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The Forecast and Analysis of Peak Carbon Dioxide Emissions in China

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Abstract: China's commitment to carbon emission peak in 2030 has been universally recognized by the international community, but some foreign research institutions and media still question whether China can reach the peak on time. In view of this, this article is based on the STIRPAT model, using national energy consumption and economic development data from 2000 to 2018, to predict China's carbon emission peak under five scenarios: low-carbon scenario, baseline scenario, high-energy consumption scenario, industrial structure optimization scenario, and technological energy saving scenario. The study found that: under the baseline scenario, China's carbon emission will reach peak in 2032, later than the 2030; under the low-carbon scenario, China's carbon emission will reach peak in 2028; and under the high-energy scenario, China's carbon emissions will peak in 2028. Carbon emissions cannot reach its peak before 2040; the peak year of the industrial structure optimization scenario and the technological energy-saving scenario are the same. The peak value of the industrial structure optimization scenario is 409 million tons lower.

Keywords: STIRPAT model; carbon emission; scenario analysis; carbon emission peak forecast

JEL Classification: C51; O14; Q56

1. Introduction

In the face of increasingly severe climate change and the resulting catastrophic impacts, how to effectively deal with global climate change and achieve win-win results in ecological environment and economic development is an important issue of general concern to all countries and regions. As the world's leading carbon emitter, China is also contributing to the fight against climate change and is committing to the world that "China's co-emissions efforts will peak by 2030 and achieve carbon neutrality by 2060".To this end, the Chinese government has formulated a policy system of '1+N' to achieve carbon peak and carbon neutrality from the national-regional-industry level, and has further promoted co-emissions from ten aspects, such as optimizing the energy structure, promoting industrial optimization and upgrading, developing circular economy and green finance, and promoting economic and social development based on the efficient use of resources and green and low-carbon development. We will accelerate the realization of green revolution in production and lifestyle, and push China's carbon peak target to be achieved by 2030.

The forecast analysis of China's carbon emission trends is now focused on the following two aspects. First, scholars use different economic models (Zhu Yongbin et al., 2009; Martin et al., 2016) or energy models (Jiang Kejun, 2009) to predict China's future carbon dioxide emissions. Using the STIRPAT model, Qu Shen-ning (2010) predicted the peak of carbon emissions in China in the future and concluded that if China's economic and social development while maintaining a continuous decline in carbon intensity, the peak time of carbon emissions should be between 2020 and 2045. Second, researchers analyze the carbon dioxide emission trend in China under different scenarios from the national level (Lin Boqiang et al., 2015), the regional level (Deng Xiaole et al., 2016; Pan Dong et al., 2021) and the industry level (Guo Juan et al., 2011; Guo Chaoxian, 2014; Liu Tian et al., 2015; Wang Yong et al., 2019). Yuan Xiaoling et al. (2020) forecast the carbon emissions peak of China's Ministry of Industry as a whole and eight sub-sectors, and believed that under the low-carbon scenario, all industries could reach the peak by 2030.

To sum up, scholars from different levels, and use a variety of forecasting models, came up with a lot of predictions about China's carbon emission peak and peak time, but specifically for the national level of carbon emission peak forecast, the existing literature set the peak scenario is more single and general, failed to accurately identify the structure and technology and other factors of the emission reduction effect. At the same time, existing literature has been used coal consumption as a proportion of primary energy consumption to set energy structure indicator, the assessment of the impact of energy structure may be biased. Therefore, on the basis of selecting the proportion of non-fossil energy as the index of energy structure, this paper effectively identifies the effect of structural factors and technical factors on China's carbon peak by refining the low, medium and high development scenarios at the national level.

2. Methodology

2.1 Model Building

Originally proposed by Ehrlich and Holden in 1971, the IPAT model is widely used to test the environmental impact of human activities, with the expression:

$$I = P \times A \times T \tag{1}$$

Among them, I represents environmental pressure, generally expressed in terms of resources energy consumption and greenhouse gas emissions; P indicates population size; A is the degree of affluence, in terms of the level of economic development; T stands for the level of technology.

