-criteria	Priority for sub-criteria	Priority for overall	Criteria Rank
Social	0.345296256	Social acceptance	0.26900477	0.09288634	1
		Social Benefits	0.25642338	0.08854203	2
		Job Creation (Labour impact)	0.25456894	0.0879017	3
		Consumer paying capacity	0.22000291	0.07596618	4
Environmental	0.236842799	Waste management	0.30199611	0.0715256	5
		Impact on GHG Emissions	0.28986199	0.06865172	6
		Land use and suitability of selected sites	0.21328851	0.05051585	9
		Local environmental impacts	0.19485339	0.04614962	11
Technology	0.165617688	Technology Maturity	0.31588697	0.05231647	7
		R&D and Innovation	0.28513759	0.04722383	10
		Technological capabilities	0.20378366	0.03375018	14
		Key Infrastructure development	0.19519178	0.03232721	15
Policy & Regulation	0.128223232	Adoption of standards and certification	0.39825154	0.0510651	8
		International cooperation	0.26448193	0.03391273	13
		Integration of Policies and Regulation	0.18749948	0.02404179	19
		Government commitment and consensus	0.14976704	0.01920361	20
	0.124020025	Potential market and demand	0.31506358	0.03907419	12
		Fiscal incentives (subsidies, financial support)	0.23151075	0.02871197	16
		Accessibility to funding and financing	0.22881991	0.02837825	17
		Cost of the combined renewable-hydrogen systems	0.22460576	0.02785561	18

[Abstract:0333] PP-018 [Accepted:Poster Presentation] [Energy Finance and Trading » Market Instruments]

A Study on the Levels and Drivers of ESG Divergence among ESG Rating Agencies: Focus on Korean Companies

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Overview:This study analyzes the divergence in ESG scores given by different assessment agencies, a pertinent issue for stakeholders in the wake of inconsistent and opaque evaluations. It aims to quantify the extent of ESG score divergence and identify the contributory drivers, focusing on Korean context. The analysis comprises a reliability assessment and a driver decomposition analysis, utilizing data from 132 KOSPI·KOSDAQ listed companies in 2022 and employing statistical methods such as correlation coefficients and Cohen's kappa for a comprehensive evaluation. The scores, sourced from the Korea ESG Institute (KC), Refinitiv (RE), S&P Global (SP), and Sustainalytics, were obtained through FnGuide, Datastream, and respective agency websites.
Methods:Our methodology consists of two parts: a reliability assessment to measure the degree of score divergence during the evaluation period and a driver decomposition analysis to identify the factors and sectors where divergence occurs. Reliability is assessed in terms of consistency (using Pearson/Spearman correlation coefficients and intra-class correlation) and accuracy (using Krippendorff's alpha and Cohen's weighted kappa). The driver decomposition analysis examines whether differences in individual sector scores or the way these scores are aggregated contribute to ESG score divergence, focusing on each ESG sector (Berg et al., 2022) as following equation:

Equation (1)
Results:In the reliability analysis, Sustainalytics demonstrated the lowest consistency and accuracy in total ESG scores compared to other agencies. Within the E/S/G sectors, the Korea ESG Institute showed the greatest deviation from others, with the Social (S) sector displaying the highest consistency and the Governance (G) sector the lowest. The driver decomposition analysis revealed that individual sector score differences significantly influence total ESG score divergence (98%), with the Social (S) sector having the most substantial impact on overall score discrepancies due to its higher weighting by agencies.
Conclusions:The study highlights considerable discrepancies in ESG scores among agencies, especially from Sustainalytics and the Korea ESG Institute, due to varied evaluation methods. It emphasizes the dominant role of individual sector scores, especially in the social sector, in score divergence, advocating for more uniform ESG evaluation standards. This research marks a critical step towards more consistent and transparent ESG assessments.
References:Berg et al., 2022, Aggregate Confusion: The Divergence of ESG Ratings, Review of Finance, 26(6), p1315–1344

Keywords: *ESG Score Divergence, Reliability Assessment, Driver Decomposition Analysis*

Equation 1: Driver decompistion equation

$$\text{ESG Divergence}^{a,b} = Var(\Delta ESG^{a,b})$$

$$= Cov(\Delta ESG^{a,b}, \Delta ESG^{a,b}) = Cov(\Delta ESG^{a,b}, \Delta^{mean}) + Cov(\Delta ESG^{a,b}, \Delta^{weight})$$

$$\Delta ESG^{a,b} = \Delta^{mean} + \Delta^{weight} = (\Delta E^{mean} + \Delta S^{mean} + \Delta G^{mean}) + (\Delta E^{weight} + \Delta S^{weight} + \Delta G^{weight})$$

Table 1: Decomposition results of drivers and sectors in ESG divergence

	Drivers		Sectors		
	Measurement	Weight	E	S	G
KC-RE	95%	5%	25%	48%	28%
KC-SP	100%	0%	19%	33%	48%
RE-SP	99%	1%	26%	41%	32%
Average	98%	2%	23%	41%	36%

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[Abstract:0335] PP-019 [Accepted:Poster Presentation] [Energy System Transition » Mineral, Land and Water Inputs]

Dynamics of Peru's Role In The Global Copper Ore Trade Network

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Overview:This study examines Peru's evolving role as a major copper ore exporter amidst rising global demand for this key mineral for the energy transition. Annual data from 2013 to 2022 of all the exporters and importers of copper ore had been used. Utilizing Social Network Analysis, the study explores changes in Peru's export values and relationships over a decade, highlighting its strategic position and resilience in the global copper trade network. Findings reveal Peru's robust trade dynamics, navigating challenges from emerging competitors like Indonesia and Brazil.
Methods:This investigation employs Social Network Analysis as a method. The research utilizes Gephi 0.10.1 to analyse the global copper ore trade in-depth, benefiting from its accessibility and capability to handle complex datasets. The study incorporates the Geo Layout plugin for geographical accuracy, enhancing the spatial understanding of trade networks. Integrating annual data from Trade Map has been collected from 2013 to 2022.
A total of 04 measures of degree and betweenness centrality have been applied. Out-degree centrality and weighted out-degree centrality reveal the countries with the most direct and significant connections, indicating influential exporters. The study also uses betweenness and weighted betweenness centrality to pinpoint countries strategically positioned as intermediaries, influencing trade dynamics and patterns. Out-degree centrality DC_{out} and weighted out-degree centrality WDC_{out} were measured through the following:

Equation (1)
Equation (2)

where vi is the focal country, vk represents all other countries, and n is the total number of countries in the network. The a is the adjacency matrix, where cell a(vi, vk) is defined as 1 if there is an outgoing link from node vi to node vi, and 0 otherwise, and vk is a country importing copper ore from country vi, and w(vi, vk) means the weighted links from vi to vk.
Betweenness centrality (BC) and weighted betweenness centrality WBC(vi) equations are as follows:

Equation (3)

where g(vj,vk) is the number of shortest paths from node vj to node vk, and g(vj, vi, vk) represents the number of shortest paths from node vj to node vk that pass through node vi.

Equation (4)

where gw(vj,vk) is the number of weighted shortest paths from node vj to node vk, and gw(vj, vi, vk) means the number of weighted shortest paths from node vj to node vk that go through node vi.

Results:The findings of this study indicate that the trade network had characteristics of scale-free property, and the network structure was characterized by heterogeneity. From 2013 to 2022, Peru has sustained a robust position as a key copper ore exporter, evidenced by a consistent Normalized Out-Degree above 0.27, indicating direct solid export relationships within the global network. Despite variations in its Normalized Weighted Out-Degree, Peru's influence remains significant. Its high betweenness centrality in the network underscores its role as a central intermediary, capable of controlling and influencing the copper ore trade flow. However, since 2020, Peru has experienced a decline in its influential power, with a partial recovery by 2022 that has yet to match pre-pandemic levels, potentially risking its position to emerging players like Indonesia and Brazil.
Conclusions:The outcomes of this research highlight Peru's enduring stature and adaptability as a copper exporter, characterized by persistent betweenness centrality and out-degree, despite market variability. The challenges Peru faced since 2020, exacerbated by global events, have tested its historical preeminence. While 2022 has seen improvement, the ascent of new contenders signifies evolving dynamics in the trade hierarchy. These findings are instrumental for informing strategic policy, suggesting a need for increased diversification and diplomatic engagement to sustain Peru's competitive edge in the ever-evolving global marketplace.
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Keywords: *Peru's Copper Ore Trade, Social Network Analysis, Energy Transition*

Equation (1)-(4)

$$DC_{out}(\mathrm{v_i}) = \sum_{k=1}^{n} a\,(\mathrm{v_i}, \mathrm{v_k}) \qquad \text{(Equation 1)}$$

$$\mathrm{WDC_{out}}(\mathrm{v_i}) = \sum_{k=1}^{n} w(\mathrm{v_i}, \mathrm{v_k}) \qquad \text{(Equation 2)}$$

$$\mathrm{BC}(\mathrm{v_i}) = \sum_{j,k} \frac{g(\mathrm{v_j}, \mathrm{v_i}, \mathrm{v_k})}{g(\mathrm{v_j}, \mathrm{v_k})}, \qquad i \neq j \neq k \qquad \text{(Equation 3)}$$

$$\mathrm{WBC}(\mathrm{v_i}) = \sum_{j,k} \frac{g^{w}(\mathrm{v_j}, \mathrm{v_i}, \mathrm{v_k})}{g^{w}(\mathrm{v_j}, \mathrm{v_k})}, \qquad i \neq j \neq k \qquad \text{(Equation 4)}$$

[Abstract:0336] PP-020 [Accepted:Poster Presentation] [Energy Efficiency » Other]

Advancing Sustainability in Districts: A Comprehensive Review of GIS and Remote Sensing for Urban Energy System Modelling

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Overview:Overview:

The need for innovative solutions in urban energy systems has increased due to the pursuit of sustainable urban development. This poster examines the potential of remote sensing and geographic information system (GIS) technologies in urban energy modelling, with a specific focus on the assessment of buildings' energy performance. The review provides a comprehensive investigation of the theoretical foundations, methodological considerations, practical applications, and potential challenges of using these technologies in the context of data collection for the modelling of sustainable urban energy systems. It aims to provide a holistic understanding of GIS and Remote Sensing within the context of urban energy modelling.

Research question:

1. What is the potential of GIS and remote sensing techniques in assessing the energy performance and heat demand of buildings?
Methods:METHOD:
This review involves a systematic literature review of existing research papers, case studies, and other relevant sources that span the intersection of GIS, remote sensing, energy performance of buildings, and urban energy demand modelling. Firstly, the most common methods for assessing building performance have been identified by reviewing recent publications on GIS and remote sensing for building energy modelling, which include thermal imaging, LiDAR (Light Detection and Ranging), Multispectral imaging, Building Information Modelling (BIM), and Geographic Information Systems (GIS). The methods are then compared based on accuracy, applicability, efficiency, required time, and sustainability.

