Global Carbon Neutral Pathways and China's Strategies under Paris Agreement Climate Goals

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Abstract. The 2 degrees temperature target or even 1.5 degrees temperature target set by the Paris Agreement has driven global climate change commitments and programs. This study simulates the specific pathway to global carbon neutrality under the 2 degrees temperature control target. The strategies for achieving carbon neutrality and temperature control goals in China are constructed by combining the emissions of different sectors in China. The key pathways to achieve carbon neutrality are to improve energy efficiency and electrification. In addition, the energy mix should be adjusted to reduce or even eliminate coal-based fossil fuels and increase the use of renewable energy. Efforts should also be made to increase carbon sinks and energy storage, and to control costs. At the same time, policies and laws will play a role in promoting the achievement of carbon neutrality. Ultimately, climate change mitigation and reduction of greenhouse gas emissions on a global scale can be achieved.

Keywords: Paris Agreement; Carbon Neutrality; China.

1. Introduction

In order to control a range of problems such as global warming due to CO_2 emissions, 171 countries signed the Paris Agreement on April 22, 2016, World Earth Day, at the United Nations headquarters, and the main climate goal of the Paris Agreement is to keep the increase in global average temperature well below 2 degrees above pre-industrial levels and to work to limit the increase to 1.5 degrees above pre-industrial levels [1]. To achieve this goal, countries have submitted nationally owned contributions to describe post-2020 climate action. The Paris agreement is a significant human effort to mitigate climate change and there is a growing consensus among policy makers that climate change mitigation is beneficial to society, yet challenges remain on the way to achieving the 2100 warming target [2][3]. Rogelj, J., et al. (2016) projected temperature increases under different scenarios and discussed reducing GHG emissions to a level that gives people a more reasonable chance to achieve climate goals well below 2 degrees [2]. Riahi, K., et al. (2021) use a multi-model comparison to find that an accelerated shift to net-zero CO_2 emissions is needed in the near term under strict temperature rise control goals. Earlier action is probable to be cost effective on long time scales and reveals sectoral and regional differences in the scenarios [3].

However, there are uncertainties and risks associated with achieving climate goals, which also depend on the magnitude of the costs. Using a meta-model, van Vuuren, et al. (2020) find that mitigation costs tend to increase as emission limits and temperature goals become more stringent. Uncertainty in mitigation costs is driven in large part by uncertainty in the "economic" system rather than the natural system [4]. Rueda, O., et al. (2021) argue that large-scale negative emission technologies (NETs), which remove carbon dioxide, the main greenhouse gas, from the atmosphere, can play a significant role in achieving temperature control goals. However, the application of negative emission technologies and their impacts still require a broader and comprehensive assessment [5]. Semieniuk, G., et al. (2021) argue that although significant efficiency gains to reduce energy demand are feasible, achieving the desired absolute decoupling of economy and energy and successful industrial development remains an unresolved policy challenge [6]. In addition, scenario simulations to analyze the achievement of climate change goals under scenarios with different levels of constraint provide support for the feasibility of temperature control goals [7][8].

The global climate governance process has accelerated after the epidemic, and countries around the world, including China, have proposed carbon neutral or net zero emission commitments, injecting great momentum to achieve the Paris Agreement goals globally China has committed to

achieve carbon peaking by 2030 and carbon neutrality by 2060. Studies on China quantitatively assess the impact on global surface temperature under the emission pathways behind China's emission reduction commitments, as well as quantify the effectiveness of climate commitments and analyze temperature changes and emissions under different scenarios and pathways [9]. He, J., et al. (2022) simulated carbon neutral pathways in China under different scenarios [10]. Zhang, S., and Chen, W. (2022) assessed the pressure of emission reduction behavior and the benefits and welfare of emission reduction under different carbon peaking time scenarios [11].

