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China's Revolutionary Transition towards Carbon Neutrality and Prevention of Relevant Risks

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Achieving carbon neutrality requires the fundamental transformation of the development paradigm, the disruptive technologies. With efficiency-improving technologies and carbon removal technologies alone, it is possible to move further towards low carbon but hard to achieve carbon neutrality. It can only be realized through thorough decoupling from fossil energy with disruptive technologies. This revolution aiming at carbon neutrality has not only made new ground in the energy market, but also the central task which is to revolutionize zero-carbon energy production and consumption through underlying changes to the relations of production and mode of distribution, thereby pushing forward the fundamental transformation of social development paradigm.

Keywords: Carbon neutrality; development paradigm; revolution in energy production; revolution in energy consumption.

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1. Introduction

Climate change is a global challenge that is faced by all countries in the world. The international community has unanimously called for greater efforts to achieve carbon neutrality by the middle of the 21st Century, so as to address the major threats to human survival posed by frequent extreme weather events resulting from climate change (IPCC, 2018; United Nations, 2020). Chinese President Xi Jinping also made clear at the 75th session of the United Nations General Assembly that China aims to "achieve carbon neutrality before 2060". Subsequently, President Xi reaffirmed China's unswerving commitment to achieving carbon neutrality in his speech at Leaders' Side Event on Safeguarding the Planet of the G20 Riyadh Summit in November 2020, and again emphasized this urgent and ambitious goal at the UN Climate Ambition Summit in December 2020, which fully demonstrated China's sense of responsibility in actively addressing climate change as a responsible major country, and also provide important strategic support for promoting China's high-quality economic development. The Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy (hereinafter referred to as "the Guidance") issued in October 2021 (Central Committee of the Communist Party of China and the State Council, 2021) has made systematic and overall planning for carbon peaking and carbon neutrality in China.

Achieving carbon neutrality, as a major national strategic decision and a long-term goal of addressing climate change, has attracted much attention once it was proposed. Neutralization of carbon emissions is a revolution in energy production and consumption, and it will bring extensive and profound changes to relations of production and fundamentally transform the social development paradigm. However, the transition towards carbon neutrality has not yet been defined clearly and thoroughly in China. Given this, this paper interprets the core meaning of the transition towards carbon neutrality, deeply analyzes the central role of fossil energy withdrawal and zero-carbon energy revolution in achieving carbon neutrality, and discusses the potential risks to carbon neutrality caused by excessive dependence on fossil energy and high carbon lock-in, so as to provide important scientific support for promoting the fundamental transformation of social development paradigm in the context of carbon neutrality.

2. Core Meaning of Carbon Neutrality

The core meaning of carbon neutrality lies in the orderly withdrawal of fossil energy. Carbon dioxide (CO_2) emissions in the atmosphere mainly come from fossil energy consumption, so the path to carbon neutrality is the path of accelerated withdrawal of fossil energy, i.e. phasing out coal and reducing petroleum and natural gas consumption in a science-based and orderly way, so as to gradually lower fossil energy consumption to near zero or even zero.

2.1. *Rigid time constraints for carbon neutrality*

Carbon neutrality is a development process with rigid target constraints. The Paris Agreement calls for net zero emissions in the second half of the 21st Century, imposing a rigid time constraint on carbon neutrality. In 2021, fossil energy accounted for 84.1% of primary energy consumption in China, while non-fossil energy consumption accounted for only 15.9%. CO_2 emissions from the combustion of fossil energy amounted to 10.5 billion tons, with the combustion of coal, petroleum, and natural gas releasing 72.9%, 19.4%, and 7.7% of CO_2 emissions respectively.[1]

It is thus clear that orderly withdrawal of fossil energy is to fundamentally remove carbon emissions, which is the key to achieving carbon neutrality. Although there is still some time before 2060, carbon neutrality allows no delay. It is necessary to start planning for the orderly withdrawal of fossil energy infrastructure as early as possible and facilitate the process of phasing out coal and reducing petroleum and natural gas consumption to achieve carbon neutrality.

