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China's provincial low carbon transition and interprovincial electricity transmission under the carbon neutrality goals

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ABSTRACT

To analysis China's provincial low carbon transition under the carbon neutrality goals, this study developed a provincial energy-environment-economy model (China TIMES-30PE). Under carbon neutrality target, each province has a different pathway for achieving carbon neutrality and requires deep decarbonization of their energy systems, with a dominant share of non-fossil energy sources, increasing electrification rates, growing hydrogen consumption and significantly reducing energy intensity. The mismatch between wind and solar resources and electricity demand has resulted in an increasing transmission volume across provinces. Power transmission from the northwest and southwest regions continues to grow, while some central provinces have transitioned from net electricity suppliers to net users. The eastern provinces continue to receive increasing long-distance power transmission and rely on ultra-high voltage transmission lines as backbone channels.

Keywords: carbon neutrality; provinces; energy system; electricity transmission

1. INTRODUCTION

As a responsible country, China has identified carbon peak and carbon neutrality as important work goals. Recent policies have moved the policy targets from controlling energy consumption and intensity to controlling total carbon emissions and intensity [1]. Specific dual control policy targets have not yet been clearly specified in the "14th Five-Year Plan" for each province. It is necessary to make scientific planning when formulating emission reduction targets and policies for each province, given the obvious differences in social and economic development levels and resource endowments among the provinces. Simulation of emission pathways and energy transition for each province under the carbon neutrality target could be an important reference for national policy making. China's government has proposed to build a new energy system and accelerate the energy transition. The "14th Five-Year Plan" and action plans for carbon peak and neutrality of each province pay close attention to the development planning of key energy technologies such as wind and solar power generation, energy storage, and BECCS. In addition, with the development of renewable energy, the mismatch between renewable resources and the distribution of population and economy will become increasingly prominent. Analysis of the inter-provincial power transmission pattern and construction of transmission facilities under the carbon neutrality target is urgent and necessary.

Table. 1 multi-regional energy-environment-economy models in China

Model Name	Model Horizon	regions
AIM-China[2]	2030	provincial
C-REM[3]	2030	provincial
China TIMES-30P[4]	2050	provincial
MESEIC[5]	2050	6-regions
REACH[6]	2030	provincial
REPO[7, 8]	2050	provincial

The existing multi-regional energy-environment-economy models [2-8] in China cover periods up to 2030 or 2050, which cannot meet the research needs of our country's 2060 carbon neutrality goal. Furthermore, there is a lack of detailed characterization of many deep decarbonization technologies under the policy goals of peak carbon emissions and carbon neutrality. Therefore, it is both necessary and feasible to construct a multi-sector, provincial-level energy-environment-economy model that covers the entire period of China's carbon neutrality policy.

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2. MATERIAL AND METHODS

2.1 China TIMES-30PE model

The International Energy Agency Energy Technology Systems Analysis Program (IEA-ETSAP) developed and maintains the TIMES model, which combines the MARKet ALlocation (MARKAL) model and the energy flow optimization model (EFOM).The previous China TIMES-30P model was developed based on the China TIMES and China MARKAL models [9-12]. The 30-province model encompasses energy supply, conversion, transmission, and end-use technologies with a 2015-2060 modeling horizon and a 5-year reporting period. The flow of various energy carriers in the optimal technology mix is described. Historical data calibration is based on statistics, reports, and official announcements. Compared to the previous version of the China TIMES-30PE model [13], this study's model incorporates updated parameters for renewable energy and CCS technologies, including their cost, efficiency, and potential, as well as deep emission reduction technologies like hydrogen energy substitution to adapt to carbon neutrality scenarios. This study also developed the renewable energy layout analysis module based on the GIS-AHP method [14] with the consideration of the distribution of renewable energy resources, land resources, infrastructure, and geographical conditions at the 0.05° grid level.

3. ASSUMPTIONS AND SCENARIOS

Based on the current policies and national carbon peak target, this study has designed the CP30 scenario to simulate China's achievement of the national carbon peak target by 2030, including the provincial carbon reduction targets in the "14th Five-Year Plan" and other policy documents such as targets for non-fossil fuel energy ratio, renewable power capacity, and energy storage capacity. Additionally, this study has designed the CN60 and CN50 scenarios by adding national carbon emission constraints to simulate the carbon neutrality pathways for each province when China reaches its carbon neutrality goal. The China TIMES-30PE model is used to simulate the mitigation pathways of each province, with the aim of minimizing nationwide mitigation costs. To reach carbon neutrality, China's carbon emissions will peak at 10.5 billion tons in 2030 and reach zero in 2060. To achieve greenhouse gas neutrality, the energy system will achieve neutrality by 2050[15]. This study has selected carbon emission pathways that consider energy system carbon neutrality and greenhouse gas neutrality as the upper limits of national emissions for the CN60 and CN50 scenarios, respectively.