However, formula (1) is only a simplified form of measuring environmental pressure, with certain limitations, it defaults that different factors contribute the same to environmental pressure, which contradicts the environmental Kuznets curve hypothesis. To overcome the limitations of this model, Dietz and Rosa (1997) based on the IPAT model and propose the STIRPAT model with the expression:

$$I = aP^{b}A^{c}T^{d}e \tag{2}$$

In order to facilitate the study, logarithms are generally taken on both sides of the model at the same time to obtain:

$$lnI = lna + blnP + clnA + dlnT + e \tag{3}$$

Where I represents environmental pressure, P represents population size, A indicates the degree of affluence, T represents technical level; a is the model coefficient, and b, c, d represent the elasticity coefficients of P, A and T respectively, and e is the error term.

In addition to population size, level of economic development and technology, environmental pressure is also affected by many social factors. In view of this, many scholars have expanded the STIRPAT model to include factors such as urbanization rate, industrial structure, energy structure and energy intensity. Therefore, on the basis of reference to previous studies, this paper selects population, per capita GDP, urbanization rate, industrial structure, energy intensity and energy structure as the factors affecting China's carbon emissions, and at the same time, in order to verify the nonlinear relationship between carbon dioxide emission and economic growth, the quadratic term of GDP per capita is added to the model, and the final expression of STIRPAT model is:

$$lnI = lna + blnP + clnA + d(lnA)^2 + flnU + glnIS + hlnEI + jlnES + lne \tag{4}$$

Where I represents carbon dioxide emission, P is population size, A is GDP per capita, U is urbanization rate, IS is industrial structure, EI is energy intensity, ES is the energy structure, a is the model coefficient, b, c, d, f, g, h and j are the elasticity coefficients of each variable, and e is a random error term.

Table 1. Description of China's carbon emissions forecast model variables

variable	symbol	indicator description	unit
carbon emissions	I	energy-related CO2 emissions	100 million tons
population size	P	year-end resident population	100 million people
GDP per capita	A	gross regional product/resident population	10 thousand yuan
urbanization rate	U	proportion of urban residents to the total population	%
industrial structure	IS	output value of the secondary industry / the GDP of the region	%
energy intensity	EI	energy consumption per unit of GDP	%
energy structure	ES	non-fossil energy consumption / the total energy consumption	%

2.2 Data Sources

This paper uses data at the national level from 2,000 to 2018, in which data on population size, GDP per capita, urbanization rate and industrial structure are derived from the China Statistical Yearbook, and data on energy consumption are derived from the China Yearbook of Energy Statistics, and the energy consumption is used to calculate the carbon dioxide emission at the national level from 2000 to 2018.

In order to calculate China's overall carbon emissions, this paper divides the carbon emissions from energy consumption into two parts, one is the direct carbon emissions from the combustion of eight fossil fuels, such as coal, coke, crude, gasoline, kerosene, diesel, fuel oil and natural gas, and the other is the indirect carbon emissions from electricity consumption. Referring to the calculation method in the IPCC National Greenhouse Gas Inventory Guide 2006 to measure the carbon emissions from China's energy consumption using the carbon emission coefficients of various energy sources, the specific calculation formula is as follows:

$$C = 44/12 \times \sum_{j=1}^{8} E_j \times F_j \times W_j \tag{5}$$

where C is carbon emissions, 44/12 represents the mass fraction of carbon in CO2, E_j is the consumption of the j-th energy source, and F_j is the jth the discount coal coefficient of the energy source; W_j is the carbon emission coefficient for the jth energy source. The discount coal coefficient and carbon emission coefficient for 8 types of energy and electricity are derived from the calculation of Li Xinyun et al. (2014).