2.2. *Net zero carbon progress as the focus of the international response to climate change*

Having gone through a long process of gaining a deeper understanding and reaching a political consensus, the international community agreed on the carbon neutrality goal, and gradually focused on net zero carbon in its responses to climate change. The United Nations Framework Convention on Climate Change (UNFCCC) adopted in 1992 did not clearly define the scope of greenhouse gases or set clear carbon reduction targets. The Kyoto Protocol reached in 1997 put limits on carbon emissions from developed countries. Although this international legal document has not been effectively implemented, it did send a positive signal to the world to reduce or limit emissions, starting the progress towards low-carbon development. In 2007, the Fourth Assessment Report (AR4) of Intergovernmental Panel on Climate Change (IPCC) and the United Nations Bali Climate Change Conference reached a consensus on the target of limiting warming to 2°C (hereinafter referred to as "the 2°C target") theoretically and politically. Later, the Copenhagen Accord reached in 2009 formalized the 2°C target for the first time but did not contain specific zero-carbon targets. The Paris Agreement reached in 2015 reaffirmed the 2°C target and further sought the possibility of limiting global warming to 1.5°C (hereinafter referred to as "the 1.5°C target"), while setting a mid-21st Century net zero carbon emission target, urging developing countries to peak carbon emissions as soon as possible, and requiring all parties to the Agreement to submit legally binding nationally determined contributions (NDCs). In its report released in 2018, the IPCC pointed out that efforts are urgently needed to achieve the 1.5°C target in responses to climate change, which means that achieving carbon neutrality by mid-21st Century is a necessary condition for reaching the warming limit targets of the Paris Agreement. At this point, the international community has developed a moral consensus at the global level on achieving the goal of carbon neutrality by 2050 (IPCC, 2018).

2.3. *Accelerated progress in carbon neutrality in developed countries' responses to climate change*

Carbon neutrality in developed countries is not achieved overnight. In the first 30 years of their responses to climate change, developed countries made very limited efforts to reduce

[1] *Source*: BP, https://www.bp.com/en/global/corporate/who-we-are.html (accessed May 22, 2023).

Table 1. Carbon emissions from major countries and regions as the UNFCCC Annex I Parties.

Year	The US	Russia	Japan	Germany	Canada	The UK	The EU
1990	6453.5	3162.7	1275.4	1241.9	595.0	797.0	5646.0
2005	7434.8	1966.3	1382.0	986.7	741.0	691.2	5231.0
2016	6537.9	2023.8	1304.9	901.4	715.0	483.3	4309.0
2017	6501.0	2080.3	1291.6	885.7	725.0	472.1	4323.0
2018	6687.5	2133.0	1247.7	850.5	740.0	463.3	4231.0
2019	6571.7	2122.6	1212.2	799.7	738.0	447.4	4057.0
2020	5981.4	1988.1	1150.1	728.7	672.0	404.8	3711.0
Average annual emission reductions in the first 25 years (1990–2015)	−3.4	45.6	−1.2	13.6	−4.8	12.5	53.5
Average annual emission reductions in the next 5 years (2016–2020)	111.3	7.1	31.0	34.5	8.6	15.7	119.6

Sources: The Lanzhou Branch of the National Science Library, Chinese Academy of Sciences, *Dynamic Monitoring Newsletters of Scientific Research on Climate Change*, Issue No. 9 of 2022.

carbon emissions, and there were fluctuations and regressions. The United States signed and approved the Kyoto Protocol in 1997, but the Bush administration refused to ratify it in 2001 on the grounds that it would affect economic development. In 2016, the Trump administration announced its withdrawal from the Paris Agreement, and in 2021, the Biden administration announced its re-entry into the Paris Agreement with a commitment to achieve carbon-free electricity by 2035 and carbon neutrality by 2050 through electricity generation from renewable energy sources.

As shown in Table 1, from 1990 to 2016, carbon emissions showed an increasing trend in some countries and regions, except for the European Union (EU). The EU, as a saturated developed economy with a decreasing population and energy demand during this period, showed a continuous downward trend in carbon emissions due to the combined actions of factors such as improved energy efficiency and optimized energy structure. Developed countries achieved carbon peaking earlier than others, and then entered a long-term plateau of high emissions. From 2016 to 2020, developed countries delivered positive results in reducing emissions. In addition to common factors such as the changes in the development stage, energy structure, industrial structure, and consumption patterns in real estate and transport, the emergence of disruptive technologies is the fundamental reason for the sharp decline in total carbon emissions in these five years.

2.4. *China's active action to promote the progress in carbon neutrality*

Taking great strides towards carbon neutrality can help China well achieve long-term sustainable development. Facing climate change, a serious challenge that threatens all humanity, President Xi Jinping has repeatedly made it clear that China will take the initiative to address climate change, emphasizing that to address climate change is not at others' request but at China's own initiative (MEE, 2018). China has committed to the international community to achieve carbon neutrality by 2060, with a clear timetable and roadmap. The guidance proposes that the proportion of non-fossil energy consumption will reach around 20% by 2025, around 25% by 2030, and more than 80% by 2060 (Central Committee of the Communist Party of China and the State Council, 2021), imposing rigid constraints on the basic withdrawal of fossil energy before 2060.

