

# Energy Transition towards Carbon Neutrality

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## 1. Introduction

Carbon peaking and neutralization in the next 20 to 40 years are significant to limit the temperature increase to well below 2 °C and avoid the negative impacts of climate change caused by the sharp increase in carbon dioxide emissions. A global transition in the energy, transportation, buildings, industry, and agriculture sectors is the key to achieving the goal of carbon peak and neutralization. The transition, however, is a complex and daunting challenge that requires different stakeholders, including governments, industries, researchers, and societies, to intertwine to identify low emission development pathways and to cope with various challenges and risks, including those associated with resource availability and interlinkages.

In a recent study, Liu et al. identified the contribution of negative emission technologies, renewable technologies, and energy efficiencies to reach carbon neutrality in China by 2060 [1]. The study indicates that to achieve carbon neutrality, China should phase out coal (and other fossil fuel) consumption and increase the share of non-fossil energy in the energy mix to 85% by 2050, which requires an increase in the installed wind and solar capacity to reach between 1500–2600 GW and 2200–2800 GW for wind and solar by 2050, respectively [1]. The transition in the energy systems have direct impacts on water and material demands [2,3] and may have several environmental impacts [4,5]. It was indicated in a recent report by the International Energy Agency (IEA) that although some clean technologies such as wind and PV solar require little water, others including concentrating solar power (CSP), biofuel, carbon capture and storage (CCS), and nuclear power are relatively water intensive [6]. In the IEA's main scenario, water withdrawal for the energy sector is expected to increase by less than 2% and water consumption by almost 60%, whereas in their scenario to limit the global average temperature rise to 2 °C in 2040, water withdrawal is expected to decrease by 12% but water consumption is expected to increase by 2%, relative to the main scenario [6]. Meanwhile, the amount of energy used in the water sector is expected to more than double, mainly due to desalination, large-scale water transfer, and increasing demand for wastewater treatment [6]. The transition in energy systems is expected to be associated with an increase in material demands as clean technologies (solar and wind) are known to require more materials than traditional technologies [7], including Cu, Al, Ni, and Ag and minor metals such as rare earth elements (REEs), indium, gallium, germanium, and tellurium [8]. Some of these metals are identified as critical for energy transition as a result of limited resources and production capacity, as well as being coproduced with other host metals in a limited number of countries. In addition, material production requires energy [9] and unless compensated by a transformation of the economy from carbon-intensive manufacturing, increasing the share of electricity and decarbonizing electricity generation, carbon and other emissions may increase [10,11].



**Citation:** Elshkaki, A.; Shen, L. Energy Transition towards Carbon Neutrality. *Energies* **2022**, *15*, 4967. <https://doi.org/10.3390/en15144967>

Received: 23 June 2022

Accepted: 6 July 2022

Published: 7 July 2022

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## 2. Aim of This Special Issue

The Special Issue, “Energy Transition towards Carbon Neutrality”, which appears in the Energy and Environment section of the journal *Energies*, focuses on analyzing carbon emission mitigation pathways in different sectors and addressing the main energy economics, policies, and technological innovations which have been playing an increasing role in the realization of global energy transition in recent years. Particular attention is devoted to exploring the dynamics and effects of the carbon neutrality goal using different approaches and models of sustainable energy supply and demand in terms of resources and environmental impacts. The topics in this Special Issue include: the energy–material–carbon nexus; the energy–water–food nexus; advances in energy supply and demand technologies; advances in energy storage technologies; technological advances in carbon intensive industries; and the role of society in energy transition.

## 3. Overview of the Papers in This Special Issue

A total of nine papers were published in the Special Issue, which mainly address current carbon emission trends and energy system transitions in China and the Belt and Road Initiative countries, with one study addressing the resources nexus in Africa. The differences of carbon emission efficiency in the Belt and Road Initiative countries were addressed in [12]. The study discusses the spatial differences in carbon emissions, which are mainly affected by economic output, energy efficiency, and energy structure, among 60 Belt and Road Initiative countries using the Theil index and Logarithmic Mean Divisia Index (LMDI) method. The study found that energy efficiency is the dominant factor affecting carbon emission efficiency differences, especially between East Asia and Central and Eastern Europe, and between South Asia and East Asia, and only some differences among countries and sectors have been caused by energy structures. The authors conclude that it is significant for countries with low carbon emission efficiency to improve their energy efficiency to catch up with other high efficiency countries, followed by the significance of improving their energy structures.

The decarbonization of heating systems is significant for achieving carbon neutrality. The decarbonization of the heating in China, which is currently mainly coal-fired heating, was discussed in [13]. The authors argue that decarbonization of heating, through the ongoing transformation from coal to gas and from coal to electricity projects, is significant for achieving the carbon neutrality target in China. The study compares the domestic and international heating modes including gas, electricity, heat pump, and biomass and solar heating, compares different types of heat pumps in China, discusses the technology potential in several sectors including industrial and building sectors, and proposes an optimal heating scheme for urban and rural areas. The authors suggested that ground-source heat pumps can be installed in urban areas with centralized heating, and a coupling system of solar photovoltaics with ground-source heat pumps (PV-GSHP) can be applied in rural areas with distributed heating.

