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A Study on Carbon Emission Peak Forecast of China's Industrial Sector and Carbon-intensive Industries

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Abstract: The industrial sector is China's pillar industry and a major carbon dioxide emitter. Predicting the time and peak value of China's industrial sector carbon emissions under different scenarios has important reference value for China's 2030 carbon emissions peak target. This article is based on the STIRPAT model, using industry-level energy consumption and economic development data from 2000 to 2018, to analyze the overall performance of China's industrial sector and four carbon-intensive industries under five scenarios: low carbon, baseline, high energy consumption, scale adjustment, and technical energy conservation. The peak time and peak value were predicted. The study found that under the baseline scenario, neither the industrial sector nor the various carbon-intensive industries can achieve a carbon emission peak in 2030. However, under the low-carbon scenario, the industrial sector and all carbon-intensive industries can achieve a carbon emission peak in 2030. At the same time, compared with the baseline scenario, the scale adjustment and technical energy conservation scenarios can also advance the carbon emission peak time of the industrial sector. In order to fulfill the carbon emission peak commitment on time, the government should formulate appropriate emission reduction policies based on the specific conditions of each industry to ensure high-quality economic development.

Keywords: industry; carbon emission peak; STIRPAT; scenario analysis

JEL Classification: C51; O14; Q56

1. Introduction

The latest report issued by the United Nations Intergovernmental Panel on Climate Change (IPCC) shows that even in the best case of substantial emission reductions, the global temperature increase may temporarily reach 1.5℃ within 20 years. Scientists say that if carbon emissions are not "immediately, rapidly and massively reduced", the goal of controlling global temperature rise to 1.5℃ or even 2℃ higher than pre-industrial levels by 2100 will be "unachievable." In order to cope with the increasingly severe climate problem, countries around the world have successively proposed the goal of achieving "net zero emissions" by the middle of this century. As the world's largest carbon emitter, China is actively making its own contribution to combating global climate change. On September 22, 2020, China's President Xi Jinping announced at the General Debate of the Seventy-fifth United Nations General Assembly: "*China will increase its nationally determined contributions, adopt more powerful policies and measures, and commit to reaching the carbon emission peak by 2030.*

Meanwhile, China will strive to achieve carbon neutrality by 2060." Although China's "dual carbon goal" commitment has received widespread attention and appreciation from the international community, at the same time, the carbon emission peak goal will also impose strict standards for China's energy conservation and emission reduction. In order to reach the goal of carbon emission peak and carbon neutrality on schedule, the government urgently needs to introduce various emission reduction policies. However, the construction of the government policy system needs to be based on science. The achievement of the peak goal not only depends on the application and promotion of various emission reduction technologies, but more importantly, the establishment of scientific and reasonable guidance plans for emission reduction paths (Shi et al., 2021). The industrial sector has been playing the dominant role in China's carbon emission, the annual carbon emissions of the industrial sector account for more than 70% of the country's total carbon emission (Yuan et al., 2020). Whether the industrial sector can achieve carbon emission peak is significance to the realization of China's overall carbon emission peak. Therefore, it is important to explore the peak time and peak value of China's industrial sector by setting different peak scenarios. This will not only help various industries to formulate countermeasures in advance, but also improve the governance capacity of the government to promote the high-quality development of China's economy (Li et al., 2021).

