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Views & Comments

A Deeper Understanding of the CO_2 Emission Pathway Under China's Carbon Emission Peak and Carbon Neutrality Goals

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Achieving carbon neutrality is crucial in dealing with climate change and containing the increase in global temperature at below 1.5 °C compared with preindustrial levels. During the general debate at the 75th session of the United Nations General Assembly in September 2020, President Xi Jinping announced that China would adopt more vigorous policies and measures against climate change. This announcement was a major strategic decision made after careful consideration, and the aim that was announced is closely related to not only the sustainable development of China but also the future of our planet. Research on optimizing the national and regional carbon emission pathways under China's long-term climate goals is fundamental for the nation to achieve a CO_2 emission peak and carbon neutrality. Furthermore, the results of such research could provide critical support in guiding local governments to fulfill ambitious climate goals.

Considerable effort has been made thus far to investigate CO_2 emission pathways. Notably, the Intergovernmental Panel on Climate Change (IPCC) proposed the shared socioeconomic pathways (IPCC-SSPs) by taking global warming, emission characteristics, and socioeconomic development into consideration [1,2]. The International Energy Agency (IEA) used the World Energy Model to investigate global energy and emission pathways under different socioeconomic and technological assumptions [3]. Similarly, the European Union (EU) adopted the FORecasting Energy Consumption Analysis and Simulation Tool (FORECAST) model to explore emission pathways driven by socioeconomic and technological factors [4][†]. These proposed CO_2 emission pathways are characterized by top–down and macroscale methods, and are therefore suitable for designing long-term national and regional strategies. Other studies have also utilized various models (e.g., the stochastic impacts by regression on population, affluence, and technology (STIRPAT) model, the logarithmic mean divisia index (LMDI) decomposition model, etc.) to investigate the impact of the energy structure and the industrial structure on CO_2 emissions, explore the driving forces, and predict future emission trends [5,6]. Despite these efforts, the findings are insufficient to support China's specific CO_2 emission pathway under the nation's carbon peak and carbon neutrality goals.

In this article, we focus on the optimization of China's CO_2 emission pathway. As the world's largest CO_2 emitter, China aims to accomplish ambitious carbon emission peak and carbon neutrality goals, as articulated in the new Nationally Determined Contribution (NDC) targets. Thus, China faces more stringent emission-reduction requirements than developed countries such as the United States and countries from the EU. Establishing a clear and reasonable national and regional emission pathway under the constraint of China's future climate goals can effectively promote the achievement of a national and regional emission peak in the optimal way and prevent some regions from pursuing high-carbon lock-ins.

To optimize China's CO_2 emission pathway, it is necessary to fully consider China's current industrial structure, coal-based energy structure, and road-based transportation structure, as well as the research, development, and application of new technologies, in order to better plan future emission levels and emission characteristics in different development stages. China's CO_2 emission pathway is also crucial in supporting high-quality socioeconomic development in the long run. This pathway will contribute to the transformation and upgrading of the current industrial structure, the formation of a clean and low-carbon energy structure, the optimization of a green transportation structure, and the coordinated control of greenhouse gases and air pollutants. Moreover, based on the concept of regional coordination, research on China's CO_2 emission pathway must consider the similarities and differences between regions in terms of economic development level and mode, resource endowment, industrial and energy structures, and so forth.

To support the national and regional strategies, it is necessary to address the optimization of China's CO_2 emission pathway from four aspects.

Key point 1: Focusing on China's specific CO_2 emission pathway under the climate goals. The first aspect of optimization should investigate China's specialized CO_2 emission pathway, which puts both the CO_2 emission peak and the carbon neutrality goal into the same research framework. Current research on CO_2

[†] https://www.forecast-model.eu/forecast-en/index.php.

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emission pathways generally investigates carbon neutrality in developed countries, with only a few studies analyzing China's emission pathway to achieve a carbon peak; moreover, research specifically targeting China's long-term emission pathway is limited [3,4,7,8]. The IPCC-SSPs have been widely used in IPCC reports and international negotiations [1,2]. However, they lack feedback from a varied range of nations, regions, and emission sectors. A regional coordination and optimization methodology is also missing in the existing literature; thus, the current research is insufficient to support national or lower level pathways for China. Furthermore, the current research conducted by the IEA and the EU is mainly on the macro level, so it is unsuitable for formulating refined environmental management strategies [3,4]. Therefore, there is an urgent need to investigate the optimization of coordinated pathways for national and regional emissions under China's carbon neutrality vision, which will support China's need for refined environmental management.

Key point 2: Assessing the interrelated relationship among industries. The second aspect of optimization must assess the interrelated relationship among industries. When developing China's CO_2 emission pathway, it is necessary to consider the workflow among different industries and build a dynamic and interactive connection between industries. Future pathways are expected to predict the development of key industries based on socioeconomic demand, the technical characteristics of industries, and changes in imports and exports both at home and abroad. Thus, an integrated model framework, such as the model for energy supply systems and their general environmental impact (MESSAGE), is needed to establish the coupling relationship within and among industries, analyze the supply and demand relationship between the upstream and downstream of the industrial chain, and build a workflow among industries. In this way, future development scenarios can be put forward for different industries.

