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Regional Forecast of China's Carbon Emission Peak in 2030 and Analysis of Influencing Factors

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Abstract: In this article, we firstly analyzed the historical development trends, regional economies, population, urbanization and carbon emissions of the four major regions which are the East, the Middle, the North-east and the West, respectively. Then we compared China's environmental Kuznets curve both in home and abroad, found that the relationship between economic development and pollution emissions varies from regions and countries. We used the IPAT model to design 48 peak CO₂ emission scenarios in order to get to more comprehensive depict of future development path of China's carbon emissions. Furthermore, we used a centralized DEA to evaluate the allocative efficiency of scenario-based CO₂ emission paths. As a consequence, we found that maintaining relatively high GDP growth (around 6%), reducing energy intensity by about 75% of average annual decline rate(around 4%); and increasing non-fossil energy to 21% to meet the Innovation plan of energy technology revolution 2016-2030 requirements is the most efficient low-carbon behaviors towards 2030 peak CO₂

emissions of 10.57Gt. We also found that China can potentially reduce CO₂ emission intensity (CEI) by up to 72.7% compared to the 2005 level in 2030, and therefore that official CEI reduction targets (60-65%) are well within reach. It is also found that in the future path of the predicted optimal scenario, only economic scale and low carbon per unit output value have a great contribution to the changes in carbon dioxide emissions.

Keywords: CO₂ emissions peak; Scenario analysis; DEA; Four regions of China; Generalized division index method

50

51 **Introduction**

52 **Global carbon emissions continue to grow rapidly**

53 According to the International Monetary Fund World Economic
54 Outlook (2019), world carbon dioxide emissions rose further in 2017
55 after a decade or so of steady growth, with global carbon emissions
56 increasing by 1% in 2017 and continuing to increase in 2018. With the
57 increase of atmospheric carbon dioxide concentration, the global threat of
58 the greenhouse effect has increased further, a trend that has put the world
59 on a dangerous path. Therefore, curbing greenhouse gas emissions is
60 important to control global temperature rise and prevent catastrophic
61 climate events, and the greenhouse effect should be the sword of
62 Damocles for global sustainability.

63 **China is a big carbon emitter**

64 According to Global Carbon Atlas (2019), China has become the
65 world's largest emitter of greenhouse gas emissions for 13 consecutive
66 years since it overstepped the United States in 2006. In 2018, China's
67 carbon dioxide emissions have reached 100.65 billion tons, accounting
68 for 26.95% of the world's total emissions, more than 85.5% of the total
69 emissions of the second-largest carbon emitter. Thus, China will play an
70 important role in whether the global greenhouse effect can be effectively
71 controlled. Meanwhile, China's government has taken steps to better meet

its emissions reduction responsibilities a range of emission reduction actions, as shown in table 1:

Table 1, China's emissions reduction targets

Time	Actions to reduce emissions	Emission reduction targets
2009	Released the "12th Five-Year Plan" to Control Greenhouse Gas Emissions;	Carbon intensity will be 17% lower in 2015 than in 2010
2011	Attended the Copenhagen Climate Change Conference	Reduce carbon intensity by 40%-45% from 2015 by 2020
2014	Released the "Joint Voice on Climate Change between China and the United States"	Peak carbon emissions around 2030 and increase the proportion of non-fossil energy use to 20%
2015	Attended the Paris Climate Change Conference	China will reduce carbon intensity by 60%-65% by 2030 compared to 2005

China is under pressure from both economic development and energy conservation and emission reduction

Although China produces the world's second largest GDP, but is still a developing country that its per capita GDP has not yet entered a high income level, China still needs economic development as the main focus. At present, most of the energy used in China is still coal with a high carbon emission coefficient per unit of energy. The aim of achieving the emission reduction target of carbon dioxide emissions peak and meet the growth of energy demand seems to be the conflict between spear of energy conservation and emission reduction.

How to solve the above difficulties? That will require the Chinese

government to vigorously promote the research on application of energy-saving and emission-reduction technologies to achieve a reduction, in carbon emissions per unit of energy as economic growth takes. Energy conservation and emission reduction targets under rapid economic growth can be effectively achieved only if both the input side (controlling energy consumption) and the output side (reducing carbon emissions per unit of energy output) are controlled.

China's regional development is uneven

China's vast territory, not only causes different geographical environment but also resulting in China's economic development level and environment are different. Because the eastern region is closer to the port, so it is easier to carry out foreign trade activities, but also easier access to more advanced production technology, according to Ricardo's theory of comparative advantage. According to the development of trade, regardless of the region's product productivity between the two sides is low or high, as long as there is a comparative advantage of input and output between goods to enhance the overall output capacity of both sides of the trade, and further enhance the professional division of labor capacity of products. Because the eastern region has certain geographical advantages and policy advantages, the eastern part of China has better economic development than the central and western regions far from the port.

When China formulates its carbon emission control policy, different regional foundations must be taken into account, such as economic development level, industrial structure, technology level, energy structure and other factors, so as to better formulate regional emission reduction policies suitable for different development environments.

As a consequence, concerning the 2030 China's carbon emission peak and emission reduction target allocation research, mainly focused on the 2030 national or local carbon emission peak research, or the national or regional industry carbon emission path research. These above researches often involve a relatively single region, most of the research is for a specific region of the industry, or the country's specific industry carbon emission path research, lack of the national sub-regional vision of the peak carbon emission path to carry out systematic research, therefore, the research dimension is not enough to deepen. These studies can not meet the Chinese government's policy reference needs for achieving the 2030 carbon emission peak target. After all, China in the formulation of carbon emission reduction program, is to carry out overall planning. However, as for carbon emission reduction policy formulation, must take into account the heterogeneity of regional development, in order to truly formulate an integrated carbon emission reduction policy.

Therefore, this paper will consider China's development strategy in recent years, the four regions including a total of 30 provinces and cities

(due to lack of data, excluding Tibet, Hong Kong, Macao, Taiwan), and consider the historical development of each region on the region's carbon emissions in the future development trend of the driving effect, At the same time, in order to better achieve the emission reduction target, we will explore in depth the impact of China's four major regional carbon emission factors on carbon emission changes, based on scenario analysis, from the historical and future perspectives of the impact of carbon emissions on each region.

Material and Method

IPAT Model

Many studies have been carried out by domestic and foreign scholars on the factors affecting carbon emissions in a country or region. The main tool used in the study of this problem is the IPAT model. In 1970, Ehrlich W (1971), first proposed the IPAT model to study the effects of human activities on the natural environment. He believes that the pollutants emitted by human beings are mainly caused by factors such as population size, economic development level and scientific and technological level. Subsequently, Waggoner and Ausubel (1999), sound on the basis of the traditional IPAT model, the Impact Analysis model is proposed. In their view, factors affecting the natural environment should include factors such as consumption and efficiency of use per unit of output, in addition

to population, affluence and skill levels.

Environment Kuznets Curve Theory

The Environmental Kuznets Curve originated from Grossman and Krueger's (1991) study of the relationship between environmental pollution and economic growth, and the two scholars firstly discovered the inverted U-shaped relationship between environmental pollution and economic growth. Stem (2015) discusses the relationship between factors related to environmental pollution and develops the research results into the environmental Kuznets Curve (EKC) theory. The environmental Kuznets curve theory shows that the primary stage of economic development will be developed at the expense of the environment, but when the level of economic development reaches a certain level, society begins to improve the relationship between economy and environment, and the degree of environmental degradation decreases. In the advanced stage of economic development, economic growth and environmental pollution are decoupling. From a very simple point of view, it can show that economic growth is good for the environment.

