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Views & Comments

Analysis of a Peaked Carbon Emission Pathway in China Toward Carbon Neutrality

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1. Introduction

Climate change is currently the most significant untraditional challenge to human development. Most countries have reached an agreement to reduce their carbon emissions to address this challenge [1,2]. As the world's second largest economy, largest energy consumer, and largest carbon dioxide emitter, China plays an important and constructive role in global climate governance [3]. Thus far, carbon dioxide emissions (referred to herein as "carbon emissions") have peaked in over 50 countries, including the United States, whose carbon emissions peaked in 2007, and Japan, whose carbon emissions peaked in 2013. Carbon emissions in the European Union (EU), as a whole region, peaked in around 1990; however, the carbon emissions of the EU member states peaked at different times. In addition, over 130 countries and regions have proposed goals for net-zero carbon emissions or carbon neutrality. Some developed countries and regions, such as the United States, EU, and Japan, have announced the goal of reaching carbon neutrality by 2050. Furthermore, six countries including the United Kingdom and Sweden have taken more aggressive steps to move the goal of carbon neutrality into a substantive legislative stage [4].

On 22 September 2020, China officially announced its intention to enhance its Intended Nationally Determined Contributions and establish more effective policies and measures, with the aim of reaching a peak in its carbon emissions by 2030 and carbon neutrality by 2060 [5]. However, unlike the carbon emissions in developed countries and regions, carbon emissions in China are still rising without reaching a peak. Therefore, in this article, we propose and analyze a peaked carbon emission pathway and possible measures in China towards carbon neutrality while fully considering related factors including economic and social development, technical accessibility, and solution feasibility.

2. Understanding the short-term goal of peaked carbon emissions and the long-term goal of carbon neutrality in China

In essence, both peaked carbon emissions and carbon neutrality involve the low-carbon transition of China's entire society. As the short-term goal, achieving a peak in China's carbon emissions by 2030 is the basis and prerequisite for achieving carbon neutrality. Achieving carbon neutrality before 2060 is the long-term goal, which requires more aggressive carbon emission reduction measures after peaked carbon emissions have been achieved. In order to achieve the long-term goal of carbon neutrality, it is necessary to reach the short-term goal of peaked carbon emissions through high-quality economic development that involves gradually reducing the intensity of carbon emissions by optimizing industrial structures and making technological improvements. It should be noted that the phrase "peaked carbon emissions" refers to a situation in which a nation or region moves past its maximum carbon emission levels and thereafter continually reduces its carbon emission levels. There are two ways to achieve a peak in carbon emissions. One way is for a nation or region to try its best to make the peak as low as possible by strictly controlling carbon emissions, while the other way is to allow the peak to reach as high as possible without any control. In China, we will not choose the second way to achieve a peak in our carbon emissions, as it will create serious barriers to achieve carbon neutrality. In order to achieve carbon neutrality, China requires a new, balanced carbon emissions pathway that combines cost efficiency, economic benefits, and social benefits to promote economic and social development while achieving China's second national centenary goal: to "build a modern socialist country that is prosperous, strong, democratic, culturally advanced, and harmonious." Achieving carbon neutrality also requires the realization of a low-carbon transition, which will lead to profound progress for China's economy and society.

In order to achieve peaked carbon emissions and carbon neutrality, it is necessary to explicitly and clearly understand the context of these two national goals. First, these two national goals will drive China's low-carbon transition and promote sustainable development with low-carbon innovation, which will help China shift from an industrial civilization to an ecological civilization. Second, they will lead to improvements in China's industrial structure, which can effectively control the impetus to develop an energy-intensive industry. Meanwhile, this shift will result in the development of new strategic emerging, high-tech, and modern service industries, bringing massive green finance investment, new economic growth points, and new employment opportunities for China. Third, these two national goals are milestones of the energy revolution, which involves the dramatic improvement of energy conservation and efficiency. The vigorous development of