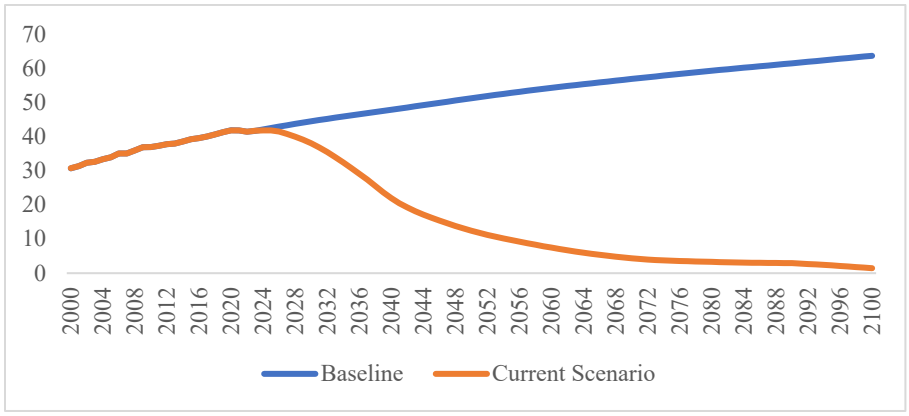
In summary, we can learn that most developed countries have already reached the peak of carbon emissions, so carbon peaking research is concentrated on developing countries. Carbon neutral studies are mostly conducted for developed countries and developing countries that have already committed. Setting long-term climate change response commitments is beneficial for achieving the global 2 degrees (or even 1.5 degrees) target. Energy efficiency improvements and energy mix transformation play an important role in achieving carbon neutrality goals. Technology-driven carbon neutrality pathways, while beneficial for achieving net-zero emissions goals, have uncertain abatement costs. China's carbon neutrality commitment has significant implications for global climate change. China's carbon neutral pathway should strengthen the improvement of energy supply and consumption structure, electrify end-use sectors, and promote technology-driven pathways. Therefore, this study focuses on global and Chinese carbon neutrality pathways and strategies under the Paris Agreement's temperature control goals.

2. Carbon Neutral Pathways under the Global 2 Degrees Climate Goal

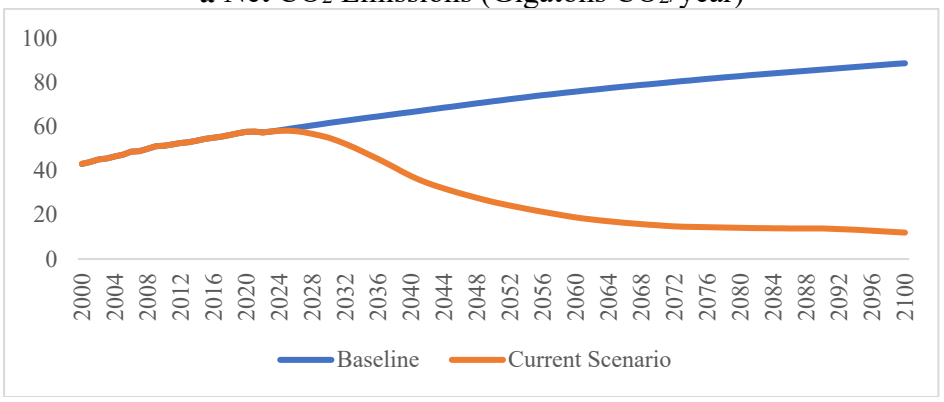
This study is based on En-Roads (https://en-roads.climateinteractive. org/scenario. html?v= 22. 11. 0&p1=33&p196=100&p202=2090&p197=2040&p7=9&p10=0.5&p16=-0.02&p18= 2070 & p19= 20&p20=2040&p39=45&p40=2025&p42=80&p43=2040&p264=0&p266=1&p47=3.8&p50=3.9& p51=2025&p53=81&p258=7&p55=83&p57=-6.7&p59=-42&p209=1&p60=-50&p61=-60& p62 = 2030&p235=1.8&p65=48&p67=24), which simulates and analyzes the pathways to global carbon neutrality under a 2degrees climate target. Specifically: Improving energy efficiency in the transport, buildings and industry sectors. High incentives for electrification in the transportation, buildings and industrial sectors. High taxes on coal, higher carbon prices, and subsidies for renewable energy sources in a bid to eliminate coal power. Restrict the use of fuel energy sources such as natural gas and oil. High reduction of deforestation and strict prevention of forest destruction. Moderate reduction of methane and other gases in the agricultural and industrial sectors.