The review process includes the following key steps:

- *Literature search*
- *Synthesis of Findings*
- *Framework Development*

Results:Expected RESULTS:
The review aims to reveal an in-depth understanding of the transformative potential and challenges of integrating remote sensing and GIS technologies for the energy assessment of buildings. This study highlights that satellite remote sensing and unmanned aerial vehicles (UAVs) have a strong potential to enhance the input data for urban energy modelling; however, their applicability has been limited. The research will present a comprehensive examination of the challenges and potential solutions of these technologies. Additionally, the findings will include a table comparing different methods used to evaluate buildings' energy performance. This analysis will specifically focus on evaluating the applicability on a large scale, the effort required, time considerations, and the level of accuracy achieved with each approach.
Conclusions:CONCLUSIONS:

It can be concluded that GIS and remote sensing techniques have the potential to play a significant role in the assessment of buildings' energy performance and heat demand. The advantages of the system presented are obvious. It has the potential to quickly record data on insulation quality for

medium-sized building complexes, e.g. office buildings, schools or administrative headquarters, for which hand-held thermography is no longer realistic, to record data on the insulation quality in a short time and this directly to the building geometry and semantics. However, there are some challenges to be solved. By leveraging these tools, researchers and practitioners can gain valuable insights into buildings energy consumption, identify areas of high energy consumption, and develop strategies to reduce energy consumption and improve building performance.
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***Keywords:** Remote sensing, GIS, Energy assessment, Building performance*

[Page: 376]

[Abstract:0361] PP-021 [Accepted:Poster Presentation] [Electricity » Markets and Prices]

Uncertainty on renewables energies (wind and solar) generation forecasts and impact on energy prices in France

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Overview:Renewable energies (RES) play an important role in the supply of clean, sustainable electricity. The European Union encourages RES while ensuring affordable energy prices. In France, the government aims to decarbonize its energy system by 2050, which means more RES in the energy mix. However, integrating these energies into the power system presents challenges, mainly due to their uncertain and intermittent nature. This can affect the energy market, influencing prices and the prioritization of certain sources. In addition, with the rise of new means of mobility such as electric vehicles, demand for these renewable energies is increasing. Existing literature (Würzburg et al., 2013; Cludius et al., 2014; Zipp, 2017) has discussed the effect of RES on price based on their zero marginal cost, omitting the impact of other characteristics: intermittency and uncertainty (real-time forecast error). To date, only two studies have focused on the long-term impact of RES on prices. The first, conducted by Weber and Matt (2022) demonstrated a twofold effect of wind on market prices in Texas. The second study, the most recent by Hosius et al. (2023), analyzes the impact of offshore wind power on energy prices in Germany, western Denmark, and Great Britain. This paper analyzes the impact of wind and solar uncertainty on prices in France between 2015 and 2018 by using fixed effect regression. Particular attention is given to the residual demand variation in relation to price change. The choice of France for this study is significant because existing literature on the subject highlights the crucial role of the energy mix (De Miera, G. S. et al.,2008; Jónsson, T. et al., 2010) and France is one of the countries with a 50% dominance of nuclear energy in its mix, which has high fixed costs as a base load energy source. Furthermore, in France, RES impact are mostly addressed from a legal (Darson, A.,2015) or technical standpoint by sciences (Haessig, P.,2011), and to a lesser extent, from an economic standpoint (González-Aparicio, I., & Zucker, A., 2015).
Methods:To do so, we gathered data from two distinct and reputable sources. Firstly, we obtained essential information from the Eco2mix platform, operated by RTE, the French electricity transmission system operator (TSO), covering the period from 2015 to 2018. This platform offers comprehensive hourly data on electricity demand, renewable energy generation (particularly wind and solar), as well as forecasts of renewable energy. Secondly, we acquired price data from the EPEX SPOT exchange, renowned for its reliability and accuracy in capturing market trends. Because of the COVID-19 and high prices observed during this period, we have not included recent data in our analysis to avoid biasing our results.

After statistically analyzing the collected data, specifically focusing on intermittency and uncertainty, we performed a fixed-effect regression to measure their influence on prices. Additionally, another aim of this study is to examine how prices vary with an increase in residual demand. To achieve this, we segmented our dataset into percentiles based on residual demand and conducted a regression analysis to explore the relationship between price changes and the rise in residual demand.
Results:To do so, we gathered data from two distinct and reputable sources. Firstly, we obtained essential information from the Eco2mix platform, operated by RTE, the French electricity transmission system operator (TSO), covering the period from 2015 to 2018. This platform offers comprehensive hourly data on electricity demand, renewable energy generation (particularly wind and solar), as well as forecasts of renewable energy. Secondly, we acquired price data from the EPEX SPOT exchange, renowned for its reliability and accuracy in capturing market trends. Because of the COVID-19 and high prices observed during this period, we have not included recent data in our analysis to avoid biasing our results.
After statistically analyzing the collected data, specifically focusing on intermittency and uncertainty, we performed a fixed-effect regression to measure their influence on prices. Additionally, another aim of this study is to examine how prices vary with an increase in residual demand. To achieve this, we segmented our dataset into percentiles based on residual demand and conducted a regression analysis to explore the relationship between price changes and the rise in residual demand.
Conclusions:In summary, three key conclusions emerge regarding the intraday market. Firstly, a country's existing conventional energy mix plays a crucial role in managing the uncertainties associated with renewable generation. In addition, interconnection contributes to price stability and ensures a secure energy supply. Finally, investment in demand response could mitigate the impact of uncertainty.
In the future, our research aims to investigate how demand flexibility could offset the costs of uncertainty and manage congestion in less interconnected regions, particularly in Brittany and south-east France. The results will help determine whether the development of demand response and interconnection can facilitate the integration of RES
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Keywords: *Wholesale electricity market, Electricity price volatility, Renewables Uncertainty/ Intermittency, Residual electricity demand, Isolated / interconnected markets, Conventional generation.*

[Abstract:0375] PP-022 [Accepted:Poster Presentation] [Energy and the Environment » Climate Change and Greenhouse Gases]

Electric Shadows: Understanding the Nexus of Coal Power Plant Failures and Air Quality Dynamics

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Overview:The structure of Polish electricity production has traditionally been dependent on hard coal and lignite and continues to be (24% lignite and 48% of hard coal in 2020). Unsurprisingly then, 50% of all greenhouse emissions in Poland come from the energy sector. In fact, ever since the EU's National Emission Reduction Commitments (NEC) Directive, which has been in force since 2016, Poland has been falling short at fully introducing the directive into the national legislation. The directive in place is concerned with the national emission reduction goals for five major air pollutants: nitrogen oxides (NOx), Sulphur dioxide (SO2), ammonia (NH3), non-methane volatile organic compounds (NMVOCs), and fine particulate matter (PM2.5).

The following project considers the need for Poland to reduce the air pollution and investigates the temperature-energy-air pollution interlinkage. It answers the following research questions: 1) how do outages affect air pollution levels, 2) did the pollution level decrease in the areas that are densely populated (heterogeneous analysis), 3) is the effect on air-pollution long lasting?

The following paper is relevant from many perspectives. Firstly, from climate policy perspective, it underlines the importance of investment in other sources of power due to pollution levels. The results of this research could possibly suggest some policy implications for drastically changing the energy mix, may it be through further investment in renewable energies or introducing nuclear power plants to increase energy security. The latter argument follows the paper by Jarvis et al (2019), who show that the nuclear plant phase-out in Germany led to replacement of nuclear energy into coal, which increased the social cost by approximately 12 billion dollars per year and created over 1000 deaths annually due to increased pollution levels. Additionally, it provides information on air pollution reduction as a result of reducing energy production through coal. The last one is especially important for private business and regulators, as higher pollution levels indirectly translate into the economic and social costs that could be saved at the national level. There is a vast and continuously growing literature identifying causal effects of air-pollution on health outcomes, human capital and labour productivity (Deryugina et al., 2019, Liu and Salvo, 2018, Zivin and Neidell, 2012).

In the context of air pollution, we are contributing to the literature in a few ways. Firstly, we are planning to estimate how did the described natural experimented affect the pollution levels using data at the daily level. Due to lack of detailed outage data and the endogeneity in the outages (Gertler, Lee and Mobarak, 2017), the existing literature has mostly focused on outages of firms using annual data (Reinikka and Svensson, 1999; Fisher-Vanden, Mansur and Wang, 2015; Abeberese, 2017, Abeberese et al., 2021). There is, an emerging development economics studying the effect of power outages on productivity losses, which suggests that agents can adapt through self-generation of electricity (Allcott, Collard-Wexler, and O'Connell, 2016). Recently also, Kassem (2021) supports this by using high frequency data in New Delhi and shows that power outages increase pollution levels, thus showing it is not obvious that a power outage leads to decrease in pollution levels. Our paper differs in two major ways. It uses data from a developed European country, which can be a better reference point for other developed countries, uses high frequency data at the national level and a longer time period. It aims to study how mechanical failures affect the pollution levels, and how long lasting this effect really is. Lastly, it aims answering the question whether the pollution level decreased in the areas that are densely populated. As suggested by Deryugina et al. (2019) pollution levels should be addressed and appropriately decreased in the areas densely populated, the general decrease in pollution level is not as urgent.
Methods:This paper uses comprehensive high frequency data from several sources. Firstly, we use

data on power plant power outages, hourly electricity generation and capacity at the plant level. The data categorizes outages as planned or unplanned with corresponding reason for each outage. This data is obtained from the European Network of Transmission System Operators for Electricity (ENTSOE). Secondly, we merge our hourly electricity generation data with rich weather data from public meteorological monitors (air temperature, wind speed, wind direction) and hydrological monitors (water temperature, water height) from the State Institute of Meteorology and Water Management. The latter consists of the 200 public weather monitors spread across Poland. Data on air temperature and meteorological variables is reported three times a day (6am, noon, 6pm), in case of water related data such as water temperature – at the daily level. We merge the two datasets based on the nearest neighbour index. We complement our analysis with pollution data observed by the public pollution monitors from Chief Inspectorate of Environmental Protection, which report particulate matter (PM 1.0 and PM2.5) at the daily level.

*The empirical strategy consists of fixed effects models, controlling for location and month*year fixed effects, as well as several control variables e.g. capacity. Error terms are clustered at the plant level to control for strategic behaviour that can happen at the plant level. Additionally, we consider instrumental variable approach, where the unplanned outage is instrumented by air temperature and water temperature.*

*Results:Our results show that electricity generation increases air pollution level proxied both by PM1.0 and PM2.5., as evidenced by statistically significant coefficients at the 99% level. When it comes to the link between outages and air pollution, we can observe substantial heterogeneity in results, proving work for further research. Namely, in a baseline panel OLS regression, with clustered standard errors at the plant level we find that as the outage occurs the air pollution level decreases by around 11%. This coefficient is rather stable as we add control variables and when we add plant fixed effects it increases to around 18%. However, the coefficient turns statistically insignificant with an addition of month*year fixed effects which control for unobserved time varying factors. This remains platform for further research. In the next step, we want to carry out heterogeneous analysis with regards to population density, and also regional variation with regards to summer-winter interactions.*

Conclusions:This study unravels ties between coal power plant failures and air quality dynamics in Poland, a nation heavily dependent on coal for energy. Employing high-frequency data and robust methodologies, our results revealed a significant increase in air pollution linked to electricity generation. However, the relationship between power outages and pollution exhibited complexities with the effect ranging from reduction of around 14% to becoming statistically insignificant. This urges further exploration.