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non-fossil fuels will decrease our reliance on fossil-fuel-based energy and help to build a new-generation power system dominated by non-fossil energy sources. Fourth, in order to achieve these two goals, a renewed understanding of China's energy resource endowment is needed. At present, the exploited renewable energy in China has not reached 10% of the potential technical capacity. In the future, renewable energy can provide a solid energy-resource foundation for the low-carbon energy transition. Fifth, these two national goals not only illustrate the principle of common but differentiated responsibilities for global climate governance and development, but also demonstrate China's positive attitude toward addressing climate change as a responsible major country. Sixth, in order to achieve these goals, China need to overcome multiple difficulties including a heavy industrial structure, coal-based energy, low energy efficiency, and dependence on a high-carbon development pathway; thus, these goals will be helpful for identifying gaps, improving development weaknesses, and following China's new development philosophy. Seventh, achieving these two goals requires not only complex and systematic engineering, but also a scientific transition, the pace of which will need to be managed via positive and steady implementation. It will be necessary to avoid simplifying the problem, and backwardness and ineffective investment should be prevented. Finally, achieving these goals will require full recognition of the function of carbon removal and utilization technologies, including carbon sinks and carbon capture, utilization, and storage (CCUS). It will be necessary to develop and utilize the potential capacity of carbon sinks. In particular, CCUS should be positively developed in the industries that are most difficult to decarbonize, such as the cement industry.

3. Carbon emission trends and peak predictions in China

In 2020, the primary energy consumption in China was 4.98 billion tonnes of carbon equivalent (Btce) and the total carbon emission was around 10 billion tonnes (Bt), as shown in Fig. 1. From 1980 to 2020, China's energy consumption and carbon emissions can be divided into three phases:

(1) The "gentle slope phase" (1980–2001), in which energy consumption and carbon emissions grew slowly, with annual growths of around 45 million tonnes of carbon equivalent (tce) and 98 million tonnes, respectively;

(2) The "steep slope phase" (2002–2013), in which both energy consumption and carbon emissions increased rapidly, with annual growths reaching 218 million tce and 477 million tonnes, respectively;

(3) The "slow growth phase" (2014–2020), in which the annual growth of energy consumption fell to 116 million tce, while the annual growth of carbon emissions decreased to 94 million tonnes.

The forthcoming decade is a crucial stage in realizing overall modernization in China, and rigid pressure toward carbon emission growth will be brought by multiple developing factors, including industrialization, urbanization, and informatization. As shown in Fig. 2, based on sector accounting results, direct carbon emissions from the energy and industry sectors in China are expected to peak in the middle or late period of 2026–2030 as positive carbon emission reduction measures are taken. The peaked carbon emission value is predicted to be 500 million–700 million tonnes larger than the annual carbon emissions in 2020. Carbon emissions will then remain stable for 3–4 years during the "platform" stage of peaking. It should be noted that different industries and sectors may not reach a peak in carbon emissions at the same time.

To ensure that China will reach a peak in its carbon emissions by 2030, it is necessary to promote the sequential peaking of emissions in different industries and sectors by 2030. The industry sector as a whole will achieve peaked carbon emissions by 2025, after which its carbon emissions will decrease steadily. The electricity, petrochemical, and construction industries will achieve peaked carbon emissions around 2030. It should be pointed out that 2021–2025 will be a key period for controlling the growth of energy consumption and promoting the low-carbon transition, considering that the rigid demand for the electricity industry, petrochemical industry, and transport sector will remain extremely high in the future. Thus, achieving peaked carbon