Table 2. Discount coal and carbon emission coefficient for each category energy

	coal	**coke**	**crude**	**gasoline**	**kerosene**	**diesel fuel**	**fuel oil**	**natural gas**	**electricity**
The discount coal coefficient	0.7143	0.9714	1.4286	1.4714	1.4714	1.4571	1.4286	1.33	0.1229
Carbon emission coefficient	0.7559	0.8556	0.586	0.5538	0.5743	0.5919	0.6185	0.4483	0.2678

3. Results

3.1 Analysis of Regression Result of STIRPAT Model

Considering the multicollinearity between the influencing factors in the STIRPAT model, this paper fits the model through ridge regression, which improves the algorithm based on the least squares method and eliminates the collinearity between factors by adding factor k to the main diagonal of the elements of the standardized matrix, thus effectively improving the estimated stability.

Using SPSS26 to regress the model and observe the ridge trace diagram, it can be found that when k is 0.1, the change of the respective variable ridge map tends to be stable, the decisive coefficient of the model R2 is 0.986, and the Goodness of Fit is high. It is shown that the model regression is ideal, and the regression result is:

$$\begin{aligned} lnI = 4.3798lnP + 0.211lnA + 0.0482(lnA)^2 + 2.4703lnU + 4.888lnIS \\ - 0.3559lnEI - 1.8028lnES - 9.8675 \end{aligned} \tag{6}$$

Through the results of the regression, it can be found that the population, per capita GDP, industrial structure and urbanization rate have positive impact on carbon emissions, especially the population and industrial structure have a strong positive impact on carbon emissions, and for every 1% increase in population and industrial structure, carbon emissions will increase by 4.3798% and 4.88% respectively. The coefficient of energy structure is negative, which indicates that the increase of non-fossil energy consumption can effectively reduce carbon emissions. The square term coefficient of GDP per capita is positive, indicating that there is no significant "inverted U" relationship between carbon emissions and economic growth.

3.2 Settings for Different Carbon Emission Scenarios

In order to explore China's carbon emission path under different economic development situations, this paper uses scenario analysis to forecast China's future carbon emissions. First of all, set the change range of population, per capita GDP, urbanization rate, industrial structure, energy structure and energy intensity according to the low, medium and high values, and then according to the magnitude of change to calculate the prediction of the various factors, and finally substitute the forecast value of each factor into the regression model to obtain the predicted value of carbon emission. In the median, the rate of change for each influencing factor from 2021 to 2025 is set in reference to the 14th Five-Year Plan and the rate of change after 2025 is set by reference to the 2035 long-term plan. After that, the median is adjusted appropriately to obtain the rate of change of the influencing factors in the low and high values. Five scenarios are created based on three different levels of change, as shown in Table 3.

Table 3. Settings of carbon emission scenarios

scenario setting	**Level of change**					
	population size	**GDP per capita**	**urbanization rate**	**industrial structure**	**energy intensity**	**energy structure**
low-carbon	low	low	low	low	low	low
the benchmark	middle	middle	middle	middle	middle	middle
high energy consumption	high	high	high	high	high	high
the optimization of industrial structure	middle	middle	middle	low	middle	middle
technology energy-saving	middle	middle	middle	middle	low	low

Table 4. the fluctuation range of the main influencing factors

fluctuation range of variables	**year**	**rate of change**					
		population size	**GDP per capita**	**urbanization rate**	**industrial structure**	**energy intensity**	**energy structure**
low value	2021-2025	0.15%	5.00%	1.00%	-1.00%	-4.00%	5.00%
	2026-2030	0.00%	4.50%	0.50%	-0.75%	-2.00%	4.50%
	2031-2040	-0.15%	4.00%	0.30%	-0.35%	-1.00%	4.00%
median	2021-2025	0.20%	5.00%	1.50%	-0.75%	-3.50%	4.50%
	2026-2030	0.05%	4.00%	1.00%	-0.50%	-1.50%	4.00%
	2031-2040	-0.10%	3.00%	0.50%	-0.10%	-0.50%	3.50%
high value	2021-2025	0.25%	5.50%	2.00%	-0.50%	-3.00%	4.00%
	2026-2030	0.10%	4.50%	1.50%	-0.25%	-1.00%	3.50%
	2031-2040	-0.05%	3.50%	1.00%	-0.05%	-0.25%	3.00%

