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Prediction and Analysis of Carbon Emissions under Specific Regional Scenarios in Anhui Province based on the STIRPAT Model

Zhaoxuan Song, Tingting Zhu, Shihan Yang, Huiqin Zong

School of Statistics and Applied Mathematics, Anhui University of Finance and Economics, Bengbu 233030, China

Abstract: In order to achieve the goal of reaching carbon peak by 2030, the STIRPAT model is used to predict carbon emissions under three simulation scenarios: baseline, optimization, and strict control of carbon emissions. Taking Anhui Province as an example, fully considering the impact of factors such as population, per capita GDP, carbon emission intensity, energy consumption intensity, energy structure, and industrial structure on carbon emissions, ridge regression and partial least squares regression were conducted respectively. Finally, the partial least squares regression method with a lower average error rate was selected to predict the model coefficients. The results show that all three model scenarios can achieve the carbon peak target by 2030, and the factors that have the greatest impact on carbon emissions are carbon emission intensity, energy consumption intensity, and per capita GDP.

Keywords: STIRPAT Model; Partial Least Squares Regression; Carbon Emissions; Simulated Scenario.

1. Introduction

In 2022, global carbon emissions will increase slightly to a record level. The International Energy Agency points out that the energy crisis has not led to a significant increase in carbon emissions, but the continued growth of fossil fuel emissions is still hindering the achievement of global climate goals. The carbon emissions report released by the IEA shows that the global energy related carbon emissions in 2022 were 321 million tons, a year-on-year increase of 0.9%, far lower than the 3.2% growth rate of global GDP that year. Data shows that in order to achieve climate goals, global carbon dioxide emissions must be reversed and continuously reduced. By 2030, global carbon emissions need to be reduced by more than 40% in order to achieve the goal of global temperature control not exceeding 1.5 degrees Celsius.

From this, it can be seen that the task of carbon reduction is still very challenging. In order to achieve this goal, it is particularly important to study inter provincial carbon emissions. Taking Anhui Province as an example, the carbon emissions of industrial energy consumption and fossil energy consumption in Anhui Province are a microcosm of the six central provinces [1], with typical representativeness. Anhui Province is rich in coal resources and sits on two major coal mining bases. After being included in the Yangtze River Delta as a whole, its carbon emissions are increasing day by day. Therefore, it is necessary to scientifically predict carbon emissions in Anhui Province, and make specific requirements for carbon emissions in various fields in Anhui Province, in order to achieve peak carbon emissions as soon as possible.

2. Research Methods and Empirical Analysis

2.1. Model Construction

The IPAT model is a method used to assess environmental stress, typically used to predict a country's carbon emissions. This model predicts carbon emissions by reflecting the comprehensive impact of population, per capita wealth, and technology. IPAT has certain limitations due to its consideration of a single influencing factor. The STIRPAT model is a regression analysis based on the IPAT model for the random effects of population, per capita wealth, and technology on the environment. Its standard form is:

$$I = aP^bA^cT^de$$

Among them, I, P, A, T representing environmental impact, population, per capita wealth, and technology respectively [2]; a represents the model coefficient; b, c, d the coefficients representing each variable; e is the model Error term.

Table 1. Explanation of Model Variables

variable	Symbol	Variable Description	Unit
Carbon emissions	C	CO_2 emission	ten thousand tons
population	P	Ending permanent population in Anhui Province	ten thousand people
Per capita GDP	A	Ending permanent population/GDP [3]	10000 yuan/person
Carbon emission intensity	T	Carbon emissions/GDP (unchanged in 2007)	tons/10000 yuan
Energy consumption intensity	P_S	Energy consumption/GDP	tons of standard coal/10000 yuan
energy-resource structure	E_s	Coal consumption structure	/%
industrial structure	I_s	Second Industry Value Added/GDP	/%

Based on the specific carbon emissions situation in Anhui Province, we will expand the IPAT model and construct the STIRPAT model:

$$\ln C = \ln a + b \ln P + c \ln A + d \ln T + e \ln P_s + f \ln E_s + g \ln I_s + h$$

In the model a is a constant term, b, c, d, e, f, g is the coefficient, g is an error.

2.2. Data Description

The carbon emission data in the model comes from the China multi-scale emission inventory model, and the other variable data are all from the Anhui Provincial Statistical Yearbook from 2007 to 2021. After organizing the selected variables, the data shown in Figure 2 is obtained.

