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Editorial

Digitalization for Resilient and Sustainable Energy Transitions

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1. The Global Energy Crisis

The energy sector was challenged by the COVID-19 pandemic in different ways. Short-term developments led to a reduction in energy demand due to lockdowns, reduced mobility, and economic slowdown. This significant decline in transportation and economic activity resulted in a decline in fuel demand and the fall of global crude oil prices, which in turn harmed the economy of fossil fuel exporting countries. Green energy technology supply chains were disrupted, resulting in delays in many renewable energy projects worldwide. International green finance flows toward developing regions were significantly affected by the economic slowdown and the reduced international mobility of experts, intensifying energy poverty and energy injustice in many world regions. This raised concerns about progress toward Sustainable Development Goal 7 (SDG7), which set a 2030 target of modern, affordable, and clean energy for all.

The post-pandemic economic recovery increased energy demand, leading to sudden growth in natural gas prices. This was exacerbated by the Ukraine–Russia war, resulting in energy price hikes and energy security challenges in some regions like Europe. While economies slowly recover from the crises, it is important to build upon the lessons learned and rethink the energy transition. This Special Issue investigates the imperatives and implications of the global energy crisis highlighting the key challenges and opportunities in the energy system, energy trends during and post-crisis, and proposing relevant energy solutions to inform international and national energy policy. Digitalization as an enabler of decentralized and renewable-based energy systems was found to be a key theme of the studies in this Special Issue, a game-changing technology toward a resilient, sustainable, and equitable energy transition.

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2. International Energy Trade and Energy Security

The energy crisis fostered the hope that fossil-importing regions like Europe would adopt a different path by relying on local renewable sources and accelerating the phase-out of fossil fuels to reduce their energy imports from other regions. However, many European nations sought new sources of (fossil) energy supply, e.g., liquified natural gas (LNG), thus resulting in new intercontinental LNG trade agreements with long-term lock-in effects and controversial climate impacts [1]. This turn in the EU energy policy, a region known as a forerunner in climate action and once leading the global efforts to reduce dependency on fossil fuels, showed the narrow line between prioritizing energy security versus environmental sustainability.

The response of the EU to the war in Ukraine was a combination of economic sanctions and energy import cuts from Russia, which resulted in energy price hikes in the European Union. The climate impact of such energy trade bans and the shift toward costlier and more carbon-intensive energy resources is a key policy question. In this Special Issue, Shepard et al. [2] applied an integrated assessment model (IAM) of global energy and land use systems, simulating the energy trade between different world regions. Their study involves the analysis of the impact of trade friction, i.e., trade ban or import tariffs, on energy security, concluding that a globally climate-compatible energy pathway will enhance energy security in energy-importing regions, such as Europe and South-East Asia, as energy supply becomes more diverse in a low-carbon world, compared to that of a fossil-fuel-based pathway.

3. Artificial Intelligence (AI) for Energy Security

The recent advancements in AI, data-driven analytics, and related technologies have spurred debate on the role of digitalization in overcoming the energy crisis. The literature has revealed many examples of AI applications in load forecasting, price forecasting, energy management, load profiling, etc., in the context of the smart grid or, more broadly, smart energy systems [3]. AI can accelerate climate-compatible energy transitions in various ways, e.g., by reducing energy demand in buildings [4], cutting energy needs of agriculture [5], developing novel green energy materials [6], mitigating carbon emissions of energy [7], enhancing energy access in vulnerable communities [8], and next-generation climate models for climate change mitigation and adaptation [9], just to name a few.

AI-based solutions gained attention as tools for overcoming energy security and price volatility during the energy crisis. For example, this Special Issue features a study involving a deep learning model based on long short-term memory (LSTM) and convolutional neural network (CNN), using return lags, price, and macroeconomic variables to train the models, which resulted in significant improvement in the model's performance [10]. The results show that the cumulative profit from trading when deploying the model is higher than those of the other models using statistical or other machine learning methods. Their study takes the financial markets as an example to train the LSTM model tuned with SARS data to predict the impact of the COVID-19 pandemic on the Brent crude oil return.

However, AI's energy demand and the related environmental impact is a big concern. The recent increasing demand from data centers, which is projected to continue to soar, has raised questions related to power adequacy, grid capacity, and rapid scale-up of new power plant installations.

4. Digitalization for Decentralized and Resilient Energy Systems

Decentralization is the cornerstone of renewable energy scenarios. Decentralized energy systems interconnect many small-scale "prosumers", entities that both consume and produce energy on-site. Large-scale AI-based models can be deployed to assess decentralized energy resources such as rooftop solar photovoltaics (PVs) [11]. Citizen science [12] and satellite imagery [13] can empower energy-poor communities to overcome the challenges related to sustainability in the absence of reliable data. Digital solutions can also enable energy trading among many small-scale prosumers, e.g., by using technologies such as blockchain for peer-to-peer trading [14]. The optimal management of so many connection points requires data collection in real time through smart meters and a digital energy management system. In this Special Issue, Sołtysik et al. [15] revealed that, during the COVID-19 pandemic, huge anomalies in electricity demand and billing were observed, thus impacting the benefits of prosumers. They used computer simulations to analyze different prosumer support schemes to estimate the unused energy that could be fed into the shared energy storage assets to ensure optimal use of unused energy.

5. The Way Forward

The science-based evidence suggests that the time and carbon budget for meeting the climate targets of the Paris Agreement safely, i.e., without or with low-temperature overshoot, is very limited [16]. A study in this Special Issue argues that the spread of infectious diseases such as COVID-19 will be more frequent and more widespread under global warming [17], calling for transdisciplinary approaches for sustainable health, ecosystem, and food to increase the resilience of human and natural systems. Model-based, data-driven simulations can enhance the adaptation capacity of human–technology systems reducing the adverse impact of such pandemics [18].

In a comprehensive study by Zakeri et al. [19], the multifaceted and complex impact of a global pandemic on the energy system is discussed. Relying on large consultations synthesizing input from scientists, policymakers, and practitioners from different parts of the world, their study identifies four major solutions to overcome the energy crisis, namely the following:

- ***Reducing energy demand:*** by rethinking energy and material consumption, based on lifestyle change, circularity, digitalization, and sharing concepts;
- ***Reinventing urban infrastructure and space:*** by applying a more holistic approach to urban planning to design cities as digitalized villages through compact neighborhoods and reducing car dependency;
- ***Decentralized energy systems:*** to advance renewable energy at a large scale, energy systems must prioritize decentralized energy solutions by developing local value chains for renewable energy supported by digitalized platforms for optimal energy management;
- ***Just and equitable energy transitions:*** by implementing energy safety nets; increasing energy access by the aid of digital solutions such as citizen science, satellite imagery, and AI; and the provision of energy/climate financial assistance for energy-poor communities.

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