In addition, it is essential to identify the energy structure and industrial structure transformation mechanisms under China's carbon neutrality vision. Future research is suggested to simulate the driving forces of major climate policies. For the energy structure transformation, future research should focus on prioritizing the development of non-fossil-fuel energy in a way that will ensure energy safety. Fossil-fuel energy—especially coal-based energy—is key in building a safe energy system. It is necessary to reduce coal use by means of fuel substitution and by promoting the clean and efficient development of coal-fired power plants. In parallel, non-fossil-fuel energy is vital in achieving China's carbon neutrality goal, given the major contribution of the energy sector to total CO_2 emissions. The rate of non-fossil energy use could be increased by promoting the development of safe nuclear power, green hydropower, wind and solar power, and other renewable energy sources according to natural resource endowment. The power system also needs to be reconfigured to match the high share of non-fossil-fuel energy. For the industrial structure transformation, future research can investigate the mechanism of a green and low-carbon transition in economic development. The industrial structure requires improvement, especially in carbon-intensive industries, and measures that include promoting low-carbon technologies and adjusting the production structure can be taken. As the technology develops, hydrogen fuel will play an important and irreplaceable role in the chemical and metallurgical industries. In addition, carbon capture, utilization, and storage technologies should be applied to help mitigate unavoidable emissions.

Key point 3: Coupling macro and micro approaches. The third aspect of optimization must consider building a model that couples both bottom–up (based on the spatial evolution theory) and top–down (based on a macro analysis of the economy, energy, and emissions) approaches to develop effective emission pathways. Most of China's CO_2 emission pathways are investigated from either a top–down or bottom–up perspective, and few studies systematically integrate both. For example, the Chinese Academy of Environmental Planning Carbon Pathways 1.2 (CAEP-CP 1.2) model couples both top–down and bottom–up approaches, thereby providing detailed analyses of the CO_2 emission pathway and offering insights into implementing management at multiple levels [9]. A top–down macro analysis is insufficient to verify predicted emissions at the micro level, nor can it be effectively fed back into the spatial or temporal emission inventory, making it difficult to support fine management and regulation at the micro level. A bottom–up approach is conducive to a deeper understanding of the internal evolution of emission patterns, as well as the impact of the spatial layout of key industries on national and regional carbon neutrality pathways. However, such research results need to be integrated with macro constraints. Otherwise, there will be significant outliers in time and space.

Future research is required to systematically couple bottom–up and top–down approaches, consider macro constraints and micro feasibility, and carry out the optimization of emission pathways while considering emission-reduction costs, social justice, and the matching of carbon sources and carbon sinks, so as to establish optimized CO_2 emission pathways.

Key point 4: Incorporating regional characteristics and differences. The fourth aspect of optimization should incorporate regional characteristics into China's CO_2 emission pathways and consider their influence on the optimization process. The energy structure, industrial structure, and resource endowment of different regions in China are highly heterogeneous, making it difficult to directly apply the national-level emission pathway to individual regions. Future research should investigate China's national and regional emission pathways with full consideration of regional characteristics (e.g., economic development levels, natural resource endowment, and industrial and energy structure). Furthermore, it is necessary to investigate coordinated regional development under the constraint of China's carbon neutrality goal. Principles—such as the grandfather principle, convergence principle, and emission-reduction efficiency principle—can be considered when developing coordinated regional emission pathways that account for the rationale behind the current emission pattern, the unified per capita emission target, and differentiated abilities and responsibilities in reducing CO_2 emissions based on income (typically regional gross domestic product (GDP) values) in the optimization process. A transfer payment system could also be adjusted and utilized to favor low-carbon development and help achieve regional coordination. In this way, research results can directly support the top-level design of the national emission pathway, guide different regions in China toward industrial and energy-related transformation, and help regions to recognize their regional development orientations.

In summary, previous studies have made efforts to investigate CO_2 emission pathways. However, research on China's carbon peak and carbon neutrality pathway is still in its initial stage, and further investigation is warranted. This article suggests that future research should focus on the interrelated relationship among industries and consider the internal workflow rather than focusing on a certain industry alone. Ignoring such interrelated relationships will greatly affect the validity of the results. In addition, it is necessary for CO_2 emission pathways to couple top–down and bottom–up approaches under optimal emission-reduction costs and social fairness, accounting for both macro constraints and micro feasibility. Moreover, it is necessary to incorporate regional characteristics, including energy structure, industrial structure, and resource endowment, in the optimization of China's CO_2 emission pathways. We believe that our deep understanding of China's CO_2 emission pathways can help to improve future research. In addition, we expect that optimizing China's CO_2 emission pathways will provide direct support and guidance for both national and local governments in designing strategies and eventually achieving the goals of a CO_2 emission peak and carbon neutrality.

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