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Keywords: *outage, air pollution, high frequency data, population density*

[Page: 378]

[Abstract:0386] PP-023 [Accepted:Poster Presentation] [Energy Modeling » Energy Demand]

Modeling Prosumer Behaviour for Effective Demand Response Management in Positive Energy Districts

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*Overview:Mitigating the impact of climate change is a main driver behind the urge for more efficient utiliz-
ation of energy. To achieve this goal, a comprehensive transformation at the urban scale is necessary [1]. Positive Energy Districts (PED), which are districts that produce more renewable energy than they consume, are an innovative solution for a complete energy transition [2]. Achieving a PED relies on different elements, one of which is the active involvement of energy prosumers [3]. The inclusion of
prosumer behavioral patterns is essential in implementing Demand Response (DR) strategies in PEDs [4]. To implement these strategies, simulation and forecasting tools that can predict demand are neces-
sary. Incorporating behavioral patterns into these models significantly enhances their reliability and the impact of DR strategies [5].*

The research question of this paper is: Which methods have recently been applied to modeling prosumer behaviour patterns in a PED? Which approach is the most compatible with applications in demand response management for PEDs?
*Methods:This paper builds on previously published work, which discusses a Home Energy Management Sys-
tem (HEMS) that can perform load scheduling enabling DR [6]. This HEMS generates and optimizes a day-ahead load profile of electrical loads in the home enabling the prosumer to take advantage of dy-
namic pricing signals and renewable energy generation. Furthermore, the model incorporates prosumer
behaviour in the system through a statistical method leveraging historical appliance use data. The objective of this paper is to further develop this behavioural component and investigate how different approaches will impact demand response management optimization. The scope of this work will not be limited to a single household; rather, it will be expanded to the district level through examining potential interactions between households and buildings.*
*The methodology consists of identifying, analyzing, and assessing different approaches to modeling behavioural patterns of households within a PED. Prevalent methods in literature, such as Agent Based
modeling, Machine Learning, and the Markov chain model, will be investigated [7] [8]. The comparison
between approaches will be based on a set of indicators such as computational efficiency, scalability, data requirement prior to initialization, and the accuracy by which they are able to model behavioural patterns of prosumers. The approach that rates the highest across all indicators will be implemented as part of the HEMS and a simulation will be performed and analyzed.*
Results:This work is expected to result in a better understanding of approaches to household behaviour modeling, which in turn will contribute to the development of demand response management of PEDs.
Conclusions:Finally, the findings of this research will be synthesized into a set of recommendations to be considered for behaviour modeling of residential consumers.
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Keywords: *Positive Energy Districts, Household Behavioural Modeling, Demand Response, Prosumer Behaviour.*

[Abstract:0387] PP-024 [Accepted:Poster Presentation] [Energy Modeling » Energy Data]

Dynamic grid environments: the evaluation of the economic impact of time-variable electricity prices and feed-in tariffs on renewable energy communities in austria

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Overview:Renewable energy communities (RECs) are emerging rapidly in Austria, reaching a total number of 675 RECs in mid-2023 [1]. RECs enable a collective generation and utilization of energy. They are considered as an important tool to increase decentralization and decarbonization. At the same time, prosumers and consumers benefit from a favourable tariff and price structure for electricity procurement and feed-in. Energy communities can cover most of their electricity requirements at midday in line with PV power generation. Otherwise, the electricity must be drawn from the grid. The increasing number of RECs in Austria leads to a spread of renewable energy sources (RES), especially rooftop solar photovoltaics (PV) and an increase in volatility in the electricity grid. There is a need to introduce time-variable tariffs for the withdrawal and purchase of electricity for the following reasons: to ensure grid stability, optimize the use of RES, and to vary costs and

incentives for using the electricity grid [2] [3]. Dynamic grid environments will directly impact the profitability of RECs and will open up new challenges for RECs. For this reason, this research aims to analyze the impact of dynamic tariff designs on the economic efficiency of RECs.
Methods:The method of approach for the economic analysis of RECs in Austria consists of qualitative and quantitative methodologies. In the first step, quantitative data of empirical energy flow and economic data of existing RECs in Austria are collected. In the next step, energetic and economic modelling techniques are applied to analyze the economic viability of specifically selected RECs without dynamic tariffs. Following that, dynamic tariffs are implemented, and their impact is assessed. Quantitative indicators such as degree of self-sufficiency and degree of self-consumption will be utilized as benchmarks for a REC's success measurement. The contribution of this paper is that actual data and experiences of RECs in Austria are analyzed, making it possible to identify current tariff structures and present the actual impact dynamic tariffs will have on the economic efficiency of the RECs.
Results:Results are obtained by investigating three case studies of RECs in Austria with different characteristics in the number of members, energy source and generation capacity. The respective data consists of two months (August and December of 2022) of electricity generation and load profile at a resolution of 15 minutes. Preliminary results show the costs and benefits of prosumers and consumers within the RECs. Figure 1 demonstrates the average saved costs of consumers and prosumers of three different RECs (A, B, and C) in one year.
Consumers can save costs from 37 to 140 €, whereas the saved costs of prosumers differ from 171 to 2045 €. Economic efficiency depends on tariff structure/allocation methods and REC characteristics such as the consumer and prosumer ratio and the energy source such as solar, wind or hydro. REC A consumes a large amount of the generated energy directly on-site, considering a self-consumption rate of 60%. REC B has a storage system, enabling a more efficient use of the electricity generated, which means that less electricity has to be drawn from the grid, leading to higher saved costs. The REC C's self-consumption rate of 40% shows that 60% is fed into the grid and remunerated. The high degree of self-sufficiency of 40% also contributes to the cost savings.
Further preliminary results show the correlation between dynamic tariffs and RECs. Figure 2 presents the load- and generation profile of REC A on August 1st 2022, and the intraday electricity price on that day. The Load profile consists of typical consumption peaks in the morning, at noon and in the evening, whereas the PV generation reaches its peak at noon.
The assumption that the electricity suppliers' dynamic feed-in and withdrawal tariffs are based on day-ahead electricity prices, this presents a challenge for RECs. REC draws electricity at times of high demand and high electricity prices and feeds in electricity at times of high supply and low feed-in tariffs. The further results of the modelling of dynamic tariffs are expected to worsen the economic efficiency and reduce the saved costs of prosumers and consumers of a REC.
Conclusions:The conclusions drawn from this research have important implications for energy communities on how their economic profitability will change with the implementation of dynamic tariffs. The evaluations of Austrian RECs show that each REC must be considered individually due to the different consumption and generation structures. The results show that environmental and economic benefits are associated with any form of REC. Furthermore, this study highlights the impact dynamic tariffs have on the economic efficiency of RECs in Austria. RECs can implement the following solutions to adapt to the changed framework conditions: 1.) Adjustment of the tariff structure, 2.) Investment in a storage system 3.) Load shifting within the REC 4.) Electricity trading of the surplus electricity. Future work aims to analyze the above solutions, in particular, the investment possibilities in a storage facility will be investigated through a community investment or a third-party investment.
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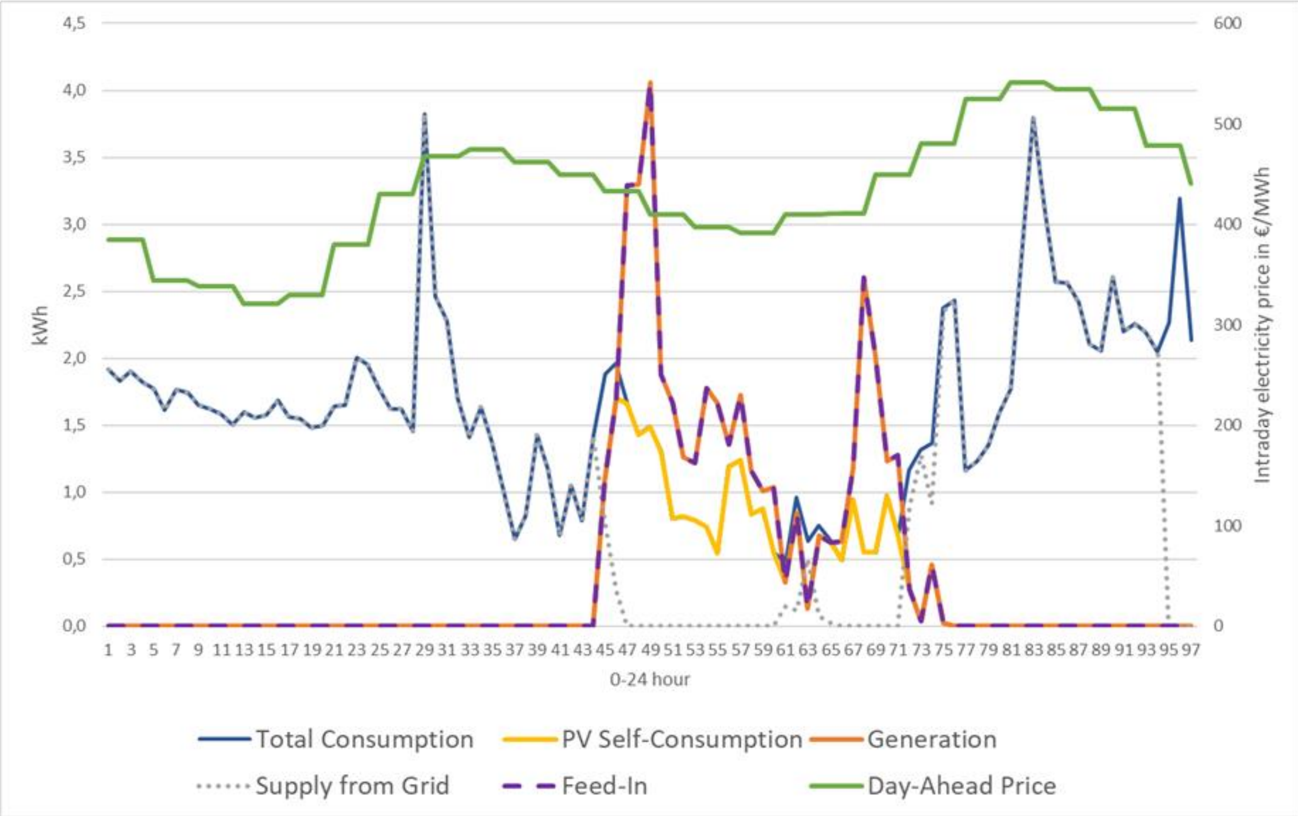
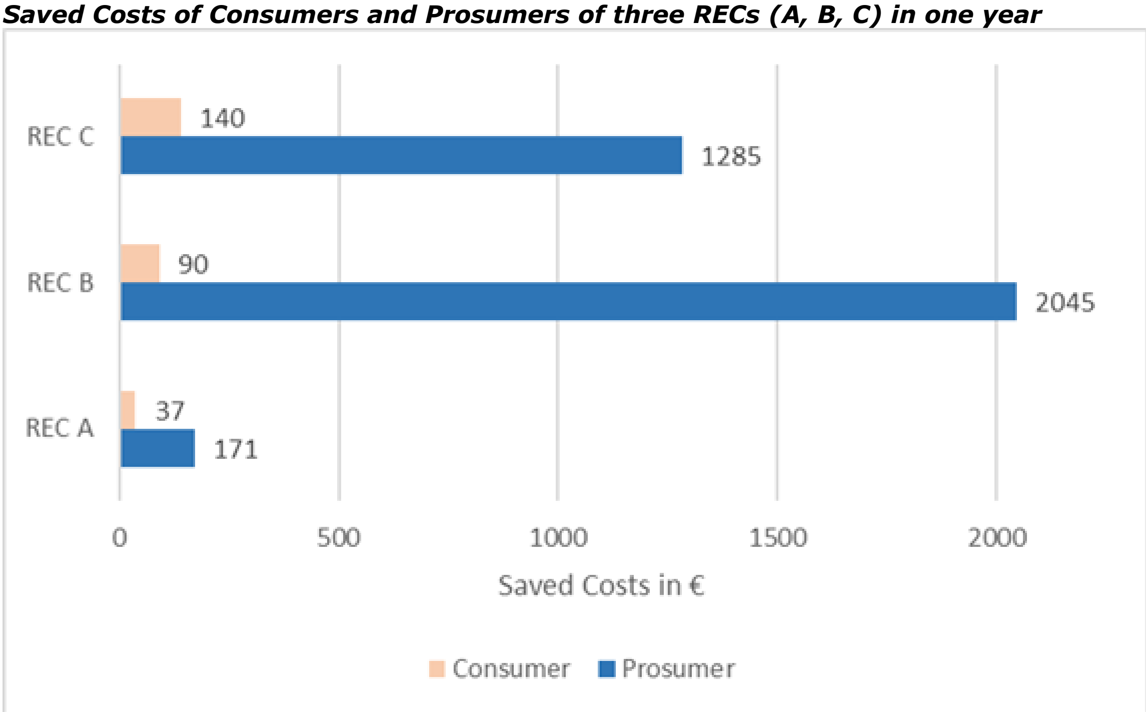
***Keywords:** renewable energy communities, cost allocation, time-variable electricity prices*

Load- and generation profile of REC A and Intraday Electricity Price – on August 1st 2022



Saved Costs of Consumers and Prosumers of three RECs (A, B, C) in one year



[Abstract:0413] PP-025 [Accepted:Poster Presentation] [Renewables » Policy and Regulation]

Impact of green energy policies on sustainable development in resource-rich countries

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Overview:This paper examines the role of green energy policies in resource-rich countries and their impact on sustainable development, encompassing social, economic, and environmental dimensions. Fossil fuels, as a predominant energy source, significantly influence a nation's economic and social growth but adversely impact environmental sustainability due to high CO2 emissions. Transitioning to green energy is a key objective in both international development agendas and national policies. However, this shift presents challenges, particularly for countries with abundant resources, due to their reliance on fossil fuels and inherent political, economic, and social vulnerabilities.