Carbon neutrality is a broad, profound, and systemic change to the society and the economy (Xinhuanet, 2021). At this stage, China's energy consumption structure dominated by high-carbon coal has made it difficult to withdraw from fossil energy. The important role of fossil energy in the current social and economic development stage has made all sectors of society less confident in the withdrawal. Based on the current timetables for achieving carbon neutrality targets announced by countries around the world, three scenarios for achieving carbon neutrality in the future can be classified as follows: In the first scenario where developed countries achieve carbon neutrality before 2050 in accordance with their stated goals and strategies, China is very likely and able to achieve carbon neutrality before 2060 through learning from and improving carbon neutrality technologies in developed countries. In the second scenario where developed countries fail to achieve carbon neutrality by 2050 on time, China, as a developing country, may not need to follow the rigid constraint of achieving carbon neutrality before 2060. In the third scenario where developed countries fail to achieve carbon neutrality by 2050 on time, China achieves the goal of carbon neutrality before 2060 according to its established plan, and it will contribute to the global response to climate change and truly act as a world leader in the global progress towards carbon neutrality.

Since 2010, China's renewable energy industry has been developing rapidly, leading the world in terms of development speed, scale and technology level, with the cost of power generation falling significantly. As of 2021, China's total installed capacity of renewable energy reached 1.063 TW, and the installed capacities of hydropower, wind power, and photovoltaic (PV) power reached 391 GW, 328 GW, and 306 GW, respectively, in which the total installed capacity of offshore wind power reached 26.39 GW, ranking first in the world (The State Council of the People's Republic of China, 2022). In his speech at the Climate Ambition Summit on December 12, 2020, President Xi Jinping announced that China will achieve its NDC target of bringing its total installed capacity of wind and solar power to over 1.2 TW by 2030 (Xinhuanet, 2020), boosting confidence in China's access to zero-carbon energy and realization of carbon neutrality through disruptive technologies. China should have the confidence and capacity to complete its transition towards carbon neutrality by 2060.

Carbon neutrality in response to climate change is an international process in which China has played an important role. However, as a developing country, China should avoid any delay or rash advance and needs to be responsible and stay in line with its national conditions. Instead of blindly making bold moves, it is important to plan for the long term, establish the new before abolishing the old, and advance steadily to reach the goal from afar (Pan, 2022a).

3. Zero-carbon Energy Revolution Needed for Carbon Neutrality

High-quality, low-cost energy services are necessary for the proper functioning of a modern economy and society, but carbon is not a necessity. Energy production and consumption are both the biggest obstacle to carbon neutrality and the strongest driving force for the carbon neutrality revolution. The process of phasing out fossil energy consumption is also the process of achieving the goal of carbon neutrality. To reach this goal, the inevitable way is to revolutionize energy production and consumption through disruptive technologies and obtain zero-carbon energy services so as to fundamentally change the way of energy production and consumption and create a new pattern in the energy market.

3.1. *Viable pathways to carbon neutrality*

There are three main pathways to carbon neutrality in order to ensure a balance between the energy demand of social development and the goal of carbon neutrality. The first path is to improve the utilization efficiency of fossil energy through efficiency-improving technologies, reduce energy use demand and fossil energy consumption, thereby reducing carbon emissions. In recent years, with the continuous improvement of coal-fired power technology and fuel vehicle efficiency, China has built the world's most energy-efficient coal-fired power units, thanks to which the coal consumption of power supply has dropped to less than 260 g of standard coal equivalent per kilowatt hour (gsce/kWh) (Economic Daily, 2022), and the average fuel consumption per hundred kilometers of fuel vehicles has been 6–10 liters, indicating a sharp rise in energy efficiency, which has played an important role in reducing carbon emissions. However, energy-saving and emission-reducing technologies can constantly lower the total carbon emissions, but they cannot achieve zero emissions, so relying solely on efficiency-improving technologies can hardly achieve carbon neutrality.

The second path is to achieve carbon neutrality through end-use carbon removal technologies. On the one hand, following the practice of desulfurization and denitrification of thermal power units, the CO_2 generated by coal-fired power can be captured, utilized, and stored through carbon capture, utilization and storage (CCUS) technology. However, compared with desulfurization and denitrification, China's annual CO_2 emissions from coal combustion are enormous, and it takes huge capital costs and geological storage space to accommodate the large-scale use of CCUS technology. There is also a risk of escape after CO_2 is sequestered, making it necessary to continuously monitor its storage status. Therefore, this is not a once-and-for-all solution. Due to the cost and space constraints, CCUS technology falls short of market competitiveness (Cai *et al.*, 2019), and therefore cannot be treated as the fundamental pathway towards carbon neutrality. On the other hand, the carbon sinks that can be used to neutralize carbon emissions are those formed by human activities, which need to be stored for a long time and must be incremental (Chen, 2022). And only the new forests as the carbon sinks intended to restore the natural environment can be counted, so the forest carbon sinks may absorb a certain amount of carbon emissions for some time to come, but cannot completely neutralize China's annual carbon emissions of more than 10 billion tons. In addition, in the long run, the impact of carbon sinks on the climate system is neutral, and the carbon absorption will not take effect forever, so carbon sinks are one of the means to achieve carbon neutrality, but cannot be seen as the ultimate guarantee.