The change rate of each influencing factor is set at the median level in the benchmark scenario. Assuming that the variables grow at a moderate rate, and the specific setting of the change rate of each influencing factor refers to the development goals formulated in the 14th

Five-Year Plan to reflect the smooth operation of China's future economic development. Low-carbon scenarios and high-energy consumption scenarios are adjusted under benchmark scenarios. At the same time, the optimization scenario of industrial structure is to keep the industrial structure at a low level, and the change rate of other influencing factors is set to the median level, while the technology upgrading scenario is to set the energy intensity and energy structure at a low level, and the other influencing factors to maintain the median level. The change in the growth values of each variable in different scenarios is shown in Table 4.

4. Prediction and Analysis of China's Carbon Emission Peak

4.1. Prediction and Analysis of China's Carbon Emission Peak in Different Scenarios

According to the regression results of STIRPAT model, China's carbon emissions in 2018-2040 under different scenarios are calculated, as shown in Figure 1. It can be seen that there are differences in peak carbon dioxide emissions time and peak value in different scenarios. Under the benchmark scenario, China's carbon emissions will reach the peak in 2032, with the peak value of 17.417 billion tons. The peak time of the benchmark scenario is later than the target time of peak in 2030, which indicates that if the current policy trend is followed, China will not be able to achieve the peak target as scheduled.

The peak situation of low-carbon scenario and high-energy scenario is quite different. Under the low-carbon scenario, China's carbon emissions will reach the peak of 15.27 billion tons in 2028, while under the high-energy scenario, China's carbon emissions will not reach the peak before 2040. As far as the low-carbon scenario is concerned, because all factors affecting carbon emissions are low, the peak time of carbon emissions is earlier than that of the baseline scenario, and the peak value is 2.147 billion tons lower than that of the baseline scenario. The high-energy consumption scenario is just the opposite to the low-carbon scenario. Under the condition that all the influencing factors are high, the carbon emissions are increasing year by year, and have not reached the emission peak before 2040, which indicates that the extensive development model aiming at economic growth is far from achieving the peak target in 2030.