The significance of green energy transition ensuring sustainable development is emphasized in international commitments such as Paris Agreement on climate change, Koyoto Protocol operationalizing United Nations Framework Convention on climate Change and 2030 Agenda for Sustainable Development, and was strengthened in the recent Climate Change Conference (COP 28) held in December 2023, emphasizing "transition away from fossil fuels and to triple renewables and double energy efficiency globally by 2030" placing social equity at the centre to support affected communities and their livelihoods, ensuring inclusivity in all aspects of energy transition by adopting national policies and sectorial programs, forming sound regulatory environment conducive to just transition, strengthening investment climate in scaling up renewable energy and enhancing energy efficiency in environmentally sustainable way.
Methods:The paper presents a systematic literature review from 2003 to 2023 analysing over 2300 peer-reviewed articles and critically reviewing 78, to understand the progression and factors influencing green energy development.

The main research question was formulated with the purpose to understand the green energy policy change process and to assess the policy impact. The sub-questions on identifying the factors underlying policy formulation and implication on sustainable development were developed. The keyword combination focused on "green energy", "sustainable development", "green energy policies" and "impact", it also included "state polices" to capture the papers that could be associated with policies in green energy development. Further the Web of Science and Scopus databases were used to ensure interdisciplinary coverage of diverse academic literature on resource-rich countries for the extensive period of 20 years. inclusion criteria defined document type and research areas covering economic, social and environmental aspects., with further inclusion of papers from fields of management, business, environmental studies, geography, public administration and development studies, social sciences and economics. The search included papers that employed all type of methodologies namely qualitative, quantitative, mixed and multi-level mixed methods and theoretical approaches. In addition, the papers on literature review in green energy were also included to identify gaps and provide insights on existing literature and trends for development of future research questions. The selection and assessment process enabled to identify papers covering 15 resource-rich countries and 7 regions.
Results:The findings show a diverse range of green energy policies in resource-rich nations, with their impact on sustainable development varying based on policy scope, economic status, natural resource dependence, institutional quality, technological advancement, human capital, and social factors. The research indicates that green energy policies are more effective in developed resource-rich countries for supporting renewable energy projects, compared to developing ones where the 'resource curse' impedes renewable energy capacity.
Conclusions:The systematic literature shows that the role of green energy policies had various impact across resource-rich countries depending on level of economic development and resource dependency, policy scope and implementation on national and local level, it also highlights that social access, affordability and accountability are one of the key aspects that demands policy focus especially in resource-rich developing countries.

The study provides future research directions and offers insights for policymakers and practitioners,

highlighting key considerations for implementing green energy policies to ensure a sustainable energy transition and development.

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Keywords: *green energy policy, sustainable development, social sustainability, environmental sustainability, economic sustainability, impact*

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[Abstract:0423] PP-026 [Accepted:Poster Presentation] [Energy Security and Geopolitics » Geopolitics of Energy]

Reshaping Global Crude Oil Dynamics: The Impact of Western Sanctions on Russian Exports

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Overview:This research paper delves into the transformative effects of Western sanctions on Russian crude oil exports, revealing a significant shift in value chains and supply/demand fundamentals within the far east. We rely on comprehensive ship tracking data provided by internationally renowned data analytics firms, such as S&P Global and the Center for Research on Energy and Clean Air (CREA), and others to underscore our findings. In the pre-sanction era, research into Russian crude supply and demand were conducted collaboratively with local Russian data analysts. However, the onset of the Russia-Ukraine conflict severed these collaborations, particularly concerning sanctioned commodities like crude oil. This rupture prompted Russia to devise innovative strategies for transporting their restricted assets and to establish entirely new value chains, connecting with eager customers. Contrary to prevailing notions of Western sanctions effectively curbing Russian oil sales,

our research offers compelling evidence that Russia has ingeniously adapted to meet the entirety of its export demand. Central to this adaptation is the redirection of crude oil primarily to China and India, where the appetite for Russian oil remains steadfast. The data-driven analysis demonstrates the resiliency of Russia's oil sector in the face of adversarial economic measures, presenting a comprehensive assessment of the profound shifts in global energy dynamics resulting from these strategic adaptations.

Methods:Overview

This study mainly consists of crude oil ship tracking and import/export data curated by global industry leaders in energy analytics, related to the Russian-Ukraine conflict.

Procedure

Using data provided by ship tracking energy analytics, custom time series were created in order to show the comparison by quarter and year in relation to Russian exports. This data (Figure 5) was further broken down further to display Russian Crude Export Recipients by Country (Graph 1), the highest recipients of Total Russian Crude Exports (Graph 2), and the Country Type of Russian Export Recipients (Graph 3).

Figure 5 Explanation (Data Driven Results)

The data contained within figure 5 encompasses the following graphs: "Russian Crude Export Recipients by Country (Graph 1)" "The highest recipients of Total Russian Crude Exports (Graph 2)" "The Country Type of Russian Export Recipients (Graph 3)". All of the data in the before mentioned graphs are directly sourced from S&P Global's public "Interactive: Global Oil Flow Tracker". This data was sourced, scraped, and then transformed into different bar graphs to represent different trends identified through this research paper.

Results:The results data driven research study can be summarized by the following themes:

1. Geopolitical Shifts - As a result of the Western sanctions enacted on Russia, Russia has shifted their exports to exclusively conduct business with the major Eastern petroleum powers such as India and China. Prior to the start of 2022 Russia exported ~3MMbbls per day, where ~65% went to Western nations. By the start of 2023, Russia exported ~3.5MMbbls per day where ~75% went to Eastern nations specifically China and India. These sanctions have strengthened the relationship of Russia, China, and India and as a result have created economic value for all parties. For example, prior to the start of 2022 India received ~.1MMbbls per day from Russia. By the same time next year, India received ~1.25MMbbls per day. At the start of 2022 China received around ~.5MMbbls per day from Russia and by the start of 2023 were receiving upwards of ~1.1MMbbls per day. These trends in the changes of Russian exports directly correlate to India and China setting records for domestic refinery throughput.

2. Effects of Western Sanctions - The original intention of Western sanctions was to disrupt Russia's ability to profit from the export of their large domestic crude oil production. This was thought to be achieved by preventing Russia from doing business from Western nations therefore reducing demand. These sanctions have been proven to be ineffective because, according to all available data Russia has exported more crude oil than before the enactment of the sanctions. For example prior to the implementation of the Western sanctions at the start of 2022 Russia exported around ~3MMbbls per day of crude oil. According to available data Russia has achieved a peak export of around ~3.7-3.8MMbbls per day which ~85-90% going to Eastern nations such as India, China, and Turkey. The data has shown that these sanctions have proven to be ineffective in preventing Russia from exporting crude oil for profit.

Conclusions:1. Although most of the Western world has enacted economic sanctions against Russia in an effort to restrict crude oil exports, this study and its associated data will show that these sanctions have failed to make sizeable impact in reducing Russian crude exports.

2. Russia has become proficient in using processes such as "Ship-to-ship" transfers and other illicit means of exporting their sanctioned crude. In order to prevent these instances, western countries need to develop new sanctions that are more effective.

3. As a result of existing sanctions, Russia has aligned with its allies in the east (India and China) to create new localized subset of crude trade that is outside traditional global markets.

4. As rapidly developing countries, China and India are refining record amounts of Russian crude oil in order to jump start their respective energy sectors. This alliance has disrupted the traditional refining landscape, strengthening the geopolitical bond between Russia, China, and India.

5. International oil companies must devote increased resources to understanding the new crude *value chain and fostering geopolitical relationships in order to continue doing business in the east, especially with entities in India and China.*

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Keywords: *Russia, Oil, Sanctions, Ship-tracking, Geopolitics*

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[Abstract:0447] PP-027 [Accepted:Poster Presentation] [Energy and the Macroeconomy » Resource Endowments and Economic Performance]

Exploring different energy transition regimes in the case of German federal states by forecasting regional GDP growth and measuring diffusion across space

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Overview:German federal states (Bundesländer) pursue different renewable energy deployment and fossil fuel phase-out strategies. This results in different regional economic development dynamics considering the transition to renewable energy. Due to the spatial heterogeneity of German energy and industry production, this is likely accompanied by a geographical shift in labour markets and overall production (McDowall et al., 2023; Sievers et al., 2019). Undoubtedly, this will create winners and losers of the renewable energy transition. Analysing how economic development diverges across space is one of the key questions of regional economics. We contribute to this issue by researching how a change in regional economic growth and economic indicators propagates into neighbouring regions.
Methods:For the case of the German federal states, we estimate a random effects spatial panel model to investigate and forecast the dynamics of regional real growth in gross domestic product. We study the cross-state effects utilizing a spatial autoregressive component. We reproduce the methodological approach developed by Jordà (2005), where impulse response functions (IRF) are estimated and inferred through local projections. Commonly, IRFs are estimated from linear multivariate Markov models such as a vector autoregression model (VAR). Estimating them from local projections can sidestep the resource-intensive task of creating a spatial VAR, which is inherently more complex as shocks propagate across space and over time (Beenstock & Felsenstein, 2007). Additionally, estimating a spatially adjusted VAR is often impossible due to the lack of geo-referenced data at a high temporal resolution. By shocking our variable of interest with its spatial

lag, we learn how economic development impacts across state borders over different time horizons. Furthermore, we apply scenario analysis to explore the effects of different energy transition regimes. Results:We find that neighbouring regions' economic growth significantly impacts the regional economy. We assess that the cross-state effects can counteract negative impacts for regions historically tied to coal-production. We identify patterns for the interaction between regions. Conclusions:Our paper explores the regional economic dynamics resulting from different energy transition regimes. We highlight the importance of recognizing the spatial heterogeneity of economic activity. The geographical divergence informs and improves the policy process towards facilitating a renewable energy transition. We contribute to the field by applying our methodological approach to the case of German federal states.
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Keywords: *Regionaleconomics, Energy transition, Spatial econometrics, Local Projections*

[Abstract:0484] PP-028 [Accepted:Poster Presentation] [Electricity » Transmission and Networks]

Impact of IBRs on System Protection

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Overview:Renewable generators exhibit different fault characteristics compared to conventional synchronous generators. This may result in misoperation of legacy protection schemes in power systems with large share of renewables. It is therefore necessary to study the performance of these protection schemes to ensure their efficiency under renewables. Methods:System studies and protection responses were analyzed. Results:System based studies were indicated. Conclusions:This report has studied the impact of IBRs on system protection, illustrated misoperation scenarios, and suggested potential solutions. Table 11-1 presents a summary of the main findings.
References:EPRI papers.

