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RENEWABLE ENERGY DEVELOPMENT: HOW CLOSE IS THE PEOPLE'S REPUBLIC OF CHINA TO ACHIEVING CARBON NEUTRALITY?

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Abstract

Goals to mitigate climate change are to be achieved through government strategies and policies, as well as the availability of low-carbon technologies, and are subject to the underlying institutional, political, economic, and other factors that promote or constrain progress and the path taken. A large CO2 emitter, the People's Republic of China (PRC), has set the goals of carbon dioxide emissions peaking by 2030 and achieving greenhouse gas neutrality by 2060. This study reviews the PRC's efforts to phase out fossil fuels and analyzes the factors that have an impact on the PRC's renewable energy development and its path towards carbon neutrality. Four factors are found to be critical in the decarbonization of the PRC: the costs of retrofitting existing coal-fired power plants and upgrading the power grid to accommodate renewable energy; institutional factors; technology factors; and market-based schemes. Given these factors and the PRC's enormous coal-dependent infrastructure, transitioning away from fossil fuels will be challenging. Another big challenge is the intermittence of renewable energy sources. Hence, the growing penetration of renewable energy in the PRC's electricity mix requires effective policy tools and appropriately designed market signals. To put it simply, the PRC has the potential to develop renewable resources on a large scale, yet it still has a long way to go to achieve carbon neutrality.

Keywords: People's Republic of China, carbon neutrality, fossil fuel phase-out

JEL Classification: P28

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1. INTRODUCTION

In December 2020, President Xi announced to the United Nations that the PRC's carbon dioxide emissions per unit of GDP would decline by 65% from 2005 levels, and the share of nonfossil fuels in the energy mix would rise to 25% (Xinhua Net 2020). This followed an earlier pledge by the President to the United Nations General Assembly on 22 September 2020 that emissions would peak before 2030 and that the country would strive to achieve carbon neutrality by 2060 (Farand and Darby 2020). Given the ambition of the PRC government, this study aims to explore what factors are critical to energy transition in the PRC and what challenges should be tackled in the process of energy transition to achieve carbon neutrality. Several measures can help accelerate energy transition, such as developing renewable energy, increasing energy efficiency, and prioritizing environmental protection.

Since 2020 when President Xi announced that the PRC would strive to achieve carbon neutrality by 2060, an increasing number of scholars have been conducting research on the PRC's climate mitigation and energy transition issues. Many of them are quantitative studies using modeling. Some reviewed the PRC's financial development on carbon emissions, analyzing the pathways, and suggested that the PRC should be focused in particular on the promotion of green finance (Zhou and Zhang 2024). Some project mitigations of carbon neutrality in the PRC (Li et al. 2022a); others focus on the projection of carbon neutrality of a specific region in the PRC, e.g., Beijing–Tianjin–Hebei Region, finding that under the constraint of the carbon neutrality target, this region should formulate more stringent emission reduction measures to ensure that the overall carbon emission will reach its peak in 2030. This indicates that the final allocation scheme will greatly encourage carbon emission reduction in Hebei Province (Zhang et al. 2023a). Zhang et al. (2023b) examine specific policies, such as the Carbon Trading Pilot Policy and its impact on the achievement of the carbon neutrality target. Besides studies using quantitative methods, a few qualitative studies look into the PRC's carbon neutrality issue from a policy or legislative perspective. Gao et al. (2023) conduct an evolutionary analysis of the issuance and implementation of the PRC's carbon neutrality policies, finding that the PRC's carbon neutrality policies and initiatives grew gradually and in an orderly manner in the preliminary and decentralized exploration stage from 2006 until 2013, and continued to grow steadily from 2014 to 2019. The PRC's carbon neutrality policies started to grow explosively from 2020. Since then, there has been a series of top-down design policies and supportive policies in various industries and sectors. Shi and He (2023) look into the PRC's current legal system in achieving carbon neutrality goals and discuss the improvement of the legal system. It is suggested that a unified legislation system among central, local governments should be established to achieve carbon neutrality.

Little research is focused on a comprehensive discussion about the roles and challenges of renewable energy development in achieving carbon neutrality in the PRC. This paper is focused on renewable energy because it is crucial for achieving carbon neutrality. Having said that, this paper intensively reviews the PRC's renewable energy development and overall current situation in phasing out the use of fossil fuels in the power sector. After that, this paper analyzes the critical factors that may have an impact on the phasing out of fossil fuels in the PRC. These factors include cost, institutions, technology, and market-based schemes. Challenges are discussed before policy implications and suggestions are provided at the end of the paper.

2. THE PRC'S RENEWABLE ENERGY RESOURCE AND CARBON REDUCTION TARGETS

There is vast potential in renewable energy resources in the PRC. It has the highest hydropower potential capacity in the world. In particular, the hydropower capacity that can be technologically harnessed is 542 GW, while the capacity that can be harnessed for economic benefits is 402 GW (Huang and Yan 2009). The potential hydropower capacity is unevenly distributed in the PRC's territories as 78% of them are concentrated in the southwest, near the Tibetan plateau (Huang and Yan 2009).