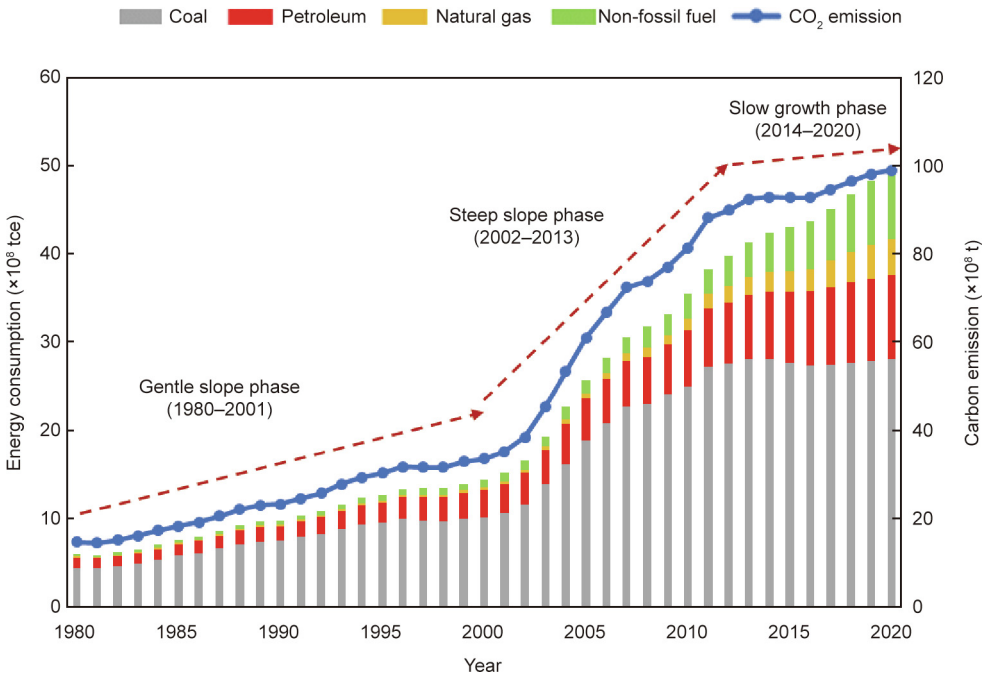

Fig. 1. Energy consumption and carbon emission trends in 1980–2020 in China. tce: tonnes of carbon equivalent.

