

Carbon emission scenario forecast and emission reduction path of China's logistics industry from the perspective of green supply chain management

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Abstract. Green logistics is an important part of green supply chain management, and its green and low-carbon level greatly affects the level of green supply chain management. In order to achieve China's targets of carbon peaking and carbon neutrality, and to study the emission reduction path of the logistics industry under green supply chain management, this paper uses the scalable STIRPAT model and ridge regression to analyze the influencing factors of carbon emissions in the logistics industry; Taking the relevant data from 2000 to 2020 as an example, combined with the scenario analysis method, this paper conducts an empirical study on the development trend of carbon emissions in China's logistics industry in the future. The results show that: under the low-carbon and enhanced low-carbon scenarios, China's logistics industry can achieve the carbon peak target of 876.6 MtCO₂ and 817.02 MtCO₂ respectively. Carbon emissions can be reduced to 234.9 MtCO₂ by 2060 in the Enhanced Low Carbon Scenario. There is still a certain distance between neutralization. In the meantime, according to the forecast results, this paper, from the perspective of green supply chain management, from the three directions of carbon trading, reverse logistics and emission reduction costs, gives suggestions on the emission reduction path of China's logistics industry under the carbon peaking and carbon neutrality goals: consider early Incorporate the logistics industry into the carbon trading market; increase support and accelerate the development of reverse logistics; increase scientific research investment in clean energy, and promote new energy vehicles. This paper innovatively stands in the perspective of supply chain management, and improves the analysis of influencing factors. For the single industry of logistics industry, the carbon peaking and carbon neutrality goals goal is put in a model, which can better reflect the complete trend and target Provide low-carbon directions and suggestions. In all, these findings contribute to the formulation and implementation of sound policies to help China achieve the carbon peaking and carbon neutrality goals.

Keywords: Logistics Industry, Green Supply Chain Management, Carbon Emission Forecast, Emission Reduction Path, Scenario Analysis, STIRPAT Model.

1. Introduction

Since the concept of global warming was put forward, the global climate issue has gradually attracted the attention of scholars. The Intergovernmental Panel on Climate Change said in its fourth assessment report that human activities have led to the burning of fossil fuels that emit a large amount of carbon dioxide, leading to global climate change characterized by rising temperatures. [1]. The impact of severe climate change will undoubtedly greatly affect all aspects of human life, and we must take measures in various fields to curb the acceleration of global warming. Since then, a series of studies have begun to focus on green and low carbon. Among them, green supply chain was proposed by the Manufacturing Research Association of Michigan State University in 1996, and it has quickly become one of the research hotspots. Green supply chain management integrates the concept of product life cycle management and producer responsibility extension into enterprise supply chain management, relying on the supply relationship, through green production, green logistics and other work, to achieve the coordination and unity of economic, social and environmental benefits [2]. Green logistics is the main section of the green supply chain, and the logistics industry is responsible for most of the carbon emissions.

As the largest developing country, China's carbon emissions are the largest in the world, which has a great impact on the global climate. Therefore, how to reduce emissions effectively has attracted widespread attention from scholars at home and abroad. China's logistics industry is one of the main sources of carbon emissions, which plays a negative role in the realization of the carbon peaking and carbon neutrality goals. Recently, a number of policies such as the "14th Five-Year Plan for the Construction of a Modern Circulation System" have emphasized the importance of green supply chain management and green logistics. Therefore, the research on carbon emissions in the logistics industry is of great significance. In the meantime, forecasting carbon emissions is the basis for formulating emission reduction policies, and accurate forecasting is of great significance to accomplish the carbon peaking and carbon neutrality goals.

The current academic research on green supply chain is mostly about driving factors and enterprise performance, or independent research on a certain enterprise, as mentioned by DR Maditati [3] in his commentary. Carbon emissions-related research is mainly aimed at influencing factors and future forecasts. For example, Liu Longzheng [4] linked economics, industrial development and carbon emissions to conduct driver studies. Carbon emission forecasts are mainly for regional carbon emissions. For example, Yue Chao's [5] prediction of China's total carbon emissions, the research on sectoral carbon emissions is still relatively blank. However, there are very few predictions of carbon emissions in the logistics industry, and the prediction mainly uses BP neural network [6], Markov model [7], etc., such models have limitations in carbon emission prediction, and the prediction accuracy needs to be further improved.