4. RESULTS

4.1 Carbon emission pathway under carbon neutrality scenarios

In 2020, China's carbon emissions amounted to approximately 9.9 billion tons. As shown in Fig.1, under the CP30 scenario, China is projected to achieve carbon peak by 2030 with a peak emission of 10.5 billion tons but will not achieve carbon neutrality by 2060. In CP30 scenario, China's carbon intensity in 2030 is expected to decrease by 65.3% compared to 2005. Under the CN60 and CN50 scenarios, national carbon emission is projected to peak around 10.3 billion tons between 2025 and 2030, with a decrease of 2% in peak emissions and an earlier peak compared to the CP30 scenario. In the CN60 scenario, China's carbon emissions will reach carbon neutrality by 2060, with emissions reaching 2.6 billion tons in 2050, representing a reduction of over 70% compared to the CP30 scenario and imposing strict constraints on the transformation of the energy system. In the CN50 scenario, national carbon emissions will achieve neutrality by 2050 and even become negative by 2060.

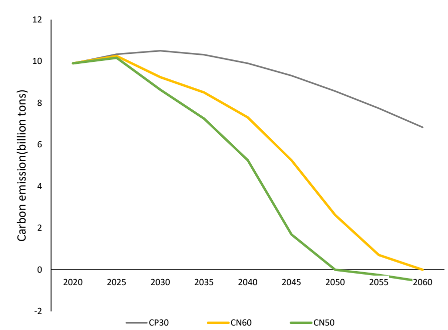

Fig. 1 China's carbon emission under different scenarios

4.2 Energy system transition under carbon neutrality scenarios

Under the carbon neutrality scenarios, the proportion of coal consumption in the energy structure rapidly decreases, while non-fossil fuels such as nuclear power, hydropower, wind power and photovoltaics rapidly increase (Fig.2). By 2060, the proportion of coal in primary energy consumption in each province will have significantly decreased, with the remaining coal consumption mainly used in industry and coal-fired power plants equipped with carbon capture and storage systems. In contrast, the proportion of non-fossil fuels in primary energy consumption in each province will have significantly increased by 2060. Provinces such as Gansu, Inner Mongolia, and Yunnan, which have abundant renewable energy resources, have a higher proportion of non-fossil fuels in their primary energy consumption as compared to other provinces.

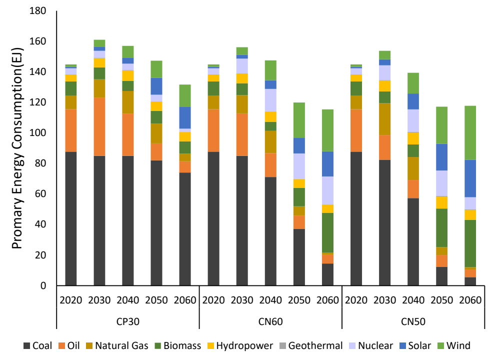

Fig. 2 China's primary energy consumption

Under the carbon neutrality scenarios, the electrification rate of end-use sectors continues to increase, while coal consumption continues to decrease (Fig.3). The electrification level of each province under the carbon neutrality scenario has greatly improved compared to 2020. The eastern regions have higher electrification levels, while the western regions have a slower increase in electrification. By 2060, Guangdong, Shandong, Zhejiang, and Jiangsu have the highest electrification rates in end-use sectors with values reaching 74%, 73%, 75%, and 73%, respectively, under the CN50 scenario. In comparison, electrification rates of Ningxia, Inner Mongolia, Guizhou, and Guangxi reach 53%, 58%, 44%, and 63%, respectively, under the CN50 scenario. Developed provinces have seen a rapid decline in the proportion of coal consumption in end-use sectors, with Beijing, Zhejiang, Jiangsu, and Guangdong all having coal consumption proportions below 10% under the carbon neutrality scenarios. However, underdeveloped provinces still have a certain proportion of coal consumption, with Ningxia, Qinghai, and Shanxi having coal consumption proportions above 10% under the carbon neutrality scenarios.