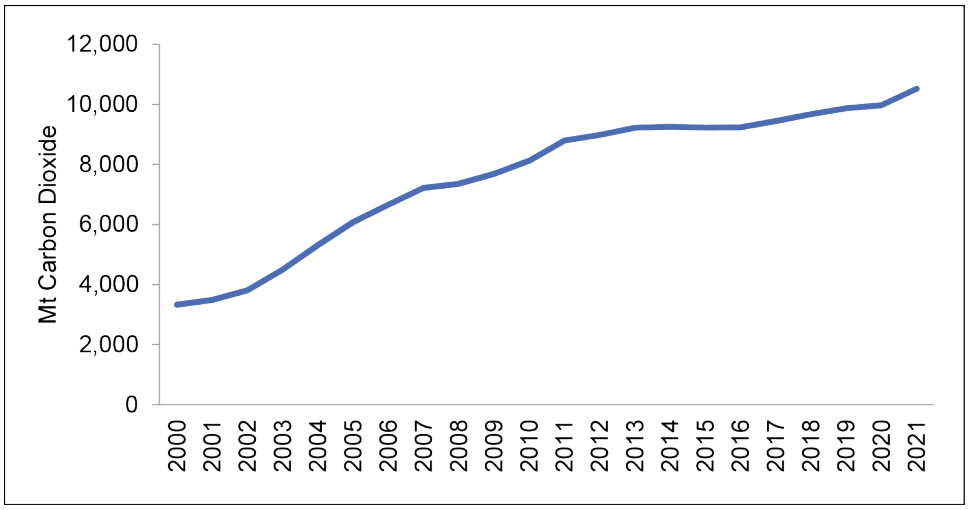
The PRC has considerable potential in utilizing solar energy. Many provinces, such as Tibet, Xinjiang, Qinghai, Gansu, Ningxia, and Inner Mongolia, have desert landscapes, high radiation, and many hours of sunshine, making them suitable for the installation of solar panels. It is estimated that if 1% of the PRC's desert area were covered by solar photovoltaic systems with an annual energy generation of 120 kWh/m^2, the PRC would generate at least 1,296 TWh from solar energy (Liu et al. 2011), almost four times the PRC's total yearly solar power generation. The PRC's solar energy potential is unevenly distributed as those places with the highest solar potential are concentrated in the northern and western areas of the country. As for wind power, the PRC has a technically exploitable onshore wind energy of 2,548 GW for places that are 10 m above ground level (Liu et al. 2011). Most of the PRC's potential onshore wind resources are concentrated in the north and northeast region, especially in Inner Mongolia. As regards offshore wind, the PRC has a potential 400–500 GW of offshore wind energy capacity that is concentrated outside the southern and southeastern coastline (Zhang et al. 2017). The PRC is also rich in biomass resources, which are mainly extracted from biogas that can be generated from industry wastewater, livestock manure straw, firewood, forest wastes, municipal wastes, and energy crops (Liu et al. 2011). According to the *BP Statistical Review 2022*, about 35% of the total electricity generation was from nonfossil fuels in the PRC in 2021. The annual growth rate of installed solar capacity and wind capacity in the PRC was about 58.3% and 21.6%, respectively, from 2011 to 2021. The share of the PRC's energy consumption from renewable resources is expected to continue to increase as the current installed electric capacity from renewable resources in the PRC is becoming more significant.

In the meantime, however, the PRC has been the world's largest emitter of carbon dioxide emissions since 2005. As of 2021, the PRC accounted for 30.9% of the world's carbon dioxide emissions (BP Statistical Review 2022). The PRC's carbon dioxide emissions from energy have risen threefold since 2000. However, the trend has been quite erratic, reacting to changes in economic policy. The growth of emissions accelerated twice in response to the economic stimuli following the Asian and Global financial crises, respectively (Figure 2.1). Since 2013, there has been a slower rising trend in CO2 emissions corresponding to the "new normal" economic situation.[1] The slowing down of the PRC's increase in CO2 emissions since 2013 is also due to the successful implementations of emissions control policies in the 13th Five-Year-Plan. Nevertheless, the PRC now accounts for about 30% of the world's carbon dioxide emissions from energy.[2]

[1] "New normal" is a concept used by the PRC government and economists to describe the fact that annual GDP growth has slowed from the double-digit levels of many years when the economy was booming.

[2] BP, *BP Statistical Review 2022.*

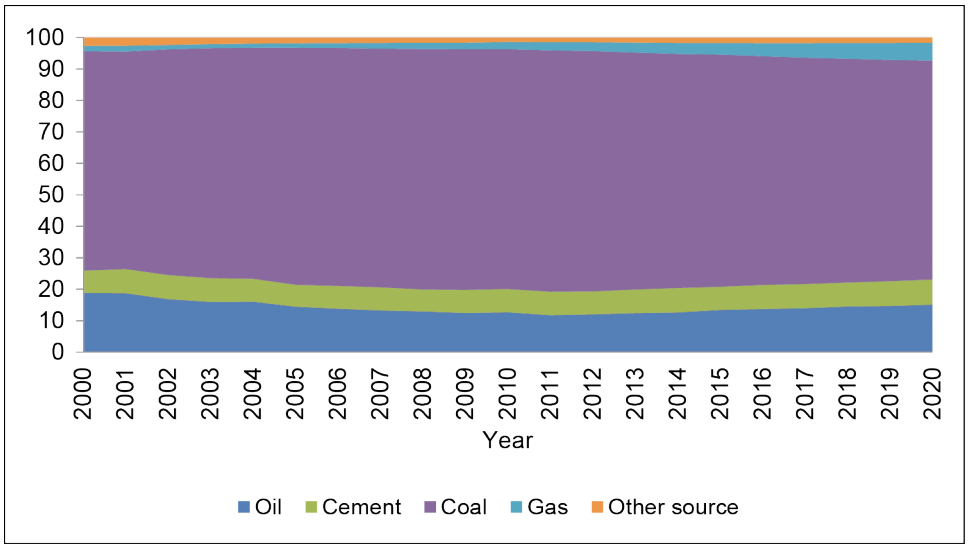
Figure 1: PRC Carbon Dioxide Emissions from 2000 to 2021
(Million Tonnes of Carbon Dioxide)[a]