To sum up, in view of the lack of carbon emission prediction of China's logistics industry from the perspective of green supply chain management, this paper tries to strengthen the introduction of supply chain-related data based on China's carbon emission related data from 2000 to 2020, and expands the STIRPAT model to affect carbon emissions. Decomposition and research of various factors, followed by prediction of carbon emissions based on regression coefficients, and finally analysis of the future development trend and emission reduction path of carbon emissions in the logistics industry, in order to provide a strong basis for the realization of "the carbon peaking and carbon neutrality goals" and also for in-depth research on green supply. Provide guidelines for chain management development.

The innovation of this article is as follows:

- (1) Putting carbon peaking and carbon neutrality targets in one model more effectively reflects overall trends.
- (2) Research on a single logistics industry is more targeted for the low-carbon development of the industry.
- (3) Divide the 40-year simulation into three phases, and propose goals for each phase in turn. And based on the actual data as much as possible to ensure the reasonableness of the forecast.
- (4) From the perspective of green supply chain management, it gives the corresponding emission reduction path.

2. Construction of a forecast model for carbon emissions in the logistics industry from the perspective of supply chain management

2.1. Indicator selection

2.1.1 Data source and processing

Since the logistics industry is not listed separately in China's industry classification, and the transportation industry, warehousing industry, and postal industry play a major role in the logistics industry, the relevant data of the three can roughly reflect the development level of logistics industry. Therefore, the logistics industry in this paper is approximately replaced by the transportation industry, the warehousing industry and the postal industry [8].

The data in this paper are mainly derived from the relevant data of China's carbon dioxide inventory (IPCC Sectoral Emissions) and the "China Statistical Yearbook" calculated by Carbon Emission Accounts & Datasets (CEAD), and the data range is 2000-2020. The variables are shown in Table. 1.

Table 1. Variable table

Variables	The data shows	Unit
Carbon emission y_1	Logistics industry carbon emissions	MtCO ₂
GDP per capita x_{11}	GDP per capita	Yuan
Stock x_{12}	Industrial enterprise inventory	100 million yuan
Population x_{13}	Population size	10,000 people
Urban road area per capita x_{14}	Urban road area per capita	Square meter
Freight density x_{15}	Freight density	10,000tons km/km
Number of people in the logistics industry x_{21}	Number of people in the logistics industry	10,000 people
Cargo turnover per capita x_{22}	Cargo turnover per capita	Tons/km
Transport strength x_{23}	Turnover/ GDP	%
Energy intensity x_{24}	Energy consumption per unit of output value	Tce/million
Economic share of logistics industry x_{31}	Logistics GDP /total GDP	%
Truck stop time x_{32}	Truck stopover time	Hour
Truck turnaround time x_{33}	Truck turnaround time	Day
Energy efficiency x_{34}	Energy efficiency	%
Transport structure x_{35}	Transport structure	%

2.1.2 Indicator brushing

This paper selects the indicators that affect the carbon emissions from three aspects related to logistics: economy, population and technology. For the data with some vacancies, the interpolation method is used to supplement the data. The correlation coefficient was used to analyze the correlation between the 14 indicators in the primary selection and the carbon emissions, and indicators in the primary selection were further screened. The results of the correlation coefficient are shown in Figure 1.