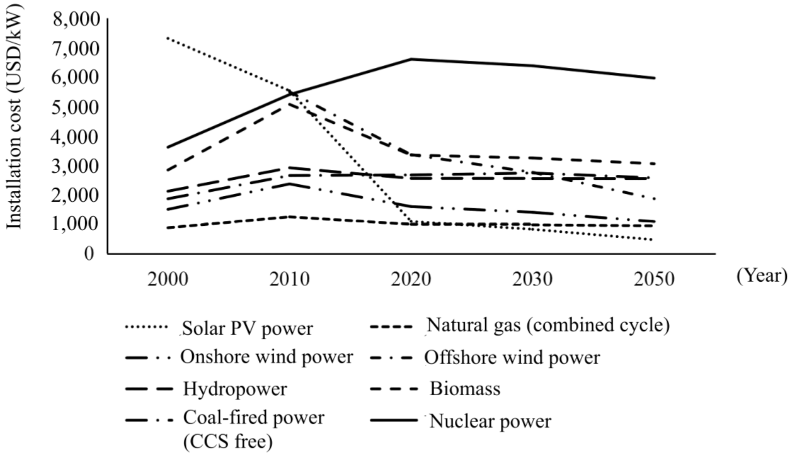
The third path is to promote the zero-carbon energy revolution with disruptive technologies, which includes the zero-carbon revolutions in both energy production and consumption. On the production side, renewable sources such as wind power, hydropower, and PV power will replace fossil energy for power generation, while on the final consumption side, zero carbon energy will replace fossil energy. Only by reforming the patterns of energy production and consumption from the root and end reliance on fossil energy can it be possible to achieve carbon neutrality while meeting people's living needs.

Carbon in the atmosphere mainly comes from the combustion of fossil fuels. However, the improved utilization efficiency of fossil fuel can only contribute to a low carbon development, but can hardly achieve zero carbon emissions; end-use carbon removal technologies such as CCUS and carbon sinks are indispensable, but they cannot take on such an important task. In summary, a disruptive energy revolution is necessary for achieving carbon neutrality, and carbon neutrality can only be achieved through the complete replacement of fossil energy services with disruptive technologies (Pan, 2022b).

3.2. *The zero-carbon revolution in energy production*

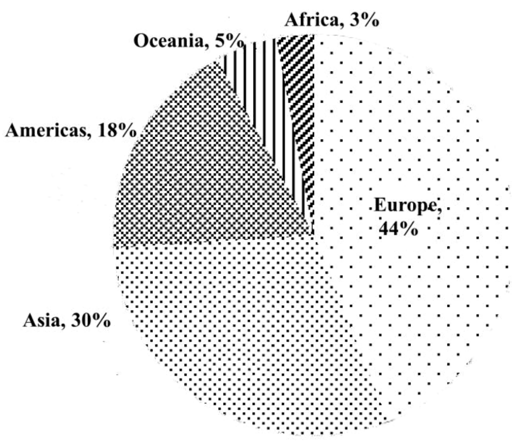
Energy services are the engine driving the economic growth of modern society. It is necessary to vigorously promote electricity generation from renewable energy in the field of energy production, phase out the generation model dominated by coal-fired power, and shift energy production from fossil energy to zero-carbon energy, promoting carbon neutrality. Differing from the conventional fossil energy, which features scattered distribution, renewable resources such as wind and light are distributed more evenly and can provide sufficient energy supply at affordable prices thus ensuring energy security. As technologies continuously advance, the cost and market competitiveness of electricity generation from renewable energy have also been greatly improved. In the past decade, the cost of electricity generation from renewable energy in the international market has dropped significantly (Fig. 1), gaining an increasing cost advantage over coal-fired power and obtaining strong market competitiveness, thus creating space for a gradual withdrawal of coal-fired power from the market (IRENA, 2021a).

China already has the capacity to disrupt conventional energy production with large-scale renewable energy, taking a dominant position in the global wind and PV power generation industries. China's PV modules are not only produced to meet domestic demand, but also have been exported to developed markets, including Europe, the Americas, and Asia (see Fig. 2), accounting for more than 80% of global PV module production capacity (IEA, 2021) (see Fig. 3). Six of the top 10 global wind turbine manufacturers in 2021 are Chinese enterprises. It is expected that by 2025, the levelized cost of energy (LCOE) of offshore and deep-sea wind power will be reduced to 0.4 yuan and 0.5 yuan, respectively. The LCOE of onshore 4–6 MW wind power generator sets in northwestern, northern, and northeastern China has dropped to 0.18–0.2 yuan. After 2023, onshore wind power will be switched to 6–8 MW generator sets, and the LCOE is expected to drop to 0.1–0.15 yuan, and by then electricity generation from renewable energy will cross the grid parity stage and enter the low-price era.