At present, scholars mainly use environmental Kuznets curve, IPAC model, STIRPAT model, grey measurement method when predicting the peak of carbon emissions. Zhu Yongbin et al. (2009) improved on the Moon-Sonn endogenous economic growth model and substituted the energy intensity under technological progress obtained from the input-output analysis into the model. They believed that at the current rate of technological progress, China will reach the peak of energy consumption and carbon emission in 2043 and 2040, respectively; Ma et al. (2016) based on the energy system optimization model, and set up scenarios according to the target of 2030 carbon emission peak, and researched that China will achieve the peak of carbon emission in 2030; Jiang et al. (2009) used the IPAC model to analyze China's future energy and greenhouse gas emission scenarios, and the results showed that under the baseline scenario, China's carbon emission from burning fossil energy will reach its peak in 2040; Qu et al. (2010) used the STIRPAT model to predict the peak of China's carbon emission in the future. It is believed that if China keeps its carbon emission intensity declining while economic and social development, the peak time for carbon emissions should be between 2020 and 2045; Lin et al. (2011) used the GM (1,1) gray forecast model to predict the trend and peak time of carbon emission in Taiwan, China. Regarding the research scale of carbon emission peak, scholars generally conduct research from the level of countries, regions, and industries. At the national level, through model prediction and scenario analysis, Lin (2015) believe that China will achieve a carbon emission peak before 2030, while Li and Liu et al. (2018) analyzed a variety of scenarios and believed that China's goal of carbon peaking by 2030 is very challenging; At the regional level, Pan et al. (2021) set up different scenarios for 11 provinces in eastern China. The study found that the overall carbon emissions in the eastern region can reach a peak around 2030; Deng et al. (2016) used the STIRPAT model to forecast carbon emission peak of the five northwestern provinces. It is believed that if the carbon emission intensity is maintained at a reasonable decline, the five northwestern provinces will be able to reach the peak before 2030; At the industry level, Yuan et al. (2020) have predicted the peak carbon emissions of China's industrial sector and eight major sub-sectors. Under the low-carbon scenario, each industry can reach its peak before 2030; Wang et al. (2017) conducted scenario predictions on 9 major sub-sectors of China's industrial sector and the peak scenarios are quite different.

In summary, scholars started from different levels and used various forecasting models to get a lot of prediction results on the peak and time of China's carbon emissions. However, in the industry-level prediction, the peaking scenarios set in the existing literature are relatively simple and general, failing to accurately identify the emission reduction effects of influencing factors such as scale and technology. Moreover, previous studies have not studied the peaking of emission in carbon-intensive industries. Therefore, on the one hand, this article has effectively identified the effects of scale and technical factors on China's industrial sector by refining the low, medium, and high scenario settings at the industry level in previous studies; on the other hand, this article has filled the gap in the research on the peak of carbon in China's carbon-intensive industries.

2. Methodology

2.1. Model Buliding

IPAT model was first proposed by Ehrlich and Holden in 1971, which is widely used to test the impact of human activities on the environment. The basic expression is:

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

where, I represents environmental pressure, which is generally expressed in terms of resource and energy consumption or greenhouse gas emission. P is population size; A is the degree of affluence, represented by the level of economic development; T stands for technical level. However, this equation is only a simplified form of measuring environmental pressure, which has some limitations. It assumes that different factors have the same contribution to environmental pressure, which is inconsistent with the hypothesis of environmental Kuznets curve. In order to overcome the limitations of this model, Dietz and Rosa (1997) proposed STIRPAT model based on IPAT model, whose expression is:

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

In order to facilitate empirical research, logarithms of both sides of the model are generally taken to obtain:

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

where, I represents environmental pressure, P represents population size, A represents affluence, and T represents technology level. a is the model coefficient, b, c and d are the elastic coefficients of P, A and T respectively, and e is the error term.

In addition to population size, economic development level and technological level, environmental pressure is also influenced by many social factors. In view of this, many scholars have extended STIRPAT model by adding factors such as urbanization rate, industrial structure, energy structure and energy intensity into the model. Therefore, referring to previous studies, this paper selected total industrial output value, year-end population, industrial energy consumption structure and industrial energy intensity, to predict the peak carbon emissions of China's industrial sector. When forecasting the carbon emission peak of different industries, four variables were selected: total industry output value, total population at the end of the year, industry energy consumption structure, and industry energy intensity. At the same time, in order to verify the nonlinear relationship between carbon dioxide emissions and economic growth, The quadratic term of GDP per capita is added to the model, and the final STIRPAT model expression is:

$$lnI_i = lna + blnIGDP_i + clnPOP + d(lnperGDP)^2 + flnES_i + glnEI_i + lne \quad (4)$$

where, I_i represents the carbon emission of *i* industry, $IGDP_i$ is the total industrial output value of *i* industry, POP is the total national population at the end of the year, $perGDP_i$ is the per capita GDP , ES_i is the energy consumption structure of *i* industry, EI_i is the energy intensity of *i* industry, *a* is the model coefficient, *b, c, d, f* and *g* are the elastic coefficients of each variable, and *e* is the random error term.