Under such a carbon neutral pathway, it can be found (Fig.1a,b) that there is a sharp reduction in net CO_2 emissions and net GHG emissions from 2030 to 2060, and then remain at very low levels after 2060 (net CO_2 emissions even converge to zero indefinitely). This is mainly due to a radical restructuring and paradigm shift in the energy mix and paradigm in the simulation through carbon pricing and subsidized renewables, as well as a high taxation system on coal, and the transformation of electrification terminals to make the transportation factor, energy factor, electricity and heat generation factors have a more significant positive impact on GHG emissions reduction including CO_2.

In addition, as CO_2 emission removal increases, it reaches a peak removal level around 2040 and then gradually converges to a stable level. This suggests that the carbon neutral pathway simulated in this study will be enhanced by increased subsidies for renewable energy, innovations in carbon removal technologies, and a strong reduction in deforestation. Other restrictions on the use of coal and other fuels, as well as improvements in energy efficiency, have also led to a decrease in carbon emissions.



a Net CO_2 Emissions (Gigatons CO_2/year)



b Greenhouse Gas Net Emissions (Gigatons CO_2 equivalent/year)

Fig 1. Net emissions

Note: data source: https://en-roads. climateinteractive. org/scenario. html?v= 22.11.0&p1 =33 &p196 =100&p202=2090&p197=2040&p7=9&p10=0.5&p16=-0.02&p18 =2070& p19= 20& p20= 2040& p39= 45&p40= 2025&p42 =80&p43= 2040&p264 =0&p266= 1&p47=3.8& p50 =3.9 &p51 =2025& p53=81&p258=7&p55=83&p57=-6.7&p59=-42&p209=1&p60=-50&p61=-60& p62 = 2030& p235= 1.8&p65=48&p67=24

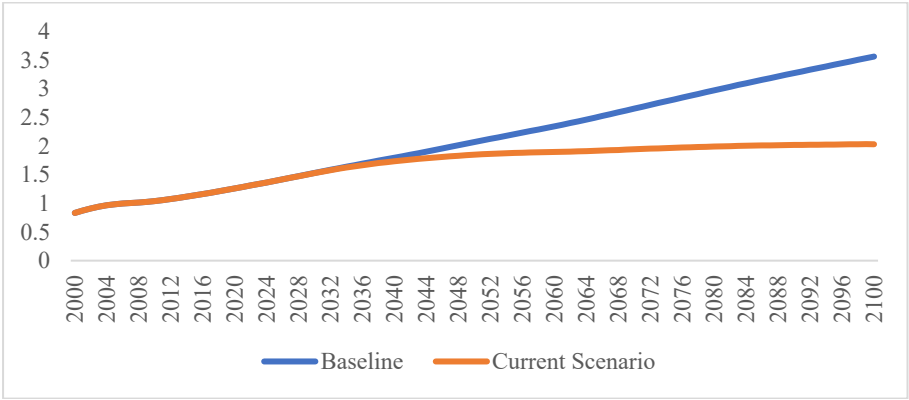


Fig 2. Temperature change

Note: data source: https://en-roads.climateinteractive. org/scenario.html? v=22.11.0&p1 =33& p196 =100&p202=2090&p197=2040&p7=9&p10=0.5&p16=-0.02&p18= 2070&p19= 20&p20= 2040& p39=45&p40 =2025&p42 =80&p43 =2040 &p264 =0&p266= 1&p47= 3.8&p50 =3.9&p51 =2025& p53=81&p258=7&p55=83&p57=-6.7&p59=-42&p209=1&p60=-50&p61=-60&p62= 2030 &p 235= 1.8&p65=48&p67=24

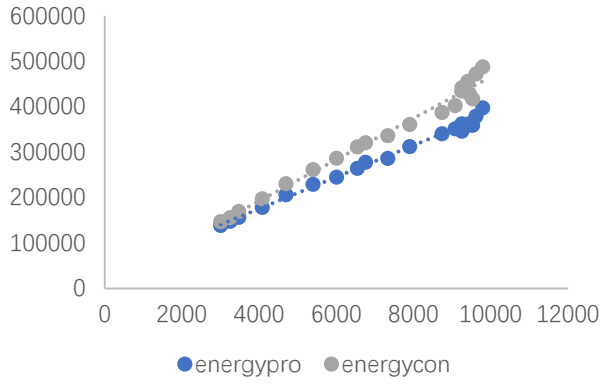
Since energy costs include all costs of all electricity and non-electric sources, the production costs of energy start to increase around 2023 and even reach an increased maximum near 2038, followed by a gradual decrease, under the projections of high taxes on coal, higher carbon prices and subsidies