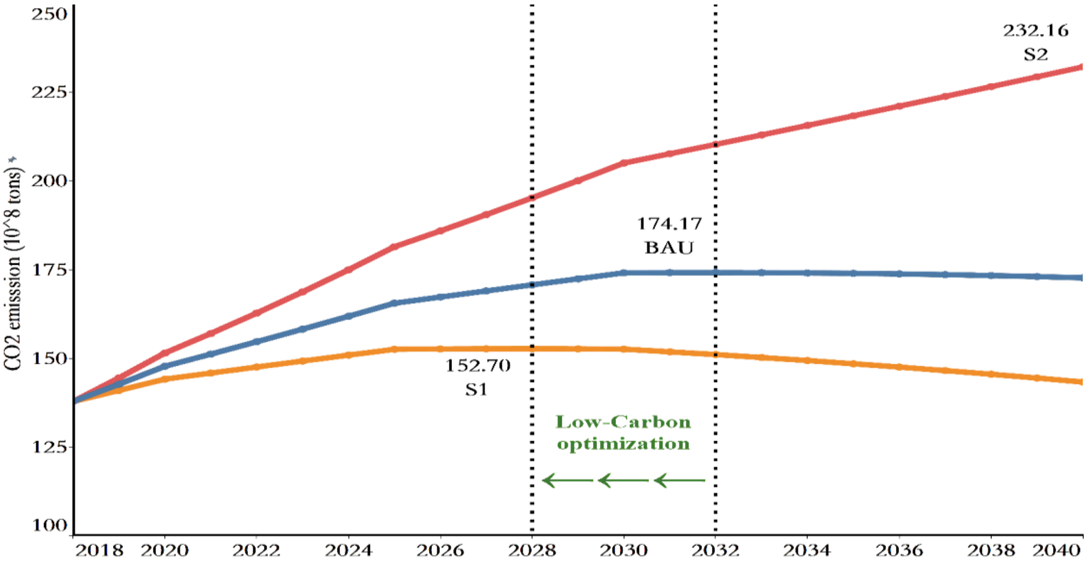

Figure 1. Trend forecast of China's carbon dioxide in the low carbon-benchmark-high energy consumption

Secondly, Figure 2 shows the prediction and analysis results of technical energy-saving scenarios and structural optimization scenarios. It can be seen that the peak years of the industrial structure optimization scenario and the technical energy saving scenario are the same, and the carbon emissions will reach the peak in 2030, with the peak values of 17.152 billion tons and 16.743 billion tons respectively. Compared with the baseline scenario, it is found that the industrial structure optimization scenario makes the peak time of China's carbon emissions advance by two years, which is in line with the target of 2030, and the peak value is reduced by 265 million tons compared with the peak value under the baseline scenario, which indicates that on the basis of the existing development plan, the traditional industries can be optimized and upgraded by curbing the blind development of industries with high energy consumption and high emissions, so that China's carbon emissions can reach the peak value in 2030 as expected. Compared with the baseline scenario, China's peak carbon dioxide emissions time under the technical energy-saving scenario is also two years ahead of schedule, reaching a peak value of 16.743 billion tons in 2030, which is 674 million tons lower than that under the baseline scenario. This shows that the increase of the proportion of non-fossil energy and the improvement of energy consumption efficiency play an important role in realizing China's peak carbon dioxide emissions path. At the same time, it is worth noting that although both the industrial structure optimization scenario and the technological energy-saving scenario will peak in 2030, there are differences in their peak values, and the technological energy-saving scenario is 409 million tons lower than the peak value of the industrial structure optimization scenario, which shows that the effect of technology on carbon emission reduction is greater than that of industrial structure adjustment.

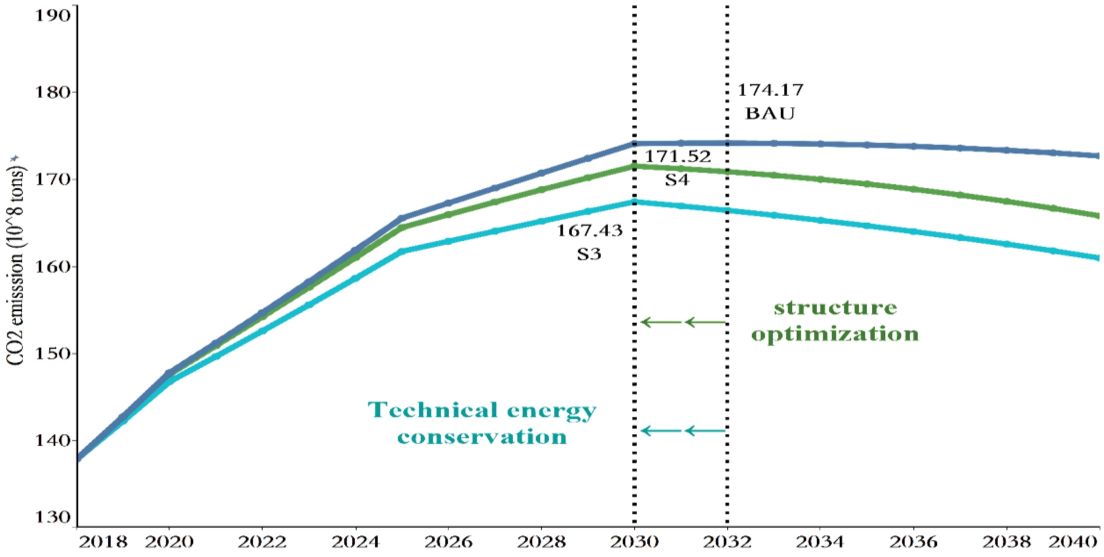

Figure 2. Trend prediction of carbon dioxide in China under different scenarios

4.2. *Comparative Analysis of China's Carbon Emission Reduction Potential under Different Scenarios*