In short, when the region's economic development to a certain level, people will put forward a higher standard for their living environment, will increase the development of energy conservation and environmental protection and low-carbon technology, so that the per unit of GDP pollution emissions fell more than the magnitude of GDP growth. Thus,

reaching the inflection point of the environmental Kuznets curve. The birth of the environmental Kuznets theory provides the theoretical basis for the world to achieve the peak of carbon emissions while maintaining economic growth.

Data envelopment analysis

The potential to reduce carbon dioxide emissions determines how the task of reducing carbon dioxide emissions is allocated, and the rational allocation of carbon emissions is also relevant to China's ability to achieve a peak carbon emissions by 2030. Data envelopment analysis (DEA) is often used to measure CO₂ reduction potential. Zhou and others (2007) proposed an environmental DEA model based on relaxation variables to simulate the performance of CO₂ emissions when the economy is inefficient. Guo(2011) used the DEA model, from the perspective of energy-saving technology and energy structure changes, measured the emission performance of 29 provinces and cities in China. Miao and other (2016) used ZSG-DEA model to measure the distribution of carbon emissions in different provinces of China. Wang and others (2014) have allocated CO₂ emissions from 30 provinces and cities in China in a fixed amount, and have recommended that different provinces and cities bear different responsibilities for reducing emission intensity and non-fossil fuel share, such as Zhou (2014), using Centralized-DEA to

determine the optimal path for China to control CO₂ emissions at the provincial and regional levels. They found an inverted u-shaped relationship between overall optimal GDP and emissions control coefficients, suggesting that the more developed regions of the economy, the more responsible they should be for reducing emissions.

Literature review

The theory of sustainable development

Sustainable development is a necessary prerequisite for the long-term development of mankind, and it is to maintain the stability of the ecological environment while providing the long-term process for human activities to meet the needs of its economic and social development. The desired result is a social state in which the living environment and resources can be sustained to meet human needs without undermining the integrity and stability of the natural system. Sustainable development can be defined as a way of development that meets the needs of contemporary life and production without sacrificing the living environment and production conditions of future generations.

Sustainable development theory can be applied to many fields of research, the use of any scarce resources should consider sustainable issues, such as the rational use and protection of water resources, mineral oil resources development and maintenance, forest resources felling and

cultivation. In order to coexist harmoniously between human beings and the earth's ecological environment for a long time, all kinds of economic activities that need to use natural resources for production inputs can be applied without sustainable development theory.

Carbon emissions peak research

Some researchers in China believe that future energy consumption will continue to increase carbon dioxide emissions, making it difficult for CO₂ emissions to peak by 2030. BP (2018) predicts that China is on track to reach a peak of carbon dioxide emissions by 2025, peaking at about 10 billion tons. Li and others (2017) suggest that China's carbon emissions will peak at 11.2 billion tons in 2026 and reduce their carbon dioxide emissions by 21.64 billion tons between 2015 and 2035. Martin and Chen (2017) used the Time S models to predict China's carbon emissions peak path, and concluded that China will reach a peak of CO₂ emissions around 2030, peaking at around 10-10.8 billion tons. Due to the different regional development foundations, there may be significant differences in carbon emission paths in different regions. Du and others (2017) have studied the trend of CO₂ emissions, and believe that carbon dioxide emissions in Beijing and Shanghai have reached their peak. Yang and others. (2015) point out that Beijing is likely to peak in 2019. Gao and others (2016) predict that Shandong Province will reach its peak by 2024

under the energy-saving scenario. It may not peak until 2030 or later.

Carbon emissions and the economy grow

Regarding the relationship between regional economic growth and carbon emissions, different scholars have different conclusions according to the different subjects of the study. Grossman and Krueger (1991) studied the relationship between environmental pollution and economic growth and found an inverted u-shaped trend between the two. However, studies such as Churchill et al. (2018) have shown that there are other relationships between environmental pollution and drivers (e.g. linear, U, N, inverted N-shaped) ".The various shapes present in different studies can be attributed to regional differences, and the EKC curves distributed across subregions will form the economic growth and carbon emission curves of the entire region."

In some regions, the EKC curve is difficult to identify, and Ozokcu and Ozdemir (2017) studied the EKC curve of economic growth and carbon emissions and found no significant correlation between the two. Olale and others (2018) analyzed the relationship between Carbon Emissions and Driving Factors in Canada and found that U-type and reverse U-type can describe the relationship between per capita greenhouse gas emissions, income and technological change.

Research background

The scale of economic development in the four major regions

Regional GDP can be used as a measure of the size of the economy, since the time span of our study is from 2009-2019, in order to better illustrate the real economic growth of the regions during this period, we consultant the four major regions of 2009-2019 GDP as shown in figure 1.

Figure 1, GDP of the four major regions from 2009 to 2019

(Unit: Hundred million)

As can be found from Figure 1, the total GDP of the region implementing the first development strategy in the east is shaking ahead. And by the end of 2019, the GDP of the four region was about 32. 82 trillion yuan in East, 12. 02 trillion yuan in Middle, 11. 68 trillion yuan in West and the North-east took the lowest point for around 5.04 trillion yuan. It is obvious that the eastern region's economy accounted for roughly 53.31 %of the country's economy, while the eastern region's GDP in 2015 increased by 19.49 trillion yuan compared while the GDP of the

other three regions increased by 17.94 trillion yuan. The Eastern region implementing the central rise strategy is similar to the total GDP of the western development strategy region, and the trend of economic growth is similar in 2015. The region with the lowest total GDP and the fewest provinces and cities covered by the northeast strategy.

The level of economic development in the four major regions

The level of economic development of the region can be measured by GDP per capita, as can be found in Figure 2, in the four regions, the Eastern region is not only the first in total, but also the first in GDP per capita.

Figure 2, GDP per capita in the four regions from 2009 to 2019

(Unit: Thousand yuan)

Population size and level of urbanization

Combined with the level of economic development, it can be found that in the four regions, the higher the level of economic development, the higher the rate of urbanization.

Figure 3, Percentage of population in each region in 2019

As figure 3 demonstrates, in 2019, the eastern region had the highest proportion of the population, accounting for about 38.4% of the total population, while the eastern region also had the highest level of urbanization, at 68.38%. The Northeastern region has the smallest percentage of the population in the country, accounting for only 8%, but the North-east, an old industrial base, has a high level of urbanization, second only to the East, at 60.49%, about 10 % higher than the Middle and West.

The rate of population growth can reflect the rate of natural population growth in a region and the degree of attraction to the population.

Figure 4, Proportion of urbanization in each region in 2019

As shown in Figure 4, the population growth rate in the East was higher than the national average during the period of 2010-2019, while the population growth rate in the Middle, West and North-east was lower.

Figure 5, Regional and national population growth rates from 2010 to 2019

However, the population growth rate in the northeast region is gradually deviating from the average according to figure 5, which shows that the development environment in the northeast region is becoming less and less attractive to the population, resulting in negative population growth.