for renewables. The energy mix has been transformed and improved because the technology has stabilized. The cost to the state and companies for this has gradually decreased. As the demand for renewable energy and energy storage grows, the costs rise. Energy sources such as wind and solar are intermittent and not available every day, thus sometimes requiring energy storage technologies. The increase in the cost of energy storage1 is caused by the fact that the cost of mitigating climate change largely affects the process and determination of global carbon neutrality, as reducing the cost of emission reductions within reasonable limits is a necessary factor in achieving the 2 degrees, or even 1.5 degrees, temperature control goal.

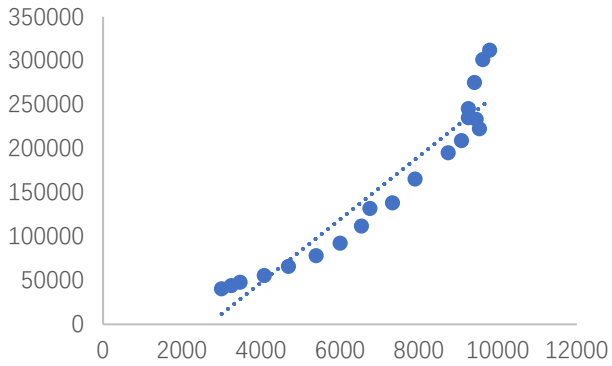
In the simulation projections of this study, global climate change succeeds in achieving the 2 degrees temperature control target, with temperatures approaching 2 degrees indefinitely after 2080, but rising temperatures are controlled after 2040, and the increase becomes flat, much less than the large uncontrolled temperature increase (Fig. 2).

3. China's Carbon Neutral Commitment and Strategic Forecast

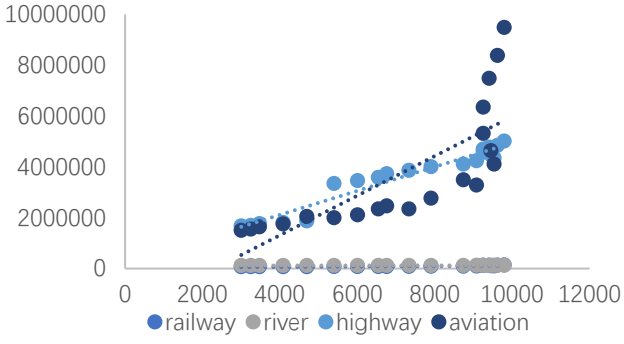
China and the United States together account for more than 40% of global emissions, followed by India, the Russian Federation and Japan. Over the last two decades, China's per capita emissions have almost tripled to reach values similar to those of the European Union (EU) in the early 2010s [12]. Therefore, without more aggressive initiatives in carbon reduction in China, there is still a large gap between China and the achievement of the global carbon neutrality target. Based on the simulation scheme of the global carbon neutral pathway, this study analyzes the correlation between carbon emissions and production or consumption data of different sectors in China based on their emissions (data sources: *China Statistical Yearbook*, *China Energy Statistical Yearbook*, *China Environmental Statistics Yearbook*, etc.) In this way, we will develop pathways and strategies to achieve China's carbon neutrality and temperature control goals.



(a)



(b)



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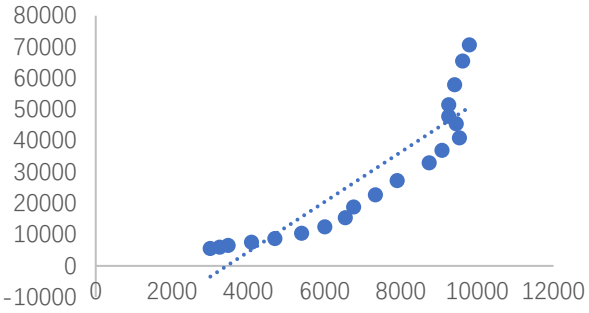

(d)

