Scenario Prediction of Carbon Peak in Fujian Electric Power Industry Based on STIRPAT Model

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Abstract. The power industry plays a crucial role in achieving the carbon reduction objectives and facilitating the transition towards a low-carbon economy and society. This study employed the IPCC carbon emission coefficient method to calculate the carbon emissions of the power industry in Fujian Province from 2001 to 2021. To predict the carbon emissions of the power industry in Fujian Province from 2022 to 2030, this article established a STIRPAT model based on ridge regression. Empirical research was carried out in this study to investigate the timing of carbon peaking and peak carbon emissions in the power industry of Fujian Province, considering various scenarios. The calculation of carbon emissions indicates that the overall carbon emissions in the electricity industry in Fujian Province showed an upward trend from 2001 to 2021. By 2021, the emissions reached 9.646×10^7 tons, and the carbon emissions peak has not been reached. Scenario simulation analysis shows that under the energy-saving scenario, the electricity industry in Fujian Province is projected to reach its carbon emissions peak in 2025, with a peak value of 9.687×10^7 tons. However, in the baseline and ideal scenarios, the carbon emissions in the electricity industry in Fujian Province are projected to not peak before 2030. By 2030, the emissions are estimated to be 9.853×10^7 tons and 1.067×10^8 tons, respectively. The article concludes by presenting a comprehensive analysis of the most effective approach towards achieving carbon peaking in the power industry within Fujian Province. This is accomplished by examining the issue from various angles, including government planning, power generation structure, industrial structure, and public awareness.

1. Introduction

Human activities have undoubtedly caused and exacerbated the global climate change crisis. If emissions of greenhouse gases such as carbon dioxide are not strictly controlled, global warming in the 21st century will exceed 2 degrees Celsius [1]. In today's society, the power industry plays a significant role in global carbon emissions and is one of the major sources of carbon emissions, accounting for approximately 42% of global emissions. With the intensification of global climate change, reducing carbon emissions from the power industry has become a major challenge faced by the world. In response to the climate crisis, China has demonstrated its role as a major country in addressing climate change. In September 2020, President Xi Jinping announced that China would strive to achieve carbon peak before 2030 and carbon neutrality before 2060 [2]. According to BP (2020) [3] data, in 2019, China's primary energy consumption reached 14.17 billion tons of standard coal equivalent, and carbon dioxide emissions reached 9.83 billion tons, accounting for 24.3% and 28.8% of the global total, respectively. There is tremendous pressure to reduce energy consumption and carbon emissions. At the same time, the power sector accounts for about 40% of China's total energy consumption and has become a significant contributor to fossil energy demand and overall energy consumption [4, 5]. Carbon emissions reduction in the power sector has also become a key focus of China's climate ambitions. Fujian Province, as an early adopter of clean energy development such as wind power and solar power, has a relatively high share of clean electricity. Moreover, Fujian Province's carbon market is the eighth pilot area for carbon emissions in the country, with the power industry playing an important role.

This paper takes the power industry in Fujian Province as an example to calculate its carbon emissions. Based on the STIRPAT model, it identifies the factors influencing carbon emissions in the power industry in Fujian Province. By combining ridge regression and scenario analysis, it studies the carbon peak trajectory of the power industry in Fujian Province and proposes corresponding development suggestions, which can provide references for carbon peak and low-carbon development in the power industry at the provincial level.

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2. literature review

The literature closely related to this paper can be divided into two parts: factors influencing carbon emissions in the power industry and carbon peaking prediction and pathway analysis in the power industry.

Among the existing literature, the research on factors influencing the power industry can be categorized into two major perspectives. The first perspective is a macro analysis from the social environment, which comprehensively considers the influences of the economy, society, and other factors on carbon emissions in the power industry. Li et al. analyzed the impact of factors such as GDP, population, per capita electricity consumption, and industrial structure on carbon emissions in the power industry, and identified GDP as an important factor influencing carbon emissions [6]. Sun et al. examined the effects of urbanization level, industrial structure, total electricity consumption, and environmental protection investment as influencing factors on carbon emissions in the power industry, and found significant heterogeneity in the main influencing factors of carbon emissions in different regions [7].

