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Editorial

Energy Planning

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This Special Issue focuses on progress in energy transition planning. Many national governments as well as sub-national governments have announced goals to achieve net zero by mid-century. In parallel, the UNFCCC has established a mechanism for its parties to formulate and communicate long-term low greenhouse gas emission development strategies (LT-LEDS, or LTS for short) to operationalize the carbon-neutral vision stipulated by the Paris Agreement. As of March 2022, 51 countries have submitted their LTS to the UNFCCC. There is a need to understand better all aspects of how energy supply and energy demand can be fully decarbonized. Given the energy system complexity, there is an important role for models and energy planning in such assessment. Long-term energy scenarios (LTES) are effective tools for policymakers to agree on how to achieve ambitious goals. While LTES have been used for decades to guide energy policy, the energy and socio-economic transformation that is caused by net zero emissions pushes the boundaries of LTES further.

This Special Issue contains 13 papers that contribute to the science of energy planning. The papers cover new country analyses from around the world (Brazil, Colombia, Ecuador, Ghana, Italy, Mexico, Sweden, Thailand, Ukraine, United Kingdom). A number of analyses use well-established energy system analysis methodologies but apply them in combination with new energy technology data in the context of specific countries. The findings suggest there is no one-fits-all solution, and that national circumstances must be considered in the design of energy transition strategies. The papers also contribute to the energy planning methodology:

- Energy and climate policy planning processes: a number of papers discuss how to combine different models to yield policy-relevant results.
- New methodologies are proposed for post-processing of modeling results: One paper discusses the breakdown of global modeling results for countries and sectors. Integrated assessment model (IAM) results are translated into lifestyle impacts, and decomposition analysis is used to identify the role of contributing factors for carbon neutrality.
- One paper assesses the impact of climate change on future solar PV generation.
- Carbon budgets at the sectoral, sub-national, national, and global levels: One paper focuses on the national and sectoral carbon budgets that follow from global models. Two papers focus on sector coupling for electromobility and decarbonization of the chemical and petrochemical industries, respectively. One paper discusses the role of liquid biofuels for transportation.
- One article focuses on the better use of modeling results for policy making, and another focuses on the role of regulation.
- Renewable energy and its technical model representations (geo-spatial and temporal resolutions): one paper discusses methodologies to compare various system aspects in the optimization of high VRE and gas-based power generation. Another paper assesses flexibility enhancement strategies.
- Definition of carbon neutrality and the role of carbon sinks, carbon removal, and carbon leakage for net zero target: one paper discusses the importance of a phase-out

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of net emissions from agriculture, forestry, and other land uses, reductions in non-carbon greenhouse gases, and land restoration to scale up atmospheric CO_2 removal.

This brief overview shows that energy planning continues to evolve rapidly. IRENA, through its LTES Network and Clean Energy Ministerial LTES initiative, is facilitating dialogue among energy planners and modelers in the government sector who develop and use. These discussions have highlighted that, for the energy and climate scenarios to be truly effective in informing decarbonization pathways and energy planning, some misalignments between the national LTES and global climate scenarios need to be addressed.

A closer look at the findings of the individual papers reveals important new insights:

Hanmer et al. [1] discuss that countries' emission reduction commitments under the Paris Agreement have significant implications for lifestyles. A novel methodology is presented for translating global scenarios into lifestyle implications at the national and household levels, which can be generalized to any service or country and versatile to work with any model or scenario. The 5Ds method post-processes integrated assessment model projections of the sectoral energy demand for the global region to derive energy-service-specific lifestyle change at the household level. The methodology is applied for two energy services (mobility, heating) in two countries (the UK, Sweden), showing how effort to reach zero carbon targets varies between countries and households. Our method creates an analytical bridge between global model output and information that can be used at national and local levels, making the lifestyle implications of climate targets clear.

