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Editorial

Energy Systems Analysis and Modelling towards Decarbonisation

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1. Introduction

The Paris Agreement establishes a process to combine Nationally Determined Contributions with the long-term goal of limiting global warming to well below 2 °C and even to 1.5 °C. Responding to this challenge, national and regional low-emission strategies are prepared by both EU and non-EU countries, outlining clean energy transition pathways.

The aim of this Special Issue is to provide rigorous quantitative assessment of the challenges, impacts and opportunities induced by ambitious low-emission pathways. It aims to explore how deep emission reductions can be achieved in all energy demand and supply sectors, exploring the interplay between mitigation options, including energy efficiency, renewable energy uptake and electrification to decarbonise inflexible end-uses such as mobility and heating. The high expansion of renewable energy poses high technical and economic challenges with regard to system configuration and market organisation, requiring the development of new options, such as batteries, prosumers, grid expansion, chemical storage through power-to-X and new tariff-setting methods. The uptake of disruptive mitigation options (hydrogen, CCUS, clean e-fuels), as well as carbon dioxide removal (BECCS, direct air capture, others) may also be required in the case of net zero emission targets but raises market, regulatory and financial challenges.

This Special Issue assesses low-emission strategies at the national and global level and their implications for energy system development, technology uptake, energy system costs as well as the socioeconomic and industrial impacts of low-emission transitions.

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2. Scientific Contribution of this Special Issue: A Brief Overview

Yang et al. [1] examine greenhouse gas emission reduction possibilities from the electricity sector. The authors develop an agent-based model of the electricity system with heterogeneous agents who invest in power generating capacity under uncertainty. The heterogeneity is characterised by the hurdle rates the agents employ (to manage risk) and by their expectations of the future carbon prices. The results show that under an increasing CO_2 tax scenario, the agents start investing heavily in wind, followed by nuclear and to some extent in natural gas fired power plants both with and without carbon capture and storage, as well as biogas fired power plants. However, the degree to which different technologies are used depend strongly on the carbon tax expectations and the hurdle rate employed by the agents. Comparing to the case with homogeneous agents, the introduction of heterogeneity among the agents leads to a faster CO_2 reduction.

The Green Deal of the European Union defines extremely ambitious climate targets for 2030 (−55% emissions compared to 1990) and 2050 (−100%). Kattelmann et al. [2] focus on how the emission reduction targets shall be distributed across EU countries. The authors analyse the necessary burden sharing within the EU from both an energy system and an overall macroeconomic perspective. For this purpose, they use the energy system model TIMES PanEU and the computational general equilibrium model NEWAGE. The results show that excessively strong targets for the Emission Trading System (ETS) in 2030 are not system-optimal for achieving the 55% overall target. Economically weaker regions would have to reduce their CO_2 emissions until 2030 by up to 33% on top of the currently decided targets in the Effort Sharing Regulation, which leads to higher energy system costs, as well as losses in gross domestic product (GDP). Depending on the policy scenario applied, GDP losses in the range of −0.79% to −1.95% relative to baseline can be found for single EU regions. In the long-term, an equally strict mitigation regime for all countries in 2050 is not optimal from a system perspective; the total system costs would be higher by 1.5%.

The achievement of climate neutrality in the European Union by 2050 will not be possible solely through a reduction in fossil fuels and the development of energy generation from renewable sources. Large-scale implementation of various technologies is necessary, including bioenergy with carbon capture and storage (BECCS), carbon capture and storage (CCS), and carbon capture and utilisation (CCU), as well as industrial electrification, the use of hydrogen, the expansion of electromobility, low-emission agricultural practices, and afforestation. Tatarewicz et al. [3] carry out an analysis of BECCS as a negative emissions technology (NET) and the assessment of its implementation impact upon the possibility of achieving climate neutrality in the EU. The modelling approach utilises tools developed within the LIFE Climate CAKE PL project and includes the MEESA energy model and the d-PLACE CGE economic model. The authors identify the scope of the required investment in generation capacity and the amount of electricity production from BECCS necessary to meet the greenhouse gas (GHG) emission reduction targets in the EU, examining the technology's impact on the overall system costs and marginal abatement costs (MACs). The modelling results confirm the key role of BECCS technology in achieving EU climate goals by 2050.

The promising power-to-gas (P2G) technology makes it possible for wind farms to absorb carbon and trade in multiple energy markets. Considering the remoteness of wind farms equipped with P2G systems and the isolation of different energy markets, the scheduling process may suffer from inefficient coordination and unstable information. An automated scheduling approach is proposed in the work of Ji et al. [4]. Firstly, an automated scheduling framework enabled by smart contract is established for reliable coordination between wind farms and multiple energy markets. Considering the limited logic complexity and insufficient calculation of smart contracts, an off-chain procedure as a workaround is proposed to avoid complex on-chain solutions. The scheduling strategy takes into account not only the revenues from multiple energy trades but also the penalties for violating contract items in smart contracts. Then, the implementation of smart contracts under a blockchain environment is presented with multiple participants, including voting in an agreed scheduling result as the plan.