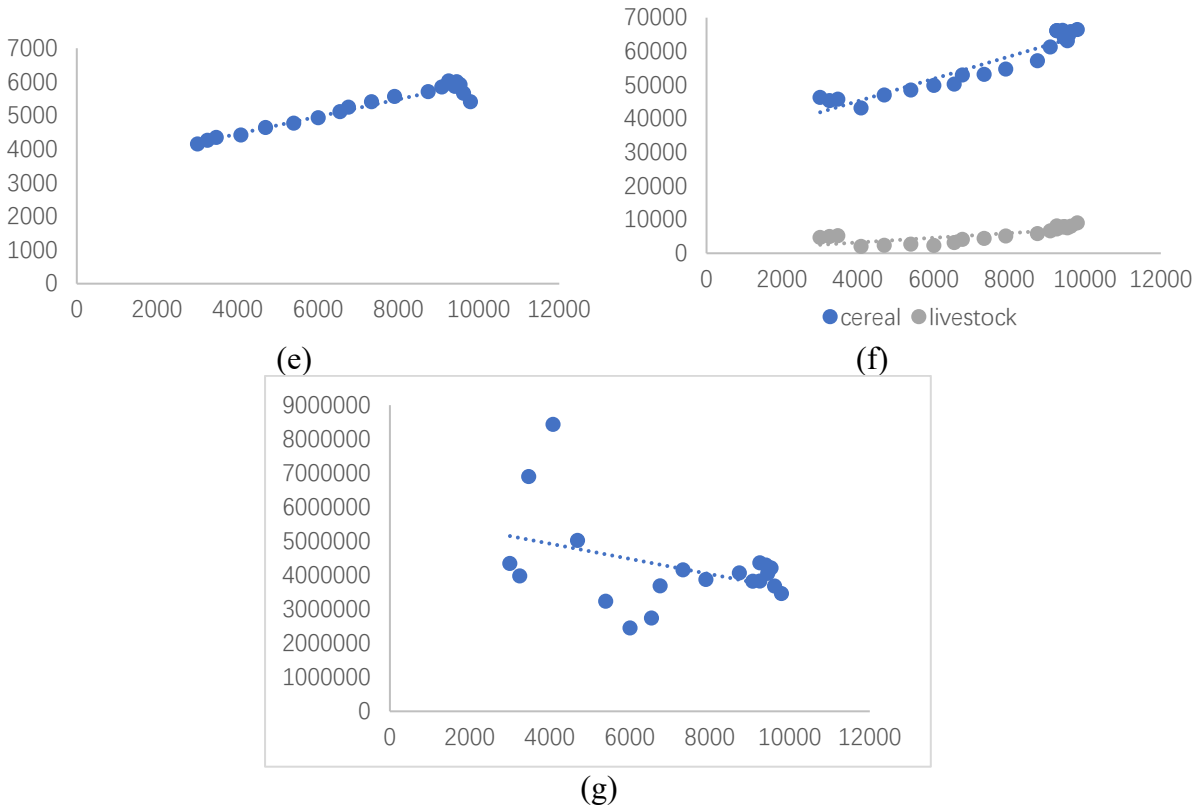

Fig 3. Relationship between production or consumption in different sectors and CO_2 in China

3.1 Energy Sector

China has abundant coal resources and high utilization rate, with the largest production and import scale in the world. The problem with the use of coal is that it is "low efficiency and high emission". Other fossil fuels, such as natural gas, emit less CO_2 than coal, but produce methane. From 2000 to 2019, China's energy consumption and energy production show a significant positive relationship with carbon emissions (Fig. 3a). It indicates that the path to reduce fossil fuel use, control energy production and consumption, and improve the energy production and consumption structure is important to achieve the carbon neutrality goal. In this regard, in order to reduce the burning of fossil fuels such as coal, oil, and natural gas, China should promote the "de-coalization" of coal and other industries and strengthen the replacement of coal by clean energy in the process of achieving the carbon neutrality target. In addition, after the national carbon trading market launched in 2017, the market mechanism should play a role in regulating high-emission industries, and for new energy sources, because the development of new zero-carbon energy sources and nuclear energy worldwide is costly, difficult to develop technology, and risky. Although China has certain achievements in nuclear power generation, the large amount of radioactive waste caused by nuclear power generation is difficult and dangerous to handle. The development of new zero-carbon energy sources requires the search for technological breakthrough points, which is costly and difficult for countries to cooperate and coordinate. Therefore, it is recommended that China's carbon neutrality goal should be achieved by not laying out a path for the development of new zero-carbon energy and nuclear energy, but by developing and utilizing renewable energy, and that China should take advantage of its renewable energy projects and its superior natural environmental resources. The deployment of renewable energy projects should be expanded and their quality improved. The gradual increase in wind power generation in Inner Mongolia, China has reduced carbon emissions significantly [13].