Saisirirat et al. [2] discuss a detailed Ghana vehicle ownership model with necessary transport parameters to construct an energy demand model to provide insight for reducing GHG emission contributions from road transport through biofuel (both bioethanol and biodiesel) using the Low Emission Analysis Platform (LEAP) modeling framework. The model setup builds on an earlier study for Thailand. Scenarios include alternative (ALT), with up to E20/B20, and extreme (EXT), with up to E85/B50, for new vehicles. Energy demand and GHG emissions were analyzed from Ghana's transport sector data to show potential benefits that accrue from biofuel usage. The findings show that 8.4% and 11.1% of GHG emission reduction in 2030 can be achieved with a 0.13% and 0.27% additional arable land requirement from the ALT and EXT scenarios.

Silva et al. [3] assess climate-related risks and countermeasures in solar power plants in Thailand using thematic analysis with self-administered observations and structured interviews. The findings can inform long-term energy planning to ensure climate adaptation capacity. The analysis points out that floods and storms were perceived as major climate events affecting solar power plants in Thailand, followed by lightning and fires. Several countermeasures are proposed, some of which require extensive investment. The findings show that enabling regulations or financial incentives are needed for the implementation of climate-proofing countermeasures. Public and private sectors need to secure a sufficient budget for fast recovery after severe climate incidents. Measures must be taken to facilitate the selection of climate-resilient sites by improving conditions of power purchase agreements or assisting winning bidders in enhancing the climate adaptability of their sites. These issues should be considered during Thailand's long-term energy planning.

Chen et al. [4] use decomposition analysis to investigate the key contributions to changes in greenhouse gas emissions in different scenarios. Decomposition formulas are derived for the three highest-emitting sectors: power generation, industry, and transportation (both passenger and freight). These formulas were applied to recently developed 1.5 °C emission scenarios by the Integrated Model to Assess the Global Environment (IMAGE), emphasizing the role of renewables and lifestyle changes. The decomposition analysis shows that carbon capture and storage (CCS), both from fossil fuel and bioenergy combustion, renewables, and reducing the carbon intensity provide the largest contributions to emission reduction in the scenarios. Efficiency improvement is also critical, but part of the potential is already achieved in the baseline scenario. The relative importance of different emission reduction drivers is similar for OECD and non-OECD regions, but there are some noteworthy differences. In the non-OECD region, improving efficiency in industry and transport and increasing the share of renewables in power generation are more important in reducing emissions than in the OECD region, while CCS in power generation and electrification of passenger transport are more important drivers in the OECD region.

Gaeta et al. [5] focus on the challenges and opportunities of reaching net zero emissions by 2050 in Italy. To support Italian energy planning, the authors developed energy roadmaps towards national climate neutrality, consistent with the Paris Agreement objectives and the IPCC goal of limiting the increase in the global surface temperature to 1.5 °C. These scenarios identify the correlations among the main pillars for the change of the energy paradigm towards net emissions by 2050. The energy scenarios were developed using TIMES-RSE, a partial equilibrium and technology-rich optimization model of the entire Italian energy system. Subsequently, an in-depth analysis was developed with the sMTISIM, a long-term simulator of power system and electricity markets. The results show that, to achieve climate neutrality by 2050, the Italian energy system will have to experience profound transformations in multiple and strongly related dimensions. A predominantly renewable-based energy mix (at least 80–90% by 2050) is essential to decarbonize most of the final energy consumption. However, the strong increase in non-programmable renewable sources requires particular attention to new flexibility resources needed for the power system, such as Power-to-X. The green fuels produced from renewables via Power-to-X will be a vital energy source for those sectors where electrification faces technical and economic barriers. The findings also confirm that the European "energy efficiency first" principle represents the very first step on the road to climate neutrality.

Petrović et al. [6] analyze the Ukrainian energy system in the context of the Paris Agreement and the 1.5 °C objective. A TIMES-Ukraine model of the whole Ukrainian energy system is deployed to analyze how the energy system may develop until 2050, taking current and future policies into account. The results show the development of the Ukrainian energy system based on energy efficiency improvements, electrification, and renewable energy. The share of renewables in electricity production is predicted to reach between 45% and 57% in 2050 in the main scenarios with moderate emission reduction ambitions and ~80% in the ambitious alternative scenarios. The cost-optimal solution includes a reduction in the space heating demand in buildings by 20% in the frozen policy and 70% in other scenarios, while electrification of industries leads to reductions in energy intensity of 26–36% in all scenarios except for the frozen policy. Energy efficiency improvements and emission reductions in the transport sector are achieved through increased use of electricity from 2020 in all scenarios except for the frozen policy, reaching 40–51% in 2050. The stated policies present a cost-efficient alternative for keeping Ukraine's greenhouse gas emissions at today's level.