The COVID-19 pandemic left a remarkable impact on how people and businesses behave. At the same time, there is still high uncertainty as to how the impacts will evolve in the future. Emissions pathways after COVID-19 will be shaped by how governments' economic responses translate into infrastructure expansion, energy use, investment planning and societal changes. As a response to the COVID-19 crisis, most governments worldwide launched recovery packages aiming to boost their economies, support employment, and enhance their competitiveness. Climate action is pledged to be embedded in most of these packages but with sharp differences across countries. The work of Rochedo et al. [5] provides novel evidence on the energy system and greenhouse gas (GHG) emissions implications of post-COVID-19 recovery packages by assessing the gap between pledged recovery packages and the actual investment needs of the energy transition to reach the Paris Agreement goals. Using two well-established Integrated Assessment Models (IAMs) and analysing various scenarios combining recovery packages and climate policies, the authors conclude that currently planned recovery from COVID-19 is not enough to enhance societal responses to climate urgency and that it should be significantly upscaled and prolonged to ensure compatibility with the Paris Agreement goals.

Scaling down the big picture at the level of businesses, more and more companies choose to disclose carbon information, respond to the national policy of carbon emission reduction and focus on the sustainable development of enterprises. The paper of Lu et al. [6] investigates the impact of carbon disclosure on financial performance based on the 2011–2018 CDP report, taking the Fortune 500 companies as a sample. The study finds that for carbon-intensive industries, carbon disclosure cannot significantly contribute to the improvement of financial performance in the current period, but for carbon-non-intensive industries, carbon disclosure can significantly contribute to the improvement of financial performance in the current period, and the positive impact of carbon disclosure on financial performance in the current period can be extended to the next period. Finally, based on the findings of the empirical study, this paper puts forward policy recommendations for the construction of China's carbon disclosure system.

Jamróz et al. [7] contribute to this SI from a technical perspective on improving the efficiency of power plants to contributing to the energy transition and reduction of emissions from power generation. Combined cycle power plants are characterized by high efficiency, now exceeding 60%. The economic analysis of the authors revealed that the difference between the annual revenue from the sale of electricity and the annual fuel cost is considerably higher for power plants set to supercritical parameters, reaching approx. USD 14 million per annum. It is proposed that investments in adapting components of the steam part to supercritical parameters may be balanced out by a higher profit.

It is widely accepted that the market uptake of electric vehicles is essential for the decarbonisation of transport. However, scaling up the roll out of electric vehicles (EV) is challenging considering the lack of charging infrastructure. The latter is, currently, developing in an uneven way across the EU countries. A charging infrastructure with wide coverage addresses range limitations but requires high investment with uncertain returns during the early years of deployment. The aim of the work of Statharas et al. [8] is to assess how different policy options affect EV penetration and the involvement of private sector in infrastructure deployment. The authors propose a mathematical programming model of the decision problem and the interaction between the actors of EV charging ecosystem and apply it to the case of Greece from the time period until 2030. Greece represents a typical example of a country with ambitious targets for EV penetration by 2030 (10% of the total stock) with limited effort made until now. The results indicate that it is challenging to engage private investors in the early years, even using subsidies; thus, publicly financed infrastructure deployment is important for the first years. In the mid-term, subsidization on the costs of charging points is necessary to positively influence the uptake of private investments. These are mainly attracted from 2025 onwards, after a critical mass of EVs and infrastructure has been deployed.

Carbon leakage features prominently in the climate policy debate in economies implementing climate policies, especially in the EU. The imposition of carbon pricing impacts negatively the competitiveness of energy-intensive industries, inducing their relocation to countries with weaker environmental regulation. Unilateral climate policy may complement domestic emissions pricing with border carbon adjustment to reduce leakage and protect the competitiveness of domestic manufacturing. Fragkos et al. [9] use an enhanced version of GEM-E3-FIT model to assess the macro-economic impacts when the EU unilaterally implements the EU Green Deal goals, leading to a leakage of 25% over 2020 to 2050. The size and composition, in terms of GHG and energy intensities, of the countries undertaking emission reductions matter for carbon leakage, which is significantly reduced when China joins the mitigation effort, as a result of its large market size and the high carbon intensity of its production. Chemicals and metals face the stronger risks for relocation to non-abating countries. The Border Carbon Adjustment can largely reduce leakage and the negative activity impacts on energy-intensive and trade-exposed industries of regulating countries by shifting the emission reduction to non-abating countries through implicit changes in product prices.

Research and Innovation (R&I) are a key part of the EU's strategy towards stronger growth and the creation of more and better jobs while respecting social and climate objectives. In the last decades, improvements in costs and performance of low-carbon technologies triggered by R&I expenditures and learning-by-doing effects have increased their competitiveness compared to fossil fuel options. So, in the context of ambitious climate policies as described in the EU Green Deal, increased R&I expenditures can increase productivity and boost EU economic growth and competitiveness, especially in countries with large innovation and low-carbon manufacturing base. The analysis of Fragkiadakis et al. [10] captures the different nature of public and private R&I, with the latter having more positive economic implications and higher efficiency as it is closer to industrial activities. Public R&D commonly focuses on immature highly uncertain technologies, which are also needed to achieve the climate neutrality target of the EU. The model-based assessment shows that a policy portfolio using part of carbon revenues for public and private R&D and development of the required skills can effectively alleviate decarbonisation costs, while promoting high value-added products and exports (e.g., low-carbon technologies), creating more high-quality jobs, and contributing to climate change mitigation.

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