Table 2. Model Indicator Data

Years	C	P	A	T	P_s	E_s	I_s
2007	21216.5	6118	1.3	2.67	0.82	99.7	42.5
2008	24377.5	6135	1.55	3.07	0.78	97.2	44.1
2009	27274.2	6131	1.77	3.43	0.73	100.3	45.3
2010	27772.2	5957	2.19	3.5	0.71	86.2	48.3
2011	30876.1	5972	2.73	3.89	0.66	82.2	50.3
2012	32904.9	5978	3.07	4.14	0.63	80.6	50.4
2013	35010.1	5988.99	3.44	4.41	0.57	78.8	49.7
2014	35539.3	5997	3.76	4.48	0.53	77.9	48.8
2015	35648.5	6011	3.97	4.49	0.52	76.8	45.5
2016	36635.8	6033	4.37	4.61	0.48	75.1	43.8
2017	37433.6	6057	4.91	4.71	0.44	72.5	42.7
2018	38333.4	6076	5.61	4.83	0.39	71.8	41.4
2019	39072.5	6092	6.06	4.92	0.38	70.2	40.6
2020	38553.7	6105	6.24	4.85	0.39	69.8	40
2021	40711.1	6113	7.03	5.13	0.36	67.7	41

2.3. Empirical Analysis

The main disadvantage of STIRPAT model is the existence of multicollinearity, and the direct regression of data will have a greater impact on the results. Partial least square regression and ridge regression can solve the multicollinearity problem well. In the analysis process, the correlation between various factors is first analyzed, and then the variables are subjected to partial least squares regression and ridge regression to obtain the STIRPAT model. Finally, the optimal model is determined by comparing the error ratio.

(1) Correlation analysis between various factors

Factor analysis was conducted on the six factors mentioned above, and the correlation matrix between KMO and Bartlett's test is shown in Tables 3 and 4. By analyzing the KMO values in Table 3, the KMO value is 0.67, which is very suitable for factor analysis. Bartlett's test $P<0.001$ rejected the original hypothesis, indicating that there is a correlation between various variables and factor analysis can be performed [4].

Table 3. KMO and Bartlett's tests

KMO test and Bartlett's test		
KMO value	0.67	
Bartlett sphericity test	Approximate chi square	185.28
	Df (degree of freedom)	15
	P (significance)	0.000***

Note: * * *, * *, * represent significance levels of 1%, 5%, and 10%, respectively

Table 4. Variable Correlation Matrix

	$\ln P$	$\ln A$	$\ln I_s$	$\ln E_s$	$\ln T$	$\ln P_s$
$\ln P$	1 (0.000***)	-0.034 (-0.904)	-0.8 (0.000***)	0.157 (-0.577)	-0.166 (-0.555)	-0.144 (-0.61)
$\ln A$	-0.034 (-0.904)	1 (0.000***)	-0.421 (-0.119)	-0.984 (0.000***)	0.974 (0.000***)	-0.98 (0.000***)
$\ln I_s$	-0.8 (0.000***)	-0.421 (-0.119)	1 (0.000***)	0.342 (-0.212)	-0.246 (-0.377)	0.581 (0.023**)
$\ln E_s$	0.157 (-0.577)	-0.984 (0.000***)	0.342 (-0.212)	1 (0.000***)	-0.956 (0.000***)	0.945 (0.000***)
$\ln T$	-0.166 (-0.555)	0.974 (0.000***)	-0.246 (-0.377)	-0.956 (0.000***)	1 (0.000***)	-0.924 (0.000***)
$\ln P_s$	-0.144 (-0.61)	-0.98 (0.000***)	0.581 (0.023**)	0.945 (0.000***)	-0.924 (0.000***)	1 (0.000***)

From Table 4, it can be seen that there is a high correlation between variables. Including per capita GDP (A)Energy structure (E_s)Energy consumption intensity (P_s)There is a high negative correlation, with correlation indices of -0.984 and -0.98, respectively. And per capita GDP (A)And carbon emission intensity (T)Energy consumption intensity, (P_s) Energy structure (E_s)There is a high positive correlation, with positive correlation coefficients of 0.974 and 0.945, respectively.

(2) Model parameter determination

After conducting factor analysis on six variables, principal component analysis was used to extract three principal components, which were then subjected to partial least squares regression to obtain the STIRPAT model:

$$\ln C = 9.0 + 0.001 \ln P + 0.008 \ln A + 1.009 \ln T + 0.021 \ln P_s + 0.009 \ln E_s - 0.021 \ln I_s$$

By analyzing the regression equation, it can be concluded that carbon emission intensity(T)Impact on carbon emissions(C)The impact is the greatest, with a positive impact, that is, when other factors remain unchanged, for every 1% increase in carbon emission intensity, the carbon emissions increase by 1.009%; And the industrial structure(I_s)Impact on carbon emissions(C)Produce a negative impact, that is, with other factors remaining unchanged, for every 1% increase in industrial structure, carbon emissions decrease by 0.021%. Based on the analysis of other relevant literature, this result is more in line with the actual situation.