Werlang et al. [7] point out the need for energy planning to quickly adapt to provide useful inputs to the regulation activity so that a cost-effective electricity market emerges to facilitate the integration of renewables. This paper analyzes the role of system planning and regulations in two specific elements in energy market design: the concept of firm capacity, and the presence of distributed energy resources, both of which can be influenced by regulation. The analysis quantifies the role of the current regulation in the total cost of the Brazilian and Mexican electricity systems when compared to a reference "efficient" energy planning scenario that adopts standard cost minimization principles and that is well suited to most of the relevant features of the new energy transformation scenario. The findings show two very common features of regulatory designs that can lead to distortions: (i) renewables commonly having a lower "perceived cost" under the current regulations, either due to direct incentives such as tax breaks or due to indirect access to more attractive contracts or financing conditions; and (ii) requirements for reliability that are often defined overly conservatively, overstating the hardships imposed by renewable generation on the existing system and underestimating the potential of technology portfolios.

Nazaré et al. [8] discuss the increase in the need for operating reserves that follows from the penetration of variable renewable energy (VRE) in thermal-dominated systems. In the case of hydro-dominated systems, the cost-effective flexibility provided by hydro-plants facilitates the penetration of VRE, but the compounded production variability of these resources challenges the integration of baseload gas-fired plants. The Brazilian power system illustrates this situation. Given the current competitiveness of VRE, a natural question is the economic value and tradeoffs for expanding the system, opting between baseload gas-fired generation and VRE in an already flexible hydropower system. This paper presents a methodology based on a multi-stage and stochastic capacity expansion model to estimate the optimal mix of baseload thermal power plants and VRE additions. The assessment method considers their contributions for the security of supply, which includes peak, energy, and operating reserves, which are endogenously defined and sized in time-varying and dynamic ways, as well as adequacy constraints. The presented model calculates the optimal decision plan, allowing for the estimation of the economical tradeoffs between baseload gas and VRE supply considering their value for the required services to the system. This allows for a comparison between the integration costs of these technologies on the same basis, thus helping policymakers and system planners to better decide on the best way to integrate the gas resources in an electricity industry that is increasingly renewable. A case study based on a real industrial application is presented for the Brazilian power system.

Correa-Laguna et al. [9] describe the construction of an integrated bottom-up LEAP model tailored to the Colombian case. An integrated model facilitates capturing synergies and intersectoral interactions within the national GHG emission system. Hence, policies addressing one sector and influencing others are identified and correctly assessed. Thus, 44 mitigation policies and mitigation actions were included in the model, in this way identifying the sectors being directly and indirectly affected by them. The mitigation scenario developed in this paper reaches a reduction of 28% in GHG emissions compared with the reference scenario. The importance of including non-energy sectors is evident in the Colombian case, as GHG emission reductions are mainly driven by AFOLU. The model allows for the correct estimate of the scope and potential of mitigation actions by considering indirect, unintended emission reductions in all IPCC categories, as well as synergies with all mitigation actions included in the mitigation scenario. Moreover, the structure of the model is suitable for testing potential emission trajectories, facilitating its adoption by official entities and its application in climate policy making.

Godoy et al. [10] analyze the pathway to develop a clean and diversified electricity mix for Ecuador, covering the demand of three specific development levels of electric transportation. The linear optimization model (urbs) and the Ecuador Land Use and Energy Network Analysis (ELENA) are used to optimize the expansion of the power system in the period from 2020 to 2050. The results show that reaching an electricity mix 100% based on renewable energies is possible and this supply can support a highly electrified transport sector that includes 47.8% of road passenger transportation and 5.9% of road freight transportation. Therefore, the electrification of this sector is a viable alternative for the country to rely on its own energy resources while reinforcing its future climate change mitigation commitments.