Source: The data is compiled from Esmall Data. The data from 2000 to 2020 is the investment costs of installed capacity based on various power generation techniques, and the data from 2030 to 2050 is the predicted values (the average value based on installed capacity data in Europe and the United States, excluding financial costs, and in 2020 U.S. dollars).

Fig. 1. Installation costs of different types of power generation from 2000 to 2050.

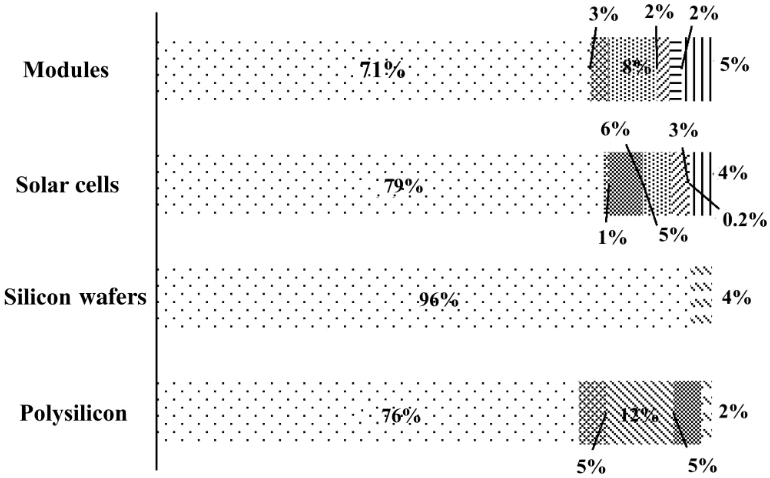


Source: The data comes from China Photovoltaic Industry Association (CPIA).

Fig. 2. Export distribution of China's PV modules in 2021.

3.3. *The zero-carbon revolution in energy consumption*

In addition to the zero-carbon revolution on the production side, the zero-carbon revolution on the energy consumption side is also an inevitable requirement for achieving carbon neutrality. It is necessary to promote energy substitution with disruptive technologies on the end-use energy consumption side, completely eliminate the dependence on fossil energy for production and living consumption, and phasing out fossil energy on the consumption side while meeting the growing consumption demand of the people, so as to achieve carbon neutrality. The demand for fossil energy on the consumption side mainly



Source: The data comes from International Energy Agency, 2021.

Fig. 3. Proportions of global PV output on the manufacturing side in 2020.

includes energy consumption of fuel vehicles in the transportation field, energy consumption of heating and cooling in daily life, and inputs as raw materials for plastic products. As a product of the oil revolution, automobiles are the main end-use consumers of petroleum products. As of 2021, China's motor vehicle parc was 395 million units, of which 302 million units are cars (MPS, 2022), according to which the estimated passenger cars per 1,000 people in China is about 213. By referring to the figures in developed economies such as the United States and Europe, the passenger cars per 1,000 people in China will at least double in the future. The rigid demand for automobiles in social life cannot be eliminated, so the thorough replacement of fuel vehicles with pure electric vehicles is an inevitable way to make end-use consumption carbon neutral (IRENA, 2021b). According to the New Energy Vehicle Industry Development Plan (2021–2035) issued by the General Office of the State Council, the average electricity consumption of pure electric vehicles will drop to 12 kWh/100 kilometers by 2025, and pure electric vehicles will constitute the majority of new vehicle sales by 2035 (NDRC, 2021a). Pure electric vehicles will surely become the mainstream of automobile research and development (R&D) and sales with their driving cost much lower than that of fuel cars, and their market scale will continue to expand with the growth of demand.

Heating and cooling is one of the important areas of fossil energy demand in people's daily life. However, coal is not a necessity for heating. Air-source heat pumps can use electric energy for cooling in summer, and ground-source heat pumps can use geothermal heat for heating and can save more than half of the energy compared with conventional boilers, with its heating coefficient about 40% higher (Shen, 2021), which can produce significant energy saving benefits. By virtue of the revolution with disruptive technologies, it is possible to completely remove coal from the heating and cooling consumer market through replacing coal with electricity, ensuring clean power supply, and using electric energy for cooling in summer and heating in winter through air-source and ground-source heat pumps.