Figure 6, Regional urbanization growth rate from 2010 to 2019

Urbanization in all four regions is growing, but the growth rate is highly volatile. As shown in Figure 6, the central and western regions with the lowest level of urbanization have a relatively high urbanization growth rate of about 1.5%.

Carbon emission characteristics

As shown in Figure 7, the size of CO₂ emissions in the four regions is in the same order as the size of the population in each region, with the highest and largest increases in CO₂ emissions in the East between 2010 and 2019. The scale of CO₂ emissions in Northeast has been at its lowest level. Judging from the trend of CO₂ emissions in all regions from 2010 to 2019, the growth rate of CO₂ emissions in the four regions has stabilized.

Figure 7, Regional CO₂ emissions trends from 2010 to 2019

(Unit: ton)

Carbon intensity

The carbon intensity in the central region is significantly lower than that in the West, indicating that the industrial structure of the Middle and West is significantly different. The highest GDP per capita and the lowest carbon intensity indicate that the eastern region has the most intensive and efficient economic development path, shown in figure 8.

Figure 8, Regional carbon intensity trends

Moreover, as shown in figure 8, the West has the highest carbon intensity, probably because its economic development is more dependent on energy-intensive industries, and the Middle's carbon intensity is nearly one unit less than that of the West, which shows that although the scale

and level of economic development in the Middle and West regions are similar.

Environmental barrier Znets is a domestic comparison

The environmental Kuznets curve theory (Grossman and Krueger, 1991) and the IPAT model-based CO₂ emission decomposition method are the most popular ways to explain the relationship between human activity and CO₂ emissions. The environmental Kuznets curve can be used to study the nonlinear relationship between economic growth and pollution emissions, and Kaika and Zervas (2013) are working to find the inflection point of the environmental Kuznets curve through the study of different countries and economic bodies. The environmental Kuznets curve theory reveals the existence of a turning point between economic development and pollution emissions, which is the cornerstone of our research and provides theoretical support for China to achieve a peak in CO₂ emissions while maintaining economic growth.

Figure 9, Regional environment Kuznets curve

(Data source: World-Economic-Outlook-october-2019, WEO 2019)

Figure 9 represents the environmental Kuznets curve of the four regions, the horizontal axis is the per capita GDP of each region, symbolizing the level of economic development of each region, the vertical axis is per capita carbon dioxide emissions, symbolizing the level of pollution emissions. The four segments are the environmental Kuznets curve for each region, with a total of 10 points per segment.

The first point to the right at the far left of each segment represents the level of CO₂ emissions and economic development in each region from 2010 to 2019. As can be found, the level of economic development in each region has been increasing from 2010 and 2019, but the increase in CO₂ emissions in each region has gradually slowed, and the Kuznets curve in each region has levelled off, which provides the possibility for each region to meet the peak target of 2030.

The environmental Kuznets curve of each region is not consistent. First of all the environmental Kuznets curve in the Northeast is on the top at the level of economic development and the corresponding carbon

emission than the other three regions. So it can be inferred that the economic development path of the Northeast is the least intensive and environmentally friendly.

The corresponding level of economic development and carbon emissions in the West in 2019 is similar to that of the in the Middle, but the carbon emission level is significantly lower than that in the West. And since 2011, the carbon emission level in the Middle is lower than that in the East at the same level of economic development, indicating that the Middle has the most environmentally friendly economic development route at the same level of economic development.

To sum up, the economic development in East is the most advanced; the Middle is the most environmentally friendly one which should continue to maintain advantages to increase the energy-saving and environmental protection technology. Then, the Northeast and West region may need to learn the emission reduction path of improving low-carbon level of economic development.

Scenarios design

Introduction of the analyzing methods

The IPAT model is an economic model proposed by ecologists Ehrlich and Holdren (1971) to analyze the effects of population growth, economic development, and technological progress on the ecological

environment. Many scholars use IPAT models to identify key drivers of pollutant emissions at the national, regional, and industrial levels. Similarly, this model can be used to predict future pollution emission paths based on trends in different key drivers, and there are many scholars (Commoner, 1972; Dietz and Rosa, 1997; Guan, etc., 2008). To use this model to predict future trends in China's pollution emissions the IPAT model is actually an abbreviation for a simple one-equation: IPAT, where the letter 'I' stands for environmental impact (impact), 'P' for population, 'A' for affluence (affluence), 'T' for environmental technology (technology). In this paper, the IPAT model is used to predict the carbon dioxide emissions in the four regions and the whole country under the uncomal scenario. The model is as follows:

$$I = P * A * T \quad (1-1)$$

This paper focuses on carbon emissions, so the environmental impact is expressed in C (CO₂ emissions), A in terms of affluence is expressed in GDP per capita, and environmental technology T is expressed in carbon intensity C/G:

$$C = P * G / P * C / G \quad (1-2)$$

Further inference:

$$C = P * G / P * E / G * C / E \quad (1-3)$$

This formula is the Kaya constant equation, proposed by the Japanese scholar Yoichi Kaya (1990) (V), widely used to assess the

factors affecting pollution emissions, C is CO₂ emissions. When the effects of population factors on CO₂ emissions are not taken into account, the Kaya formula is distorted to:

$$C = G \frac{E}{G} \frac{C}{E} \quad (1-4)$$

The rate of change of the drivers is added to formula 1-4, and the time factor can be used to predict CO₂ emissions from future regions:

$$C^t = G^0 (1+r)^t \frac{E^0}{G^0} (1+g)^t \frac{C^0}{E^0} (1+v)^t \quad (1-5)$$

According to the above formula (1-5), r、g、v, represent the average annual rate of change of GDP, energy intensity and carbon emission per unit of energy consumption, respectively. This paper applied GDP, energy intensity, carbon dioxide emissions per unit of energy dioxide emissions in the future annual rate of development scenario design. And then applying the formula (1-5) can get the development trajectory of carbon dioxide emissions in the four regions under different scenarios.

Economic development scenario design

As shown in Figure 10, China's economy experienced rapid growth in the 10 years from 2010 to 2019 , but the trend has gradually slowed , with GDP growth in 2019 already at less than 7.5%.

Figure 10, The GDP growth rate of the four regions and the whole country

Moreover, the summarize of the forecasts of China's GDP growth rate for 2016-2030 by the world's major authorities, as shown in table 2.