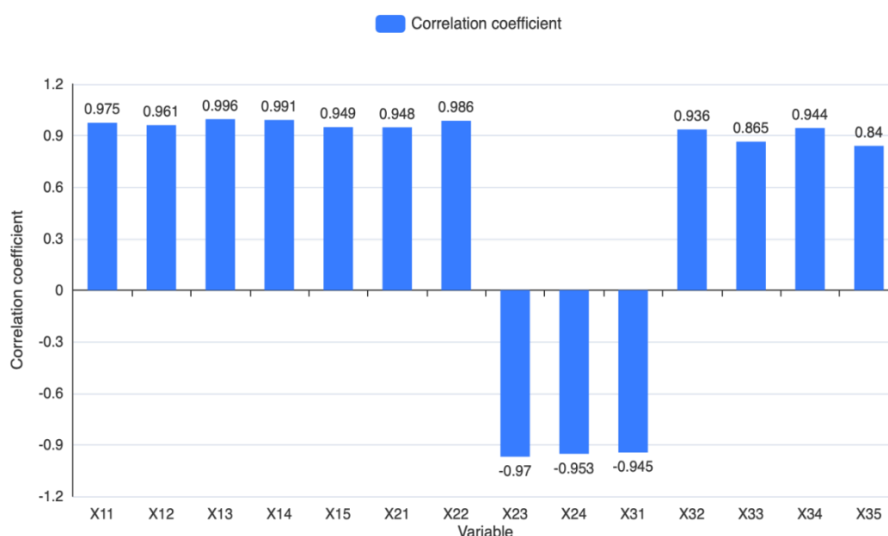


Figure 1. Correlation coefficient figure

In general, it can be considered that the correlation coefficient greater than 0.95 indicates that there is a strong correlation between the two. After screening the indicators in Figure 1, 5 factors that have

strong correlation with carbon emissions are finally obtained. At the same time, it can be seen that there is a strong correlation between population, economy and inventory, indicating that in the next emission reduction measures, attention should be paid to reducing economic growth and green warehousing.

2.2. Model method and principle

The overall flow chart is shown in Figure 2.

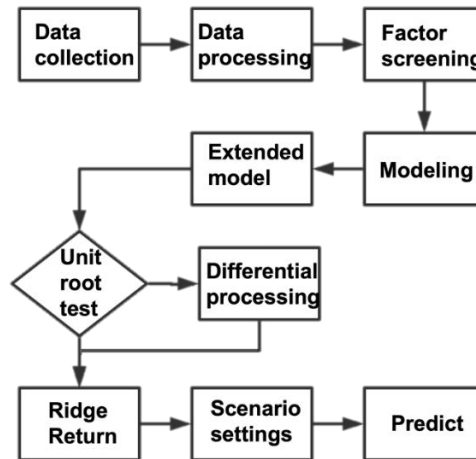


Figure 2. Flow chart

2.2.1 STIRPAT Model

The IPAT model is the earliest environmental assessment model that combines environmental issues with human drivers [9]. However, York et al. [10] pointed out the limitations of the IPAT model in subsequent studies, that is, the IPAT model does not allow the driving factors to produce non-monotonic or non-proportional effects, and the IPAT model is improved to obtain the STIRPAT model. It has strong scalability and regards population, economy and technology as the main factors affecting the environment. The basic formula is shown in (1).

$$I = aP^bA^cT^de \quad (1)$$

In formula (1), e is a random error term, I , P , A , and T represent environmental pressure, employment scale, economic level, and technological level, respectively, and a , b , c , and d are parameters to be estimated. To reduce the influence of model heteroscedasticity, take the logarithm of both sides of Equation (1) to obtain Equation (2):

$$\ln C = \ln a + b \ln P + c \ln A + d \ln T + \ln e \quad (2)$$

In formula (2), C , P , A , and T represent carbon emissions, population, economy, and technological level, respectively, a , b , c , and d represent the elastic coefficients of each index, and e is the error.

2.2.2 Extended STIRPAT Model

Aiming at the status quo of carbon emissions, this paper establishes a theoretical analysis framework for the influencing factors of carbon emissions in the logistics industry by constructing the STIRPAT expansion model. Taking the carbon emissions of the logistics industry as the explained variable, and introducing per capita cargo turnover, industrial enterprise inventory, carbon intensity, population size and economic development as explanatory variables, the expanded expression is shown in Equation (3).

$$\ln C = a + b_1 \ln T + b_2 \ln S + b_3 \ln I + b_4 \ln P + b_5 \ln G + \ln e \quad (3)$$

In the formula, C , T , S , I , P , and G represent carbon emissions, per capita cargo turnover, industrial enterprise inventory, carbon intensity, population size, and per capita GDP, respectively.

3. Empirical Analysis

3.1. Unit root test and accuracy analysis

Since there may be a pseudo-regression situation, that is, the variables increase or decrease with time, but there is no real connection. Therefore, it is necessary to first use the unit root test to judge the stationarity of each variable to ensure the accuracy of the regression results. The test results are shown in Table. 2.