2.2. Scenario Settings

In order to study the carbon emission path of China's industrial sector, this article uses scenario analysis to predict the future carbon emissions of China's industrial sector.

Baseline scenario: In the baseline scenario, the rate of change of each influencing factor is set at the median level, and the specific setting of the rate of change of each influencing factor refers to the development goals set in the "14th Five-Year Plan". For example, since policymakers have shifted from simply pursuing economic growth to pursuing high-quality economic development, the annual economic growth rate is set to float around 5%. In terms of population, China has begun to implement the three-child policy, and it is expected that the population growth rate will increase.

Low carbon scenario: In the low-carbon scenario, the rate of change of each influencing factor is set at a low level. Under this scenario, the government implements a relatively strict low-carbon development policy, it will reduce energy intensity and at the same time increase the proportion of clean energy in energy consumption, so energy intensity and energy structure are both set to low values, and lower energy intensity will influence economic growth to a certain extent, so per capita GDP is also set to low value.

High energy consumption scenario: In the high energy consumption scenario, the change rate of each influencing factor is set at a high value level. Due to the huge impact of the epidemic in 2020, in order to stimulate economic development, the government may adopt a more extensive economic development model and relax restrictions on the development of the energy and resources industry.

Scale adjustment scenario: Under the scale adjustment scenario, the population size and the total output value of the industry are set at the low level, and other factors are kept at the median level. In this scenario, although the government has implemented the three-child policy, the population size is at a low value due to the increase in living costs, which has not stimulated residents' willingness to have children.

Technical energy conservation scenario: In the technology improvement scenario, the energy intensity and energy structure are set at a low level, and other influencing factors are kept at a medium level. In this scenario， the government actively supports the development and utilization of technologies related to renewable energy, therefore, energy intensity and energy structure are at low value.

Table 1. Scenario setup for China's industrial sector

Scenarios	**Variation trend**				
	POP	IGDP	PerGDP	EI	ES
BAU	Medium	Medium	Medium	Medium	Medium
Low-carbon (S1)	Low	Low	Low	Low	Low
high energy consumption (S2)	High	High	High	High	High
Scale adjustment (S3)	Low	Low	Medium	Medium	Medium
Technical energy conservation (S4)	Medium	Medium	Medium	Low	Low

2.3. Data Sources

In this paper, the data of China's industrial sector from 2000 to 2018 are taken as samples. The total industrial output value, population size, per capita GDP and other data come from China Statistical Yearbook. The energy consumption data were derived from the China Energy Statistical Yearbook, and were used to measure industry-level CO2 emissions from 2000 to 2018.

In order to calculate the carbon emissions of China's industrial sectors, this paper divides the carbon emissions generated by energy consumption into two parts, one is the direct carbon emissions generated by the combustion of coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil and natural gas, and the other is the indirect carbon emissions generated by electricity consumption. According to the calculation method in IPCC Guidelines for National Greenhouse Gas Inventory 2006, the carbon emission coefficient of various energy sources is used to calculate the carbon emission generated by energy consumption in China's industrial sector. The specific calculation formula is as follows:

$$C_i = 44/12 \times \sum_{i=1}^{8} \sum_{j=1}^{8} E_{ij} \times F_j \times W_j \quad (5)$$

where, C_i is the carbon emission of *i* industry; 44/12 represents the mass fraction of carbon element in CO2; E_{ij} is the consumption of the *j* energy in *i* industry; F_j is the standard coal coefficient of *j* energy; W_j is the carbon emission coefficient of the *j* energy.

3. Results

3.1. Results of STIRPAT Model

Taking into account the multicollinearity existing between the various influencing factors in the STIRPAT model, this paper uses ridge regression to fit the model. Ridge regression improves the algorithm based on the least squares method. The factor K is added to eliminate the collinearity between the factors, thereby effectively improving the stability of the estimation. Using SPSS26 to regress the above model, the K value and model related parameters of the industry as a whole and each industry are obtained. As shown in Table 2.