In addition, a number of Chinese enterprises have been carrying out research and practice to replace fossil energy raw materials in fiber products with biomass materials, and have achieved fruitful results. The input cost of biomass materials has also been continuously reduced as new technologies have become more widely used, gradually approaching the cost of fossil energy raw materials, making it possible to replace fossil energy as the intermediate goods in production.

3.4. *The social impact of zero-carbon energy revolution*

In 2020, China's dependence on oil imports was as high as 73.5%.[2] China spends up to 2 trillion yuan a year on buying oil from petroleum-exporting countries, and needs to invest diplomatic and defense resources with risks to maritime transportation safety. But such large-scale petroleum imports have limited effects on driving China's economic and employment growth. With the continuous improvement of people's living standards, China's future energy demand will continue to grow, and China's car parc will increase by at least two times. If no replacement is made on the energy consumption side and the current energy production and consumption patterns stay unchanged, i.e. relying on conventional fossil fuels as the energy supply of automobiles, the petroleum security risks will not only remain but increase.

Carbon emissions are generated from the use of fossil energy, and if fossil energy consumption is completely eliminated through disruptive technologies, the related carbon emissions will also disappear. Carbon is not a necessity for economic and social development, so its complete removal will not have a negative impact on social well-being. Disruptive technologies have emerged in the Chinese market and are beginning to be promoted and used. If the energy import funds are invested in the R&D and construction relating to renewable energy sources, it will be possible to promote the continuous improvement and upgrading of the renewable energy industry, and stimulate development at all links of the industry chain to contribute to economic growth; it can also create new jobs at the production, installation, operation, and maintenance level of relevant equipment; it will be able to keep reducing the cost of using renewable energy sources under the combined actions of various factors such as technological progress, economies of scale and market competition, thus saving consumers heavy expenditures on energy consumption. This will gradually eliminate dependence on conventional fossil energy, ensure national energy security, and improve the well-being of consumers.

4. Prevention of Relevant Risks During the Transition Towards Carbon Neutrality

Energy is the "blood" of economic and social operations, and the transition towards carbon neutrality contains huge market opportunities. But the high carbon lock-in situation and

[2] *Source*: Ministry of Commerce of the People's Republic of China, http://www.mofcom.gov.cn/article/tongjiziliao/sjtj/jsc/202105/20210503063494.shtml (accessed May 22, 2023).

high exit costs caused by the excessive dependence of the energy structure on high-carbon fossil energy will hinder the withdrawal of fossil energy and cause potential risks, which are mainly reflected in three aspects: High carbon lock-in risk, market crowding-out risk, and international trade risk.

4.1. *High carbon lock-in risk*

Relevant statistics show that, as of 2021, the total installed capacity of coal-fired power in China reached 1.297 TW, and from January to April 2022, a total of 58 new coal-fired power projects were added in China, with a new installed capacity of 44 GW and a total investment of 130.3653 billion yuan.[3] According to the Guidance, by 2060, the proportion of fossil energy in China should be controlled within 20%. If China will retain 100 GW of coal generator sets by 2060, then at least 1.2 TW of coal-fired power units need to be withdrawn in an orderly manner in the next 38 years. The construction of a megawatt-class coal-fired power unit requires an average investment of more than 5 billion yuan, and the average service life is 50 years. It is estimated that the coal-fired power units currently under construction will need to operate until 2070, and if they are forced to withdraw in 2060, this will cause huge assets being left idle, and a large amount of social capital will be wasted while forming a high carbon lock-in situation.

4.2. *Market crowding-out risk*

As its cost continues to fall, electricity generation from renewable energy has gained strong market competitiveness. In 2021, the NDRC of China clearly announced that it would no longer subsidize centralized PV power generation and onshore wind power projects, and require those projects to achieve grid parity by referring to the local benchmark price for coal-fired power (NDRC, 2021b). At present, the nationwide feed-in tariff of hydropower and PV power generation is close to or even lower than that of coal-fired power. With pollution control and carbon emissions restricting coal mining and coal-fired power projects, coal power prices may show an upward trend in the future. If the cost of zero-carbon electricity is lower than the price of thermal power, and the power supply, grid, load and energy storage can operate smoothly, then coal-fired power will inevitably be crowded out of the market by renewable energy sources.

According to the annual report released by the China National Coal Association, in 2021, the production capacities of the four major industries of modern coal chemical industry — coal-to-liquid, coal/methanol-to-olefins, coal-to-gas, and coal/syngas-to-ethylene glycol industries — reached 9.31 million tons/year, 16.72 million tons/year, 6.125 billion cubic meters/year, and 6.75 million tons/year, respectively (CNCA, 2022), indicating that all the industries except for coal-to-olefins reached new highs in production capacity. However, no matter what low-carbon technologies are applied in the coal chemical industry, its attribute of carbon-emitting will not change. And in practical terms,

[3] *Data source*: Power.IN-EN.com (https://power.in-en.com/html/power-2405418.shtml, accessed August 16, 2022).

with the gradual replacement of pure electric vehicles for fuel vehicles and the continuous rise in petroleum prices since the outbreak of the Russia–Ukraine conflict, petroleum is being gradually crowded out of the market as its competitiveness is weakened. Therefore, coal-to-liquid is unlikely to be competitive in the long term.