3.2 Industrial Sector

A range of greenhouse gases are released from the burning of fuels in industrial production and manufacturing processes. From 2000-2019, China's industrial GDP shows a significant positive

relationship with carbon emissions (Fig. 3b). The industrial sector is the focus of achieving carbon neutrality, and it needs to innovate policies and technologies to regulate the consumption and production side to reduce carbon emissions and apply emission reduction technologies. Among the industrial sectors, steel is the largest carbon emitter, and the steel industry is an energy-intensive and high carbon emitting industry. China, as the world's largest producer and consumer of steel, should strengthen the rate of capacity phase-out. However, more efforts are still needed to achieve the goal of 2 degrees, or even 1.5 degrees temperature control, and to accomplish the goal of carbon neutrality by 2060. With the support and promotion of various policies, we should strengthen the "thermal" decarbonization of industrial production processes and innovate industrial processes.

3.3 Transportation Sector

Air, road, and rail transportation use fossil fuels, which are the main contributors to greenhouse gas emissions. At the same time, economic development, urbanization expansion, and continued expansion of China's automobile market have increased GHG emissions from the transportation sector. As the overall consumption level increases, the demand for travel and car purchase increases, and the pressure for carbon neutrality in the transportation sector is high. From 2000-2019, China shows a significant positive relationship between various transportation and carbon emissions (Fig. 3c). Economic growth and rising consumption levels have led to an increase in the volume of public and private transportation trips. The focus of the transportation sector is on the automotive sector, with electrification of the automotive industry being a top priority. Achieving carbon neutrality goals and near-zero emissions requires integrated planning and green transformation throughout the entire industry chain from vehicle production to consumption. In addition, the use of new energy vehicles will increase the supply pressure of the electric power industry, which should also replace fossil fuels with renewable energy in order to achieve a fundamental reduction in total carbon emissions. Electrification of long-distance transportation such as aviation and railroads are difficult to achieve and costly to upgrade technology, and the supply of clean energy with high energy storage to the transportation sector should be enhanced. At the same time, joint venture cooperation between China and foreign companies allows foreign companies to gain access to the Chinese market on the one hand, and China can benefit from technology and knowledge transfer on the other.

3.4 Construction Sector

Carbon emissions from the building sector are associated with increasing urban size. From 2000-2019, China's construction sector shows a significant positive relationship with carbon emissions (Fig. 3d). The building sector needs to achieve a low-carbon transition and sustainable development from the upstream input and use of building materials to the downstream construction and building use. Therefore, energy-saving transformation of buildings, greening of building materials use, low carbonization, and carbon neutral realization in the construction process should be carried out to facilitate carbon reduction in the building sector. For the design of heating in the building sector, electrification of heating systems should be promoted to reduce the dependence on fossil fuels. In addition, innovative use of renewable energy sources, such as solar energy, enhances the use of solar energy. The heavy use of domestic fuels also affects the decarbonization of the building sector, for example, the use of large amounts of fossil fuel-based energy as a source of cooking and heating in rural areas, and the use of cooking appliances generates large amounts of greenhouse gas emissions, which is not conducive to carbon neutrality in the building sector. Therefore, it is also important to focus on the construction of power grids in rural areas and to restructure the consumption of domestic energy.