Keywords: *impact, IBRs, protection*

[Abstract:0520] PP-029 [Accepted:Poster Presentation] [Energy Efficiency » Residential and Commercial Buildings]

CEEG, A dataset on energy efficiency grade of white goods in mainland China at regional and household levels

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Overview:White goods (WGs), including washing machines, room air conditioners, and water heaters, are large, important and popular household appliances (HAs)1 that account for approximately 40% of noncooking household electricity consumption2,3. To improve energy efficiency and energy-saving management, energy efficiency labels (EELs) for WGs were gradually introduced in the 2000s4. EELs provide information on the energy efficiency grade (EEG), an integer between 1 (high level, more energy-efficient) and 5 (low level, less energy-efficient), and its related parameters (RPs). After more than a decade of development, both WG EEG standards and energy-saving technologies have been improved5. However, how effective the promotion of WGs with high EEGs has been in China is still not clear. It is vital for policy-makers to have a complete view of the EEGs of products sold in the market and to evaluate and adjust the implemented EEG policies and standards.
To the best of our knowledge, there are few statistics that can be implemented to solve the EEG promotion evaluation problem. Scholars have attempted to estimate the energy-saving ability of WGs from a regional perspective. In some studies, sales data from certain online shopping platforms have been introduced6,7. However, due to limited actual data, studies are often limited to one or two types of appliances (mostly refrigerators6-8), and the time span of the data is relatively short (mostly cross-sectional data). Hence, it may be difficult to accurately understand the overall trends and situations.
In other studies, the aim has been to explore promotion effectiveness by utilizing consumer behavior decision theories. For WGs, purchase behaviors are more heterogeneous9,10 among households or individuals. Thus, numerous factors may influence WG purchase behaviors and, consequently, the market share of high EEG WGs. This possibility has increased the need for related questionnaire surveys11,12 or simulation experiment13 data. However, these approaches are either costly or regionally limited and are difficult to apply in other regions.
In addition to analyzing historical developments in the market share of high EEG WGs, it is vital to forecast future trends by using regional and household statistics and methods. For instance, traditional econometric models14,15 and machine learning (ML) algorithms16,17 have been widely used in research with similar data sizes. These types of studies allow the current EEG policies and standards to be assessed and can play an important role in effectively and efficiently promoting energy-efficient WGs.
Within these contexts, the China Energy Efficiency Grade (CEEG) of WGs dataset is developed in this study. The dataset provides average EEG data from both the regional and household perspectives. It contains 5 kinds of WGs, including impeller washing machines (IWMs), drum washing machines (DWMs), electrical water heaters (EWHs), room air conditioners (ACs), and variable-speed room air conditioners (VACs), which account for 78% of WG-related household electricity consumption in China3. The regional part contains sales information for the 5 kinds of WGs and the average EEG weighted by sales data for 30 provinces in mainland China (except for Tibet) from 2012 to 2019. The household part comprises household socioeconomic, demographic, living and EEG-related information on 1327 households in the Haidian District, Beijing, China, in 2019 and 2021. Due to the tedious process of raw data acquisition and processing, we also establish models to predict the annual average EEG of the purchased WGs based on socioeconomic information at different scales and provide the prediction results.
In summary, the aims of this study are as follows:
(1) To collect, process, and provide data related to the EEGs of WGs at the regional (including national and provincial) level from 2012 to 2019 and at the household level in 2019 and 2021.
(2) To predict EEGs through socioeconomic, demographic and living factors and compare the variables and methods for various prediction models at the regional and household levels.
By providing EEG-related data and prediction models at different spatial scales, the CEEG dataset will facilitate the advancement of research on household energy consumption, HA consumer choice, and the assessment of EEL-related policies.
Methods:The research framework consists of three modules: data acquisition, processing and cleaning; modeling; and validation.

(1) Data acquisition, processing and cleaning: We first acquire EEG information, WG sales data, economic/socioeconomic data and household WG survey data by retrieving, web crawling and surveying. Then, we clean the EEG information and WG sales data by conducting uniqueness and matching checks, and we clean the household WG survey data by applying a survey completion check, energy usage check and 3-sigma principle. Additionally, we attempt to fill in missing values (mainly for EEG information) through manual retrieval. Finally, we use the "query" and "category summary" methods in SQL to fuse and process the EEG information and WG sales data and to calculate average EEG weighted by sales.
(2) Modeling: We deploy traditional econometric methods and ML algorithms to establish a regional average EEG prediction model (REPM) for each kind of WG and a household average EEG prediction model (HEPM) for the average EEG and EEG attitude. As the regional average EEG data are continuous and the household data are categorical, regression and classification are employed for the REPM and HEPM, respectively.
(3) Validation: We present the descriptive statistics of the data, evaluate and compare the models based on performance indicators (e.g., R2), and identify key features in the ML algorithms by calculating the importance of the features to validate the credibility of the dataset.
Results:Descriptive Statistics
From 2012 to 2019, the market share of WGs in the phase-out and compete-with-gas categories decreased. Specifically, the market share of IWMs decreased from 78% to 45%, that of ACs decreased from 59% to 23%, and that of EWHs decreased from 69% to 54%. In contrast, the market share of WGs in the phase-in category increased. Specifically, the market share of DWMs increased from 22% to 55%, and that of VACs increased from 41% to 77%.
The energy efficiency of IWMs, DWMs, EWHs, and VACs in the 2012-2019 period showed upward trends (i.e., the EEG values decreased). This result indicates that WGs purchased in China were more energy efficient. However, the opposite trend was observed for ACs. Additionally, a significant shock to the average EEG of ACs was observed in 2014. This finding might be because of the end of energy-efficient household appliance subsidy policies in 2013, according to All View Cloud. Thus, consumers tended to buy cheaper but less energy-efficient ACs. At the provincial level, the trends of the upper pivot, median, and lower pivot of the provincial average EEG distribution over time were all similar to the trends of the national average EEG.

Prediction RESULTS: The R2 values of the best regression methods were all above 0.76, and the F1 scores of the best classification methods were all above 0.85, indicating that the methods were generally well fitted. The ML algorithms performed better than traditional econometric methods at both the regional and household levels. In further analysis, we chose the methods that achieved the best performance for (i) each kind of WG in the REPM in terms of the RMSE or (ii) each kind of WG in the HEPM in terms of the F1 score. The XGBoost algorithm was more suitable for all methods. For the predicted values (shaded part in Fig. 4), better performance, i.e., a higher average EEG, was predicted for IWMs, ACs and EWHs. For DWMs and VACs that had increasing market shares, the average EEG might decrease, i.e., be less energy efficient. These predicted values and their 95% confidence intervals (CIs) were also included in the dataset.

Feature Importances
We compare the importance of each feature and identify the features with the highest importance, which are referred to as the "key factors". At the regional level, economic variables (especially the Engel coefficient and RPI) and the place variable are more important in predicting the EEG, i.e., they have a larger effect on the prediction results. For DWMs and VACs, the most important variable in predicting their average EEG is the RPI; for ACs, the Engel coefficient is the most important variable; and for EWHs, the place variable is the most important variable.
For the HEPM, housing factors, especially the housing location and housing age, are the most important variables in predicting both the average EEG and EEG attitude, which is similar to the fact that the place variable is the most important variable in the REPM for IWMs and EWHs. Economic/socioeconomic factors, including family income and HH education, also show significant impacts on the EEG, with weights of 0.27 and 0.26, respectively.
Conclusions:After establishing, predicting and verifying, the following data records can be accessed and downloaded in both XLSX and JSON formats: (1) the national and provincial market shares of the 5 kinds of WGs considered; (2) the national and provincial average EEGs and RPs of WGs weighted by sales; (3) household information, the average EEG and the HH EEG attitude; and (4) the variables and hyperparameters used in provincial- and household-level modeling. Additionally, the questionnaire both in Chinese and in English translation is provided.
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Keywords: *White goods, energy efficiency grade, household survey*

[Page: 385]

[Abstract:0550] PP-030 [Accepted:Poster Presentation] [Energy and the Environment » Energy-Water Nexus]

Microgrid Applications and Business Models in Agriculture: A Case Study of Algerian Farms

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Overview:The agricultural sector is essential in the economic development and food security of Algeria. As the country strives to improve the efficiency and sustainability of its agricultural practices, integrating microgrids is a promising solution. However, to fully capitalize on the potential of microgrids as sustainable energy sources, implementing a suitable business model is crucial. Energy business models hold the key to delivering cost-effective energy to consumers, generating revenue, and ensuring a profitable return on investment for farmers.
Methods:The research methodology employed in this study integrates various approaches to comprehensively assess the technical and economic aspects of microgrid adoption in the Algerian agriculture sector. Case studies serve as a foundational component, providing real-world insights has similar contexts to our farm case study.
The inclusion of field surveys further enhances the research, providing on-the-ground data and observations that contribute to a clear understanding of the specific needs and conditions within the selected case study, Tlemcen in Algeria as part of the MG-farm project (1). Additionally, in economic and energy modelling, Julia and AnyMoD, establish a critical analytical framework for the assessment of the financial feasibility of microgrid adoption.
This integrated methodology aims to ensure a comprehensive and robust evaluation of the technical and economic dimensions surrounding the implementation of microgrids in the context of Algerian agriculture.
Results:The findings aim to assess business models suitable for Algerian farmers engaged in different agricultural activities.
Conclusions:In conclusion, the paper contributes to the ongoing discourse on sustainable energy solutions for agricultural development in Algeria. Exploring the application and business models of microgrids provides a roadmap for harnessing clean and reliable energy to enhance the resilience and productivity of the Algerian agricultural landscape.
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Keywords: *Microgrids, Business models, Financial analysis, Energy modeling, Agriculture, Algeria*

[Abstract:0606] PP-031 [Accepted:Poster Presentation] [Energy Finance and Trading » Other]

Voluntary Carbon Market Supply and Demand Dynamics and an Outlook on Demand for Carbon Credits

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Overview:Despite the accelerating decarbonization efforts to limit temperature to 1.5 C° above pre-industrial levels, there is still a gap between today's commitment and the needed cut by nearly 55

giga tonnes of CO2eq in global emissions by 2050. To bridge this gap, trading carbon offsets in carbon markets can enhance cooperation and reduce GHG emissions in accordance with Article 6 of the Paris Agreement. Both compliance and voluntary carbon markets have grown significantly over the last 5 years but they are still fragmented.
Methods:Voluntary carbon markets are uncharted and immature markets with little to no regulatory supervision, where currently the supply of carbon credits is surpassing the demand due to mixed market signals. At this time of uncertainty around the future of VCM, this paper aims to examine the supply and demand dynamics of VCM from 2015 to 2023 and provide an outlook on the voluntary carbon market's possible demand scenarios in 2030 and 2050 based on Net-Zero commitments of companies and organizations, CORSIA, and Nationally determined contributions as well as IPCC climate scenario (1.5 C°).
Results:The analysis of the current VCM supply and demand dynamics suggests that the issues related to integrity of carbon credits, fragmentation, under-regulation, change of policies in CCM are all reasons halting demand. The issuance of nature-based solutions declined by 20% compared to 2021 levels. Issuance levels decreased by 27% from 2021 levels.
Demand of carbon credits from companies' commitment and CORSIA frame work only make up 30% of the offsetting capacity required by the 1.5 C° IPCC climate scenario. The base case demand for carbon credits in 2030 and 2050 is estimated to be 0.37 and 2.46 billion credits respectively. The additional number of offsets needed based on NDCs is estimated to be 0.8 billion tonnes in 2030 and 6 billion tonnes in 2050
Conclusions:In conclusion, with more companies stepping forward to pledge climate goals and more development of sectoral based frameworks such as CORSIA being rolled out, the demand for carbon credits would likely increase. As voluntary carbon markets grow into one global market governed by the anticipated Article 6 global registry, VCM might gains more recognition as a mechanism to help the world decarbonize, and consequently the demand for carbon credits would likely increase as well.
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Keywords: *Carbon market, voluntary carbon market, offsets, net zero*

[Abstract:0626] PP-032 [Accepted:Poster Presentation] [Energy System Transition » Policy]

The energy infrastructure reinvestment provision of the united states inflation reduction act. where did the money go?