Table 2, GDP Forecast (2016-2030)

Organization	2016-2020	2021-2025	2025-2030	2031-2040
China Energy Research Association (2016)	6.8%	5.5%	4.5%	-
World Bank (2012)	7%	5.9%	5.0%	-
Mckinsey (2009)	-	6.5%	6.5%	-
International Energy Agency (2014)	-	4.5%	4.5%	-
British Oil (2018)	-	-	4.5%	-

Based on the forecast data of China's future economic development, this paper designs three different scenarios for China's future GDP development, as shown in table 3:

Table 3, China's GDP Development Scenario

Scenario	2016-2020	2021-2025	2026-2030	2031-2040	Average
A1 (Rapid)	7.0%	6.0%	5.0%	4.0%	6%
A2 (Moderate)	6.5%	5.5%	4.5%	3.5%	5.5%
A3 (Low)	6.0%	5.0%	4.0%	3.0%	5%

466

467 During the years of 2009-2019, GDP in the East, the Middle, the
468 Northeast, the West and the Nationwide grew at an average annual rate of
469 10.77%、11.6%、10.65%、12.35% and 11.20%. At the same time, the
470 economic growth rate of the four regions is gradually slowing down,
471 taking into account the heterogeneity of regional economic development,
472 we assumed that under different economic growth scenarios, the
473 economic growth rate of each region will remain proportional to the GDP
474 growth rate of the corresponding scenario. The relative proportion of
475 GDP growth in the four regions is calculated on the basis of the average
476 annual GDP growth rate for each of their regions for the decade of
477 2010-2019. The future GDP growth rate of each region can be calculated
478 by formula (4-6):

479
$$S_i^t = S_z^t \frac{S_i^{2010-2019}}{S_z^{2010-2019}} \quad (1-6)$$

480 In this formula, $i=1-4$ represents four regions, and
481 $t=2019/2020/2021/2025/2026/2030/2031-2040$ represents the time
482 interval involved in the forecast: the S_i^t and S_z^t represent the growth rate
483 of regional 'i' and national GDP within the period of 't', respectively. The
484 economic growth rate of the four regions will remain relative to the
485 projected GDP growth rate of the whole country, and the GDP growth
486 rate of the four regions and the whole country will remain unchanged due
487 to the relative proportion of $S_{i2010-2019}/S_{z2010-2019}$. Based on this formula,

the GDP growth rate of the four regions in each scenario can be calculated over different forecast periods, as shown in table 4:

Table 4, Forecasts of GDP growth under different scenarios in the four regions

Scenario	Region	2016-2020	2021-2025	2025-2030	2031-2040
A1	East	6.73%	5.77%	4.81%	3.85%
	Middle	7.25%	6.21%	5.18%	4.14%
	North-east	6.65%	5.70%	4.75%	3.80%
	West	7.72%	6.62%	5.51%	4.41%
A2	East	6.25%	5.29%	4.33%	3.37%
	Middle	6.73%	5.70%	4.66%	3.62%
	North-east	6.18%	5.23%	4.28%	3.33%
	West	7.17%	6.06%	4.96%	3.86%
A3	East	5.77%	4.81%	3.85%	2.89%
	Middle	6.21%	5.18%	4.14%	3.11%
	North-east	5.70%	4.75%	3.80%	2.85%
	West	6.62%	5.51%	4.41%	3.31%

Energy intensity scenario design

From the historical data on energy intensity from 2010 to 2019 (Figure 11), we can see that the energy intensity of the four major regions of the country is declining at an average annual rate of 5% to 6%, and the annual energy intensity decline rate of each region during the decade is 5.61% in the East, 5.55% in the Middle and 5.95%, although the rate of 5.14% degrees in the West is almost similar.

However, there is a clear difference between the absolute amount of energy intensity among the regions. The East with the highest per capita GDP has the lowest energy intensity, while the West with the lowest per

capita GDP has the highest energy intensity.

Figure 11, Energy intensity in four major regions from 2010 to 2019

In 2019, the energy intensity of the West is even higher than that of the eastern region in 2010, considering that with the continued implementation of the four regional energy conservation and emission reduction strategies in the future, the energy efficiency of all regions of China will be further improved, and the energy intensity will continue to decline. As there may be few concrete forecasts for the decline rate of energy intensity in the future regions. Meanwhile, in order to better describing all possible scenarios of energy intensity changes in various regions of China in the future, the energy intensity decline rate in the four regions based on Figure 12 in 2010-2019 has designed the future development scenarios of energy intensity in four regions of China.

Figure 12, The rate of energy intensity decline in the four regions from 2010 to 2019

Considering that the potential for future energy intensity decline decreases with the implementation of emission reduction control policies, it is more appropriate to set the high-speed decline scenario of energy intensity based on the average energy intensity decline rate of each region from 2010 to 2019. For the purpose of covering more forecast intervals, design scenarios using the quarterback method, the lower rate of the medium-speed scenario is 75% of the high-speed scenario, the rate of decline of the low-speed scenario is 50% of the high-speed scenario.

The average annual decline in energy intensity in the four regions from 2016 to 2040 is shown in table 5.

Table 5, Regional Energy Intensity Development Scenario

Scenario	Changing Rate	Region	2016-2020	2021-2025	2025-2030	2031-2040
B1	Rapid (about 5.0%)	East	5.61%	5.47%	5.33%	5.19%
		Middle	5.55%	5.41%	5.27%	5.13%
		North-east	5.95%	5.80%	5.65%	5.50%
		West	5.14%	5.01%	4.88%	4.76%
B2	Moderate (about 4.0%)	East	4.21%	4.10%	4.00%	3.89%
		Middle	4.16%	4.06%	3.95%	3.85%
		North-east	4.46%	4.35%	4.24%	4.13%
		West	3.86%	3.76%	3.66%	3.57%
		East	2.81%	2.74%	2.67%	2.60%

B3	Low	Middle	2.77%	2.70%	2.64%	2.57%
	(about	North-east	2.97%	2.90%	2.82%	2.75%
	2.5%)	West	1.29%	1.25%	1.22%	1.19%

The potential for energy intensity decline in each region decreases over time, and we have set the rate of energy intensity decline in 2021-2025, 2026-2030 and 2031-2040 for each scenario as 97.5%, 95% and 92.5% of the energy intensity decline rate for the period of 2016-2020, respectively.

Energy structure development scenario design

According to China's statistical yearbook 2019, China's energy consumption structure in 2019 was: coal accounted for 63.70% oil for 18.30%, natural gas for 5.90%, clean energy for 12.10%. The energy structure of one region is no low carbon can be reflected by carbon dioxide emissions per unit of energy consumption. Moreover, a regional energy consumption CO₂ emissions can be based on the proportion of various types of energy in the region and the corresponding energy carbon emission factors, the calculation formula is such as shown in the model (4-7):

$$\frac{C}{E} = \frac{\frac{E_{coal} * r_{coal} + E_{oil} * r_{oil} + E_{gas} * r_{gas} + E_{clean} * r_{clean}}{E_{coal} + E_{oil} + E_{gas} + E_{clean}}}{\frac{\frac{E_{coal} * r_{coal}}{E} + \frac{E_{oil} * r_{oil}}{E} + \frac{E_{gas} * r_{gas}}{E} + \frac{E_{clean} * r_{clean}}{E}}{\frac{E_{coal}}{E} + \frac{E_{oil}}{E} + \frac{E_{gas}}{E} + \frac{E_{clean}}{E}}} = \frac{E_{coal}}{E} * r_{coal} + \frac{E_{oil}}{E} * r_{oil} + \frac{E_{gas}}{E} * r_{gas} + \frac{E_{clean}}{E} * r_{clean} \quad (1-7)$$

E_{coal} , E_{oil} , E_{gas} , E_{clean} Representing the region's energy consumption of coal,
 oil, natural gas, and clean energy. r_{coal} , r_{oil} , r_{gas} , r_{clean} as carbon emission factors for each energy
 source, according to the Intergovernmental Panel on Climate Change
 (IPCC) released in 2016 includes carbon emission factors of 2.64, 2.08,
 1.63, 0 tonnes/standard coal tonnes for coal, oil, natural gas and clean
 energy. The formula (1-7) deduces the CO₂ emissions per unit of energy
 consumption in all regions of China in 2019 as shown in Figure 13:

Figure 13, Regional energy unit emissions in 2019

Figure 13 shows that the difference in CO₂ emissions per unit of
 energy consumption in China's four regions is not large, namely 2.15,
 2.03, 2.17, 1.98 tons / ton of standard energy.