[a] BP, BP Statistical Review 2022.

In terms of CO2 emissions by fuel type, most of the PRC's CO2 emissions are emitted from the use of fossil fuels, including coal, crude oil, and gas. Figure 2.2 shows the breakdown of the PRC's CO2 emissions by fuel type from 2000 to 2020. In general, most CO2 is emitted from the use of coal, which accounts for 70%–80% of all CO2 emissions. The use of oil accounts for the second-highest amount of CO2 emissions at around 15% of the total, while emissions caused by using cement and gas account for the remainder. From 2000 to 2010, the percentage of emissions from using coal steadily increased from around 70% to 76.4% of all emissions in the PRC. However, from 2011 to 2020, this figure dropped from 76.4% to 69.5%, which suggests that the PRC's decarbonization policies have proven their effectiveness.

Figure 2: Shares of the PRC's CO2 Emissions by Fuel Type (2000–2020)
(%)



Source: Our World in Data (2022).

On top of this, the PRC government is continuing with its targets in reducing energy intensity. It plans to reduce its industrial energy consumption per unit of GDP by 13.5% during the period 2021–2025 by introducing new technologies and financial services. Further, as industries account for about 65% of the total national energy consumption, it is believed that improved efficiency would be a critical measure in reducing energy intensity. By improving the energy efficiency of industrial enterprises, about 37% of the country's planned carbon emission reductions could be achieved from now until the middle of this century (Reuters 2022).

Given the PRC's rich renewable energy resources and its target of carbon reduction, the country can build on its current renewable energy momentum, as a power sector dominated by renewables can accelerate the PRC's renewable energy transition. In other words, the accelerated development of the PRC's renewable sector is a concrete step in the country's efforts to make carbon emissions peak by 2030 and to achieve carbon neutrality by 2060.

3. FOSSIL FUEL PHASE OUT

The PRC has a detailed plan to reduce fossil fuels in its energy mix. Different PRC master plans for national energy development have outlined that the share of fossil fuel is expected to drop to below 20% by 2060 (Regan 2021). Furthermore, the PRC's 14th Five-Year Plan on energy aims to phase out 30 GW of inefficient coal-fired capacity, which accounts for about 3% of the current installed power capacity (Lin 2022). To phase out inefficient capacity, the PRC is expected to shut down a significant proportion of its coal power plants from now until 2030. Moreover, the PRC is expected to continue to improve the efficiency of its coal-fired units and reduce the average amount of coal used for each kilowatt-hour of electricity to reduce the greenhouse gas emissions of its coal-fired power plants (Xue and Ng 2021).

However, the demand for Chinese goods has surged since the world started to reopen after COVID-19. Chinese factories hence need a lot more electricity, more than half of which is produced by coal. In the meantime, coal production has been slowed down as the PRC government attempts to make the country carbon neutral by 2060. Restrictions on the import of Australian coal made the shortage of coal supply even worse. The balance between supply and demand pushed up coal prices, while electricity prices were strictly controlled by the government. As a result, coal-fired power plants drastically reduced their output as they were unwilling to operate at a loss (Hoskins 2021). These power shortages have caused many incidents of blackouts across the PRC, with some power grid operators having to ration electricity for important businesses and industries (You 2022). To mitigate the crisis, President Xi Jinping announced that coal was still the PRC's main source of energy, which was followed by PRC government meetings that ordered more than 150 coal mines in major coal-producing regions, such as Shanxi, Shaanxi, and Inner Mongolia, to produce an extra 220 million tonnes of coal (You 2022). As such, the PRC government had to relax coal mining operation regulations, reform power pricing, and mandate coal-fired power plants to increase their output to ensure that the PRC has enough energy to operate its economy (Xue and Ng 2021). Although the PRC had previously announced its plan to phase out coal-fired power plants in the future, the immediate power crisis has led its government to ramp up coal production for now.

After this power crisis, the PRC announced plans to construct new coal-fired power plants. To facilitate these new projects, the PRC's economic planners have approved a state investment of more than 24.1 billion yuan (USD3.8 billion) to produce more than 19 million tonnes of additional coal annually. According to the joint research conducted by the *Center for Research on Energy and Clean Air* and *Global Energy Monitor*, 106 GW of new coal-fired generation capacity was approved by the PRC government in 2022, the equivalent of two large coal power plants per week. The new capacity spread across 82 sites in the PRC, with a total of 168 coal-fired units (CREA and GEM 2023). Moreover, the PRC plans to retrofit 200 GW of coal-fired power plants between 2021 and 2025 to increase the flexibility of its electricity production, which will enhance the grid's capability to rapidly ramp up its transmission in the case of low production of renewable energy resources (Yin 2022). This move was motivated by the decision of the PRC's political leaders to assert that the significance of coal power in the PRC's energy mix will not change in the short term to accommodate the demands for electricity.