Saygin and Gielen [11] assess the techno-economic potential of 20 decarbonization options in the chemical and petrochemical sectors. While previous analyses focused on the production processes, this analysis covers the full product life cycle CO_2 emissions. The analysis elaborates the carbon accounting complexity that results from the non-energy use of fossil fuels, and highlights the importance of strategies that consider the carbon stored in synthetic organic products—an aspect that warrants more attention in long-term energy scenarios and strategies. Average mitigation costs in the sector would amount to USD 64 per ton of CO_2 for full decarbonization in 2050. The rapidly declining renewables cost is one main causes for this low-cost estimate. Renewable energy supply solutions, in combination with electrification, account for 40% of total emission reductions. Annual biomass use grows to 1.3 gigatons, green hydrogen electrolyzer capacity grows to 2435 gigawatts, and recycling rates increase six-fold, while product demand is reduced by a third, compared to the reference case. CO_2 capture, storage, and use equals 30% of the total decarbonization effort (1.49 gigatons per year), where about one third of the captured CO_2 is of biogenic origin. Circular economy concepts, including recycling, account for 16%, while energy efficiency accounts for 12% of the decarbonization needed. Achieving full decarbonization in this sector will increase energy and feedstock costs by more than 35%. The analysis shows the importance of renewable-based solutions, accounting for more than half of the total emission reduction potential, higher than previous estimates.

Teske et al. [12] present two global non-overshoot pathways (+2.0 °C and +1.5 °C) with regional decarbonization targets for the four primary energy sectors—power, heating, transportation, and industry—in 5-year steps up to 2050. The normative scenarios illustrate the effects of efficiency measures and renewable energy use, describe the roles of increased electrification of the final energy demand and synthetic fuels, and quantify the resulting electricity load increases for 72 sub-regions. Non-energy scenarios include a phase-out of net emissions from agriculture, forestry, and other land uses, reductions in non-carbon greenhouse gases, and land restoration to scale up atmospheric CO_2 removal, estimated at −377 Gt CO_2 in 2100. An estimate of the COVID-19 effects on the global energy demand is included, and a sensitivity analysis describes the impacts if implementation is delayed by 5, 7, or 10 years, which would significantly reduce the likelihood of achieving the 1.5 °C goal. The analysis applies a model network consisting of energy system, power system, transport, land use, and climate models.

Carvajal et al. [13] focus on the use of long-term energy scenarios (LTES) in the government sector, and specifically how the new challenges and opportunities brought by the clean energy transition change the way in which governments use LTES. The information tends to remain tacit, and a gap exists in understanding the way to enhance LTES use and development at the government level. The experience from national institutions that are leading the improvement in official energy scenario planning is used as a basis to derive a set of overarching best practices in three ares (i) strengthen LTES development, (ii) effectively use LTES for strategic energy planning, and (iii) enhance institutional capacity for LTES-based energy planning. The best practice experience was collected through the International Renewable Agency's LTES Network activities. The LTES-based energy planning methodologies need to adapt, reflecting the changing landscapes, and that more effective and extensive use of LTES in government needs to be further encouraged.

The energy planning field must continue to evolve rapidly in the coming years as the energy transition is globally high on the political agenda and carries the information that is needed for decision making changes.

In the context of the LTES initiative and network, four areas will be developed further in the coming years [14]:

- Exchange of net zero scenarios between LT-LEDS climate planners and energy planners.
- Collecting best engagement practices with stakeholders in the scenario process. This includes the preparation of model and scenario input parameters as well as the translation of findings into policy-relevant conclusions and actions.
- Stock take of scenario findings—collection and comparison of scenarios as well as identification of scenario gaps for global government decarbonization action.
- Identification of modeling robustness and weaknesses including better representation of aspects such as infrastructure modeling, behavioral change, and the need for systemic innovation for mission-driven change.

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