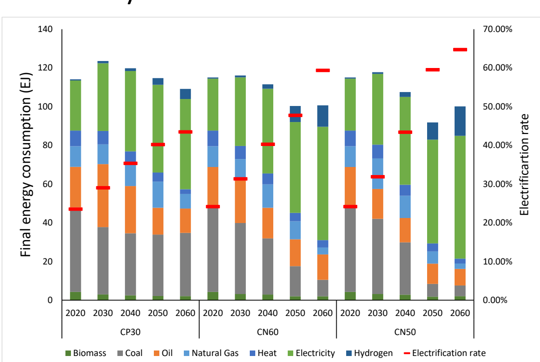

Fig. 3 China's final energy consumption and electrification rate

4.3 *Interprovincial electricity transmission*

Under the target of carbon neutrality, the interprovincial electricity transmission and transmission capacity continue to increase (Fig.4). By 2060, under the carbon neutrality scenarios, the inter-provincial power transmission will increase to 6747 TWh ~ 7057 TWh, accounting for 36% ~ 39% of the total power generation. As the proportion of renewable energy increases, the distance from the load center in the east to the renewable energy bases in the western provinces increases, leading to an increasing proportion of inter-regional power transmission in the interprovincial power transmission. Under the carbon neutrality target, the interprovincial electricity transmission capacity will increase rapidly. The strengthened emissions constraints on eastern provinces will drive the construction of interprovincial transmission lines.

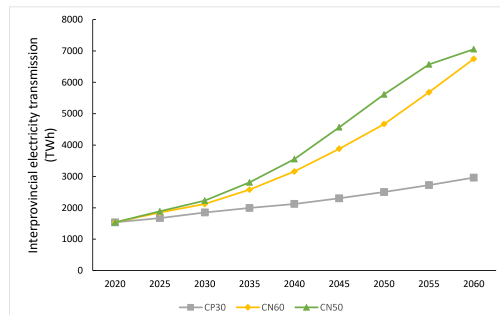

Fig. 4 Interprovincial electricity transmission under different scenarios

As the renewable energy in the northwest provinces grows, the long-distance, inter-regional electricity transmission will continue to increase. Under the carbon neutrality scenarios, the pattern of interprovincial electricity transmission will shift: the exports of electricity from the northwest provinces and Inner Mongolia, Sichuan, and Yunnan will continue to increase, and cover more target provinces; the export provinces in the Northeast will shift from Liaoning to Heilongjiang; central provinces such as Hubei will shift from electricity exports to electricity imports; the load centers such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and Guangdong will continue to receive more long-distance electricity transmission.

With the advantages of long transmission distance, high transmission capacity, and low transmission losses, ultra-high voltage transmission technology plays an important role in interprovincial electricity transmission (Fig.5). As the power sector undergoes a deep decarbonization process, the development of ultra-high voltage transmission lines will continue. By 2060, the proportion of ultra-high voltage transmission capacity in inter-provincial power transmission will further increase. The primary long-distance transmission channels rely on ultra-high voltage transmission lines as the backbone, including Inner Mongolia to Shandong, Beijing, and Tianjin; Xinjiang to Henan, Jiangsu, Anhui, and Zhejiang; Ningxia to Hubei; Qinghai to Jiangsu and Henan; Gansu to Jiangsu, Zhejiang, and Hunan; Sichuan to Shanghai; Yunnan to Guangdong.

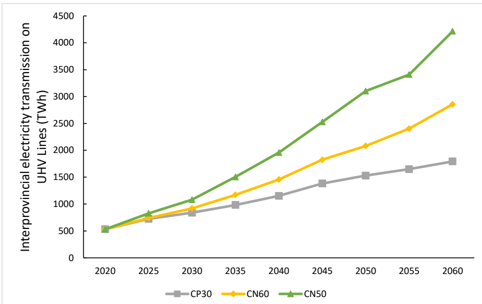

Fig. 5 Interprovincial electricity transmission on UHV lines

4.4 Deployment of wind and solar power plants

In this paper, Qinghai Province is used as an example to show the deployment of renewable energy (Fig.6). By 2060, the Haixi Prefecture renewable energy base will be primarily located in Golmud, Delingha, and the southern Haixi region. Under the CN60 scenario, the installed capacity of wind and solar power in Haixi Prefecture renewable energy bases will exceed 165GW, with over 137GW being distributed in the Golmud area. In Hainan Prefecture, wind and solar power plants will be mainly concentrated in the northern and central Hainan region, particularly in the Gonghe City, with a total installed capacity exceeding 42GW. Under the CN60 scenario, Qinghai Province will transmit electricity to the Yangtze River Delta region and Henan, reaching an estimated capacity of 143TWh and 35TWh respectively in 2060. In CN60 scenario, Haixi Prefecture renewable energy base will export electricity through the Qinghai to central and eastern region UHV line which in the recent policies. Similarly, Hainan Prefecture renewable energy base will export electricity to Henan through the Qinghai-Henan UHV line.