To analyze the optimality of partial least squares regression and ridge regression, ridge regression was used to regress the model and calculate the STIRPAT model under ridge regression:

$$\ln C = 6.431 + 0.297 \ln P + 0.092 \ln A + 0.467 \ln T - 0.143 \ln P_s - 0.157 \ln E_s + 0.319 \ln I_s$$

By analyzing the regression equation, it can be concluded that carbon emission intensity(T)Impact on carbon emissions(C)The impact is the greatest, with a positive impact, that is, when other factors remain unchanged, for every 1% increase in carbon emission intensity, carbon emissions increase by 0.467%; In addition, both energy consumption intensity and energy structure have a negative impact on carbon emissions, that is, with other factors unchanged, for every 1% increase in energy consumption intensity, carbon emissions decrease by 0.143%, and for every 1% increase in energy structure, carbon emissions decrease by 0.157%. And it can be found that the impact of changes in energy structure on carbon emissions is higher than the impact of energy consumption intensity on carbon emissions. Although this result contradicts actual economic theory, it is similar to the research conclusions of Zhao Ci et al. and Sun Yi.

A comprehensive analysis of the ridge regression fitting chart and partial least squares regression fitting chart is shown in Figure 1. It can be found that the fitting effect of partial least squares regression is better than that of ridge regression. When comparing the average error rates of the two models, the average error rate of partial least squares regression is 0.19%, and the average error rate of ridge regression is 1.34%, as shown in Table 5. Therefore, it can be inferred that partial least squares regression is superior to ridge regression. The following specific scenario analysis uses partial least squares regression results to predict carbon emissions.

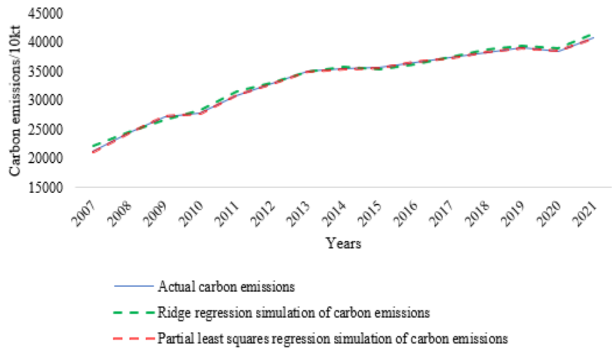

Figure 1. Comparison of Ridge Regression and Partial Least Squares Regression Fitting

Table 5. Comparison and Analysis of Actual Carbon Emission Values and Fit Values

year	Actual carbon emissions/10 000 tons	Ridge regression simulation of carbon emissions/ 10000 tons	Error rate/%	Partial least squares regression simulation of carbon emissions/ 10000 tons	Error rate/%
2007	21216.5	22142.16	0.042704	21168.03	-0.00229
2008	24377.5	24596.63	0.008949	24354.16	-0.00096
2009	27274.2	26562.96	-0.02642	27220.55	-0.00197
2010	27772.2	28451.57	0.024168	27736.18	-0.0013
2011	30876.1	31481.79	0.019427	30823.8	-0.0017
2012	32904.9	33114.32	0.006344	32814.78	-0.00274
2013	35010.1	34948.7	-0.00176	34936.33	-0.00211
2014	35539.3	35737.27	0.005555	35476.94	-0.00176
2015	35648.5	35358.86	-0.00816	35605.92	-0.0012
2016	36635.8	36255.68	-0.01043	36554.83	-0.00221
2017	37433.6	37426.42	-0.00019	37329.82	-0.00278
2018	38333.4	38715.02	0.009906	38255.05	-0.00205
2019	39072.5	39399.66	0.008338	38985.32	-0.00223
2020	38553.7	38971.26	0.010772	38465.79	-0.00228
2021	40711.1	41450.95	0.01801	40645.25	-0.00162
Average error rate	0.013409			0.001945	

3. Specific Scenario Analysis

3.1. Setting of Specific Scenario Parameters

In order to comprehensively and clearly predict the carbon dioxide emissions in Anhui Province, this article sets three carbon emission scenarios from the perspectives of economic development and environmental protection.

(1) Base scenario: This refers to the relevant documents on climate change and energy arrangements released by Anhui Province. Based on the current development situation and speed, predict six factors: population, per capita GDP, energy consumption intensity, carbon emission intensity, energy structure, and industrial structure [4].

(2) Optimization scenario: Based on the current basic situation, in addition to vigorously promoting various climate change response and energy optimization policies, we also strengthen the transformation of carbon emissions. Starting from multiple aspects, optimize carbon emission intensity, energy structure, industrial structure, and energy consumption intensity.