The second perspective is a micro analysis focusing on the power source structure, specifically analyzing the influence of fuel structure and the proportion of thermal power generation on carbon emissions in the power industry. Xu et al. analyzed the effects of thermal power installed capacity, thermal power generation, the proportion of thermal power generation, and economic level on regional carbon emissions in the power industry. They conducted a temporal and spatial analysis of the main factors affecting carbon emission efficiency, which supplemented the theoretical system of carbon emission efficiency and its influencing factors in the thermal power industry [8]. Li et al. studied the impact of factors such as fossil fuel power generation structure, fossil fuel consumption coefficient, the proportion of thermal power generation, power generation consumption per capita, and transmission and distribution losses on carbon emissions in the power industry. Based on their findings, they proposed constructive suggestions for carbon emission regulation in the power industry [9].

Due to the fact that carbon emissions in the power industry are influenced by both macro indicators such as economy and population, and micro indicators such as the proportion of thermal power generation and fuel structure, it is necessary to conduct an in-depth analysis of the influencing factors of carbon emissions in the power industry by combining macro and micro perspectives. However, existing research has mainly focused on either macro or micro analysis of influencing factors, and only a limited number of studies have combined both perspectives. Therefore, it is necessary to integrate both macro and micro perspectives to thoroughly analyze the factors influencing carbon emissions in the power industry.

Furthermore, since China proposed its goal of peaking carbon emissions by 2030, a considerable amount of research has shifted towards exploring carbon peaking predictions and pathway assessments at regional or industry levels. However, existing studies mostly focus on macroeconomic entities such as national, regional, or provincial levels. Zhao et al. combined the BP neural network model with scenario analysis to predict the carbon peaking scenario in Henan province and studied the variation rates of various influencing factors under the carbon peaking scenario [10]. Yao et al. used scenario analysis to set five scenarios: low-carbon, energy-saving, intermediate benchmark, ideal, and unrestricted development scenarios, and combined them with the STIRPAT model to predict carbon emissions in Shanghai from 2020 to 2040 [11]. Overall, it is generally believed that the eastern coastal regions will peak earlier [12], while the western regions will peak later [13]. In the past two years,

some scholars have started to focus on analyzing carbon peaking scenarios and pathways at the industry level. Liu et al. used the LSTM model to scenario predict carbon emissions in China's transportation industry and provided relevant suggestions based on the prediction results to support carbon peaking in the transportation industry [14]. Pan et al. studied the carbon peaking situation in China's steel industry under different scenarios based on the LMDI-STIRPAT model, proposed the implementation pathway for carbon peaking in China's steel industry, and put forward policy recommendations such as strict control of new capacity, elimination of excess capacity, and consolidation of large-scale steel industry [15]. In summary, the main approaches include modeling carbon emissions in the power industry using models such as IPSO-BP neural network model [16], expandable stochastic STIRPAT model [17], LSTM neural network model [18, 19], and conducting long-term simulations using scenario analysis methods.

The aim of this paper is to explore the carbon peaking time, scale, and pathway of the power industry in Fujian Province through quantitative analysis, in order to provide scientific decision-making support. Based on existing literature, this paper mainly uses the IPCC carbon emissions accounting model to calculate the carbon emissions data of the power industry in Fujian Province from 2001 to 2021. The STIRPAT carbon emissions prediction model is established using ridge regression, and different scenarios are used to predict the carbon emissions of the power industry in Fujian Province, aiming to find the optimal model and emission reduction pathway for carbon peaking in the power industry of Fujian Province.

3. Model and Methods

3.1 IPCC Carbon Emission Factor Model

Since the official data on CO2 emissions for various sectors in China is not publicly available, it is necessary to estimate carbon emissions using other relevant data. The estimation method employed in this study is based on the Carbon Emission Factor Model issued by the Intergovernmental Panel on Climate Change (IPCC).

Based on the emission guidelines provided, the estimation formula is represented as Equation 1:

$$I = \sum S_i \times C_i \tag{1}$$

In the equation: I represents carbon emissions. i represents the energy type, which can include coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, liquefied petroleum gas, and natural gas. The specific carbon emission factors for each energy type are provided in Table 1. S_i represents the consumption of energy type i. C_i represents the carbon emission factor for energy type i.

Table 1 Energy carbon emission coefficient

Energy type	raw coal	diesel fuel	fuel oil	petroleum coke	Refinery dry gas	natural gas
kgCO2/kg	1.62	3.09	3.17	3.03	3.34	2.16

3.2 STIRPAT Model

The STIRPAT model is a classical theoretical model widely used for studying carbon emissions' impact and prediction. Compared to more complex machine learning methods such as neural network models, the STIRPAT model offers advantages of simplicity and flexibility in incorporating new features based on actual conditions and policy implementations [20, 21]. In this study, the data from Fujian Province between 2001 and 2021 is used as the research subject. The extended STIRPAT model is fitted using ridge regression to provide parameter basis for subsequent scenario analysis. The basic form of the model is as follows:

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

In the equation, a represents the model coefficient, and b, c, d are the estimation coefficients, while e denotes the error coefficient.