Further, oil and gas consumption is expected to peak between 2025 and 2030. In particular, the CNPC Economics and Technology Research Institute (ETRI) estimated that the PRC's oil consumption will peak at about 780 million tonnes per year by 2030, while the demands for diesel fuel, gasoline, and kerosene consumption will peak at about 390 million tonnes per year by 2025. Demands for oil and gas are expected to decrease from 2030 when most vehicles will be electrified (Munroe and Xu 2021). Meanwhile, the consumption of natural gas, which is supposed to be the bridging fuel during energy transition, will peak at around 650 billion cubic meters per year by 2040 (Munroe and Xu 2021). These estimates align with the PRC's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy, which aims to gradually reduce the reliance on fossil fuels in energy consumption.

In the upcoming years, the PRC plans to increase the capacity of oil and gas in its energy mix to accommodate its energy consumption demand. According to Yin (2022), the PRC plans to increase natural gas production from 205 billion cubic meters (Bcm) in 2020 to 214 Bcm in 2022 and 230 Bcm in 2025, while the annual domestic crude oil production will increase from 199 million metric tonnes (mt) in 2021 to 200 million mt from 2022 to 2025. Henceforth, state-owned energy companies in the PRC have outlined plans to increase their oil and gas production accordingly (Lin 2022). Moreover, the PRC aims to have a 55–60 Bcm gas storage capacity by 2025, which is a significant increase on the 21 Bcm of gas storage in 2020 (Lin 2022). While gas-fired power emits fewer greenhouse gas emissions than coal-fired power, gas is still a fossil fuel energy resource, which may compromise the PRC's efforts to move away from fossil fuel energy.

4. CRITICAL FACTORS IN ACCELERATING RENEWABLE ENERGY ADOPTION

4.1 Cost

Cost of Retrofitting Coal-Fired Power Plants to Integrate Variable RE

Carbon reduction requires huge investments to upgrade and retrofit power plants so that they can offset fluctuations caused by renewable energy production. In the upcoming decades, the PRC needs to retrofit about 200 GW of coal-fired power plants, especially with small units below 300 MW, so they can quickly ramp up to accommodate the intermittent electricity generation of solar and wind farms (Yin 2022).

According to Xu and Geddie (2021), the costs of retrofitting coal-fired power plants involve retooling and retrofitting the facilities as backup generators for the national electricity transmission systems. In the meantime, improvement of storage capacity is also necessary to address the intermittency of solar and wind power. On average, the general cost of upgrading a 300 MW coal plant is estimated at over USD23 million (Xu and Geddie 2021). Because the PRC has hundreds of coal plants, the total financial cost related to retrofitting is estimated at USD34 billion(Xu and Geddie 2021). As such, reducing emissions in the PRC can be financially costly with the retrofitting of existing coal-fired power plants.

Cost of Upgrading Electricity Grid Infrastructures

The most expensive part of phasing out fossil fuel is the cost of upgrading electricity grid infrastructures to be compatible with renewable energy production. Because renewable energy production is intermittent and is concentrated in specific geographical regions, investments are needed to enhance the grid to accommodate such patterns of energy production. As such, Xu and Geddie (2021) estimated that upgrading the system would be five times more costly than building new solar plants and wind farms. In October 2021, Mao Weiming, the former chairman of the State Grid Corporation of the PRC, mentioned that investments in the PRC's grid and other associated costs are expected to exceed 6 trillion RMB yuan, equivalent to about USD896 billion, from 2021 to 2025 (Xu and Geddie 2021), USD350 billion of which would be spent on upgrading the electricity grid systems with improved voltage regulation capability and better compatibility with renewable energy (IRENA 2022). In general, the integration cost of renewable energy may account for 15% of the total system costs (Wang et al. 2022), which suggests that financial costs associated with the improvement of electricity grid infrastructures are the most challenging obstacle for phasing out fossil fuels and developing renewable energy in the PRC.

There needs to be a significant investment to develop interregional electricity transmissions to accommodate the development of renewable energy and the phasing out of fossil fuels. In particular, the most significant investment would be made in the electricity transmission systems from the north and northwestern provinces that produce most solar and wind energy to the central and eastern parts of the PRC that consume most electricity (Zhuo et al. 2022). Additionally, it is also expensive to operate the ancillary services from flexible generation resources to enable the integration of renewable energy, and finance to improve the energy storage systems would also be needed to achieve carbon neutrality (Zhuo et al. 2022). It is estimated that the total cost of improving the electricity grid systems from 2020 to 2050 would reach about 50 trillion yuan (USD7.31 trillion) (Zhuo et al. 2022). This figure illustrates the huge financial costs associated with the PRC upgrading the power grid system.