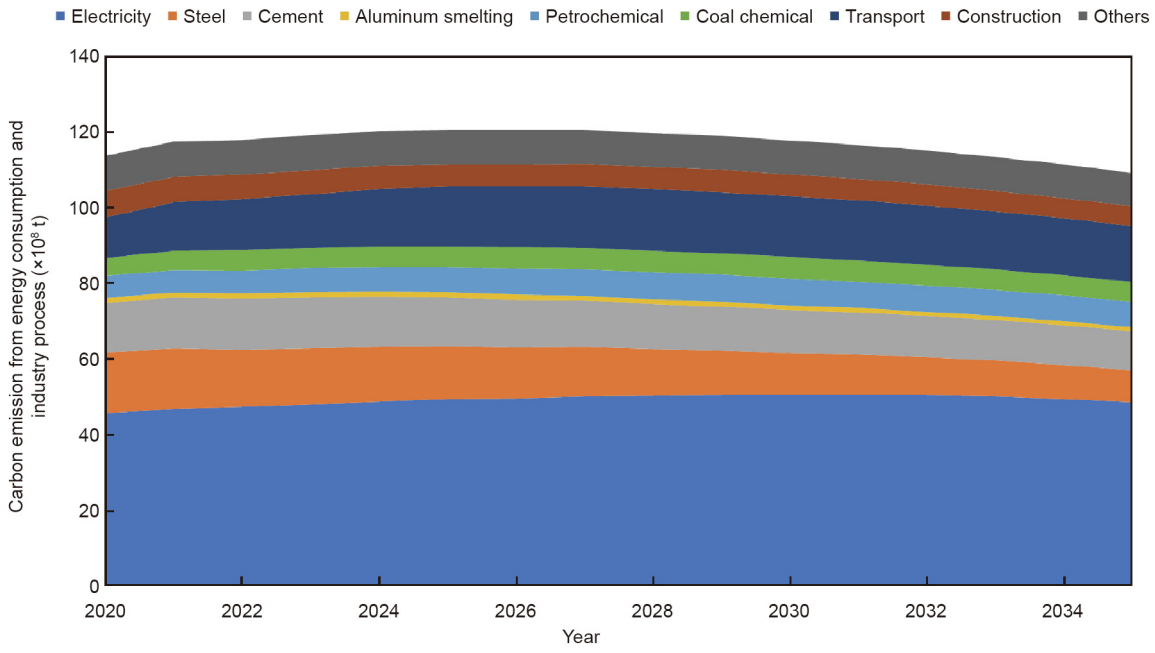

Fig. 2. Predicted carbon emissions from several key industries and sectors in terms of energy consumption and industrial processes in China.

emissions in these industries and sectors will determine China's carbon emission trends prior to 2030.

4. Pathway and measures of peaked carbon emissions toward carbon neutrality

In 2020, it was estimated that the electricity, steel, cement, nonferrous metals, petrochemical, coal chemical, transport, and construction industries and sectors accounted for 90% of total carbon emissions. Therefore, these eight areas are identified as the key industries and sectors for reducing carbon emissions and applying different pathways and strategies for achieving peaked carbon emissions. The following subsections outline these pathways and strategies in detail.

4.1. Building a high-efficiency, low-carbon, and circular industrial system with energy conservation and reduced energy consumption

In 2020, carbon emissions from the industry sector were around 3.7 Btce; they are expected to reach a peak during 2035 through positive efforts. To fulfill this goal, the industrial sector should focus on building a high-efficiency, low-carbon, and circular industrial system. Detailed measures include:

(1) **Strictly controlling the disorderly expansion of energy-intensive and highly polluting projects.** In principle, new domestic coal-fired power plants should be forbidden, except for coal-fired thermal plants. Meanwhile, traditional coal-based chemical and oil refining industries should be included in the search to replace older technologies with newer low-carbon technologies that have equal capacities. In addition, the government will firmly phase out low efficiency capacity and control the proportion of energy-intensive and low-value-added products being exported. Furthermore, new coal-based chemical projects will not be approved unless they are already included in the national plan.

(2) **Powerfully promoting energy conservation and reducing energy consumption in the industry sector.** The energy consumption per unit allowance standards of important industries such as the steel, cement, aluminum electrolysis, petrochemical, chemical, and coal-based chemical industries should be strictly controlled such that the energy efficiency of China's main industrial products can reach advanced world levels by 2025.

(3) **Accelerating the establishment of a low-carbon and circular industrial system.** The construction of material recycling systems should be comprehensively reinforced. Scrap steel recycling should be increased, and the in-house reuse of scrap aluminum should be promoted. Improvements are also needed in the integrated utilization of solid waste—such as household waste, carbide slag, and thermal coal—in combination with their alternative proportions in raw material and fuel.

4.2. Strictly controlling fossil-fuel-based energy consumption and promoting an energy-structure transition

Carbon emissions mainly originate from the consumption of energy based on fossil fuels such as coal, petroleum, and natural gas. In 2020, China consumed around 4 Bt of coal in total. To achieve peaked carbon emissions, China's coal consumption should be the first type of fossil-fuel-based energy consumption to be reduced; it should not increase during 2021–2025, be restrained to no more than 4 Bt of coal in 2025, and decrease to less than 3.8 Bt during 2026–2030. China should strive to achieve a peak in petroleum consumption during 2026–2030, with a peak value of around 0.73 Bt. A peak in natural gas consumption should be achieved during 2035–2040, with a peak value of around 650 billion cubic meters. Detailed measures include:

(1) **Accelerating the low-carbon energy-structure transition.** The non-fossil-fuel energy consumption ratio should account for more than 26% of total energy consumption by 2030.

(2) **Insisting on restriction of total coal consumption in key air-pollution-prevention areas.** Local governments are responsible for controlling local coal use. The coal consumption of the Beijing–Tianjin–Hebei region and the Yangtze River Delta region should decrease by more than 10%, while the coal consumption of the Fenwei Plain should achieve negative growth.