The basic form of the STIRPAT model analyzes the environmental conditions using only three variables: population, economic affluence, and technological level. However, this approach is limited in its ability to provide accurate and comprehensive assessments. Therefore, besides selecting appropriate factors to represent these three variables, it is necessary to include additional expanded features to improve the model's accuracy.

The carbon emissions of the power industry in Fujian Province are influenced by multiple factors. Based on the existing literature [22-24] and considering the specific circumstances of Fujian Province, this study supplements the research on factors affecting carbon emissions in the power industry. Three basic variables, including total population, per capita gross domestic product (GDP), and energy intensity, are selected. Additionally, three additional factors, namely industrial structure, the proportion of thermal power generation, and urbanization level, are included as expanded variables. By incorporating these factors, the STIRPAT model is expanded to construct the research model in this study:

$$I = aP^b A^c T^d CJ^e TP^f U^g h \tag{3}$$

In the equation, I represents carbon emissions (in 10,000 tons), a is a constant term, P represents the total population represented by the resident population, A represents the economic condition indicated by per capita gross domestic product (GDP), T represents energy intensity, calculated as the total energy consumption in Fujian Province divided by regional gross domestic product and converted to standard coal equivalent. CJ represents the industrial structure, represented by the proportion of value added in the secondary industry to the total domestic product. TP represents the power structure, represented by the proportion of thermal power generation to total power generation. U represents the level of urbanization, measured by the ratio of urban population to resident population. Finally, e represents the random disturbance term in the model. The variables of the model are shown in Table 2.

Table 2. Model variable description

variable	unit
Carbon dioxide emissions (I)	1×10^4 ton
population (P)	1×10^4
GDP per capita (A)	1×10^4 yuan/person [1]
energy intensity (T)	ton of standard coal/ yuan
industrial structure (CJ)	1
Proportion of thermal power (TP)	1
Urbanization level (U)	1

Taking the natural logarithm of both sides of equation (3), we obtain equation (4):

$$\ln I = \ln a + b\ln P + c\ln A + d\ln T + e\ln CJ + f\ln TP + g\ln U + \ln h \tag{4}$$

In equation (4), b, c, d, e, f, and g represent the elasticity coefficients, indicating the percentage change in I resulting from a 1% change in P, A, T, CJ, TP, and U, respectively.

3.3 data sources

The data for per capita regional GDP, population size, urbanization level, and industrial structure in Fujian Province in this study are sourced from the "Statistical Yearbook of Fujian Province" for the years 2002-2022. The data on the proportion of thermal power generation and energy consumption in the electricity industry in Fujian Province are obtained from the "China Energy Statistical Yearbook" for the years 2001-2020. The values for energy carbon emission coefficients and carbon emission factors are sourced from the "Guidelines for National Greenhouse Gas Inventories" (IPCC 2006).

4. Model Construction

4.1 Calculation of Carbon Emissions in the Power Industry in Fujian Province

Based on the calculations using the IPCC carbon emission coefficient model, the trend of carbon emissions in the power industry in Fujian Province is shown in Figure 1. From 2001 to 2021, the total carbon emissions in the power industry in Fujian Province showed a continuous upward trend. The carbon emissions in the power industry of Fujian Province increased steadily from 2001 to 2011. There was a slight decrease in carbon emissions from 2011 to 2016, followed by a continuous increase in carbon emissions in the power industry in Fujian Province after 2017. The period from 2016 to 2018 witnessed the highest

growth rate in carbon emissions.

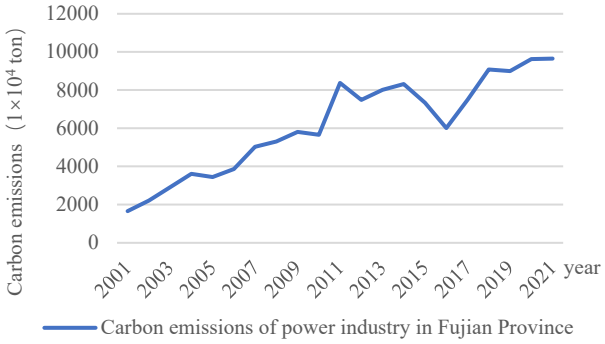

Figure 1. Change Trend of Carbon Emissions in Electric Power Industry in Fujian Province from 2001 to 2021.