4.2 Potential Institutional Factors

The fossil fuel phase-out progress in the PRC may be problematic given the fragmented energy governance among different levels within Chinese bureaucracies. Among these government institutions, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) are the most important authorities that influence the energy sector, in which the NDRC sets the energy prices and makes policies and development strategies, while the NEA formulates and oversees the implementation of key energy policy plans and initiatives (Zhang and Andrews-Speed 2020). As such, before the representatives of the NEA can report their policy plans to the State Council and other stakeholders in the industry,

they need to present them to the director of the NDRC and get approval (Xu and Cao 2022). Furthermore, the approval is also fragmented as it is made via a collective leadership style, in which many directors, vice-directors, and senior staff of both the NEA and NDRC need to agree on the making of political decisions (Xu and Cao 2022). Hence, the processes of drafting and approving fossil fuel phase-out policies need to go through different government officials and different government authorities before they are implemented throughout the energy sector, which may slow down the fossil fuel phase-out progress.

The fragmentation of energy governance in the PRC is also reflected in the bureaucratic reform in 2018, with the establishment of the Ministry of Ecology and Environment (MEE) diluting the authority of the NDRC and NEA over environment-related issues of energy development. Climate change duties were shifted to the responsibilities of the MEE in 2018 instead of the NDRC as before. As such, the MEE has been responsible for formulating air, water, and soil quality standards since 2018, which are related to the establishment of fuel standards, the phasing out of inefficient fossil fuel technology, and the closure of small factories (Voïta 2018), thereby making the MEE significant in influencing the fossil fuel phase-out progress. As such, the authority of overseeing fossil fuel phase-out progress is divided among the NDRC, the NEA, and the MEE, which requires complex coordination that may slow down the progress.

In addition, contestation between the central and provincial authorities may also complicate the phasing-out process. As the PRC has announced ambitious decarbonization targets, the central government expects provincial governments to carry out policies to help the nation achieve such targets. However, the provincial authorities may have different interests from the central authorities because they face different circumstances of economic development and infrastructural status (Downie and Wallace 2021). For instance, provinces in the north that are more reliant on fossil fuel energy to operate their economy may face more challenges in reaching fossil fuel phase-out targets than cities such as Beijing and Shanghai (Downie and Wallace 2021). As such, provincial authorities may either be key partners or key obstacles to the success of the fossil fuel phase-out progress in the PRC, which depends on their degree of cooperation with the central authorities (Kyle and Tan 2020). That said, Inner Mongolia is a case in point, representing an extreme example of the contestations between the central authorities and the provincial authorities regarding the fossil fuel phase-out progress.

The economy of Inner Mongolia has long been reliant on coal-fired power plants that run energy-intensive manufacturing industries. As such, the authorities of Inner Mongolia were reluctant to comply with the decarbonization plans mentioned in the 13th Five-Year Plan (2016–2020). Hence, Inner Mongolia saw a 1.5% increase in the energy intensity rate in this period, while the average for the PRC was a decline of 21.7% (Downie and Wallace 2021). Hence, Inner Mongolia was judged by the central authorities to be the only province to have failed to meet the centrally assigned “dual-control” targets for reducing energy intensity and energy consumption in 2019 (NDRC 2019).

Consequently, Inner Mongolia was under pressure from the central government. In particular, the central authorities assumed that the authorities of Inner Mongolia were involved in corruption with fossil fuel energy companies, which made them reluctant to phase out the fossil fuel industry and resulted in the loss of their benefits. In the late 2010s, various corruption investigation campaigns against Inner Mongolian officials were announced by the central government, which targeted current and former senior officials in the province with ties to the coal industry (Huang 2020). Consequently, in

2020, the central authorities called Inner Mongolian officials to Beijing over the province's high energy consumption levels and instructed them to implement central mandates "without talking about special conditions or making accommodations or giving breaks" (NDRC 2021).

Facing immense pressure, the authorities of Inner Mongolia had to follow the directions of the central authorities. Inner Mongolia's 14th Five-Year Plan features President Xi's mandate about "ecological prioritization and green development" as one of its leading themes (Downie and Wallace 2021). The FYP emphasized advancing green, circular, and low-carbon development and various energy consumption control targets (Downie and Wallace 2021), which suggests that they had to comply with the fossil fuel phase-out targets after the previous decade of contesting against the central authorities. A similar contestation between the central and provincial authorities regarding the phasing out of fossil fuel also took place in northern provinces such as Hebei and Shanxi due to the prevalence of the fossil fuel sector in those provinces. Hence, the contestation between the central and provincial authorities may slow down the fossil fuel phase-out progress until the central authorities impose stronger measures that require the provincial authorities to comply with them.

4.3 Technology

The PRC has advantages in manufacturing renewable technology equipment. The country's solar PV manufacturing has supported the installation of 71% of the all-time global solar capacity, and this figure is expected to rise in the future (Lai 2021). As of 2022, the PRC controls 84% of the global solar panel manufacturing capacity, in which its polysilicon, wafer, cell, and panel production accounts for 79.4%, 96.8%, 85.1%, and 74.7%, respectively, of the global production output (Prasad 2022). To put it simply, the PRC has various technological advantages in developing solar energy that will help to replace fossil fuels.