Table 2. Results of ridge regression and STIRPAT analyses for China's industry

Sectors	K	POP	IGDP	PerGDP	EI	ES	a	R^2
Industry	0.01	6.2294	0.3029	0.0309	0.0950	3.0052	-25.1983	0.99
Oil industry	0.2	4.5386	0.1403	0.1004	0.0846	0.5236	-10.8524	0.98
Chemical industry	0.1	2.9940	0.1132	0.0694	0.0701	1.3725	-11.3868	0.98
Steel industry	0	7.3246	0.4630	-1.1161	0.0395	0.3498	-18.2842	0.99
Power industry	0.1	3.3840	0.1212	0.0732	0.1099	7.3360	-38.9658	0.99

Through regression, it is found that population has the greatest impact on the carbon emissions of China's industrial sectors, and the impacts of the industry sector's total output value and per capita GDP are also in line with expectations; in different industries, the impact of energy intensity on carbon emissions is not the same. It may be related to the characteristics of various industries; the impact of energy structure on carbon emissions is in line with expectations, that is, a reduction in the proportion of coal in fossil energy consumption can significantly reduce carbon emissions.

3.2. Results of China's Industrial Sector Carbon Emission Forecasts

Based on the ridge regression equation of the China's industrial sector and different industries, combined with the previous five scenarios (baseline scenario, low-carbon scenario, high energy consumption scenario, scale adjustment scenario and technical energy conservation scenario), the carbon emissions of China's industrial sector from 2020 to 2040 is predicted, and the specific results are described. See Figure 1 and Figure 2.

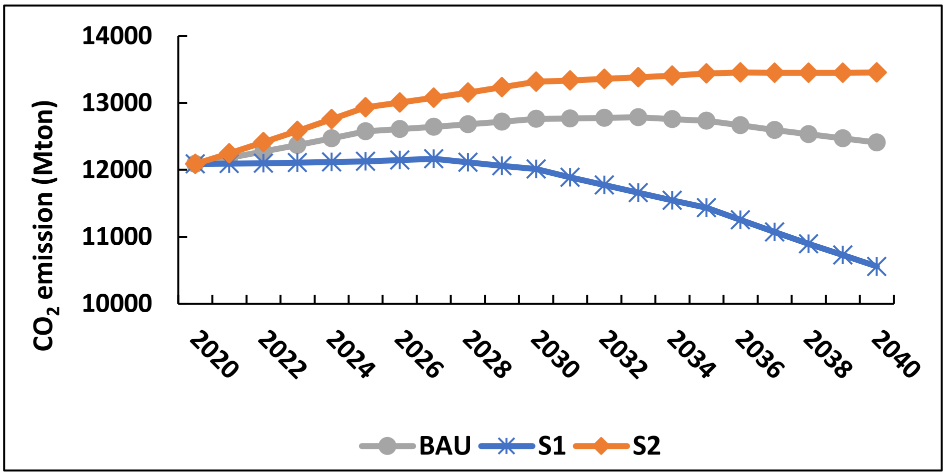

Figure 1. The carbon emission trend of China's industrial sector in BAU-S1-S2 scenarios

It can be seen from Figure 1 that the gap between the peak value and the peak year of China's industrial sector's overall carbon emissions is relatively obvious under different emission reduction efforts. Among them, in the baseline scenario, the overall carbon emission peak of China's industrial sector is 12.786 billion tons, which will reach the peak in 2033, and the carbon emission peak time will be later than 2030; in the low-carbon scenario, the carbon emission peak will be 12.166 billion tons in 2027, the carbon emission peak time is slightly earlier than 2030, and the set goal of carbon emission peak can be achieved; and under the high energy consumption scenario, the carbon emission peak will not be achieved before 2040. This result shows that under the current established emission reduction efforts, it is difficult for China's industrial sector to achieve carbon emission peak on time. Only by strengthening emission reduction efforts can carbon emission peak be achieved before 2030.