4.2 Carbon emission prediction model

Using the SPSS PRO software, a linear regression was conducted on the data of per capita regional GDP, population size, urbanization level, industrial structure, and the proportion of thermal power generation from 2001 to 2021 in Fujian Province, based on the linear STIRPAT equation. The results are shown in Table 3. The variance inflation factors (VIF) for the logarithmic coefficients of per capita regional GDP and population size were found to be 186.922 and 294.137, respectively, which are significantly higher than the threshold of 10. This indicates the presence of severe multicollinearity among the independent variables. Therefore, the reliability of the coefficient estimates obtained through linear regression is low, and it is not appropriate to make judgments based solely on the regression results. It is necessary to address the issue of multicollinearity in the independent variables [25].

Table 3. Linear regression results for variables

variable	standard coefficient	t	P	VIF
constant	-	-1.014	0.328	-
P	0.341	1.721	0.107	186.922
A	1.564	6.299	0.000	294.137
T	0.522	4.026	0.001	80.206
CJ	-0.021	-0.816	0.428	3.119
TP	0.307	14.571	0.000	2.111
U	-0.389	-1.448	0.170	343.687

Given the limited sample size, ridge regression can effectively prevent overfitting of the model. Therefore, ridge regression was chosen for the model estimation. The results are shown in Table 4.

In this study, is selected as the evaluation criterion for selecting the regularization coefficient, where represents the goodness of fit of the overall model, taking into account the distribution and differences between the predicted and true values of the samples. A value closer to 1 indicates a better fit of the model.

Table 4. Ridge Regression Estimation Results(k=0.148)

variable	coefficient	standard error	t-statistic	p	R2
constant	-8.603	1.658	-5.190	0.000***	
ln*P*	1.524	0.138	11.001	0.000***	
ln*A*	0.196	0.012	15.883	0.000***	
ln*T*	-0.188	0.041	-4.609	0.000***	0.981
ln*CJ*	1.348	0.367	3.673	0.003***	
ln*TP*	0.858	0.121	7.071	0.000***	
lnU	0.963	0.072	13.307	0.000***	

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

$$\ln I = -8.603 + 1.524\ln P + 0.196\ln A - 0.188\ln T + 1.348\ln CJ + 0.858\ln TP + 0.963\ln U \quad (5)$$

Based on the simulation results of the STIRPAT model, predictions for future carbon emissions in Fujian Province can be made. The specific formula for the model is as follows:

$$I = \exp(-8.603 + 1.524\ln P + 0.196\ln A - 0.188\ln T + 1.348\ln CJ + 0.858\ln TP + 0.963\ln U) \quad (6)$$

According to the coefficients of the carbon emission prediction model for the electricity industry in Fujian Province (equation 6), a 1% change in population, per capita GDP, energy intensity, industrial structure, share of thermal power, and urbanization level can lead to a change of 1.524%, 0.196%, -0.188%, 1.348%, 0.858%, and 0.963% in carbon emissions, respectively. The different coefficients indicate that each feature has a varying degree of impact on carbon emissions in Fujian Province. Based on the magnitude of their impact, the features can be ranked as follows: population, industrial structure, urbanization level, share of thermal power, per capita GDP, and energy intensity.

By using historical data on per capita GDP, population size, urbanization level, industrial structure, share of thermal power, and energy intensity, this study simulated carbon emissions in Fujian Province and performed a regression analysis comparing the simulated values with historical data. The results showed a good fit of the model with an R2 value of 98.2%. Therefore, using model (equation 6) to forecast future carbon emissions in the electricity industry of Fujian Province is feasible. The

comparison between the model fit and historical data is illustrated in Figure 2.