3.5 Agricultural Sector

The achievement of China's carbon neutrality commitment should focus on the achievement of carbon neutrality in rural areas, in addition to reducing urban carbon emissions. Fertilizer use in agriculture increases nitrous oxide emissions, and animal husbandry, including animal feeding

processes, also generates significant GHG emissions. Factor inputs and production in China's agricultural sector show a significant positive relationship with carbon emissions during 2000-2019 (Fig. 3e, f). The agricultural sector needs to combine livestock manure recycling, etc., to build rural biogas digester construction and waste separation, to realize rural biogas digesters through anaerobic engineering technology, to turn livestock manure into treasure, and to strengthen straw composting, etc., which can promote the development of recycling, low-carbon agriculture. In addition, to improve the utilization rate of chemical fertilizers, promote fertilizer industry innovation, and popularize organic fertilizers are also necessary initiatives. Increase the use of organic fertilizers and reduce the use of high-emission fertilizers such as nitrogen fertilizers. The greenhouse gases produced by livestock industry mainly come from the use of feed, lighting, and feeding for breeding, etc. The low carbonization of livestock industry should be enhanced by electrifying the production process and improving the supply efficiency.

3.6 Land Use Sector

Land use change and forestry activities play an important role in mitigating climate change. During 2000-2019, the amount of plantation forestry in China showed a significant negative relationship with carbon emissions (Fig. 3g). This also indicates that afforestation projects play an important role in carbon emission reduction and removal, providing support for achieving net zero emissions. There is a need to continue to promote the implementation of afforestation projects, strengthen the management of existing forestry and newly planted forestry, combine with new carbon neutral lifestyles, and inject personal power. China has largely prevented deforestation and afforestation on a large scale. Forests are an important carbon sink resource, and expanding afforestation areas, through government-supported projects and people's spontaneous afforestation, allows forest carbon sinks to play an important role.

4. Carbon Neutral Analysis for the 2022 Winter Olympics

The 2022 Beijing Olympic Winter Games is a good example of China's efforts to achieve carbon neutrality, with the 2022 Olympic Winter Games focusing on four carbon neutral pathways. The first is to transmit renewable energy from Zhangjiakou to Beijing through the "Zhangbei Flexible DC Grid Pilot Demonstration Project", as Zhangjiakou is rich in wind and solar power resources and is only 200-360 km away from the Beijing Winter Olympic Games, so it can provide clean energy to meet the electricity demand of the Winter Olympic venues. And the Winter Olympic Games organizers to create cross-regional green power trading platform, during the Winter Olympic Games competition, all venues are using green power. Secondly, all venues of the Beijing Winter Olympics will meet the three-star green building standard through energy-saving renovation, etc. The ice surfaces of the ice venues of the 2022 Winter Olympics will use environmentally friendly refrigeration systems and refrigerants. The National Speed Skating Stadium, Capital Gymnasium, Shouti Short Track Speed Skating Training Center and Wukesong Ice Operation Center of the Beijing Winter Olympic Games use carbon dioxide refrigerants, reducing a total of 900 tons of carbon emissions [14]. Thirdly, most of the vehicles to be used for security during the Beijing Winter Olympic Games are energy-efficient and clean energy vehicles. Beijing Automotive Group has 212 hydrogen-fueled buses and 330 electric vehicles to serve the Winter Olympics [15]. The "Transportation Resource Management System" established during the Winter Olympic Games provides a more efficient way to mobilize vehicles and deploy transportation support work. Fourth, the million-mu afforestation and greening project and the construction project of ecological water source protection forest in Beijing and Hebei provide sufficient carbon sinks for the Winter Olympic Games. Three companies, including China National Petroleum Corporation, State Grid and Three Gorges Group, donated certified carbon emission reductions (CCERs). Carbon sinks and carbon emission reductions are used for carbon elimination to help achieve carbon neutrality for the Beijing Winter Olympics.

5. Conclusion

This study simulates the global carbon neutrality pathway under the 2 degrees temperature control target of the Paris Agreement, and identifies specific options to control climate warming, and thus predicts and develops strategies for China's carbon neutrality and temperature control goals. Energy efficiency improvement and electrification are the two most important pathways to be considered to achieve the temperature control target, and are also the key factors. Controlling or even eliminating coal-based fossil fuels and improving the energy mix will help reduce greenhouse gas emissions. At the same time, a thorough transformation and restructuring of the energy mix is needed in conjunction with the transportation sector, the building sector and the agricultural sector. It is also necessary to focus on the increase of carbon sinks, i.e., to reduce deforestation and increase the area of afforestation. Develop policy solutions that combine administrative instruments with market mechanisms, and play the role of policies such as carbon trading. Ultimately, it will be possible to achieve global temperature control goals and China's carbon neutral commitments.

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