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Overview:This research project undertook an examination of the practical implementation and viability of over 150 projects facilitated by the $250 billion federal funding allocated through the Energy Infrastructure Reinvestment Provision (EIR) under the Inflation Reduction Act. This provision serves as an incentive for investments in renewable energy, infrastructure development, and energy efficiency initiatives, aligning with objectives to address the climate crisis, fortify the U.S. position in domestic clean energy production, and further the Biden-Harris administration's goals for a net-zero economy. Employing a comprehensive methodology, this study entailed an analysis of legislative frameworks, an investigation into approved projects, an exploration of trends in allocated funding, and an assessment of realized outcomes of the Inflation Reduction Act. The insights derived from this study revolved around the oversight and accountability measures implemented by the United States Loan Programs Office, characterization surrounding the distribution of funds, and to date realized impact on job outlook and emission levels. The outcome of this project aims to offer valuable insights for domestic and international policymakers, industry leaders, and stakeholders, guiding evidence-based decision-making to collectively encourage responsible production and consumption of sustainable, reliable, and abundant energy future.
Methods:A comprehensive approach was taken involving legislative analysis, assessment of approved projects, and examination of funding trends. Key methods included data analysis of fund distribution, job creation metrics, and emission reduction outcomes. Numerous research platforms were utilized to import data surrounding real time fund disbursement and allocation by recipient class, project type, funding category, and state. Imported data was then extrapolated into figures to demonstrate the variance surrounding funding disbursement and utilization.
Results:The completion of this research produced intriguing insights, ranging from the challenges posed by inadequate project progress tracking to the already growing clean energy workforce. The findings can be summarized as follows:

1.Identify the specific allocation of designated funding:

Project classes with the greatest funded amount out of $2,925,116,126:

1.Weatherization assistance for low income persons: $1,376,264,439

2.Manufacturing and Energy supply chain demonstrations for commercial application's: $797,741,560
3.Grid infrastructure deployment and Resilience: $541,748,580
4.State Energy Program: $170,468,880

2.Geographically map the distribution of allocated funds:
States with the greatest allocation of funding out of $2,907,623,723:

1.Missouri: $257,704,245
2.North Carolina: $213,036,119
3.Illinois: $195,324,240
States with the least allocation of funding out of $2,907,623,723:
1.Georgia: $1,400,000
2.Delaware: $2,928,990
3.Connecticut: $6,865,420
3.Monitor the advancement of supported projects:

Upon exploring the USA Spending website, a government sponsored platform that centralizes data on the disbursement of funds, I discovered that the platforms project progress data failed to account for actual realized progress. This system accounted for time elapsed since funding allocation rather than the advancement of the project to its completion. Each project type held the same timeline for completion, therefore was displayed as on track for completion. Throughout my research in the program and funding guides pertaining to the IRA, a large emphasis on accountability and transparency measures appeared. In practice, the Government Accountability Office and the Loan Programs Office have not maintained an accurate method of progress reporting for IRA stakeholders.
4.Examine the realized impact on employment opportunities:
Clean energy jobs grew by 3.9%, totaling an addition of 114,000 jobs nationwide
Clean energy jobs constitute over 40% of the total energy jobs
Solar and wind energy technologies contributed to more than 84% of new electric power generation jobs, resulting in an addition of over 21,000 jobs (a 3.6% growth)
Conclusions:The EIR is a monumental step towards shaping a clean energy future through progressing sustainable energy project development and research, emission reduction outcomes, and climate crisis objectives. Through demonstrating the impact of policy and legislation on clean energy initiatives, this project assesses the successes and challenges associated with government intervention surrounding the progression of the energy industry. The distribution surrounding greatest allocated amounts of funds, indicate a prioritization of initiatives aimed at both aiding low-income households and advancing commercial applications in energy production and infrastructure. Providing assistance for low income households curtails emissions associated with residential real estate. The funding disparity among states demonstrates the variance associated with funding awarded due to variable amounts of innovative project ideas, research, resources, and population by state. Furthermore, the impact on domestic employment opportunities have been realized by 3.9% since its conception. Finally, the critical need for improvement in accountability and transparency practices surrounding monitoring the progress of supported projects. This research demonstrates the positive impact of policy, areas of improvement, and most importantly serves as a model for peer nations to adapt for their domestic energy transitions as we collectively address the energy trilemma.
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Keywords: *energy-trilemma, climate-crisis, emission-reduction, energy-policy, energy-transition, clean-energy*

AuthorToEditor: *I am a student. I am entering my abstract to participate in the student research category. Thank you for your time and consideration!*

[Abstract:0005] PP-033 [Accepted:Poster Presentation] [Hydrogen » R&D and Emerging Technologies]

Visualizing the Revised FIT for Solar PV in Taiwan

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Overview:Renewable energy grows much faster than any other energy in recent years. According to the recent information revealed on the website of IEA, since 1990, global renewable energy sources have grown at an average annual rate of 2.1%, which is slightly higher than the 1.8% growth rate of world TES. Growth has been especially high for solar PV and wind power, which grew at average annual rates of 36.0% and 22.6%, respectively. However, comparing to the global energy supply, the renewable energy still accounts only a tiny part (see Figure 1). Apparently, it's very tough to reach 2050 net zero emission without any technology change or more aggressive policy implemented. Taiwan government confronts even tougher job due to the non-nuclear home policy and the limited land problem. To reach the 20% renewable energy relative share for all power generation, Taiwan Government tried very hard to revise the FIT policies. Among them, the solar energy FIT rates are worthy to be shared with other countries. This paper uses the visualization skills to draw all different FIT rates for solar PV in Taiwan. Hope we can shed some light for those countries to expand the rapid installation of solar PV.
The purpose of this paper is to reveal the FIT rate evolution of solar PV in Taiwan by applying the visualization techniques. We will draw many visualization figures to capture the improvement of FIT rates for different types of solar PV. We believe some snag shots of these evolution would help more people to capture FIT rates revision in Taiwan.
Methods:After reviewing all related articles, we tackle this issue step by step as below:
1. Collect the annual data of all solar FIT rates for different types of solar PV from Bureau of Energy in Taiwan.
2. Collect the annual data of all solar PV installation from Bureau of Energy in Taiwan.
3. Collect all policies been announced by Government for solar PV from Bureau of Energy in Taiwan.
4. Draw many Figures of all FIT rates and some related data for different types of solar PV.
5. Examine the policy effectiveness from all above Figures.
Results:Using the annual data of all solar FIT rates and solar PV installation for different types of solar PV from 2011 to 2021, we draw several interesting Figures (e.g. Figure 2). Our preliminary visualization data results show that Taiwan government tries very hard to create the incentives for private firms. In order to find every inch of the limited land to build up more solar PV, the Government addressed more new kinds of premium to raised up the FIT rates for inducing the private firms installing solar PV in the unsuitable land areas before.
Conclusions:More aggressive solar PV installation is a good way to reach 2050 net zero emission. However, land limitation for building up more solar PV is the big obstacle for many countries. This paper visualizing the trend of revised FIT rates movement in Taiwan. Hope we can shed some light for those countries to expand the rapid installation of solar PV.

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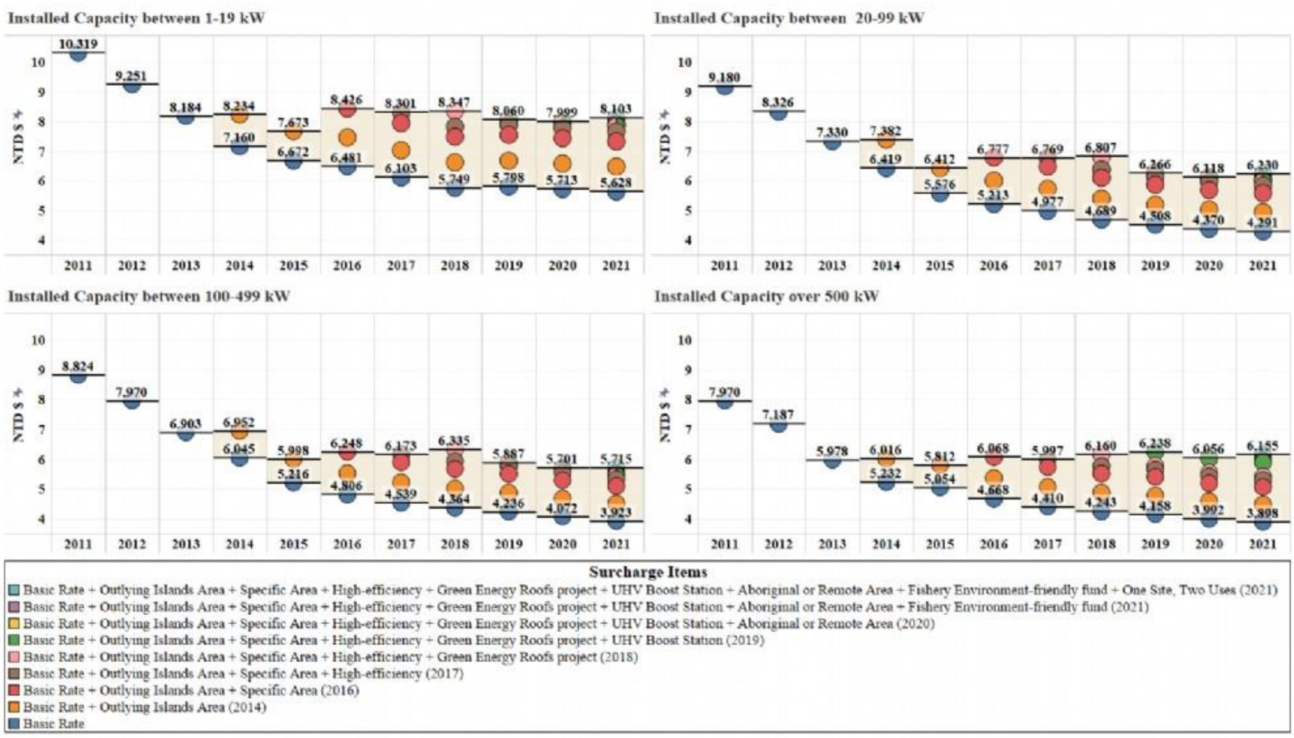
Keywords: *Solar Photovoltaic System, Feed-in tariff, Data Visualization*

The Evolution of FIT rates movement for different installed capacities of solar PV in Taiwan



[Abstract:0090] PP-034 [Accepted:Poster Presentation] [Energy Efficiency » Other]

Assessment of the Resource-use Efficiency in Agriculture at the Provincial Level in China from the Food-Energy-Water Nexus Perspective