Table 6. The change rate of indicators under three carbon emission prediction scenarios

Data Name	Base scenario	Optimization scenario	Strict scenario
P	high	medium	low
A	medium	medium	medium
P_s	medium	medium	high
T	medium	medium	high
E_s	low	medium	high
I_s	low	medium	high

In order to predict the carbon dioxide emissions from 2025 to 2035, the parameter settings are shown in Table 7.

Table 7. Parameter Settings for Three Modes

pattern	variable	2021-2025	2026-2030	2031-2035
Base scenario	P	0.20%	0.10%	-0.10%
	A	5%	4%	2%
	P_s	2.60%	2.37%	2.03%
	T	-3.50%	-3.00%	-2.50%
	E_s	5.86%	5.92%	5.96%
	I_s	5.30%	4.30%	5.50%
Optimization scenario	P	0.30%	0.25%	0.20%
	A	6%	5.65%	5.24%
	P_s	-2.03%	-1.59%	1.34%
	T	-4.50%	-4.00%	-3.50%
	E_s	-4.80%	-5.15%	-5.50%
	I_s	-3.80%	-4.10%	-4.30%
Strict scenario	P	0.28%	0.24%	0.22%
	A	6.20%	6.02%	5.84%
	P_s	-2.39%	-2.26%	2.17%
	T	-4.63%	-4.52%	-4.35%
	E_s	-5.63%	-5.82%	-5.91%
	I_s	-4.22%	-4.34%	-4.43%

(3) Strict scenario: All industries and regions strictly implement the clean energy structure route, focusing on the use of renewable energy such as solar and wind energy. By adjusting the energy structure and developing and utilizing new energy-saving energy sources, we will promote economic development.

By using the STIRPAT model, six carbon emission influencing factors, namely population, per capita GDP, energy consumption intensity, carbon emission intensity, energy structure, and industrial structure, were constructed, and three combinations of low, medium, and high were set to predict each influencing factor[4]. The specific combinations are shown in Table 6.

3.2. Carbon Emission Peak Prediction

Carbon emission peak prediction refers to the process of a stable downward trend in carbon dioxide emissions in a certain region from this year onwards. From the figure below, it can be seen that the peak time in Anhui Province varies among the three scenarios. The baseline scenario, optimized control of carbon emissions, and strict control of carbon emissions reached their peak in 2028, 2026, and 2025, with peaks of 3.21, 3.24, and 336 million tons, respectively. Among them, in the baseline scenario, carbon emissions showed a rapid decrease from 2023 to 2026, and the rate gradually slowed down after 2027. Under the optimized control of carbon emissions, the carbon emissions showed a rapid decrease from 2023 to 2028, and gradually slowed down after 2029. Under strict control of carbon emissions, carbon emissions from 2023 to 2029 showed a rapid decrease, while carbon emissions after 2030 showed a slow decrease trend.

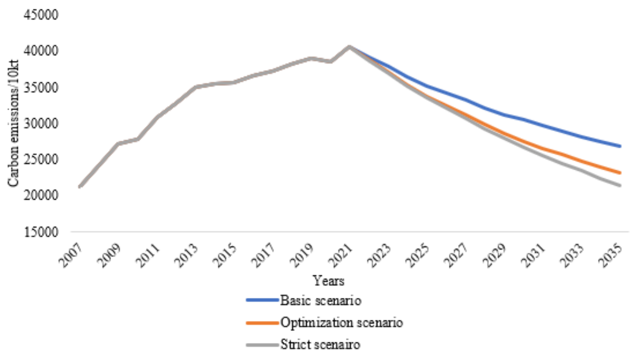

Figure 2. Carbon emission peak prediction under three scenarios in Anhui Province

4. Conclusion and Suggestions

Analyzing the above results, it can be found that Anhui Province will reach the peak under the baseline scenario in 2028, the peak under the optimized control of carbon emissions in 2026, and the peak under the strict control of carbon emissions in 2025. The carbon emission peaks corresponding to the three specific scenarios are 321 million tons, 324 million tons, and 336 million tons, respectively. Based on the above research results, our suggestions for effective measures to reduce carbon emissions are as follows:

(1) Optimize the energy structure, minimize the use of coal as much as possible, and increase the use of clean energy such as natural gas and low-carbon energy. To achieve diversification and enrichment of energy use.

(2) Population has a significant impact on carbon dioxide emissions, and the government should provide appropriate

guidance to improve population quality, advocate green and low-carbon travel. Minimize its impact on carbon dioxide emissions as much as possible.

(3) Accelerate the transformation of industrial structure and promote industrial transformation and upgrading through technological innovation. At the same time, corresponding preferential policies are provided to motivate residents to reduce carbon emissions and enhance the government's macroeconomic regulation and attraction.

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