4.3. *International trade risk*

Although China's solar PV industry chain accounts for more than 80% of the world's total, and the production capacity and technology of its PV modules, energy storage batteries, and pure electric vehicles have obvious competitive advantages in the international market, China still falls short of a voice in it. Since 2011, the United States has repeatedly initiated trade friction incidents involving China's PV products, and launched anti-dumping investigations on China's solar PV exports. The United States also passed the Uyghur Forced Labor Prevention Act (UFLPA) to restrict the import of PV modules produced by Chinese companies. These incidents may lead to overcapacity in the domestic PV industry. However, due to the rigid constraints of the Paris Agreement on warming limit targets, this risk may turn into a passport for China to expand the international market.

5. The Transformation of Development Paradigm in the Era of Carbon Neutrality

Carbon neutrality is a systemic change to the economy and society, and the new revolution on the energy production and consumption sides has brought underlying changes to the relations of production and mode of distribution in the era of carbon neutrality. Both the rigid carbon neutrality goal and the rigid energy consumption demand by the economy and society indicate that it is necessary to facilitate the fundamental transformation of development paradigm, break through the production relations and production mode of industrial civilization, and accelerate the progress towards carbon neutrality.

5.1. *Revolutionary breakthroughs in production relations*

Under the development paradigm of industrial civilization, scale expansion and capital monopoly are important characteristics of economic growth. The unevenly scattered distribution of fossil energy sources such as petroleum, coal, and natural gas also makes it easy to form a highly concentrated, ultra-large-scale and monopolistic mode of production. Under the system of industrial mass production, the boundary between fossil energy production and consumption is clearly defined, and economies of scale are achieved through centralized production and scale operation.

In contrast, renewable resources are more evenly distributed, and the ownership of solar radiation and wind power as the means of production cannot be monopolized. The property rights structure of PV equipment in Germany shows that as of 2019, most of the country's installed capacity of PV equipment is owned by private individuals and farms, accounting for 48%, while the small and medium-sized industrial and commercial enterprises owning 24.8% of the total PV installed capacity, and the energy suppliers only 6% (BMWi, 2021).

It can be seen that this property rights structure has broken through the development model of industrial civilization, which is in scale, capital-based, and prone to monopoly aggregation, and formed a new development paradigm. The use of renewable energy sources can also produce certain environmental benefits: For example, PV panels can reduce water evaporation from grasslands, improve soil moisture, and facilitate plant growth. The PV power station in the Hainan Prefecture of Qinghai Province was completed and put into operation, and the number of mu[4] per sheep in the grassland under the PV panel was reduced from 15 mu of land to 5 mu of land, which increased herdsmen's grazing income to a certain extent.

5.2. *Underlying changes to the mode of distribution*

The transition towards carbon neutrality is leading to an underlying change in distribution. Differing from the conventional mode of distribution that separates supply from demand in energy production and achieves equilibrium in distribution through the market, the energy production and consumption, supply and demand in the era of carbon neutrality show a trend of integrated development. Taking rooftop distributed solar PV as an example, residents install distributed PV power stations on their own rooftops to form a mode of power self-production and self-consumption, with no need for economies of scale and intermediate links, eliminating the dividing line between supply and demand under economies of scale so as to integrating production and consumption. In this way, the decentralization of ownership breaks the monopoly of large capital in the distribution of revenue.

An automobile factory in Guangzhou City invested about 47 million yuan on rooftop distributed solar PV, and the annual power generation capacity can reach up to 7 GWh after completion, which not only revitalizes the roof resources of the factory, but also transforms the conventional mode of distribution in electricity consumption by power self-production and self-consumption (Guangming Net, 2022). The conventional mode of large-scale economic development contradicts the rigid constraints of natural capacity, resulting in local and decentralized modes of energy production and distribution, bringing disruptive changes to the ownership and income distribution of rooftop and other space resources, and promoting the development and growth of self-sufficient zero-carbon units, thus fundamentally changing the mode of distribution.