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Overview:China's agricultural sector has undergone substantial expansion in terms of crop production and resource input, giving rise to complex challenges including resource scarcity, carbon emissions, and ecological degradation. The sustainable development potential of the current agricultural system remains unknown. Insufficient research has been conducted on dynamic resource-use efficiency (RUE) in relation to the food-energy-water (FEW) nexus.
Methods:We established a framework in combination with input-output analysis that transforms data on water use, provincial crop production, machinery, fuel, and fertilizers in China from 1987 to 2020 into a standardized energy unit (GJ/ha/y). This framework provides a method for quantifying the resource inputs for crop production and the resource-use efficiency of 31 provinces and seven sustainable developing agricultural zones.
Results:The findings indicate that after an initial upswing, agricultural intensification commenced to decrease around 2017, and RUE displays a U-shaped pattern. RUE for China is approaching 3, which is still below the global average. Although technological innovation is increasing RUE and mitigating the adverse effects of intensification and extensification, it is insufficient to guarantee resource saving or land sparing.
Conclusions:Our study, based on the input-output framework from the FEW nexus, evaluated the regional and provincial resource-use efficiencies of China's agriculture. The findings have policy implications for the development of agri-food policy and land management strategies in China, as improving RUE is the key to achieving more sustainable agriculture with minimal resource consumption and environmental impacts.
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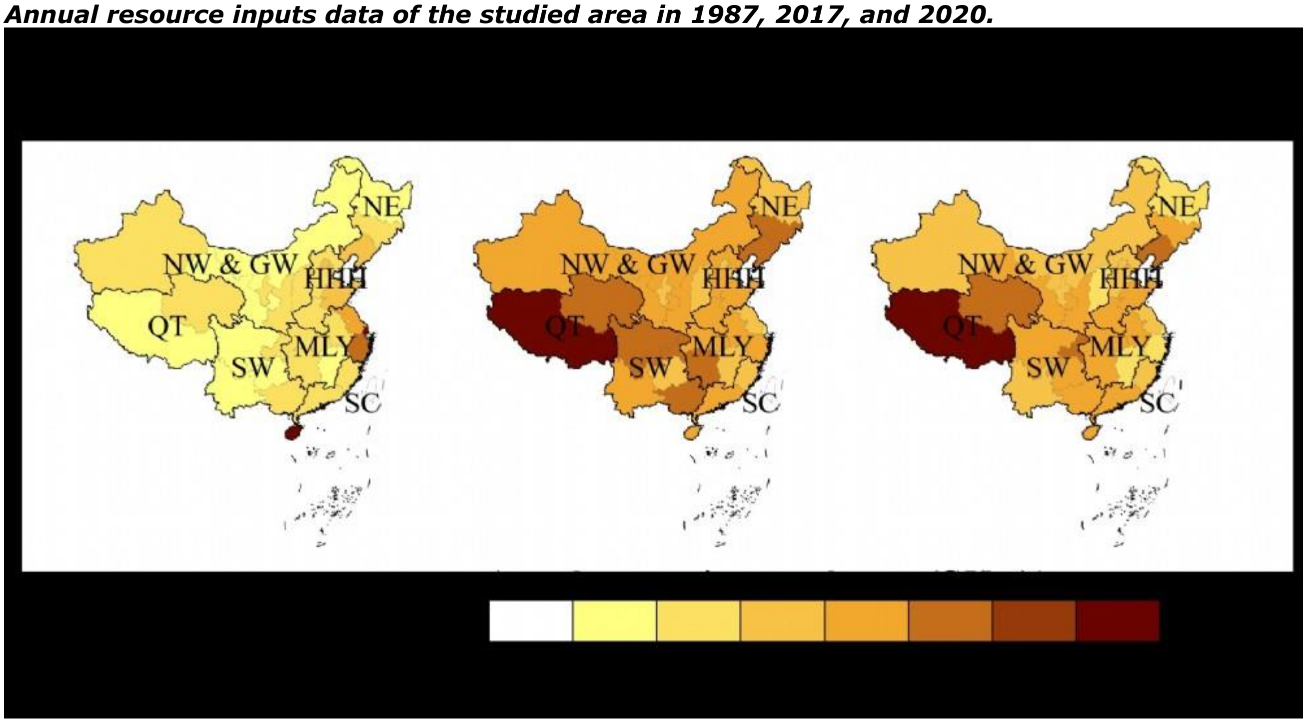
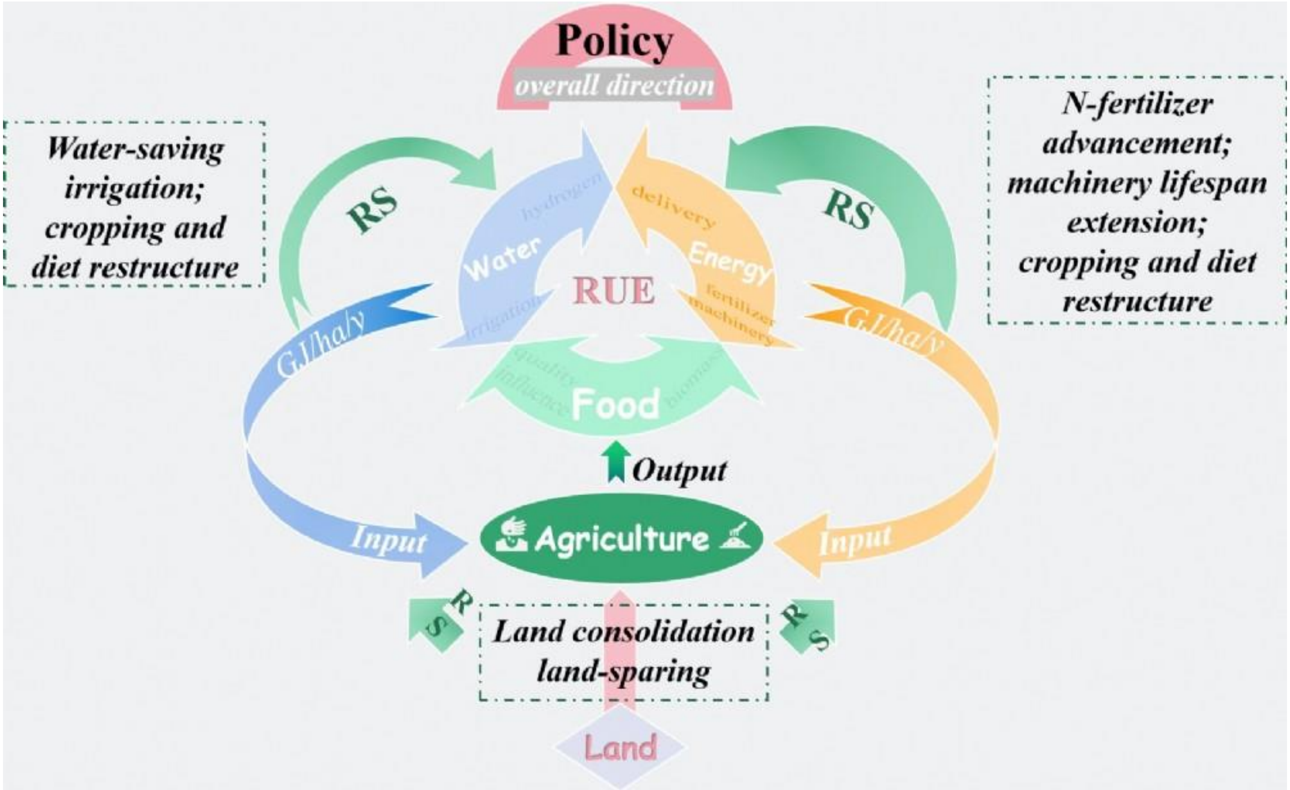
Keywords: *Energy efficiency, resource efficiency, water-energy-food nexus, China, agriculture*

Annual resource inputs data of the studied area in 1987, 2017, and 2020.