The phase out of coal has been announced in several countries, as this is important for a carbon neutral future, and although China has emphasized coal reduction, it has not explicitly proposed phasing coal out due to the influence of local governments, coal-related enterprises, and the public. The possibility of declaring a phase out of coal in China from different perspectives, including the government, enterprises, and the public, and the reason for doing so have been discussed in [14]. The analysis in this paper is based on an evolutionary game model with two correlations and the entropy method. The study found that it is difficult for China to announce a “coal phase-out” at present, and the Chinese government can phase out coal only when coal-related enterprises and the public can benefit from reducing coal production and consumption and when stable economic and social development that does not affect people’s daily lives can be ensured. Meanwhile, China should improve the efficiency of coal use, install carbon capture and storage facilities, vigorously develop renewable energy, and reduce the share of coal in the energy system. On the other side, the concerns of a power shortage (the gap between power

demand and supply) in China due to the radical policies of low-carbon transformation of the electric system to achieve peak carbon and carbon neutrality and over-reliance on renewable energy were addressed in [15]. The analysis was carried out using a modified LEAP model and a scenario analysis of thermal power generation and installed capacity in 2025 and 2030 under normal and extreme weather scenarios. The authors argued that a low-carbon transformation path should be explored with more flexibility for power security, and concluded that China should diversify energy sources and enhance power supply security capabilities while strengthening the development and utilization of renewable energy.

The transportation sector is one of the significant sectors for carbon neutrality. In China, transportation is responsible for about 10% of the carbon emissions. Therefore, China and several other countries have promoted liquefied natural gas (LNG) as a replacement for diesel in heavy-duty vehicles to achieve carbon peak and neutrality in the transportation sector. A comparison between an LNG tractor-trailer and its diesel counterpart in China on a full suite of environmental impacts using a life-cycle model for environmental load differences covering vehicle and fuel cycles was addressed in [16]. The study found that the LNG tractor-trailer consumes less aluminum but more iron and energy; emits less nitrogen oxide, sulfur oxide, non-methane volatile organic compounds, and particulate matter but more greenhouse gases (GHG) and carbon monoxide (CO), mainly driven by a poor fuel economy; and causes less abiotic depletion potential, acidification potential, and human toxicity potential impacts but more global warming potential (GWP) and photo-oxidant creation potential (POCP) impacts. The authors argue that switching to the LNG tractor-trailer could reduce carbon dioxide and the GWP impact if it attains a parity fuel economy with its diesel counterpart and suggests that policymakers should modify the regulations on fuel tax and vehicle access, which discourage improvements in LNG engine efficiency, and adopt incentive policies to develop the technologies.

To understand how the world views China's carbon policy, a study carried out a sentiment analysis of twitter data between 2008 and 2020 [17]. The study showed the inter- and intra-annual trends in the count of tweets about China's carbon policy, conducted sentiment analysis, extracted the top frequency words from different attitudes, and analyzed the impact of China's official Twitter accounts on the global view of China's carbon policy. The study shows that the global attention paid to China's carbon policy gradually rose, and the proportion of Twitter users with negative sentiment about China's carbon policy has increased rapidly and has exceeded the proportion of Twitter users with positive sentiment since 2019; people in developing countries hold more positive or neutral attitudes towards China's carbon policy, whereas developed countries hold more negative attitudes. Furthermore, the study shows that China's official Twitter accounts serve to improve the global view of China's carbon policy.

The demand side of energy is as important as the supply side for reaching carbon neutrality. In this regard, the role of heterogeneous intentions in reducing household energy consumption was discussed in [18]. The authors discuss how low-carbon knowledge and publicity could help reduce household energy consumption based on 1335 survey questionnaires of household energy behavior in Henan Province, China, and an integrated knowledge-intention-behavior model. The study indicates that low-carbon knowledge or publicity cannot positively impact household energy-saving behavior in developing areas, even if mediated by energy awareness and energy-saving attitudes, and although low-carbon knowledge improves energy-saving attitudes, attitude does not decrease household energy consumption directly. In addition, the study shows that familiarity with particular energy-saving knowledge would decrease household energy consumption, although not significantly, but the heterogeneous effects of purchase-based intentions and habitual intentions explain energy consumption behavior. Economic factors including income and energy prices play key roles in explaining household energy consumption behavior in rapid urbanization areas.

Another significant issue in reaching carbon neutrality is the management of food waste and food supply chains of production, transportation, cooking, and processing,

which result in unnecessary greenhouse gases. This issue was addressed from a life cycle perspective in [19]. The authors quantified students' food waste and collected canteen operation data in the three canteens at Taiyuan University of Technology (China) in 2019 through the weighing method and interviews. The environmental and cost impacts of food waste were quantified based on the Life Cycle Assessment and Life Cycle Costing. The study found that the carbon footprint caused by food waste was 539.28 t CO<sub>2</sub>-eq and the cost was 4,729,900 yuan, and most of the impacts come from the use of energy in food cooking and the consumption of animal food types. In addition, the study highlights the key role of the labor required for cooking.

A resources nexus is another important issue in achieving carbon neutrality and the UN Sustainable Development Goals (SDGs). A study [20] addressed the decoupling of the production of energy, water, and food from GHG emissions in 15 African countries from 1990 to 2017. The study applies Tapio's decoupling method to analyze the relationship between GHG emissions and EWF resource use. The study found that the decoupling of water and energy resources from GHG emissions in most African countries has not been reached and recommends that countries in Africa should support environmentally friendly water and energy infrastructures and promote an integrated, mutually managed, whole resource interaction system.

**Author Contributions:** A.E. and L.S. both equally contributed to writing this article and preparing the Special Issue. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** We thank the staff of MDPI *Energies* for their editorial support.

**Conflicts of Interest:** The authors declare no conflict of interest.

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