5.3. *Fundamental transformation of development paradigm*

The fundamental transformation of the development paradigm is not only the logical result of its ecological development, but also a necessary path of historical development. Carbon neutrality is a well-targeted revolution in energy production and consumption, which can promote a revolutionary breakthrough in the relations of production and bring an underlying change to the distribution relationship in the society. China will face more severe and

[4] mu, Chinese unit of land measurement that is commonly 0.165 acre, or 666.7 square meters.

arduous challenges than developed countries do in achieving carbon neutrality. Therefore, China should not completely copy the experience of developed countries when building its own path towards carbon neutrality, but gradually revise and eventually abandon the scale economic development model of Western industrial civilization on the basis of learning experience from Western countries, promote the innovation and transformation of development paradigm, and finally form a new development paradigm featuring harmonious coexistence between man and nature.

The transformation of development paradigm towards carbon neutrality emphasizes the quality of development and changes the modes of energy production and consumption through a revolution with disruptive technologies, thereby leading to a revolutionary breakthrough in relations of production and an underlying change to distribution relations. Moreover, through institutional changes in soft technologies, the awareness of carbon assets is built into policy making to maintain, extend, and amplify the social utility of carbon assets, changing the high-carbon social development and operation model. Existing infrastructure and house buildings are fixed assets containing a large amount of carbon asset precipitation, which are owned by the whole society. When dealing with these assets, full consideration should be given to social wealth and carbon stocks, and efforts should be made to eliminate large-scale demolition and construction through the social reform of institutional robustness, preserve social carbon assets, and maximize the social utility of carbon stocks, so as to do half the work with double results.

5.4. *The momentum unleashed for zero-carbon transition*

Zero-carbon energy can bring multiple benefits such as promoting growth, creating new jobs, reducing costs, and removing pollution. The market momentum unleashed by the revolution aiming at carbon neutrality is emerging and constantly being amplified. China's fossil energy resource endowment is relatively limited, but China has abundant renewable resources. Unlike fossil energy, which is subject to the moral suppression and market existing risk, the zero-carbon energy market can be expanded without any moral constraints, and the market potential is huge. China's renewable energy industry now occupies a leading position globally in terms of both production capacity and output. From 2005 to 2021, the cost of PV power generation in China dropped from 4 yuan/kWh to less than 0.3 yuan/kWh, a decrease of 92%. The core of the global industry chain for electric vehicles is also taking shape in China. The global installed capacity of an electric vehicle battery reached 296.8 GWh in 2021, in which that of Contemporary Amperex Technology Co., Limited (CATL), a Chinese company, alone reached 96.7 GWh, with a market share of 32.6%, 8% up from the 2020 level.[5]

The continuous development of renewable energy sources can create a large number of new jobs. The PV power generation industry has a long industry chain composed of many links, including the raw materials of crystalline silicon (silicon ore extraction, metallurgical grade silicon, solar grade polysilicon materials) and silicon rods/ingots/wafers in the

[5] *Source*: SNE Research, https://www.sneresearch.com/en (accessed May 22, 2023).

upstream, PV cells and PV modules in the midstream, PV system application products in the downstream, and subsequent installation, use and maintenance, signifying great market potential, and employment-boosting capacity. In order to solve the problem of intermittent instability of wind, solar, and electric power, the energy storage industry has undergone substantial development. China is also deploying pumped storage hydropower plants on a large scale. According to the Medium- and Long-term Development Plan for Pumped Hydro Storage (2021–2035) (hereinafter referred to as "the Plan") issued by the National Energy Administration (NEA, 2021), the total installed capacity of pumped storage hydropower plants in operation in China has reached 32.49 GW, and they are mainly distributed in East China, North China, Central China, and Guangdong Province; the installed capacity under construction is 55.13 GW, about 60% of which are distributed in East China and North China. Both of the figures rank first in the world. The Plan sets the goals that by 2025, the total installed capacity of pumped storage will reach more than 62 GW; by 2030, about 120 GW of installed capacity will be put into operation; by 2035, a modern pumped storage industry featuring advanced technology, high-quality management, and strong international competitiveness will be formed to meet the needs of a high proportion of large-scale development of new energy sources, and a number of leading pumped storage enterprises will be fostered. According to the 14th Five-Year Plan for the Development of New Energy Storage issued by the NDRC and the NEA, the cost of electrochemical energy storage systems will be reduced by more than 30% by 2025, and it will realize the full market-oriented development of new energy storage by 2030 (NDRC and NEA, 2022). The development of technologies such as energy storage equipment and microgrids can compensate for the intermittent instability of wind and solar resources, expand the use of electricity generated from renewable sources, and also further promote market development and employment in related fields.

China's renewable energy industry already has a good foundation for development. It is necessary to seize the development opportunities in the era of carbon neutrality, shift to a safer, more economical, cleaner and fairer development paradigm, amplify the market momentum of the renewable energy industry, promote continued growth of economy and employment while helping to achieve the goal of carbon neutrality, and ensure the balanced and stable development of the society and economy.

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