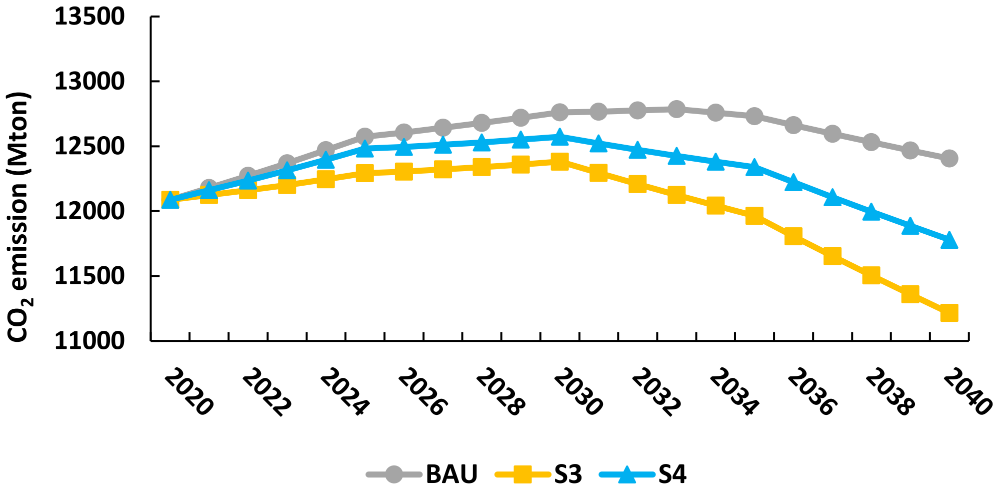

Figure 2. The carbon emission trend of industrial sector in BAU-S3-S4 scenarios

According to the analysis of the previous content, we found that the goal of carbon emission peak in 2030 can only be achieved by strengthening the reduction of emissions. Therefore, in this section, we adjust the scale and the influence of technical factors according to the baseline scenario. It can be seen from Figure 2 that both in the scale adjustment scenario or in the technical energy conservation scenario, the carbon emission peak can be effectively reduced and the goal of reaching the carbon emission peak in 2030 can be achieved. However, the difference between the two scenarios lies in the amount of emission reductions value. In the scale adjustment scenario, the peak value of carbon emission is 12.382 billion tons, and in the technical energy conservation scenario, the peak value of carbon emission is 12.573 billion tons. Compared with technical energy conservation scenario, scale adjustment can achieve more carbon emission reduction. The reason for this performance may be that China's population size and economic aggregate have a large volume. In the future emission reduction process, we need to adopt both scale adjustment and technical energy conservation methods. Only by taking a two-pronged approach can emission reduction be achieved more efficiently. In addition, considering the size of China's population and economic aggregate, scale adjustment may not be easy. Therefore, the way of technical energy conservation is worthier of our attention.

3.3. Results of China's Carbon-intensive Industries' Carbon Emission Forecasts

In order to further explore the carbon emission peak of different industries, four different carbon intensive industries' carbon peak situation are forecasted, and the five scenarios (baseline scenario, low-carbon scenario, high energy consumption scenario, scale adjustment scenario and technical energy conservation scenario) of the oil industry, chemical industry, steel and power industry are compared.

- The analysis of oil industry carbon emission trend

  As an energy industry sector that extracts oil (including oil, oil shale and natural gas) and refines it, the oil industry produces a large amount of carbon dioxide emissions. As shown in Figure 3, in the five scenarios, the oil industry cannot reach the carbon emission peak before 2030; in the high energy consumption scenario, it cannot reach the carbon peak before 2040; in the baseline scenario, low carbon scenario, scale adjustment scenario and technical energy conservation scenario, it can reach the carbon emission peak before 2040. Due to the characteristics of oil industry, its carbon dioxide emission reduction needs to rely on the development of new energy and the raise of energy efficiency.