According to the study background above, we designed the
 development scenario of the energy structure of the next four regions.
 CO₂ emissions per unit of energy consumption is a comprehensive
 indicator of energy composition, and lower CO₂ emissions per unit of
 energy consumption means cleaner energy composition. The Energy
 Technology Revolution Innovation Action Plan (2016-2030), released by

the State Energy Administration, aims to achieve 20% of China's total clean energy consumption by 2030. Yan Yu (2016) predicts that China's non-fossil energy, oil, natural gas and coal will account for 21%, 16.8%, 11.9% and 50.3% of total energy consumption in 2030, respectively. 3%.

For the construction of clean energy technology breakthrough scenario C1, we refer to the China Energy Research Association released the "China Energy Outlook 2030" forecast for the future development of energy structure, by 2030, China's non-fossil energy use will reach 22%, coal use will fall below 50%.

The Technology Stagnation Scenario (C4) assumes that the energy structure remains the same and that CO₂ emissions per unit of energy consumption will be consistent with 2015 levels by 2030. We will design a low-speed development scenario C3 for the energy structure as a baseline scenario (C2) and a technology stagnation scenario (C4) transition. Considering that energy can be traded between the four regions, we assume that the four regions will maintain the same rate of reduction in CO₂ emissions per unit of energy consumption under the established scenario, and that the unexequested scenarios for the energy structure of the four regions are presented in table 6.

Table 6, Regional energy structure development scenarios

Scenario	Instructions
	By 2030, China will have achieved a breakthrough in clean energy technology, with clean energy accounting for 22% of

Technology breakthrough scenario (C1)	energy consumption, 17% of oil use, 12% of natural gas use and 49% of coal use. Average annual reduction in CO ₂ emissions per unit of energy consumption in each region: d ₁ =1.05% By 2030, China's clean energy technology will develop steadily, with clean energy accounting for 21% of energy consumption and oil use reaching 16. 8%, the proportion of natural gas use reached 11.9%, the proportion of coal use fell to 50.3%.
The baseline scenario (C2)	Average annual reduction in CO ₂ emissions per unit of energy consumption in each region: d ₂ =0.95% By 2030, China's clean energy technology is developing slowly, and clean energy accounts for 16. 55%, the proportion of oil use reached 17.55%, the proportion of natural gas use reached 9%, the proportion of coal use fell to 57. 0%
Technology is slowly developing Scenario (C3)	Average annual reduction in CO ₂ emissions per unit of energy consumption in each region: d ₃ =0.46% By 2030, the energy structure will remain unchanged from 2015.
Stagnant scenario (C4)	

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591 ***Peak scenario***

592 Based on the comprehensive analysis of economic growth, energy
593 intensity and possible future changes in energy structure in various
594 regions, we have constructed 3*4*4=48 scenarios for the future
595 development of China's carbon emissions. **The peak and peak levels of**
596 **CO₂ emissions in 48 scenarios are shown in Figure 14.** We can divide
597 48 scenarios into five groups depending on when CO₂ emissions peak,

and the first four scenarios can be deduced from China's goal of peaking carbon emissions by 2030: there are 21 scenarios.

Figure 14, Peak conditions and peak numbers in 48 scenarios

(Data from simulating results)

Table 7, Peak Scenario

Peak Scenario	B1	B2	B3	B4
A1	C1-4	C1-3	-	-
A2	C1-4	C1-3	-	-
A3	C1-4	C1-3	-	-

According to the Blue Book of China's Low Carbon Development Report 2015-2016, China's total coal consumption may have peaked in 2013 (International Energy Agency, 2018). Therefore, the main reason for the increase in China's carbon dioxide emissions in the future is the growth of China's oil and gas demand. According to the United Nations (2011), Chinese will peak around 2027, before continued population growth leads to demand for oil and gas, so the likelihood of CO₂

emissions peaking by 2025 is low. Current researchers widely predict that China's carbon dioxide emissions will peak between 2025 and 2030. If China wants its carbon dioxide emissions to peak by 2025, it will need strict demands on economic growth, energy efficiency improvements and energy structure optimization.

Therefore, we define the peak scenarios for 2015 (peaks of about 9.3 billion tons) and 2020 (peaks of about 9.5 billion tons) as reference scenarios. A scenario that peaks in 2025 (about 10 billion tons) and 2030 (about 11 billion tons) is defined as a viable scenario. Table 4 and 6 show that each of China's economic growth scenarios has seven scenarios corresponding to achieve the peak of carbon dioxide. If the efficiency of energy utilization in the future is increased at a high rate in accordance with the B1 scenario, then even if China does not optimize its energy structure, the economy can achieve a high level of CO₂ emissions. However, if energy efficiency is low in the future (Scenario B3-4), even in the context of a clean energy breakthrough, there is no scenario to reach a peak by 2030. It can be seen that the full improvement of energy efficiency is very important to achieve the 2030 CO₂ emissions peak target as shown in table 7.

Results and discussions

Method Introduction

Based on environmental production techniques, policymakers often want to maximise expected output (GDP) and minimize non-expected co-production (CO₂). The Centralized-DEA model is a linear planning method for analyzing the efficiency of calculating resource allocation under resource constraints, proposed by Zhou and others, compared with traditional packet analysis, the Centralized-DEA model also considers the impact of weak disposal of pollution emissions and regional development base on regional carbon emission allocation efficiency, and has a better research effect on how to achieve the efficient allocation of carbon emission quotas between regions. In this article, we used this method to maximize China's desired yield in the context of a given amount of CO₂ emissions. If CO₂ emissions are allocated in 30 provinces and cities in China according to optimal quotas calculated by the Centralized-DEA model, higher distribution efficiency will be achieved, freeing up more economic output. The Highd-DEA model is shown in the same style (8):

$$\begin{aligned}
 & \text{Max} \sum_{l=1}^k \hat{y}_l^t \\
 & \text{St.} \sum_{k=1}^k z_k^t x_{ik}^t \leq x_{il}^t, i=1, \dots, m; l=1, \dots, k \\
 & \sum_{k=1}^k z_k^t y_1^t \geq \hat{y}_l^t \\
 & \sum_{k=1}^k z_k^t c_1^t = \hat{c}_l^t \\
 & \sum_{l=1}^k c_l^t = \sum_{l=1}^k \hat{c}_l^t \\
 & z_k^t \geq 0, \hat{y}_l^t \geq 0, \hat{c}_l^t \geq 0
 \end{aligned} \tag{8}$$

In the formula (8), x_{il}^t means l province's production inputs i (e.g.,

capital, people, energy); $\hat{y}_i^t$ and y_i^t present the best output of CO₂ emissions and actual CO₂ emissions in i province during t period; c_i^t and $\hat{c}_i^t$ present the best and actual disposition of CO₂ emissions in i province during t period (Fare e.g., 2005). Finally, we maximize the $\sum_{l=1}^k \hat{y}_l^k$, which represents the greatest output of the country's expectations.