Table 2. ADF inspection form

Variables	Differential order	t	p	Critical Value		
carbon emission (co ₂)	0	-1.107	0.712	-3.809	-3.022	-2.651
	1	-16.058	0.000***	-4.223	-3.189	-2.73
	2	-5.662	0.000***	-3.859	-3.042	-2.661

Note: From left to right in the Critical Value represents the significance levels of 1%, 5%, and 10%, respectively.

It can be seen that after the first-order difference processing, the P value is 0.000***, which is notable at the level, and the variables all pass the test, that is, there is no unit root, and it is a stationary time series, which meets the test conditions. Secondly, this paper selects ridge regression to perform regression analysis on the extended STIRPAT model. Ridge regression is a method based on the least squares method to make the regression results more realistic by reducing the accuracy of the regression. The influence of each variable on the carbon emission of the logistics industry is obtained, and the accuracy of the results is further tested by comparing the fitted value and the actual value of the carbon emission. The regression results are shown in Figure 3. The goodness of fit R^2 is 0.993, the average error is 3.416%, and the model performance is relatively good.

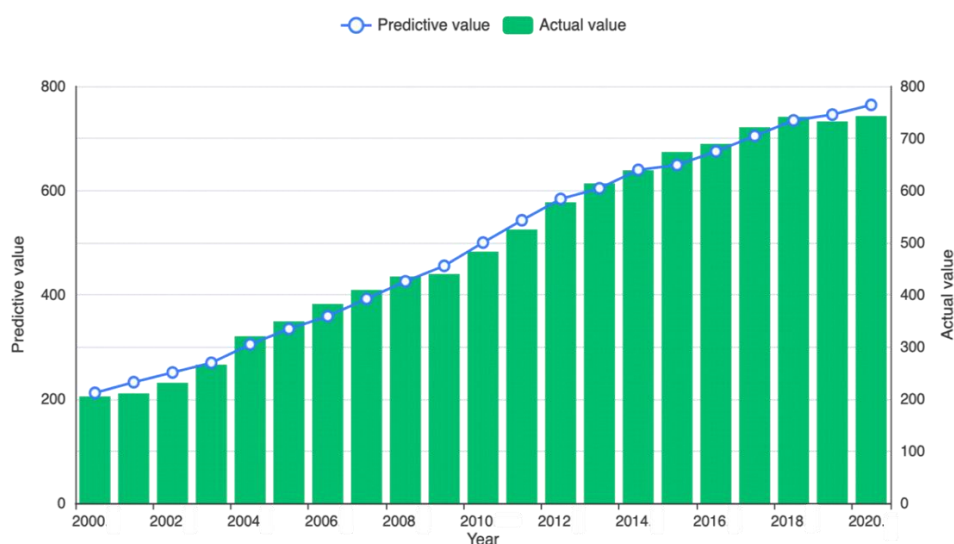


Figure 3. Fitting graph

3.2. Scenario Analysis Settings

Scenario analysis (SA) is a method of predicting the future state of an object with high uncertainty, combining quantitative and non-quantitative data to generate future scenarios through prediction, assumption or simulation. A more systematic explanation appeared in 1967 in Kahn and Wiener's "2000—Conjectures About the Next 33 Years" in the Framework [11]. It is widely used in long-term forecasting, such as Lootsma F.A et al. [12] for exploring long-term strategies for national electricity supply, and Relvas Hélder et al. [13] for exploring air pollution control strategies.

This paper sets three carbon emission scenarios considering two factors related to economic and social development and emission reduction. 1) Baseline scenario, according to the current economic growth trend, predict the changes of five factors of population, per capita GDP, per capita goods turnover, industrial enterprise inventory, and carbon intensity according to the conventional speed, and basically do not adjust the logistics industry. 2) Low-carbon scenario, referring to the current the carbon peaking and carbon neutrality goals related policy documents in China's logistics industry, based on the benchmark scenario, in addition to implementing various climate change response and energy optimization policies, it is also necessary to strengthen low-carbon transformation. 3) Strengthen the low-carbon scenario, further strengthen regulation based on the low-carbon scenario, actively introduce various low-carbon measures, and make significant progress in green supply chain management, green logistics, etc. It also assumes that there will be no major technological breakthroughs before 2060. This article divides the period from 2020 to 2060 into three phases. 2020-2030 is the carbon peak stage, 2030-2050 is the rapid emission reduction stage, and 2050-2060 is the carbon neutral stage. Since the rate of each influencing factor varies in practice in different stages, such a setting is more realistic than using a uniform rate.