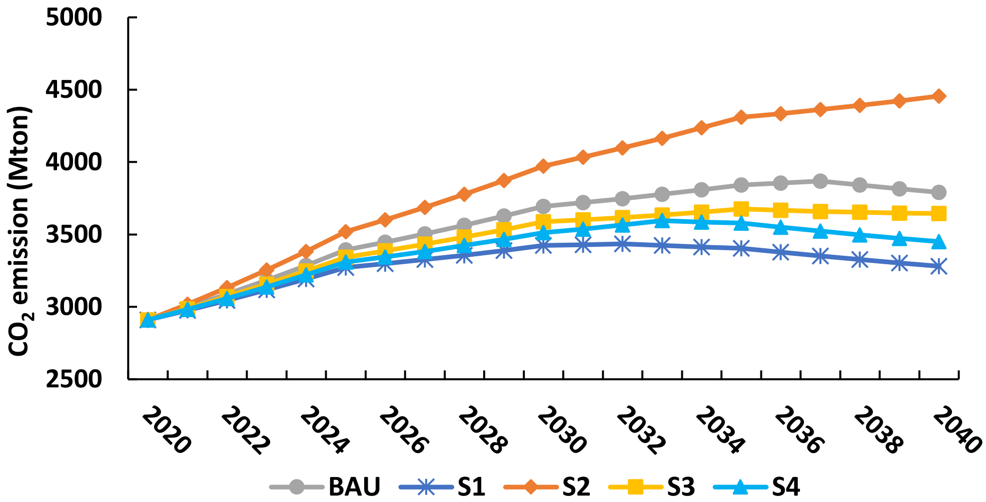

Figure 3. The carbon emission trend of oil industry in BAU-S1-S2-S3-S4 scenarios

- The analysis of chemical industry carbon emission trend

  The chemical industry is the country's basic industry. The development speed and scale of the chemical industry have a direct impact on all sectors of the society and economy. Due to the diverse categories and product of the chemical industry, it emits various and toxic gas. Therefore, the chemical industry is a big emitter. The sustainable development of the chemical industry has important practical significance for human economic and social development. As shown in Figure 4, The chemical industry can achieve a carbon emission peak in 2030 under the low-carbon scenario, and achieve the carbon peak target by 2040 under the baseline scenario, scale adjustment scenario, and technical energy conservation scenario, and under the high energy consumption scenario, it failed to achieve carbon emission peak before 2040. The chemical industry’s carbon emission reduction is under great pressure. Although it produces less carbon emissions compared to the oil industry, due to the complexity of the industry and the special status of the industry, it is necessary to consider a variety of emission reductions in order to achieve carbon emission reduction.

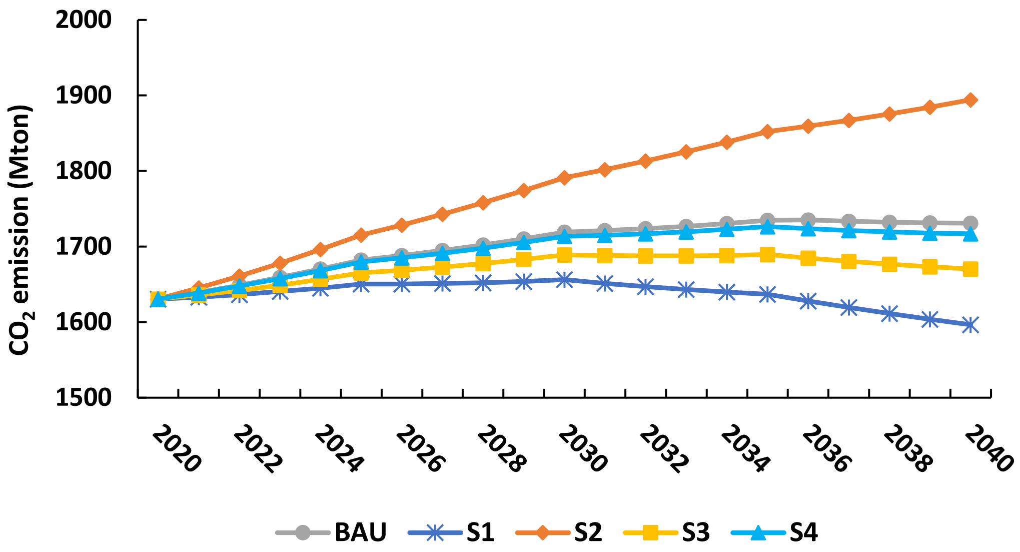

Figure 4. The carbon emission trend of chemical industry in BAU-S1-S2-S3-S4 scenarios

- The analysis of steel industry carbon emission trend

The steel industry is an industry that is mainly engaged in industrial production activities such as ferrous metal mineral mining and ferrous metal smelting and processing, including mineral mining and dressing of metallic iron, chromium, manganese, ironmaking, steelmaking, and steel processing industries. Ferroalloy smelting industry, steel wire and its products industry and other sub-sectors, is one of the country's important raw material industries.