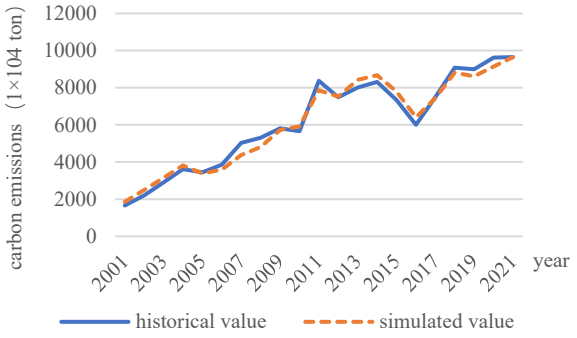

Figure 2. Comparison of simulated value and historical value of carbon emissions in power industry in Fujian Province

5. Future carbon emission trend analysis of power industry in Fujian Province

5.1 Parameter Settings

This study sets the growth rates of six influencing factors: per capita GDP, population size, energy intensity, urbanization level, industrial structure, and the share of thermal power, to three levels: low, medium, and high. The specific parameter settings and their justifications are presented in Table 5. The parameter settings are as follows:

Per Capita GDP: During the "13th Five-Year Plan" period, the average annual growth rate of per capita GDP in Fujian Province was 6.9%. For the low-growth scenario, the growth rate is set to decrease by approximately 1% every 5 years, based on relevant studies by Li et al. [26]. For the medium-growth scenario, the growth rate is set at 5.4% per year, as mentioned in the "14th Five-Year Plan and 2035 Vision Outline for Economic and Social Development in Fujian Province." Therefore, the growth rate of per capita GDP for the medium-growth scenario in the years 2022-2025 is 7.4%. By following the pattern of growth rate changes between low and medium scenarios, the growth rate for the high-growth scenario in 2022-2025 is estimated to be 7.9%.

Population Size: The projected population size for the medium-growth scenario is based on the "Spatial Planning of Land in Fujian Province (2021-2035)" and aims for a resident population of 47 million by 2035, with an average annual growth rate of 0.863%. According to Zhang Xianling's research on population predictions for China, the population of China is expected to enter negative growth after 2027 [27]. Based on this trend, the estimated growth rate for the resident population in Fujian Province is 1.86% for 2022-2025 and 0.83% for 2025-2030. The high and low-growth scenarios for Fujian Province are set based on the highest and lowest values of the average annual growth rates every 5 years between 2001 and 2022.

Energy Intensity: From 2000 to 2019, the average annual decrease in energy intensity in Fujian Province was 2.4%. Assuming that the energy intensity reduction rate in the medium-growth scenario follows this trend, the low-growth and high-growth scenarios for energy intensity in Fujian Province are set to decrease by an additional 0.4% and 0.2% every 5 years, respectively, based on the research by Pan [28].

Industrial Structure: The proportion of the added value of the secondary industry to the total GDP in Fujian Province is 58.81%, which exceeds the national average of 53.5%. Therefore, stabilizing the primary industry, controlling the secondary industry, and developing the tertiary industry are the main objectives for optimizing the industrial structure in Fujian Province. In recent years, the proportion of the secondary industry in Fujian Province has been declining. During the "13th Five-Year Plan" period, the annual average decrease rate of the secondary industry's proportion was 1.33%. This rate is set as the change rate for the industrial structure in the medium-growth scenario in Fujian Province. Based on existing research [26], the change rate for the industrial structure in the high-growth scenario is set at -0.93%, and in the low-growth scenario, it is set at -1.73%. The industrial structure is assumed to decrease by 0.2% every 5 years.

Share of Thermal Power: According to the "China Energy Statistical Yearbook," the total electricity generation in Fujian Province has been increasing year by year. However, with the intensification of global climate change and the deterioration of atmospheric environmental quality, the country has implemented policy measures prioritizing the development of clean energy such as wind power, nuclear power, hydropower, and photovoltaic power. The total thermal power generation in Fujian Province reached a peak of 1280.31 billion kilowatt-hours in 2013. Based on the research by Wang [29], combined with the clean power development goals in the "14th Five-Year Plan for Energy Development in Fujian Province," the change rate of the share of thermal power in the low-growth scenario is assumed to be -2.23% for 2022-2025 and -2.73% for 2025-2030. Fujian Province places emphasis on clean energy power and actively promotes clean energy development. Assuming that the decline rate of the share of thermal power in Fujian Province is higher than the national average, based on the research by Ding [30], the change rate of the share of thermal power in the high-growth scenario is assumed to be -1.76% for 2022-2025 and -2.26% for 2025-2030. For the medium-growth scenario, the change rate of the share of thermal power is set as the average of the low and high scenarios, namely -3.23% for 2022-2025 and -1.97% for 2025-2030.