Apart from solar technology, the PRC is also making great progress in advancing wind technology. The PRC accounts for 50% of the global manufacturing capacity for wind turbines (Evans 2022), most of which serve the domestic demand for building wind farms. The country's current operation of half of the world's installed offshore wind capacity, with 26 GW of the global total of 54 GW (Vetter 2022), reflects the PRC's advance in wind energy manufacturing capacity. The world's biggest turbine is also being developed by MingYang Smart Energy, a Chinese wind turbine manufacturer (Venditti 2022), indicating that the PRC's advantages in having a large and advanced manufacturing capacity for wind energy development ensure that it plays a role in helping phase out fossil fuels.

The PRC currently holds 90% of the global battery storage manufacturing capacity (Bloomberg 2022), which benefits the country's renewable energy development. In the 14th Five-Year Plan, the PRC aims to have 30 GW of cumulative storage installations by 2025, and 100 GW by 2030, which is accompanied by the growing interest of Chinese enterprises in battery manufacturing (Shaw 2021). These enterprises include Contemporary Amperex Technology Limited (CATL), which participated in a 50 MW storage project in Qinghai province; Sungrow, which promoted a solar energy storage system of 1500 V; and Shanghai Electric Gotion, with a lithium battery production base that has an annual capacity of 5 GWh (Shaw 2021). In the long run, energy storage will play an increasingly important role in the PRC's energy transition. To develop energy storage technology, the 14th FYP for Energy Storage Development calls for new technology breakthroughs and commercialization of the storage industry. The PRC's energy storage capacity reached 46.1 GW in 2021. The 14th FYP on Energy Storage

Development aims to reduce the system cost per unit of electrochemical energy storage by at least 30% by 2025 (Bian 2023).

However, given the unstable and weather-dependent power supply of renewable energy, the PRC needs to address several technology barriers before it can achieve further progress in carbon reduction. Hence, power system flexibility is critical to a transformed power system with a high share of variable renewable energy. This requires advanced technologies to ensure system stability, such as energy storage, smart grid upgrades, and digital technology. With regard to energy storage, the PRC's energy storage industry has been commercialized. In 2017, the NDRC and several other ministries issued "Guidelines for Promoting the Development of Energy Storage Technology and Industry" (NDRC et al. 2017), which largely promotes energy storage technologies. However, market reform is needed for the energy storage developers to have the right signals for investment. The PRC's lack of an electricity spot market is hindering the widespread deployment of energy storage technology. In this regard, the PRC tried to conduct electricity trading in shorter time periods. By the end of 2021, most provinces in the PRC had established spot market pilots, although they had relatively small trading volumes (Hove 2022). In November 2022, the National Energy Administration (NEA) released "Basic Rules of Electricity Spot Market (Draft for Comments)" and "Supervision Measures of Electricity Spot Market (Draft for Comments)." On 7 September 2023, the NDRC and NEA issued "Basic Rules of Electricity Spot Market (Trial)." The trial rules clarify how the PRC's electricity spot markets should be operated and managed. The "Supervision Measures of Electricity Spot Market (Draft for Comments)" and the "Basic Rules of Electricity Spot Market (Trial)" suggest that new energy will continue to enter the power market (CNESA 2022). The spot markets are more likely to have sufficient trading volume to ensure that renewable energy is competitive. Along with spot markets expanding across the PRC, spot electricity trading can help discover the real-time prices of electricity so as to better reflect demand and supply. Therefore, the surplus electricity capacity, being in the real-time market, will compete on the grid. This will help make electricity supplies more cost-effective. Besides energy storage, distributed energy resources and electrification, and digitalization are also drivers of energy transition and become a new task for the PRC's policymakers. Distributed energy systems are taking the place of centralized power supplies along with the expansion of renewable resources, which enable power to be generated in smaller and localized units instead of large-scale power plants. This requires innovative technologies such as diversified digital solutions. Chinese power producers have in recent years built up sufficient experience of digital solutions. Increasing the adoption of digitalization and more data availability to further facilitate the power sector transition will soon be seen in the PRC (Zheng 2022).

Further, the supply of raw materials to manufacture renewable energy equipment in the PRC has been challenging due to global supply chain disruptions and geopolitical tensions. In particular, the PRC processes more than 50% of the cobalt, rare earth, and lithium for the manufacturing of solar panels, wind turbines, and batteries, most of which, however, are imported from abroad (Venditti and Jamshed 2022). When the COVID-19 pandemic occurred, the flows of these raw materials into the PRC were halted when the PRC enforced strict quarantine policies. Moreover, geopolitical tensions can also cause a shortage of raw materials. For example, the US recently imposed trade bans on Chinese solar manufacturing companies due to allegations of them using forced labor in Xinjiang, which resulted in some difficulties in the PRC's solar manufacturing industry when the US ban made it difficult for the PRC to import foreign raw materials (Angel 2022). The country has to face increasing anti-PRC sentiment in Western markets and will have to rebuild its brand as a responsible superpower. As the PRC relies heavily on imports for these materials, it may face more

constraints in gaining enough raw materials for its manufacturing of renewable energy technology. This creates uncertainty in the development of technology under the current international upheaval, as well as in the scaling up of renewable energy.