According to the relevant data from the National Bureau of Statistics of China, the potential growth rate of China's per capita GDP is around 6%, and with the growth of the economy, the growth rate will decline year by year; According to the World Bank, China's fertility rate has been declining in recent years and has grown close to zero; per capita cargo turnover It will grow with economic growth, but at a slower rate; with policy support and technological development, carbon intensity will gradually decrease; industrial enterprises will reduce inventories as appropriate. The specific scene parameter settings are shown in Table. 3.

Table 3. Scenario factor setting (%)

stage	scene mode	GDP per capita	population	Cargo turnover per capita	carbon intensity	Industrial Enterprise Inventory
2020-2030	benchmark					
	low carbon	6.20	0.06	2.20	-3.80	12.00
	fortified low carbon	5.80	0.03	1.80	-4.30	8.00
2030-2050	benchmark	5.40	0.00	1.40	-4.80	4.00
	low carbon	3.80	-0.18	0.80	-1.80	8.0
	fortified low carbon	3.40	-0.22	0.60	-2.10	4.0
2050-2060	benchmark	3.00	-0.24	0.40	-2.40	0.0
	low carbon	2.40	-0.28	0.50	-0.90	6.0
	fortified low carbon	2.00	-0.30	0.35	-1.20	2.0
		1.60	-0.34	0.15	-1.50	-2.0

Note: These rates are derived from relevant policies, documents, etc., such as "the World Population Outlook 2022".

3.3. Example calculation prediction, result analysis and research on emission reduction path

Based on the STIRPAT expansion model, the carbon emissions of China's logistics industry from 2020 to 2060 under different scenarios are predicted. The results are shown in Figure 4.

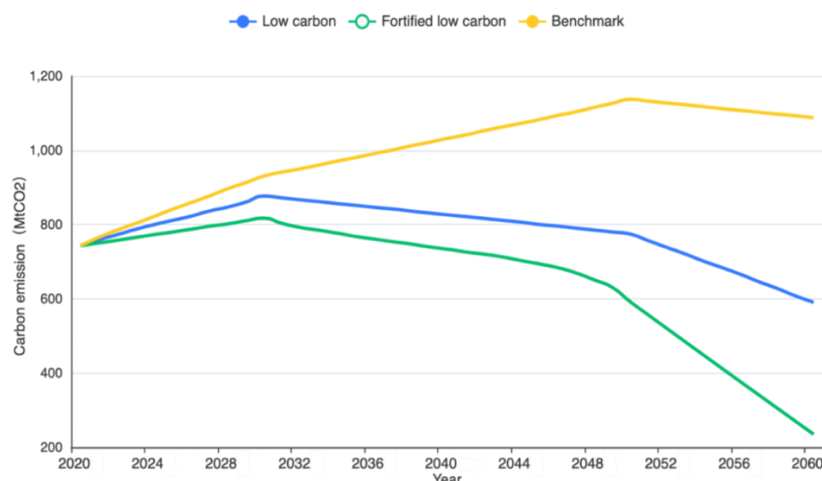


Figure 4. Trend forecast

For the 2060 carbon neutrality target, there are two definitions due to different policy directions. One is overall carbon neutrality, that is, the logistics industry itself does not need to achieve zero carbon, but to formulate a carbon reduction path based on the per capita carbon emissions that the country can achieve as a whole, and the national carbon sink reserve undertakes the neutralization task. The other is the zero carbon of the logistics industry itself, that is, zero CO₂ emissions from logistics-related activities by 2060. It can be seen from the forecast results that under different scenarios, the logistics industry's carbon peak time and peak value are different. Under the baseline scenario, it will peak at 1137.1 MtCO₂ in 2050. Obviously, carbon emissions from China's logistics industry will be difficult to stop growing in a short period of time without corresponding measures for the "carbon peaking and carbon neutrality goals"; under the low-carbon scenario, it can be achieved in 2030. Carbon peaking target, the peak value is 876.6 MtCO₂, but there is still a long way to go from carbon neutrality; under the strengthened low-carbon scenario, in addition to fulfilling the carbon peaking target, the carbon emission can be reduced to 234.9 MtCO₂ in 2060, fast and close to zero emissions. It can be seen that under the scenario of maintaining low-carbon policies and continuously strengthening energy-saving technologies and awareness in the future, it is possible to achieve the overall carbon neutral control goal. policies and vigorously develop green supply chains.