Urbanization Level: According to the "14th Five-Year Plan for Economic and Social Development of Fujian Province and Vision Outline for 2035," the target urbanization rate for the permanent population in Fujian Province in 2025 is set as the growth rate for the urbanization level in the medium-growth scenario. The urbanization level growth rate for Fujian Province from 2022 to 2025 is set at 0.6%. During the "13th Five-Year Plan" period, the urbanization level growth rate in Fujian Province was 1.5%. This rate is used as the growth rate for the urbanization level in the high-growth scenario from 2022 to 2025. Based on the trend of the urbanization level growth rates in the medium-growth and high-growth

scenarios, the calculated growth rate for the urbanization level in the low-growth scenario from 2022 to 2025 is 0.24%. It is assumed that from 2025 to 2030, the growth rate for the urbanization level in Fujian Province will continue according to the rates observed during the "13th Five-Year Plan" period in the low, medium, and high-growth scenarios.

Table 5. Change rate setting of each influencing factor in Fujian Province

Rate of change type	period	Change rate setting(%)					
		P	A	T	CJ	TP	U
Low	2022-2025	1.76	6.90	-2.0	-1.73	-2.23	0.24
	2025-2030	1.26	5.90	-2.2	-1.53	-2.73	0.24
Middle	2022-2025	1.86	7.40	-2.4	-1.33	-1.99	0.60
	2025-2030	1.36	6.40	-2.6	-1.13	-2.49	0.60
High	2022-2025	2.18	7.90	-2.8	-0.93	-1.76	1.50
	2025-2030	1.68	6.90	-3.0	-0.73	-2.26	1.50

5.2 Scenario Analysis

Scenario analysis is commonly used in research related to energy consumption and carbon emissions. Many researchers in the field adopt this method to study future carbon emission trends, with different approaches to scenario settings. In this study, based on the background, premises, and requirements of national carbon emission development, as well as the low-carbon development policies and regulations in Fujian Province, and taking into account the opportunities, challenges, and potential future carbon emission scenarios in the power industry of Fujian Province, we made assumptions according to relevant studies [28]. Considering the demands for low-carbon development in different stages, we set five scenarios:

Low Carbon Scenario (S1): All factors are set to low change rates.

Energy-saving Scenario (S2): In this scenario, industry structure and the proportion of thermal power generation are set to low change rates, while population, energy intensity, per capita GDP, and urbanization level remain at moderate change rates.

Baseline Scenario (S3): All factors are set to moderate change rates. This scenario represents the baseline scenario, providing important reference values for this study.

Ideal Scenario (S4): In this scenario, energy intensity and the proportion of thermal power generation are set to low change rates, population size and industry structure are set to moderate change rates, while the remaining factors are set to high change rates. This scenario represents an ideal situation for balanced development in the economy, energy, and population.

High Carbon Scenario (S5): All factors are set to high change rates. This scenario represents a high-carbon situation.

The settings of each scenario are presented in Table 6.

Table 6. Scenario Setting Table for Carbon Peak Prediction in Fujian Electric Power Industry

Scenario	scene setting					
	P	A	T	CJ	TP	U
S1	L	L	L	L	L	L
S2	M	M	L	L	L	M
S3	M	M	M	M	M	M
S4	M	H	L	M	L	H
S5	H	H	H	H	H	H

6. Forecast Results Analysis

The trends of carbon emissions, as well as the timing and magnitude of carbon peaking in the power industry of Fujian Province, under different scenarios are shown in Figure 3 and Table 7. Among the five scenarios, only the Low Carbon Scenario and Energy Saving Scenario can achieve carbon peaking by 2030. However, there are significant differences in the timing and magnitude of the peaking.

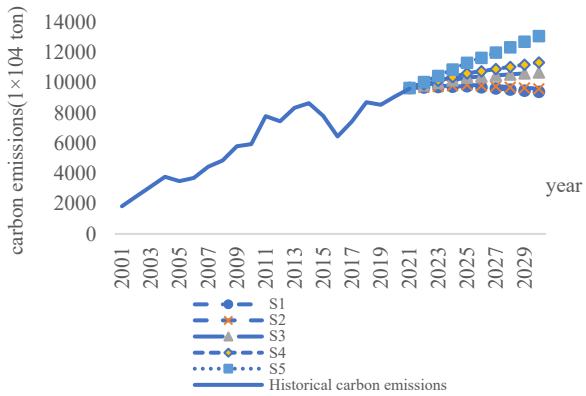

Figure 3. 2022-2030 Carbon Emissions Forecast of Electric Power Industry in Fujian Province under Various Scenarios

