Research on Energy Carbon Emission Situation Prediction Technology: A Case Study of Fujian Province

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Abstract. In this paper, Fujian Province was taken as an example to build a general analysis framework for urban carbon emission analysis. Firstly, carbon emission was measured, and then the LMDI method was used to decompose the influencing factors of carbon emission from the aspects of energy structure, industrial structure, social and economic development level, etc. On this basis, the carbon emission trend was analyzed and predicted. A data mining method for carbon emission situation prediction of energy and electric power is proposed.

Keywords: Carbon emission decomposition · Carbon emission projections · LMDI decomposition method · Scenario analysis · Energy and power industry

1 Introduction

Actively responding to climate change has become a common challenge for humanity. Reducing greenhouse gas emissions and developing a low-carbon economy with "low pollution, low energy consumption, and low emissions" has become a common choice for all countries in the world [17]. As the largest developing country, China has been the second-largest economy and the world's largest carbon emitter since the early 21st century. At the same time, China has pledged to strive for the peak of carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060, pointing out the direction for China's low-carbon development. Energy is the blood of economic development, but it is also an essential source of carbon emissions. Like many developed countries, China has been caught in the dilemma of balancing economic development with energy conservation and emission reduction in economic development [14]. Since 2000, China's GDP has maintained a high growth rate, and the level of urbanization and industrialization has been dramatically improved, which has led to a significant increase in energy carbon emissions. As an intermediate link between the economy and the environment, the energy system is crucial to the sustainable development of the economy and society. Therefore, it is necessary to identify the driving factors of energy carbon emissions and forecast them accordingly to determine the path to restrain the growth of carbon emissions.

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Carbon emissions are closely related to production and life. With the improvement of the economic development level, the optimization of industrial structure and energy structure, and the transformation of residents' lifestyles, the scale and trend of regional carbon emissions will continue to change. In addition, due to the vast territory of China, there is pronounced heterogeneity in economic activities in different regions, and the trend of carbon emissions in different regions is different. Because of this, when considering the prediction and emission reduction trajectory of regional total carbon emissions in the future, on the one hand, it is necessary to use a simple and convenient accounting model that is internationally recognized and relatively unified across regions; On the other hand, it is necessary to design a measurement model that fully shows the characteristics of urban carbon emissions and emission reduction trajectories. However, previous studies often focused on the significance of low-carbon development and emission reduction paths. They should have intensely discussed the impact mechanism and future development of carbon emissions of individual cities in the economic and social system. China has launched several pilot projects for low-carbon cities and provinces, but the path measures for individual cities to control carbon emissions and promote low-carbon transformation need to be clarified.

Therefore, this study uses Fujian Province as an example to build a general urban carbon emission analysis framework. Firstly, the carbon emission is calculated, and then the LMDI method is used to decompose the influencing factors of carbon emission from the aspects of energy structure, industrial structure, and social and economic development level. On this basis, the trend of carbon emission is analyzed and predicted. This paper proposes data mining methods suitable for energy and electric power carbon emission situation prediction. The decomposition of driving factors of carbon emissions helps to understand the contribution of different factors to carbon emissions. In contrast, the prediction of carbon emissions can get the future trend of carbon emissions in different scenarios and then formulate different emission reduction strategies, which have specific practical significance for controlling carbon emissions in cities.

2 Literature Review

There are mainly three studies on carbon emissions: the measurement method, the influencing factors of carbon emissions, and the prediction of carbon emissions.

2.1 Measurement of Carbon Emissions

The measurement of carbon emissions will directly affect the time when the carbon peak is realized. In the calculation of carbon emissions, the common practice is to use the carbon emissions calculation method in the IPCC Guidelines for National Greenhouse Gas Inventories issued by the Intergovernmental Panel on Climate Change (IPCC) in 2006 and use the input-output tables of countries or regions for calculation. However, according to the research of Chinese scholars, China's energy emission coefficient is greatly overestimated according to the IPCC method because China's energy consumption mix needs to be considered. By adopting the new carbon emission factor estimation, the carbon emissions of China's cement production from 2000 to 2012 were reduced by 45% compared with the international estimate [7]. Some scholars improved the energy classification system and carbon emission calculation method based on the IPCC-recommended method and more accurately calculated the carbon emissions and energy carbon emission efficiency [3].