(3) **Insisting on the substitution of clean energy for coal in terminal consumption.** The scope of clean energy heating will be expanded in northern China to reach up to 80% by 2025 and to be close to 100% in 2030. Meanwhile, the replacement of coal-

fired industrial furnaces with gas or electric furnaces will be encouraged.

(4) **Transitioning key coal-consuming industries toward achieving peaked carbon emissions and carbon neutrality.** During 2021–2025, a reduction of coal consumption by the steel, nonferrous, and coal-based chemical industries should be promoted.

4.3. Building a new electrical power system pattern and accelerating the transformation of the power-source structure

As electricity is the industry that generates the most carbon emissions, accelerating the low-carbon transition under a safe supply of electricity is the most important factor in achieving carbon neutrality by 2060. Energy growth will mainly originate from electricity demand from the residential sector and the information and communications technology (ICT) sector in the next decade. It is estimated that carbon emissions from the electricity industry, including combined heat and power (CHP), will peak before 2030, if given sufficient efforts. Coal-fired power plant projects must be strictly restricted, and growth in coal consumption should also be controlled to a limited amount. During 2026–2030, coal consumption should gradually be reduced, with the coal power generation ratio decreasing to 42%. Great efforts should be made to build a power network based on renewable energy. Detailed measures include:

(1) **Using wind and solar power to meet the growth in power demand.** China will exploit wind and solar energy faster in order to consistently raise the capacity of renewable energy generation, with a total installed wind and solar power capacity of more than 1600 GW by 2030.

(2) **Building a new power system and enhancing the regulation ability to achieve a balanced electrical system.** Flexible reformation will be applied to promote the generation unit of existing coal-fired power plants, and full use will be made of their existing regulation abilities. Novel energy-storage techniques and large-scale applications should be promoted. Local power grids and micro-grids should also be encouraged in order to enhance the local consumption of renewable energy. Finally, China will establish a national unified electricity market and strengthen its low-carbon power-dispatching mechanism in order to accommodate the rapid development of renewable energy.

4.4. Building a low-carbon and high-efficiency transportation system and promoting greater electrification of the transportation system

In the transport sector, vehicles generate more than 80% of carbon emissions, making them a key factor in reaching a peak in carbon emissions and achieving carbon neutrality. Direct carbon emissions from railway transport have already decreased, carbon emissions from waterway transport are predicted to remain stable during 2026–2030, and carbon emissions from highway transport are expected to slowly increase, with the goal of reaching a peak in carbon emissions during 2026–2030. Carbon emissions from the aviation industry are expected to keep rising. In general, it is estimated that the transport sector as a whole will reach peaked carbon emissions around 2028. Detailed measures include:

(1) **Promoting vehicle energy efficiency and renewing vehicle energy consumption access standards.** China should implement transport vehicle standards to speed up the process of updating vehicles with high energy consumption levels so that they consume less energy.

(2) **Accelerating energy substitution with clean fuel.** In 2030, the sale ratios of new energy passenger and commercial vehicles fueled by renewables are projected to increase to more than 40% and 10%, respectively, and all government-level official vehicles should be updated to new vehicles fueled by renewables. Both a timeline and a roadmap for stopping sales of fossil-fuel-based vehicles will be released in due course. The electrification levels of ship and railway transport will be enhanced, and the onshore power utilization rate of ports will be increased.

(3) **Optimizing transportation structures.** Medium-distance and long-distance bulk cargo transportation will transition from road transport to railway or waterway transport. It is also necessary to promote the transport capacity and service level of the railway and to build port collection and distribution systems for passengers and freight in ports dominated by green transportation. Multi-modal transport and green urban freight transport also need to be developed to a greater extent.

(4) **Building a consistent green commuter system and optimizing public transportation.** More public transportation will be provided to citizens. The construction progress of the rail transport network for urban agglomeration also needs to be accelerated. In addition, local governments will strengthen non-motor vehicle systems, including urban pedestrian and bicycle systems. The green commuter rate should be higher than 70% by 2025 and should reach 75% by 2030.