Table 7. Carbon peak situation and carbon dioxide emission peak of power industry in Fujian Province before 2030 under different scenario combinations

Scenario	Carbon peak situation	Peak value (maximum value) (unit: 1×10^4 tons)
Low Carbon Scenario(S1)	Carbon peak in 2022	9674.81
Energy-saving Scenario(S2)	Carbon peak in 2025	9853.92
Baseline Scenario(S3)	Not peaked before 2030	10671.72
Ideal Scenario(S4)	Not peaked before 2030	11326.13
High Carbon Scenario(S5)	Not peaked before 2030	13069.77

Low Carbon Scenario (S1): The low carbon scenario is based on the "14th Five-Year Plan for Energy Development in Fujian Province." During the 14th Five-Year Plan period, Fujian Province will continue to promote energy and industrial restructuring, vigorously practice a green and low-carbon lifestyle, and adopt necessary low-carbon measures, making some concessions in terms of economic development level and power source structure. In this scenario, the carbon

emissions from the electricity industry in Fujian Province will peak in 2022, with a peak value of 96.7481 million tons. After reaching the peak, carbon emissions will decline at a relatively fast rate. Compared to the baseline scenario (S3) emissions in 2030, the peak value in the low carbon scenario is reduced by 9.9691 million tons of carbon emissions.

Energy-saving Scenario (S2): The energy-saving scenario will continue the path of ecological priority and green development during the 14th Five-Year Plan period. In this scenario, Fujian Province will continue to adjust industrial and power source structures. In this scenario, the carbon emissions from the electricity industry in Fujian Province will peak in 2025, with a peak value of 98.5392 million tons. Both the low carbon scenario (S1) and the energy-saving scenario (S2) can achieve carbon peaking in the electricity industry in Fujian Province before 2030, but the peak time differs by 3 years. Compared to the baseline scenario (S3) emissions in 2030, the peak value in the energy-saving scenario reduces carbon emissions by 8.178 million tons.

Baseline Scenario (S3): Analyzing the achievements of the 13th Five-Year Plan and the changing trends of factors specific to Fujian Province, the economic growth of Fujian Province has shifted from high-speed to medium-high-speed growth stage. This scenario will continue the development of current planning policies without additional adjustment measures, maintaining the existing policy efforts. In this scenario, the carbon emissions from the electricity industry in Fujian Province do not peak before 2030, with emissions of 106.7172 million tons in 2030. The S3 scenario implies that if the energy plan of the 14th Five-Year Plan in Fujian Province continues to be implemented without more aggressive carbon reduction policies or additional adjustments to energy consumption, the carbon emissions from the electricity industry in Fujian Province will not peak before 2030.

Ideal Scenario (S4): In this scenario, strict control of energy consumption, accelerated industrial transformation and upgrading, substantial adjustments to the energy structure, and increased proportion of clean energy consumption are emphasized to ensure high-quality and high-speed economic development in Fujian Province, while balancing economic development and carbon reduction, aiming for a harmonious coexistence. In this scenario, the economy of Fujian Province grows at a high speed, urbanization level continues to increase, and the industrial structure is continuously optimized while reducing the proportion of coal-fired power. However, considering the balance between economic development and carbon reduction, carbon peaking is not achieved before 2030. In 2030, the carbon emissions from the electricity industry are projected to be 113.2613 million tons. This scenario represents an increase of 6.5441 million tons compared to the baseline scenario (S3) in 2030, accounting for 6.13% of the baseline scenario's carbon emissions. Additionally, the per capita GDP and urbanization level in the ideal scenario in 2030 are 102.87% and 108.34% of the baseline scenario, respectively. Although carbon emissions from the electricity industry in Fujian Province do not peak before 2030 in this scenario, the rapid improvement in economic and urbanization levels has significant implications for the development of the electricity industry in Fujian Province.

High Carbon Scenario (S5): This scenario implies that Fujian Province will continue to prioritize economic development in the near future, focusing on recovering from the impact of the pandemic and maintaining high-quality economic growth. It also means that environmental issues and climate change will take a backseat, resulting in an imbalance between economic development and environmental protection. In this scenario, the carbon emissions from the electricity industry in Fujian Province cannot achieve the target of peaking in 2030. The carbon emissions in 2030 are projected to be 130.6977 million tons, which is a 35.09% increase compared to the peak value in the low carbon scenario (S1). Without proper control and regulation on economic development and energy construction, the carbon emissions from the electricity industry in Fujian Province will not peak before 2030 and will gradually increase, hindering the overall carbon peaking goal of Fujian Province. Therefore, Fujian Province must make detailed plans based on its own characteristics and implement macro-level controls on energy structure and industrial structure.