Distribution efficiency and potential output capacity of the peak scenario

To better compare the differences between regional carbon emission paths in different peak scenarios and regional carbon emission paths optimized by Centralized-DEA, and to evaluate the efficiency of carbon emission allocation, we introduced deviation indices to measure differences in CO₂ emissions from each region before and after Each year, as shown in the model (9):

$$d(s) = \sum_{t=1}^T \sum_{l=1}^k |C_{ls}^t - \hat{C}_{ls}^t| \quad (9)$$

In the formula (4-9), $K=30$ represents 30 provinces and cities; $T=25$ represents the time range studied spanning 25 years from 2016 to 2040; c_{is}^t means i province's CO₂ emissions during t period under scenario s ; $\hat{c}_{is}^t$ represents i province's CO₂ emissions during t period under scenario s after the optimization of Centralized-DEA; $|\hat{c}_{is}^t - c_{is}^t|$ is the absolute deviation of c_{is}^t and $\hat{c}_{is}^t$; The lower $d(s)$ means that scenarios are

more efficient in allocating carbon emissions.

We divide the optimized total yield of Centralized I-DEA under the established scenario (s) by the total carbon dioxide emissions, and arrive at $e(s)$ to measure the potential yield capacity in each scenario, as shown in the model (4-10):

$$e(s) = \sum_{t=1}^T \sum_{l=1}^K \hat{Y}_{ls}^t \quad (10)$$

In this way, we can understand the potential GDP size of each scenario under a given CO₂ emissions scenario, and the higher the (S), the higher the potential output in that scenario. The CO₂ distribution efficiency measurement reveals which scenario CO₂ emission configuration is better able to boost GDP growth. Based on formula 4-(8-10), we calculated a deviation index reflecting the efficiency of CO₂ emission distribution in 21 peak scenarios, as shown in figure 15, in order for countries that reached the peak of carbon emissions earlier to allocate CO₂ emission quotas more efficiently among regions.

As mentioned earlier, China is less likely to peak CO₂ emissions by 2025, so we should focus on analyzing the scenarios where carbon emissions will peak in 2025 and 2030, as shown in Figures 15, in 2025 and 2030 A2B2C1 and A1B2C2 have the lowest deviation indices, respectively, meaning that the CO₂ emission path in the A2B2C1 and A1B2C2 scenarios is closest to the optimal path optimized by Centralized-DEA. So the A2B2C1 and A1B2C2 scenarios are the most

efficient for co2 emissions distribution in 2025 and 2030, respectively.

Figure 15, The deviation value of 21 peak scenarios

(Unit: CO₂ per ten thousand ton)

Using the maximum potential output per unit of CO₂ emissions as an evaluation criterion (based on formulas 10), we further assessed the potential output efficiency of scenarios that peak in 2025 and 2030, as shown in Table 7, where scenario A1B2C2 has the highest potential emission efficiency in scenarios where carbon emissions peak by 2030. In the peak scenario in 2025, A1B2C1 has more stringent requirements for optimizing the energy structure than A1B2C2, and the potential output efficiency of CO₂ emissions is slightly lower than that of Scenario A1B1C4, which is approximately equal to A2B2. CU scenario A1B1C4 because there is no optimization of the energy structure (C4) and the optimization of energy efficiency requirements are higher (B1), neither realistic and difficult to achieve, the feasibility is poor, after excluding scenario A1B1C4 can be inferred, A1B2C1 and A1B2C2 are the most efficient scenarios for potential CO₂ emissions in 2025 and 2030,

respectively. However, C2 is relatively less constrained to changes in energy structure than C1, the A1B2C2 scenario is easier to achieve than the A1B2C1 scenario, and also meets China's commitment of 20% non-fossil energy use by 2030, providing more flexible space for policy implementers, and the highest distribution efficiency in the peak scenario in 2030. Therefore, we chose the A1B2C2 scenario, which will peak in 2030, as the optimal peak scenario for further analysis shown in table 8.

Table 8, Peak Scenario Potential Output Rankings

Peak time	Top three rankings for potential output of peak scenarios
2025	A1B1C4 (0.190) > A1B2C1 (0.181) $\approx$ A2B2C1 (0.180)
2030	A1B2C2 (0.179) > A1B2C3 (0.168) $\approx$ A2B2C3 (0.167)

As can be seen from table 8, in the optimal peak scenario, the eastern and north-eastern regions, after 2015, are redistributed by Centralized-DEA with less optimal carbon emissions than the actual carbon emissions. In the Middle, the optimal carbon emissions from Centralized-DEA redistribution after 2015 are higher than actual carbon emissions. As mentioned earlier, we have found that the GDP per capita

in the East and Northeast is in the first and second place, respectively.

It can be found that in the optimal peak scenario, the economically developed East and Northeast regions should bear more responsibility for emission reduction, because the two regions have less room for emission reduction. Moreover, the allocation of carbon emissions to the less developed Middle and West regions can improve the efficiency of carbon emission distribution, creating more output. The economic development of the less developed West region should be allocated more carbon emissions rights, because of its current inefficient energy use, its potential energy marginal output of the increase in space.

Optimal peak scenario characteristic analysis

According to the analysis of CO₂ distribution efficiency and potential output efficiency, A1B2C2 is the optimal peak scenario to achieve China's carbon emission targets and international commitments. As shown in Table 8, in Scenario A1B2C2, China will continue to grow at a rapid rate of GDP, with GDP growing by 140% in 2030 compared to 2015 to 172.6 trillion yuan, and **its GDP growth rate in 2016-2030 will similar to the data of World-Economic-Outlook-october-2019 as shown in table 9** and slightly lower than the benchmark designed by Yuan and other (2014) scenarios. GDP per capita will reach \$176,000 in 2030.

Table 9, The development trend of economic scale and economic

development level under the optimal peak scenario

Year	Metrics	Unit	China	East	Middle	North-east	West
2015	GDP	trillion	72.17	37.3	14.7	5.78	14.4
	GDP per capita	yuan ten thousand	5.28	7.10	4.03	5.28	3.91
2020	GDP	trillion	101.37	51.66	20.85	7.98	20.88
	GDP per capita	yuan ten thousand	7.16	9.24	5.60	7.21	5.57
2025	GDP	trillion	135.87	68.39	28.19	10.53	28.77
	GDP per capita	yuan ten thousand	9.49	11.78	7.62	9.67	7.73
2030	GDP	trillion	172.59	86.49	36.28	13.28	36.55
	GDP per capita	yuan ten thousand	11.96	14.34	9.89	12.42	9.90

(Data source: World-Economic-Outlook-october-2019, WEO 2019)

As a consequence, the next step is that we can allocate the stimulating data from table 8 and combine it with the forecast data from the World Economic Outlook 2019 (which is shown in table 9) to achieve the more exact data of China's four major regions' future economic developing trend.

Peak time and peak of CO₂ emissions

Northeast has always been China's oldest industrial base, although the current level of economic development is high, but due to

over-reliance on heavy industry, GDP growth is slow, because economic development is also one of the important drivers of regional CO₂ emissions. The slow growth of the economy to reduce the growth rate of CO₂ emissions and the average annual population growth rate in the Northeast. The stable growth of population size will also make a regional energy consumption tends to stabilize, so it is easier for the Northeast to peak emissions relative to the Middle and West.