(5) **Promoting the integrated development of transportation and clean energy.** Research facilities will focus on the potential of renewable energy and evaluating the energy self-sufficiency of transportation infrastructure and energy-generating buildings. Projects focusing on prosumers in transportation infrastructure and energy-generating buildings will also be carried out.

4.5. Optimizing the energy consumption of buildings and promoting photovoltaic, energy-storage, direct current, and flexible building development

In 2020, direct carbon emissions from the building sector were around 0.7 Bt and exhibited a slow declining trend. To achieve carbon neutrality in the building sector before 2030, it is necessary to speed up the low-carbon transition of building electricity and heating while reducing indirect carbon emissions. Detailed measures include:

(1) **Promoting energy-conserving and low-carbon development for buildings, including a transformation toward building electrification, motivated by standards.** China should revise the standards and specifications for buildings' electromechanical systems, with strict requirements for new buildings to be energy conserving and electrified (i.e., to use electricity for all internal purposes, including heating and cooking). In northern areas that require additional heating, existing buildings should be renovated to include energy-conserving facilities, while urban heating pipe networks should be renovated to include energy-conserving and safe facilities.

(2) **Optimizing the energy consumption structure of buildings through multiple measures.** Both urban and rural areas should realize low-carbon heating. Northern towns must update central heating systems using zero-carbon heating sources, including nuclear power and industrial waste heat. In rural areas, bulk coal should be replaced by renewable energy, electricity, and biomass energy, according to local circumstances. By 2025, the clean heating ratio in northern China should be around 80%.

(3) **Accelerating the development of photovoltaic, energy-storage, direct current, and flexible (PEDF) buildings to transform buildings from consumers to prosumers in the low-carbon energy system.** General specifications for energy conservation and renewable energy utilization in the building sector should be proposed and published, and it should be made an essential requirement to have surface photovoltaic installations, which are key for green buildings. In urban areas, new and existing buildings should utilize a novel PEDF power distribution system, with large-scale renewable energy, including solar and wind power, being accommodated effectively through flexible power consumption. In rural areas, new energy systems should be developed based on solar energy.

4.6. Developing a green, low-carbon, and circular economy and strengthening the high-efficiency utilization of solid waste

Developing a circular economy and improving the level of solid waste classification and resource utilization are crucial pathways for achieving peaked carbon emissions and carbon neutrality. Detailed measures include:

(1) **Reducing landfills and achieving a higher waste utilization rate.** For example, food waste can be dealt with using an anaerobic digestion process, which can reduce carbon emissions from landfills while recycling the greenhouse gas methane.

(2) **Strengthening renewable resource utilization in solid waste.** For example, coal consumption by and carbon emissions from the steel industry can decrease significantly by transitioning from the long process, which uses raw materials like ironstone and raw coal, to the short process, which uses steel scrap.

(3) **Enhancing the utilization of new solid waste in energy transformation and solving the problem of renewable energy's dependence on related key mineral resources.** Manufacturing renewable power devices, including wind power generators and solar panels, requires massive amounts of mineral resources. Enhancing the resource utilization level after the retirement of renewable power devices can provide a long-term and stable material supply for the development of renewable energy.

5. Summary

Achieving peaked carbon emissions and carbon neutrality are China's national goals, based on the nation's current situation and new awareness of human civilization. Reaching these goals will require an extensive and profound systemic reform for the economy and society. Such a reform must be closely aligned with sustainable development and community building in China, based on the concept of a shared future for humanity. To achieve these two goals, we must have a correct understanding and clear judgement of their context and what they entail. It is also necessary to precisely research and predict China's future carbon emission trends, enhance top-level design, and propose a realization pathway and roadmap toward peaked carbon emissions and carbon neutrality. In this way, China will achieve beneficial outcomes for the economy, energy, environment, and climate in the future.

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