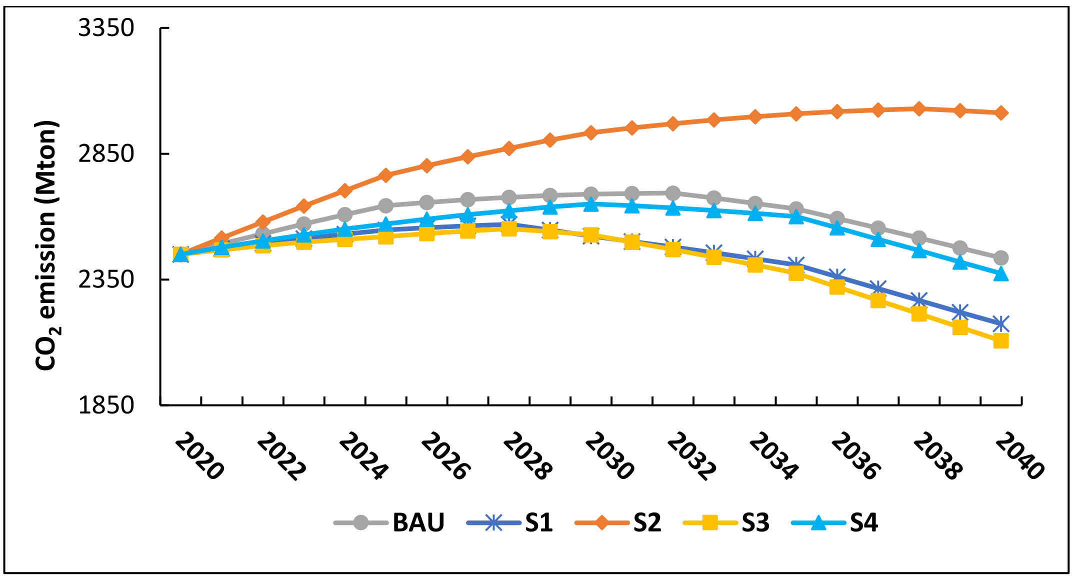

Figure 5. The carbon emission trend of steel industry in BAU-S1-S2-S3-S4 scenarios

As show in Figure 5, according to carbon emission trend forecasts, the steel industry can achieve carbon emission peak before 2030 under low-carbon scenarios, scale adjustment scenarios, and technical energy conservation scenarios, and achieve carbon emission peak before 2040 under baseline scenarios and high energy consumption scenarios. Since China's steel industry has been developing under a situation of overcapacity and weak demand since 2013, the reduction of emissions in the steel industry should consider methods such as resolving overcapacity, carrying out structural restructuring, increasing product innovation, and promoting green development.

- The analysis of power industry carbon emission trend
  As an industry that produces, transmits and distributes electric energy, the power industry mainly relies on coal, oil, natural gas and other fossil energy sources for its raw materials. Therefore, this industry will produce a large amount of carbon dioxide emissions, which leads to great pressure on emission reduction. As show in Figure 6, the power industry can only achieve the carbon peak goal in 2030 under the low carbon scenario, and can achieve the carbon peak goal in the near time after 2030 under the baseline scenario, scale adjustment scenario and technical energy conservation scenario, and can't achieve the carbon emission peak goal before 2040 under the high energy consumption scenario. As the power industry directly consumes fossil energy, its carbon dioxide emission reduction should increase the consumption proportion of clean energy, reduce the consumption proportion of fossil energy, and improve the energy utilization mode to produce, transport and distribute electric energy by comprehensively utilizing various energy sources and methods.