Figure 16, The peak time and statistic of CO₂ in the A1B2C2 scenario

As shown in Figure 16, in scenario A1B2C2, China's CO₂ emissions peaked at 10.57 billion tons in 2030. CO₂ emissions from the East and Northeast peaked in 2025 and peaked in 2030 of the Middle and West . The East has the highest level of economic development, and the higher level of economic development also indicates a lower potential for economic growth. Compared with the lower level of economic

development in the Middle and West, the GDP growth rate in the East is also low. According to the Kuznets curve theory, when a region's economic development to a certain stage, carbon emissions may decrease, because of the high level of economic development. Therefore, the East's economic development process is closer to the Kuznets U-shaped curve inflection point, so the East is more likely to reach the peak.

In addition, the economic development degree of the Middle and West is low, the relationship between economic development and carbon emissions is closer to the first half of the Kuznets U-shaped curve, with the release of future economic development potential and the improvement of economic level. Economic development on the growth of carbon dioxide emissions will gradually decline, so the Middle and West need to achieve CO₂ emissions peak at a slower rate.

Peak time and peak of carbon dioxide per capita

As shown in Figure 17, in Scenario A1B2C2, the country's per capita CO₂ emissions will peak in 2025, peaking at 6.96 tons. The East peaked in 2015, the Northeast peaked in 2025, and the Middle and West regions will not peak until 2030.

Moreover, the table 10 shows that the higher the level of economic development in the four regions, the sooner the per capita carbon dioxide emissions peak. The four regions had the highest CO₂ emissions in the

Northeast and West, at 81 tons and 36 tons, respectively. The peak per capita CO₂ emissions in the eastern region will be earlier than their CO₂ emissions peak, a phenomenon caused by the high population growth rate in the eastern region (see Table 10). Zhu and others (2001) found that cross-provincial population growth was concentrated in the economically developed eastern regions. We can infer that rapid population growth will be one of the main reasons for delaying the peak of CO₂ emissions in the eastern region.

Table 10, Average population growth rate

Region	East	Middle	North-east	West
Population growth rate	1.24%	0.37%	0.18%	0.33%

Figure 17, The peak time and peak of CO₂ per capita in the A1B2C2 scenario

(Data from simulating results)

Under the A1B2C2 scenario, China's energy intensity will be 45% lower in 2030 than in 2015.

The magnitude of the decrease in carbon intensity

It is clear that the reduction in carbon intensity in the optimal scenario is much greater than our current emission reduction targets, and that the reduction in carbon intensity in the optimal scenario is similar to the results in the ambitious scenarios in the Liu and other (2018) 37 studies, i.e. by 2020 and 2030 Carbon intensity is 52.54 % lower than 2005 levels and 71.36% lower than 2005 levels, respectively) did not effectively limit global warming to 2 degrees Celsius. Stern and Green (2015) point out that it would be more effective for China to set a target of reducing carbon dioxide emissions by less than 10 billion tons (less than 7 tons per capita) by 2030 to keep global warming within 2 degrees Celsius. Therefore, setting stricter carbon intensity reduction targets is particularly important to prevent global warming and ensure that carbon emissions peak by 2030, as shown in table 11.

Table 11, Industrial energy intensity and energy structure

Industry	First Industry	Second Industry	Third Industry
Average annual decline in energy intensity 2005-2015 (%)	3.73%	3.42%	1.12%

Energy intensity in 2015 (tons of standard coal / 10,000 yuan)	2.36	13.09	3.73
Industrial structure in 2015 (%)	8.8%	40.9%	50.2%
Average energy intensity in 2015 (tons of standard coal / 10,000 yuan)	-	7.4	-
Average annual decline in energy intensity 2016-2030 (%)	3.73%+0.5%	3.42%+0.6%	1.12%+0.6%
Industrial structure in 2030 (%)	8%	32%	60%
Average energy intensity in 2030 (tons of standard coal / 10,000 yuan)		4.1	
Rate of decline during energy intensity 2016-2030 (%)		45%	

(Data source: China's Energy Outlook 2030)

As can be known from table 10, the average annual decline in energy intensity in the first, second and third industries in 2010-2019 was 3.73%, 3.42% and 1.12%, respectively. If the rate of decline in energy intensity of various industries increases by 0.5%, 0.6% and 0.6% in the future, the industrial structure will develop like Li Cedar and so on (2016) Year will reach 8%, 32%, 60%, China's energy intensity will be reduced by 45% compared to 2015, with the optimal situation A1B2C2 convergence, but lower than Yuan and other (2014) forecast. At the same time, the decline in energy intensity under the optimal scenario is lower than the historical (2005-2015) downward trend, so in improving the efficiency of energy use in various industries, but also to speed up the

optimization of industrial structure, enhance the proportion of output value of the tertiary industry in total output. In addition, if the energy structure is optimized, it is in line with Liu (2018). It is predicted that by 2030, non-fossil energy sources will account for 21% of China's energy consumption o China's carbon intensity will be 53.46 percent lower than in 2015, 72.7% lower than in 2005, exceeding the emission reduction target of 60%-65%.

Study on the impact factors of carbon emissions in four regions based on history and future

In this section, we will analyze the contribution of the CO₂ emission path from 2009-2030 using the broad Dix index decomposition method to the various CO₂ influence factors based on the optimal scenarios analyzed and find out the absolute contribution of the influence factors of regional historical trends (2006-2015) and forecasting trends (2016-2030).

As we can see from Figure 18-21, the absolute contribution of carbon emission factors in the four regions is very similar in size, but slightly different. Among the four regions, economic scale contributes the most to the growth of CO₂, while low carbon per unit of output contributes the most to CO₂ emission reduction, and energy efficiency, energy composition, economic development level and population size all contribute less to CO₂ emissions.

Analysis of the impact of economic regulation and economic development

Figure 18 shows that from 2006 to 2030, in addition to the West in the period of 2011-2015, the contribution of economic regulations to carbon emissions increased slightly, whether historical trends or forecast trends, the contribution of GDP to carbon emissions in the four regions has been decreasing annually. It shows that the contribution of economic scale to carbon emission growth under the optimal peak path will gradually decline.

During this period, the contribution of the four regional economic development levels to carbon emissions is directly negative, indicating that the improvement of regional economic development level does contribute to the reduction of carbon dioxide emissions. But in the historical interval and forecast range, the contribution of economic development level to carbon emission reduction is small, indicating that even under the optimal peak path, the improvement of economic development level is not the main factor driving carbon dioxide emission reduction.

Energy structure analysis of low carbon impact of energy structure and unit output value

Low carbon per unit of output, also known as carbon intensity, China currently plans to reduce carbon intensity by 60% to 65% by 2030 compared with 2006. This index is one of the main reference objectives of China's emission reduction policy.

Figure 18-21 show that carbon intensity contributes the most to CO₂ emissions reductions in the four regions, both in the regional historical range (2006-2015) and in the forecast range (2016-2030), while energy efficiency and energy structure contribute less. Thus, carbon intensity can be derived from the product of energy consumption per unit of GDP and carbon emissions per unit of energy consumption, which means the low carbon output per unit of output in the region is affected by the region's energy efficiency and energy structure, so we can infer that the indirect emission reduction contribution of energy efficiency and energy source structure is greater than its direct contribution, which should be attributed to the development of low-carbon production technology. Furthermore, the production of the same output value with less and less expected output, the low-carbon effect of economic development energy efficiency and optimization of energy structure will become more and more prominent. Therefore, it is particularly important to accelerate the upgrading of industrial structure in major regions, complete the transformation of medium- and high-carbon industries to low-carbon industries, and increase the development and introduction of low-carbon

production technologies to achieve indirect emission reduction contributions to energy efficiency and energy structure optimization.