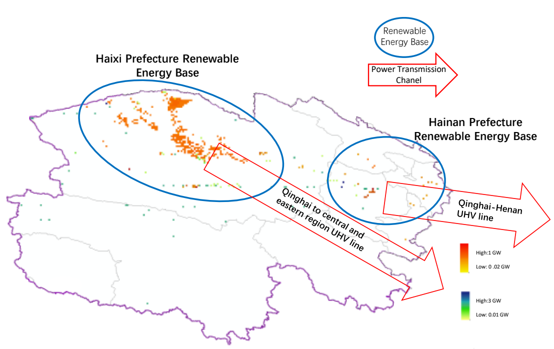

Fig. 6 Deployment of wind and solar power plants in Qinghai Province

5. DISCUSSION AND CONCUSIONS

Under the carbon neutrality scenarios, the carbon intensity reduction rate during the 14th and 15th "Five-Year Plans" will further increase compared to the 13th Five-Year Plan. The carbon emissions and carbon emission intensity of each province will greatly decrease. Under the carbon neutrality scenario, the energy supply structure of each province will undergo a profound transformation from coal-driven to renewable energy-driven, with non-fossil fuels accounting for over 90% by 2060. The capacity of power plants in each province will continue to increase, with renewable energy becoming the primary source of power generation. Deep decarbonization of end-use sectors will rely on fuel substitution.

Provincial governments should consider carbon neutrality goals when formulating current emissions reduction policies and plans. They should balance development with controlling pre-peak carbon emissions to reduce the pressure of emissions reduction from 2030 to 2060 and ensure the carbon neutrality goals. The rapid growth of carbon emissions before reaching peak levels will pose greater challenges to provinces to reduce emissions between the peak and carbon neutrality targets. Provincial governments should actively explore low-carbon economic growth opportunities, ensuring high-quality development. Efforts should be made to control emissions levels before reaching peak levels and reduce the pressure of emissions reduction from peak to carbon neutrality targets.

Interprovincial electricity transmission will play an important role in resource allocation among provinces under the carbon neutrality target. While planning the development of renewable energy, the plan for related infrastructure such as transmission lines, energy storage systems and hydrogen production should be considered, to enhance the ability of resource allocation among provinces.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

REFERENCE

[1] Xi J. Hold High the Great Banner of Socialism with Chinese Characteristics and Strive in Unity to Build a Modern Socialist Country in All Respects. 2022.

[2] Wang H, Zhu Y, Jang C, Lin CJ, Wang SX, Fu JS, et al. Design and demonstration of a next-generation air quality attainment assessment system for PM2.5 and O-3. J Environ Sci. 2015;29:178-88.

[3] Da Z. Development and Application of China's Provincial Energy-Economy Model, C-REM: Tsinghua University; 2014.

[4] Li N, Chen W, Zhang Q. Development of China TIMES-30P model and its application to model China's provincial low carbon transformation. Energy Economics. 2020;92.

[5] Zhang Y, Ma T, Guo F. A multi-regional energy transport and structure model for China’s electricity system. Energy. 2018;161:907-19.

[6] Xu Z. Development and Application of China's Regional Comprehensive Assessment Model, REACH. Beijing: Tsinghua University; 2015.

[7] Xiong W. Development and Application of China's Renewable Energy Power Planning and Operation Model. Beijing: Tsinghua University; 2015.

[8] Yang Y, Zhang H, Xiong W, Zhang D, Zhang X. Regional power system modeling for evaluating renewable energy development and CO2 emissions reduction in China. Environmental Impact Assessment Review. 2018;73:142-51.

[9] Chen W. The costs of mitigating carbon emissions in China: findings from China MARKAL-MACRO modeling. Energy Policy. 2005;33:885-96.

[10] Chen W, Wu Z, He J, Gao P, Xu S. Carbon emission control strategies for China: A comparative study with partial and general equilibrium versions of the China MARKAL model. Energy. 2007;32:59-72.

[11] Chen W, Li H, Wu Z. Western China energy development and west to east energy transfer: Application of the Western China Sustainable Energy Development Model. Energy Policy. 2010;38:7106-20.

[12] Chen W, Yin X, Ma D. A bottom-up analysis of China’s iron and steel industrial energy consumption and CO2 emissions. Applied Energy. 2014;136:1174-83.

[13] Zhang Q, Chen W. Modeling China’s interprovincial electricity transmission under low carbon transition. Applied Energy. 2020;279.

[14] Uyan M. GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey. RENEWABLE & SUSTAINABLE ENERGY REVIEWS. 2014;28:11-7.

[15] Yang LP, Xunzhang; Chen,Wenying. Evaluating the equity of carbon neutrality targets - A study based on carbon allowance allocation models(in Chinese). Advances in Climate Change Research. 2022;34:1-7.