4.4 Supportive Schemes

Policy support is critical for promoting renewable energy. One of the most important policies that promote renewable energy development is the feed-in tariff (FIT) system, which is a price mechanism whereby the government provides subsidies to make renewable energy more competitive (Schuman 2010). According to solar power resources and construction costs in different resource zones, the PRC's FIT price for solar energy in 2021 was set at RMB0.9,[3] RMB0.95, and RMB1 per kWh, respectively. Moreover, the distributed PV power generation was given a subsidy of RMB0.42 per KWh in 2021 (IEA 2021). For wind energy, the PRC imposed a fixed FIT of RMB0.85/MWh for offshore wind, which lasted until the end of 2021 (Lin 2022).

In 2021, the PRC ended the FIT system for new solar and onshore wind projects, as they became increasingly cost-competitive with other energy sources. The PRC has introduced other supportive schemes that would help drive renewable energy development, such as the price auction scheme and emissions trading system (ETS). According to Lucas, Ferroukhi, and Hawila (2013), the NDRC is in charge of holding onshore wind auctions, while the NEA regulates solar and offshore wind auctions. Bidding agencies such as Zhongshe International Bidding Co. Ltd. and the China Hydro Power Project Consult Group have participated in the auctions. These bidding agencies are evaluated by members of the NDRC, NEA, provincial development and reform commissions, state-owned grid companies and their provincial branches, bidding agencies, and technical experts (Lucas, Ferroukhi, and Hawila 2013). These auctions choose the company that offers the lowest electricity price based on different legal and technological criteria.

The introduction of the FIT scheme in the initial years of renewable energy development was a government incentive to encourage companies to phase out fossil fuels by developing renewable energy sources. As the technology becomes more efficient and developers have more experience with renewable energy projects, the costs of developing renewable energy are reduced, which makes the sector become more attractive. Hence, the removal of the FIT scheme signifies that the Chinese renewable energy sector has been attractive enough to facilitate the fossil fuel phase-out progress based on the market conditions instead of state intervention as before.

In addition to FIT, the ETS is expected to play an important role in the PRC's pursuit of carbon neutrality by 2060. The PRC launched its national ETS in 2017, which became operational in 2021 and currently covers 2,162 companies in the country's power generation sector. The present scope of the ETS represents annual emissions of close to 4.5 billion tonnes of CO2 per year. The Shanghai Environmental and Energy Exchange (SEEE), which operates transactions of the national ETS, disclosed that its trading volume had reached 10.12 billion RMB yuan in total transactions as of 22 December 2022. This is a milestone for the Chinese ETS (Xue 2022). The pace of development of the country's carbon market was expected to slow down in 2023 as the energy supply was at the top of the government agenda given the global energy crisis in 2022.

[3] One RMB yuan is equivalent to about USD0.15.

5. GOVERNMENT'S EFFORTS TO ADDRESS CHALLENGES IN RENEWABLE ENERGY ADOPTION

Intermittent renewable energy sources create challenges for users, which is a hurdle for phasing out coal power. Large-scale production of power from intermittent renewable resources such as solar and wind creates challenges for the stability of the electricity grid. Further, big growth with limited utilization harms the rate of return for renewables projects.

System inflexibility and transmission bottlenecks are the main causes of the curtailments. One big challenge lies in the connection of electricity produced by renewables to the power grid. Since there is a time lag between the output of renewable electricity and grid companies obtaining permits to build local grid facilities, there is significant wasted solar and wind power (Chen 2017). To solve this problem, the PRC government has suspended approval since March 2016 for new wind farms in provinces where annual wind curtailment[4] rates have exceeded 20%. Since June 2018, this threshold has been further tightened from 20% to 5% (Guo et al. 2023).

The development of energy storage is another strategy aimed at tackling the curtailment problem. As outlined in the 14th FYP on Energy Storage Development, the PRC would achieve large-scale commercialization of new energy storage technologies with more than 30 GW of installed nonhydro energy storage capacity by 2025. As of 2021, there were 146 approved energy storage projects inside the PRC (Bian 2023).

Another challenge in adopting renewable energy comes from the reluctance of local companies to use these intermittent sources. For example, power grid companies in different provinces work collectively to buy electricity generated from renewable energy, in accordance with the requirement of the Renewable Energy Law that obliges them to purchase renewable electricity. However, the power grid companies appear to give priority to locally generated and more price-competitive electricity. Some even doubt the safety of long-distance transmission lines, as the intermittent power flows may cause system instability and major power outages (Chen 2017).

Overcoming these challenges requires the government to develop prudent policies and to be strict with implementation. In particular, given the decelerating economy, the adoption of renewable energy could be challenging and difficult. It is an energy problem, but solutions can be found outside the energy sector itself. The government has issued policies to encourage energy consumers to use more renewable energy. These policies include the Clean Energy Consumption Action Plan, and an obligation to use renewable energy for provinces, grid companies, and large energy consumers (Hove 2020). However, many of these policies are government mandates, whereas few market incentives are created. To address these challenges, market incentives, particularly for energy storage investment, are needed. The market mechanism for energy storage is still in its infancy. The current electricity pricing mechanism does not fully reflect the value created by new energy storage, which discourages investment in new energy storage projects. Hence, improvements in the pricing mechanism are necessary, which would to some extent support the commercialization of new energy storage technologies (S&P Global 2023).

[4] The phenomenon that some electricity cannot be integrated in the power grid is called "curtailment."