By comparing the peak value in different scenarios with the baseline scenario, it can be found that the emission reduction potentials of low-carbon scenarios, industrial structure optimization scenarios and technology-saving scenarios are quite different. The low-carbon scenario has the greatest emission reduction potential of 2.147 billion tons, and its emission reduction potential far exceeds that of other scenarios adjusted and optimized based on the baseline scenario, as shown in Table 5. It can be seen that the emission reduction potentials of the industrial structure optimization scenario and the technical energy-saving scenario are relatively small, which are 265 million tons and 674 million tons respectively, which indicates that the emission reduction effect brought by single or partial factor changes is not significant compared with the comprehensive adjustment of the change levels of various factors affecting China's carbon emissions, and the policies set for industrial structure and technological development may be ineffective, thus affecting the realization of China's peak carbon dioxide emissions goal in 2030.

Table 5. The peak year, peak value and emission reduction potential of China's carbon emissions under different scenarios

Scenario	Peak year	Peak/100 million tons	Emission reduction potential/hundred million tons
Low-carbon	2028	152.7	21.47
Benchmark	2032	174.17	/
High energy consumption	Didn't reach the peak before 2040	/	/
Industrial structure optimization	2030	171.52	2.65
Technical energy-saving	2030	167.43	6.74

5. Conclusions and Policy Implications

Based on STIRPAT model, this paper uses the data of energy consumption and economic development from 2000 to 2018 at the national level, and according to the government's recent development plan and the forecast of future development trend, sets up five different development scenarios to predict the peak time and peak value of China's overall carbon emissions. The results show that under the baseline scenario, China's carbon emissions will reach the peak in 2032, with the peak value of 17.417 billion tons, and the peak time will be later than 2030. Under the low-carbon scenario, China's carbon emissions will reach its peak in 2028, with the peak value of 15.27 billion tons. Under the scenario of high energy consumption, China's carbon emissions will not reach the peak before 2040; The peak years of the industrial structure optimization scenario and the technical energy-saving scenario are the same, and the carbon emissions will reach the peak in 2030, which is lower than that of the benchmark scenario, which is 17.152 billion tons and 16.743 billion tons respectively, and the technical energy-saving scenario is 409 million tons lower than that of the industrial structure optimization scenario.

In view of the current situation and trend analysis of China's carbon emissions, this paper puts forward the following policies to further serve China's 30-60 carbon targets, as follows:

First, optimize the industrial structure and develop a low-carbon economy. The government actively guides the optimization, upgrading and technological transformation of traditional industries to improve the energy utilization efficiency of traditional industries; Vigorously cultivate sustainable industrial development and promote low-carbon industrial development. Secondly, vigorously promote green and clean energy and speed up the adjustment of energy structure. Advocate the use of clean energy, increase the proportion of renewable energy, reduce the dependence on fossil energy such as coal, encourage enterprises to develop and use clean energy, and subsidize polluting industries with low-carbon transformation, so as to optimize energy utilization structure and improve emission reduction efficiency. Finally, improve the implementation and efficiency of emission reduction policies. Government environmental departments should strengthen the inspection and supervision of environmental quality and strengthen the construction of law enforcement ability; Considering the economic development and environmental carrying capacity, the implementation efficiency of emission reduction policies in different situations will be continuously improved.

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Conflict of interest: none

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