4. Conclusions

This paper firstly constructs the carbon emission prediction index system of China's logistics industry. Secondly, the STIRPAT model of in line with the carbon peaking and carbon neutrality goals and the perspective of green supply chain management is established and adaptively expanded. At the same time, unit root test and ridge regression analysis are carried out to ensure the accuracy of the model. Finally, combined with the scenario analysis method, the carbon emission forecast of China's logistics industry from 2022 to 2060 is presented. The study found that: the carbon emissions of China's logistics industry will not decline in a short time, and the double-carbon target cannot be achieved under the baseline scenario; under the low-carbon scenario, due to the adoption of relevant policies, the carbon peak in 2030 can be achieved; under the enhanced low-carbon scenario, carbon neutrality in 2060 can be roughly achieved, but it will greatly affect the development of the economy and other aspects, and the impact of the projected population reduction on carbon emissions is not small, and China is taking measures to increase the declining fertility rate.

This paper improves the analysis of carbon emission factors in existing logistics industry, and also lays the foundation for the subsequent prediction of the carbon peak in the logistics industry. From the perspective of green supply chain management, it makes up for certain dead spots in carbon emission forecasting and emission reduction. It should be noted that this paper makes predictions from the perspective of green supply chain management and industry, based on the data of the national logistics industry; however, regional development is unbalanced, and follow-up research can consider

combining regions and industries. Further regional comparative analysis was carried out. Although the scenario setting takes into account the actual changes of various policies, documents and various influencing factors, it is still subjective, and follow-up research can explore more objective methods. In order to better achieve the carbon peaking and carbon neutrality goals, based on the research results and development trends, this paper puts forward the following suggestions for my country's logistics industry emission reduction policies:

1) The logistics industry joins China's carbon finance market. Market mechanism as a new way to reduce emissions, this led to the emergence of carbon dioxide emissions trading (carbon trading). Among them, carbon quotas play a restrictive role in enterprises and promote the development of green technologies. In July 2021, after the opening of China's carbon emission rights trading market, the cumulative transaction volume reached 7.661 billion yuan by the end of the year. However, the carbon market does not cover a wide range of industries, and it is not considered to join the logistics industry in the short term, and only expects to join the civil aviation industry. The New Zealand carbon trading system already includes industries such as industry, electricity, construction, transportation, aviation, waste, and forestry. As the main carbon emission industry in the tertiary industry, the logistics industry has great significance to join the carbon market.

2) Strengthen the development level of reverse logistics, support the development of related enterprises; improve the overall efficiency; promote the circulation of resource elements. Reverse logistics is the complete and efficient use of the product life cycle, which can not only improve economic efficiency, but also protect the environment [14]. The intelligent operation of reverse logistics in China is still in its infancy. In 2021, the State Council proposed to accelerate the improvement of the green development cycle system. Reverse logistics, as a member of the green economy, can not only reduce carbon emissions but also promote economic growth, and its market potential is huge.

3) When researching emission reduction paths, reduce the cost of emission reduction as much as possible, and improve the informatization of green supply chain. According to other scholars' research on industry emission reduction costs [15], the logistics industry is a traditional industry with low technical emission reduction rates and difficult technical upgrading, and the technical emission reduction costs are relatively high. Relevant research should be strengthened, and technologies such as blockchain, big data, and cloud computing should be integrated to accelerate the advancement of informatization and digitization, and strive to achieve exponential technological development. At the same time, in the life of residents, the production and sales of fuel vehicles will be gradually reduced, more new energy vehicles will be advocated instead of fuel vehicles, and economic support will be given to relevant enterprises.

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