6. CONCLUSIONS AND POLICY IMPLICATIONS

The PRC has the potential to develop renewable resources on a large scale, yet it still has a long way to go to achieve carbon neutrality.

There is still a risk that the PRC's growing coal capacity may harm the country's efforts to decarbonize its energy mix. The fossil fuel phase-out progress may face a setback due to the power shortages in 2021 that prompted the PRC government to take measures to increase coal production to safeguard energy security. Despite having announced the country's willingness to phase out coal-fired power plants, the PRC has recently increased its coal production to mitigate its power crisis, which caused many incidents of blackouts across the PRC (You 2022).

After this power crisis, the PRC announced plans to construct new coal-fired power plants. In the first six weeks of 2022, a total of 7.3 GW across five new coal-fired power plants were approved for construction (You 2022), 90 GW of new coal-fired power plants were under construction, and 160 GW of coal-power projects were in earlier development stages (Tay 2022). To facilitate these new projects, the PRC's economic planners have approved a state investment of more than 24.1 billion yuan (USD3.8 billion) to produce more than 19 million tonnes of coal annually. As a result of these policies, Chinese coal production in January and February 2022 reached 690 million tonnes, which was a 10.3% year-on-year increase (You 2022). Moreover, the PRC has a plan to retrofit 200 GW of coal-fired power plants during the period 2021–2025 to enhance the flexibility of its electricity production, which will increase the grid's capability to rapidly ramp up its transmission in the case of low production of renewable energy resources (Yin 2022). This move was motivated by the decision of the PRC's political leaders to assert that the significance of coal power in the PRC's energy mix will not change in the short term to accommodate the demands of the economy. Consequently, the PRC has been burning more coal to drive its economic goal. In particular, its coal consumption in 2021 increased by 4.6% compared to the 2020 level, which was the strongest growth rate in the last decade (Ferris 2022). The construction of 33 GW of new coal-fired power plants in 2021 and increasing coal production in existing power plants have led to an increase of 4% compared to the 2020 level in the PRC's carbon dioxide emissions (Ferris 2022).

There have been various concerns over the implications of the PRC's renewed interests in coal-fired power plants for its previously announced fossil fuel phase-out goals. As coal-fired power plants are still needed for the PRC's industrialization, the country may face problems in reaching its decarbonization targets by 2025 and 2030, and the additional coal-fired power plants that may render the PRC unable to make its coal consumption peak by 2030. Some observers express different concerns, such as over the life span of the PRC's coal-fired power plants that are expected to last until 2040 before being mostly phased out, which will result in the prolonged use of coal-fired power plants in the PRC's energy production (Xie 2021). Hence, although the PRC has announced various goals and strategies with a view to phasing out fossil fuels, its recent interests in coal-fired power plants have prompted concerns about whether its goals can be fulfilled by their stipulated deadlines.

Given the above restraining factors and the PRC's enormous coal-dependent infrastructure and large heavy-manufacturing base, transitioning away from fossil fuels will be challenging. The success of the renewable energy plan relies on large-scale renewable energy bases and supportive schemes to deploy renewable technology. The growing penetration of renewable energy in the PRC's electricity mix requires effective

policy tools and appropriately designed market signals. The market-based schemes need time to be mature enough to support renewable development.

Yet despite the challenges, the PRC is seriously making its way toward decarbonization. It is currently the top global producer of renewable energy power, and a leading manufacturer of electric vehicles. It has initiated a carbon trading scheme, and it has improved energy efficiency dramatically across multiple sectors.

Having said that, the PRC should invest in the necessary infrastructure, particularly advanced power grids, as future deployment of thousands of solar and wind facilities will increasingly require flexibility in power grids. The PRC should also focus on institutional reforms that could facilitate faster deployment of low-carbon technologies within the decade (Lee and Schrag 2022). More importantly, the PRC could prioritize the pursuit of short-term mitigation targets that can take effect as soon as possible, as opposed to long-term ambitions that may appear unrealistic to the public. This also requires the relevant institutional reforms to be in place to facilitate the realization of the short-term targets.

As far as institutional factors are concerned, the role of centralized government planning, standards, regulations, subsidies, and other supportive schemes have made impressive contributions to the country's low-carbon success. Large state-owned companies may continue to play an important role in building and operating the PRC's electricity system. National energy infrastructure projects always involve high costs that take years to recover. For example, huge projects such as long-distance transmission lines will need longer time and more expense than local-level small projects (Lee and Schrag 2022). Therefore, it could be expected that strong state intervention and financial support are still needed for renewable energy development in the PRC.

Further, market forces are key to solving today's problems. As for the supportive schemes, the PRC has carried out the EET pilot projects in several provinces, including Henan, Zhejiang, Fujian, and Sichuan, since 2017. Large energy-intensive enterprises are covered by the EET system. Since the PRC's EET system and ETS overlap as far as the coverage of enterprises is concerned, Li et al. (2022b) argue that ESQ and CO2 allowances can be mutually converted to avoid repeated accounting of CO2 emissions reduction and energy savings. In addition to an emissions trading system, it is also crucial to develop an advanced new energy storage industry, as this is the key for expanding renewable energy adoption. In this regard, it is suggested that a market-oriented approach should be adopted rather than relying on government policies.

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