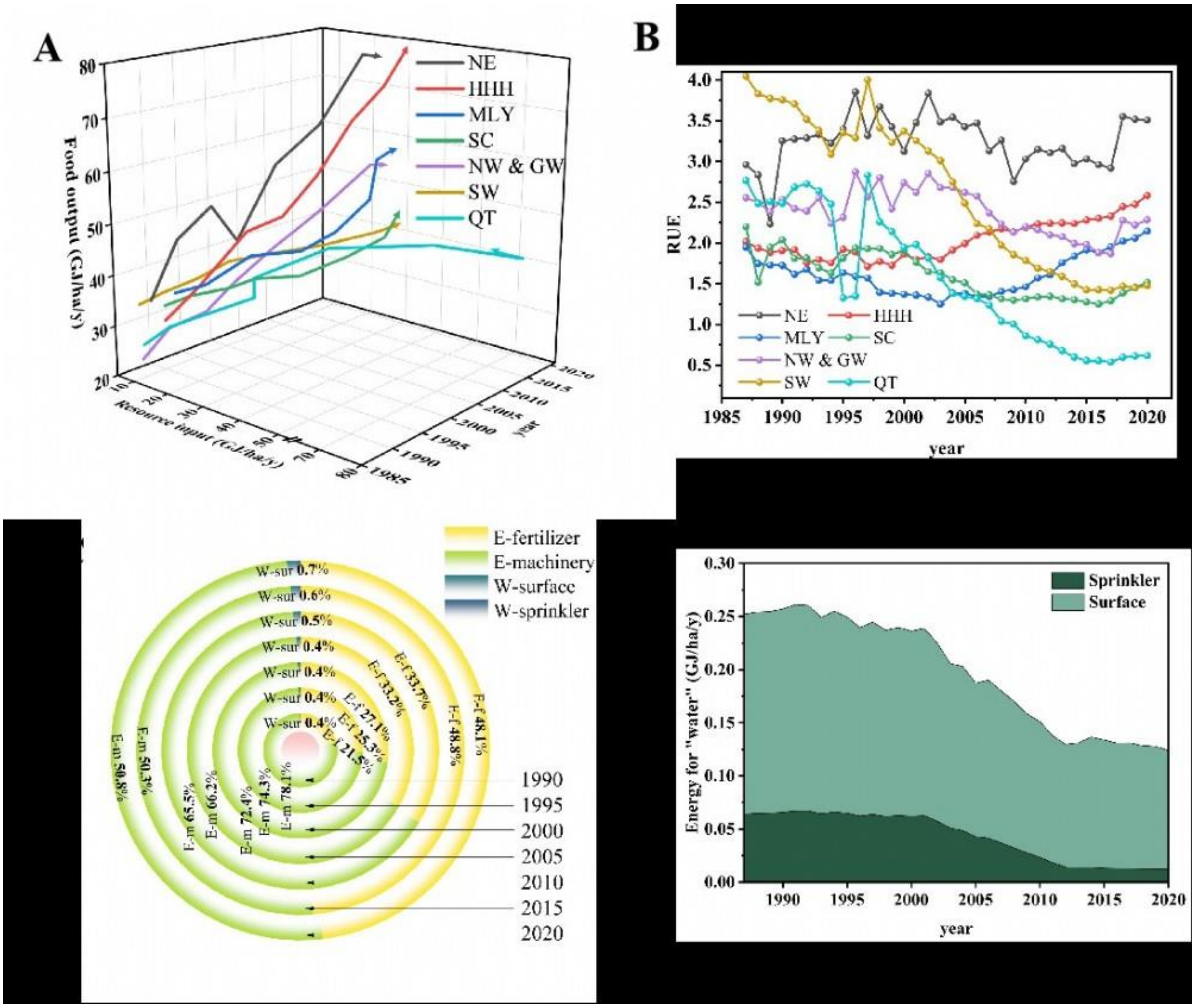


Conceptual framework of our study from the perspective of FEW nexus



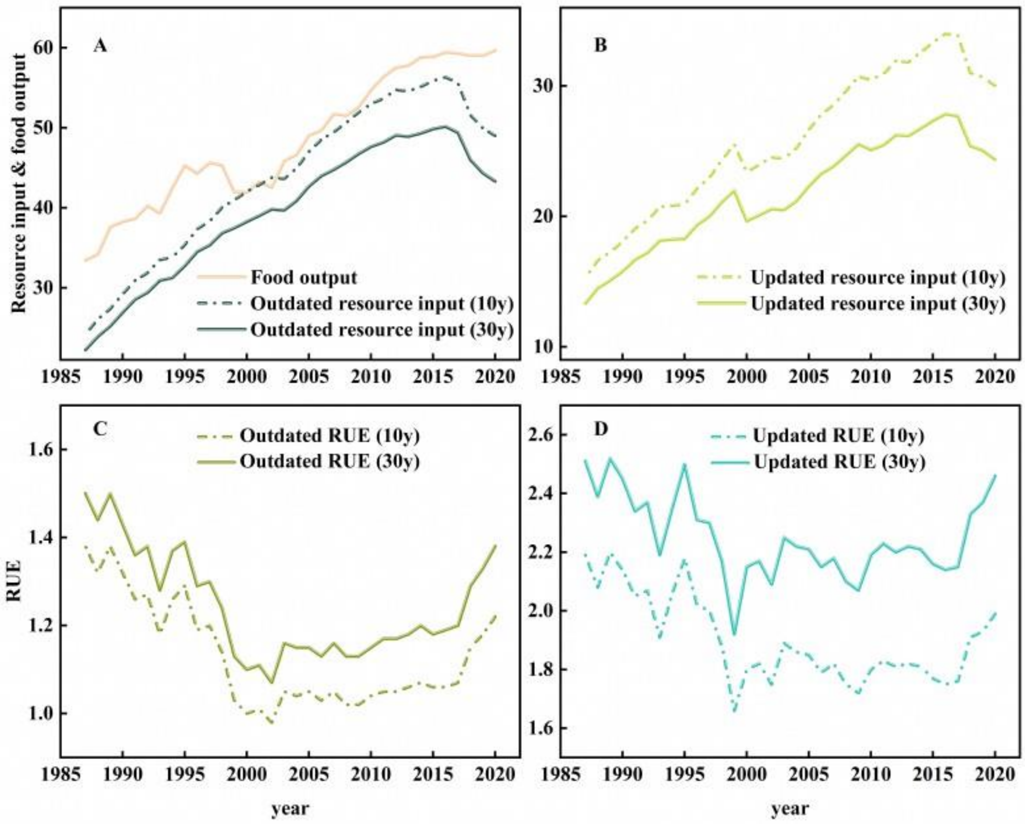
In this framework, RUE (Resource-use Efficiency) and RS (Resource Saving) are key considerations. Energy flows throughout the entire ecosystem, influenced by technological advancement, societal adaptations, and adjustments.

Figure 3



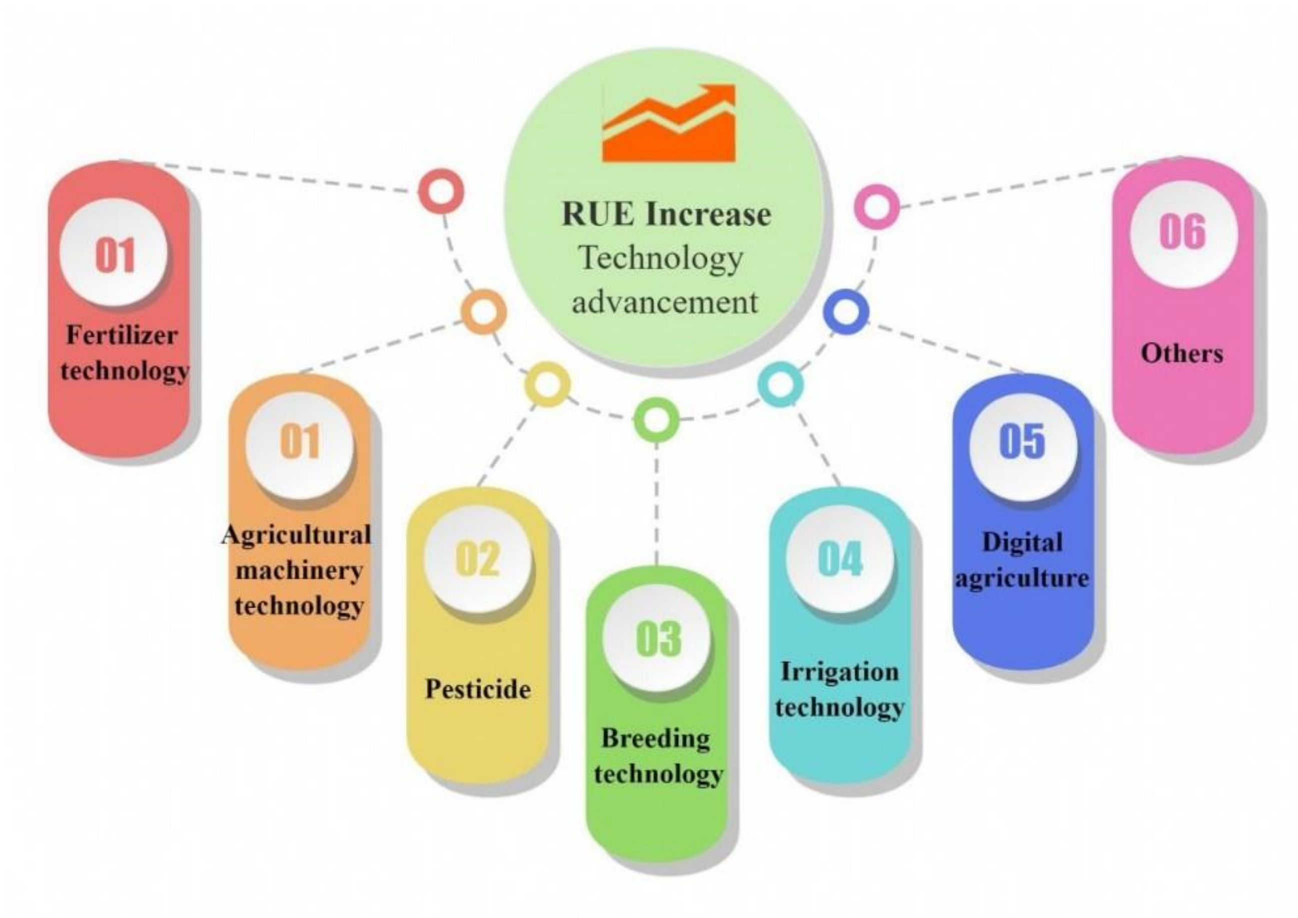
(A) Food output as a function of resource input for seven zones for 1990, 1995, 2000, 2005, 2010, 2015, and 2020 (Chongqing had missing data before 1997, and Hainan has missing data for 1987, so these years' data for them are not included here). (B) RUE for seven zones is represented as the ratio of food output (GJ/ha/y) to resource input (GJ/ha/y) from 1987 to 2020. (C) Average proportion of energy (including fertilizer which is shown as "Energy-fertilizer", machinery and fuel which are shown together as "Energy-machinery") and water (energy consumption of surface and sprinkler system are respectively shown as "Water-surface" and "Water-sprinkler") parts for 31 provinces in 1990, 1995, 2000, 2005, 2010, 2015, and 2020. (D) Energy consumption of the surface and sprinkler irrigation systems from 1987 to 2020.

Figure 5

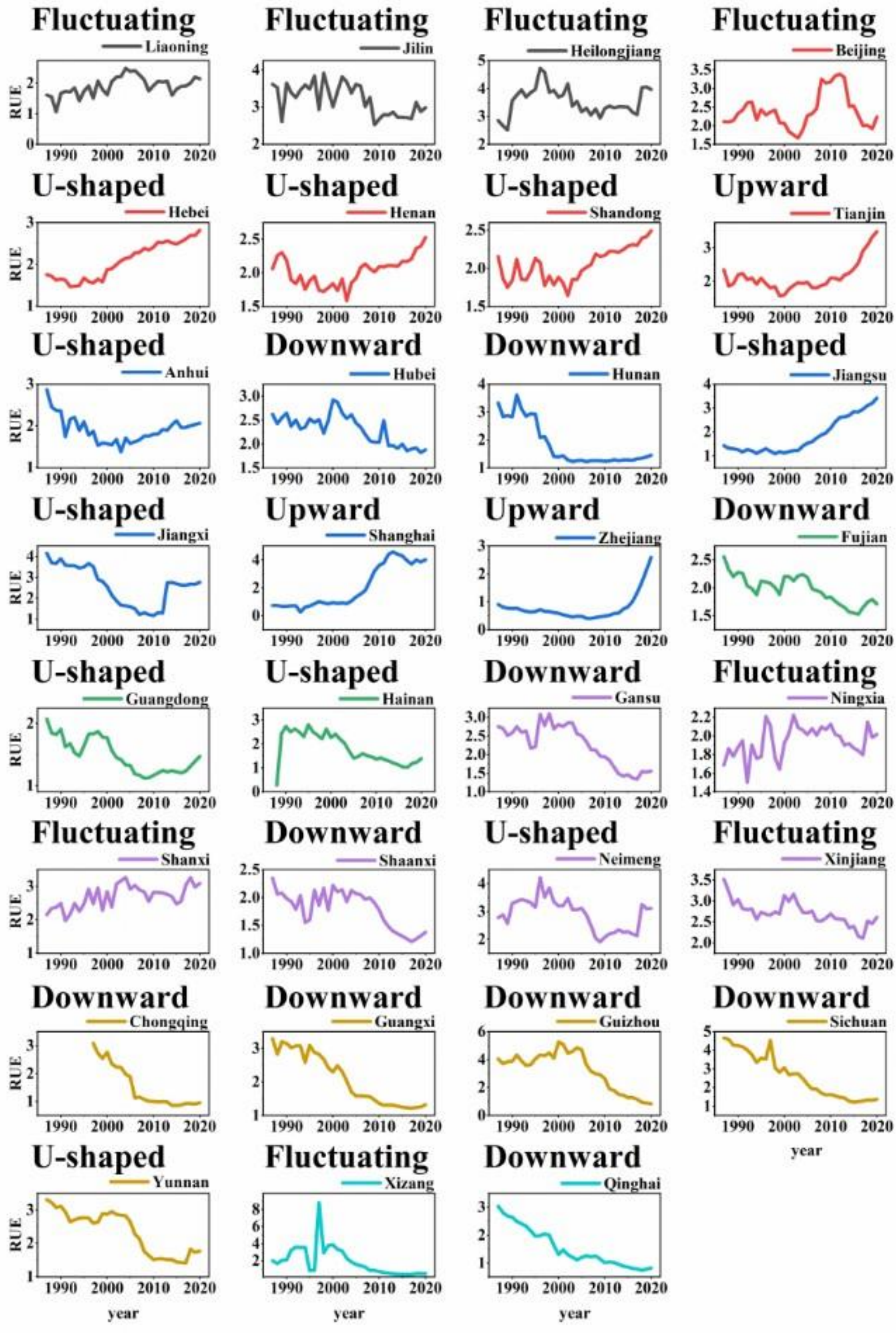


(A) Total annual outdated resource input (GJ/ha/y), food output (GJ/ha/y) of 31 provinces from 1987 to 2020. (B) Total annual updated resource input (GJ/ha/y) of 31 provinces from 1987 to 2020. (C) Outdated RUE of 31 provinces from 1987 to 2020. (D) Updated RUE of 31 provinces from 1987 to 2020. "Updated" and "Outdated" refer to the calculation method that takes the industrial energy-efficiency increase in synthesizing ammonia (detailed in Methodology) into consideration or not. Resource input and RUE are presented in two machinery lifespan scenarios: 10 y (broken line) and 30 y (solid line).

Technological advancements that increase RUE



The RUE from 1987 to 2020 for 31 provinces



We divided these trends into four categories: U-shaped (the trend experienced both first-declined and final-increased progress), downward, fluctuating (being tortuous with basically the same begin-end values), and upward.

EditorToSelf: *Görken Hocanın talebine istinaden iptal edilmiştir. (Mail-20.05.2024)*

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