In summary, the low carbon scenario (S1) and the energy-saving scenario (S2) will both achieve carbon peaking in the electricity industry in Fujian Province by 2030. Considering that Fujian Province is an important coastal province in China with a significant role in foreign trade, it is necessary to balance economic development. Therefore, the energy-saving scenario (S2) that appropriately restricts economic development, controls energy consumption, and balances environmental protection and development is a suitable alternative for the electricity industry in Fujian Province in the near future. At the same time, in the ideal scenario (S4), although carbon peaking is not achieved before 2030, the electricity industry in Fujian Province can provide crucial energy support for social development and contribute to economic growth, promoting socialist modernization. Therefore, the ideal scenario (S4) also holds important reference value for the development of the electricity industry in Fujian Province.

7. Conclusion and Recommendations

7.1 Conclusion

This study employed a expanded model with five variables: population size, per capita GDP, urbanization level, industrial structure, and the proportion of thermal power generation, to analyze carbon emissions in Fujian Province from 2001 to 2030. Ridge regression was used to fit the parameters of the expanded model, and the ridge regression model achieved the highest R2 value at k=0.148, indicating good predictive capability. Based on this, the final carbon emissions prediction model for the electricity industry in Fujian Province was established.

The coefficients of the carbon emissions prediction model (Equation 6) indicate that each variable has a different degree of influence on carbon emissions in Fujian Province. Ranking the variables according to their influence, the order is as follows: population size > industrial structure > urbanization level > proportion of thermal power generation > per capita GDP > energy intensity. Considering that the population size is not expected to decline significantly in the near future, industrial structure becomes the most important factor for reducing carbon emissions in the electricity industry of Fujian Province, aside from population size.

Based on the carbon emissions prediction model and incorporating previous studies and government development reports, three levels of changes (high, medium, and low) were set, and five different scenarios were analyzed to forecast carbon emissions in the electricity industry of Fujian Province from 2022 to 2030. The results indicate that in the low carbon scenario, carbon emissions in the electricity industry of Fujian Province will peak in 2022, reaching a peak value of 96.7481 million tons. In the energy-saving scenario, carbon emissions will peak in 2025, reaching a peak value of 98.5392 million tons. In the baseline, ideal, and high carbon scenarios, carbon emissions in the electricity industry of Fujian Province will not peak before 2030, with respective carbon emissions in 2030 of 106.7172 million tons, 113.2613 million tons, and 130.6977 million tons.

7.2 Suggestions

Based on the research findings in this study regarding the factors influencing carbon peaking in Fujian Province, the following policy recommendations are proposed:

Address key factors influencing carbon emissions in the electricity industry and promote low-carbon development in industrial and population distribution. As the secondary industry plays a significant role in Fujian Province and has high energy consumption, it is crucial to establish an industrial structure that is energy-efficient and low in energy consumption to achieve carbon peaking in the electricity industry. Promote the green development of the economy, vigorously promote high-quality economic development, encourage enterprises to undergo green transformation, and facilitate the low-carbon transformation of the industrial structure. Continuously optimize population structure and distribution, seeking a balance between population growth, accelerated urbanization, and low-carbon development.

Improve supporting laws and regulations to provide a green policy environment. The government can adopt a macro perspective to develop differentiated emission reduction paths for carbon peaking in the electricity industry and provide legal and regulatory support to ensure the implementation of the carbon peaking targets. Develop feasible action plans for carbon peaking in the electricity industry based on the characteristics of Fujian Province and promote the implementation of relevant supporting laws and regulations to overcome obstacles to carbon peaking. Enhance policies for energy conservation and emission reduction in the electricity industry, encourage the green transformation of the industry, and increase the motivation for carbon reduction within the sector.

Optimize the power source structure. Fujian Province should promote the green development of the electricity industry, further optimize the power source structure, increase the proportion of clean energy generation, and actively promote the construction of clean energy power plants. This will help reduce the carbon intensity of electricity generation in Fujian Province, decrease reliance on coal as a fuel source, and increase the capacity of clean energy installations. It is essential to harness innovative forces to explore low-carbon power generation technologies, improve the utilization of raw materials in power generation, and reduce material consumption.

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