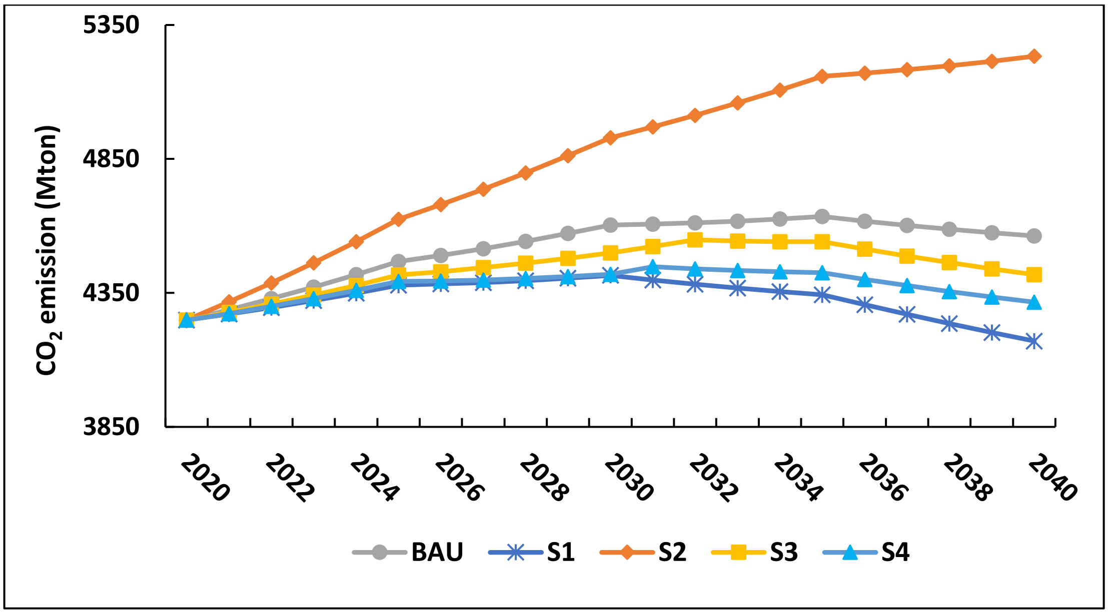

Figure 6. The carbon emission trend of power industry in BAU-S1-S2-S3-S4 scenarios

4. Conclusions

This paper uses the STIRPAT model to predict the carbon emission peak time and value of China's industrial sector and four carbon-intensive industries under different scenarios. The study found that under different emission reduction efforts, the gap between the peak year of China's industrial sector and various carbon-intensive industries is relatively obvious. In general, if the development goals set in the baseline scenario are followed, the industrial sector and the carbon-intensive industries will not be able to complete the peak targets on time. However, under the scale adjustment scenario, technical energy conservation scenario, and low-carbon scenario, each industry reaches its peak. Under the high energy consumptions scenario, China's industrial sector cannot achieve carbon peaks before 2040. This conclusion is more consistent with Yuan's (2020) research. Her research shows that under the baseline scenario, China's industrial sector and various industries will reach their carbon emission peak around 2032. Under the low-carbon scenario, the industrial sector and various industries will peak in 2028. Under the high energy consumption scenario, the industrial sector and various industries will peak in 2040. However, the conclusions of this paper are quite different from Wang's (2017) research. His research shows that under the baseline scenario, the peak time of the industrial sector and various industries is quite different. Some industries will reach their carbon emission peak in 2030, but some industries will reach their carbon emission peak after 2040. In the high energy consumption scenario, industry and most industries will peak in 2036.

In order to promote the realization of carbon peaking and carbon neutrality as scheduled, this paper puts forward the following suggestions for the design of carbon peaking policy in the industrial sector: First, all industrial sectors should further implement the concept of green and low-carbon development, actively develop renewable energy, and constantly adjust the energy consumption structure; secondly, since the peak time of various industries in the energy conservation scenario is earlier than that in the scale adjustment scenario, the use of technical means to reduce the carbon emission intensity of the industrial sector should become the focus of emission reduction, managers should strengthen the guidance and support of public policies for energy technology and process improvement; finally, considering the differences in the peak time, peak value of various industries in different scenarios, the government should strengthen cooperation between different industries and formulate corresponding peak-achieving strategies according to the specific conditions of each industry.

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Conflict of interest: none

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