Analysis of the scale of energy consumption and the impact of carbon dioxide per capita

From Figure 18-21, it is also easy to see that the four regions, whether in the regional historical range (2006-2015) or in the forecast range (2016-2030), the scale of energy consumption and the pull of carbon dioxide per capita on carbon emissions are declining, and the per capita CO₂ emissions in the East and Northeast regions have even contributed to emission reductions between the forecast areas. It can also be found that in the historical range, the scale of energy consumption and the absolute value of the contribution of carbon dioxide per capita during the 12th Five-Year Plan period compared with the 11th Five-Year Plan period, indicating that the clear emission reduction policies set during the 12th Five-Year Plan period have a better effect on curbing energy consumption and the growth of carbon emissions per capita.

Population size impact analysis

By Figure 18-21, the four regions are either in the historical range of each region (2006-2015) or in the forecast range (2016-2030). The contribution of the factors of population size change to the change of

carbon dioxide is small, and all three regions except the eastern region have contributed less to the change of population size in the forecast range, possibly because the factors of aging are taken into account in the prediction of population data, and the change in the growth of Chinese mouths is relatively small.

As a result, population changes contribute less to carbon emissions. On the other hand, due to the economic development and environment in the East is better (the highest level of economic development and the lowest low carbon per unit output value), and urbanized water level is higher, good economic development and environment for the population adsorption effect, population growth is slightly higher than the other three regions, and faster population growth will lead to more carbon demand, which will provide a positive contribution to the increase in carbon emissions.

Finally, due to the high level of urbanization in the East and the low level of urbanization in other regions, there may be a shift in the lifestyle of more people to a low-carbon lifestyle in the future urbanization process, which will make a positive contribution to regional emission reduction.

Figure 18, Contribution of CO₂ influence factors in the Eastern region under the optimal peak scenario

Figure 19, Contribution of CO₂ influence factors in the North East region under the optimal peak scenario

Figure 20, Contribution of CO₂ influence factors in the Middle region under the optimal peak scenario

Figure 21, Contribution of CO₂ influence factors in the Western region under the optimal peak scenario

Conclusions

This paper devotes itself to studying the concrete way for China to achieve its 2030 carbon emission peak and corresponding emission reduction targets. Considering the heterogeneity of China's regional development, based on the regional coordination development strategy of the four major sectors implemented in recent years, this paper reviews the historical trend of economic, population, urbanization and carbon

emission development in the four regions, and draws a number of scenarios for china's four major regions using scenario analysis and IPAT models combined with the forecast of authoritative institutions. Using The Centralized-DEA analysis method is used to evaluate the distribution efficiency and potential output efficiency of each peak scenario, and combined with the feasibility analysis, it is concluded that the optimal peak scenario A1B2C2 with both distribution efficiency and potential output efficiency is compared according to the carbon emission path of the area before and after the optimal scenario Centralized-DEA, and we find that the focus points of different regional emission reduction policies should be different. In order to better identify the evolution of the contribution of carbon emission factors in the region in the process of achieving peak, we used the broad Di's index decomposition method to dynamically analyze the contribution of carbon emission influence factors in the historical and forecasting ranges of the four regions. Through our analysis of the current situation of carbon emission development and optimal peak path in the four regions above, we draw the following conclusions.

When economic development reaches a higher level, there is no obvious positive correlation between CO₂ emissions per capita and the level of economic development. By comparing the Kuznets curves in the four regions, this paper finds that the positions of the environmental

Kuznets curves in each region are not consistent, but they are stable with the development of economy. The environmental Kuznets curve in the north-east region is at the top, which means that its economic development path is the least environmentally friendly, while the central region has the most environmentally friendly economic development path at the same level of economic development.

Through international comparison of the environmental Kuznets curve, it is found that even if China's GDP continues to grow at a high rate, China's carbon emissions are more likely to reach the peak target of 2030.

Energy intensity is a key determining factor in achieving a peak in CO₂ emissions. If the average annual rate of decline in energy intensity continues at China's 2009-2019 average, carbon emissions in all relevant scenarios will reach the peak target of 2030. If China's energy intensity is no higher than 2.5% down-rate development (B3 and B4), even if the energy structure optimization achieves the optimal scenario (C1), the economy is growing at a low rate (A3), China's carbon dioxide will not peak by 2030.

When China maintains high economic growth (AI scenario), energy intensity decline rate increases at the rate of 75% of China's average annual energy intensity decline rate from 2009 to 2019 (B2 scenario), and energy structure adjusts according to the forecast of the Energy

Technology Revolution Innovation Action Plan (2016-2030), through the analysis of CO₂ allocation efficiency and potential output efficiency, combined with previous studies and feasibility analyses. The AIB2C2 scenario will be the best way to achieve China's carbon emissions targets and international commitments. In the optimal peak scenario, China's carbon dioxide emissions will peak at 10.57 billion tons by 2030, while China will enter high-income countries by 2024.

Emission reduction space varies from region to region. In the forecast range of the optimal scenario, China's provincial carbon dioxide emissions will converge generally below average, and the eastern region will encounter bottlenecks in improving carbon intensity. At the same time, the Central and Western regions have more room to reduce carbon dioxide emissions, and increasing their CO₂ emission quotas will free up more potential production.

Economically developed areas will peak earlier. Under the optimal scenario, the higher the level of economic development in the four regions, the sooner the per capita CO₂ emissions and CO₂ emissions peak. The country's per capita CO₂ will take precedence over the carbon dioxide peak, population growth will be the main reason for delaying the peak of CO₂ emissions in the eastern region and the country. The east and north-east will peak carbon emissions by 2025 and the central and western regions by 2030.

Based on the study of the four regional carbon emission factors based on history and future, this paper finds that the absolute contribution of the four regions' influence factors is very similar in size, but slightly different. Of the four regions, economic scale contributes the most to the growth of CO₂ emissions, while low carbon per unit of output contributes the most to CO₂ emission reduction. Changes in energy efficiency, energy structure, economic development, and population size all contribute less to CO₂ emissions. In the historical trend, the regional economic scale, unit output value low carbon degree, energy consumption, per capita carbon emissions have contributed to the change of CO₂ emissions, and under the future path of the optimal scenario, only the economic scale, low carbon per unit output value have a greater contribution to the change of CO₂ emissions.

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1075 **Authors' contributions** The authors contributed to the study conception
1076 and design. Material preparation, search, and collection of relevant
1077 articles and reviews were performed by Dawei Wang and Wenxing Shen.
1078 The first draft of the manuscript was written by Dawei Wang. Wenxing
1079 Shen and Shengliang Zhang thoroughly checked the first draft. All
1080 authors have read and approved the final manuscript.

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1082 **Declarations**

1083 **Availability of data and materials** All the data and materials in the
1084 manuscript are resourced from our research and analysis , so they all can
1085 be Guaranteed available, creditable and editable.

1086 **Ethics approval and consent to participate** Not applicable

1087 **Consent of publication** Not applicable

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