2.2 Influencing Factors of Carbon Emissions

Exploring the influencing factors of carbon emissions is an essential prerequisite for reducing carbon emissions. Regarding the influencing factors of carbon emissions, scholars generally believe that economic development and energy consumption significantly impact carbon emissions. Some scholars believe that China is currently in the stage of urbanization and industrialization. The main characteristics of energy consumption are the rapid growth of consumer demand and the rigidity of energy demand. Due to the constraints of cost and resource endowments, most developing countries can only choose the coal-based energy structure, which will inevitably lead to serious greenhouse gas emissions and environmental pollution. China's carbon emission reduction cannot be separated from the law of phased social development. However, it can reduce carbon emissions by appropriately controlling the speed of urbanization and improving energy efficiency [10]. According to the environmental Kuznetz curve (EKC) hypothesis, economic growth has an inverted U-shaped relationship with environmental pressure and resource consumption. When the economy reaches a particular stage of development, it can achieve low environmental pressure and resource consumption through new technologies and low-carbon policies and achieve sustainable and rapid economic growth. Yuan Yuan and Li Guoping (2016) [15] further constructed a model that regional carbon emissions are affected by industrial structural changes, holding that factors such as population size, technology level, and capital input will affect economic development. Economic development is carried out according to different industries, and its energy consumption is closely related to its output and energy-related technology level. These factors are all affected by the total economic output and industrial structure. Different stages of economic development have different characteristics of industrial structure. Optimizing industrial structure can effectively reduce the negative externalities brought by economic development on the environment so that regional carbon emissions tend to decline [4].

In recent years, scholars at home and abroad have mainly used the regression model or decomposition method to analyze the influencing factors of China's carbon emissions. Compared with regression analysis, index decomposition analysis (IDA) can quantify the driving factors behind the change in total carbon emissions, such as the structural change of economic activities and the intensity change of energy consumption. It can intuitively show the key influencing factors of carbon dioxide emissions. Therefore, IDA has unique advantages in studying energy consumption and carbon emissions. Specifically, it includes the log-mean Di (LMDI) decomposition method, the two-factor Fisher index [1], and the Laspeyres index [12]. The Kaya (1989) [6] identity established the corresponding relationship between carbon dioxide emissions and population, economic development level, energy efficiency, and other factors. On this basis, decomposition technology has been rapidly developed. Ang et al. (2004) [1] improved the log-average

Dili index (LMDI) decomposition method to achieve complete decomposition, effectively solving the problem of zero and negative values [18]. Since then, the LMDI method has been widely used in national, regional, sectoral, and industry-level research. Li et al. (2010) [11] found that China's carbon emissions are affected by a variety of factors, such as the level of economic development, population size, energy use, and technological progress, and the growth of China's economic aggregate is an important reason for the increase of carbon emissions in the stage of accelerated urbanization and industrialization. Ang et al. (2015) [2] extended the LMDI decomposition method from time decomposition to multi-regional spatial decomposition in the study of manufacturing carbon emissions in 30 provinces in China. Shao et al. (2017) [13] focused on the impact of investment on the carbon emissions of China's manufacturing industry by using the generalized DI index decomposition method and then conducted a dynamic scenario analysis of the carbon emissions of China's manufacturing industry from 2015 to 2030 based on Monte Carlo simulation.

2.3 Prediction of Carbon Emissions

Accurate carbon emission peak prediction is the basis and premise of balanced economic development and carbon emission control. There are two main types of carbon emission prediction methods: one is to build economic models; for example, Zhao et al. (2017) [16] used the input-output model to forecast carbon emissions of 30 industries in China; The other is to establish a model of the relationship between carbon emissions and influencing factors and simulate and forecast through setting scenario analysis. The representative model is the STIRPAT model, which can fully reflect the impact of population, economic development, technology, industrial structure, energy structure, and other independent variables on carbon emissions, and comprehensively study various factors in peak prediction. Liu et al. (2017) [9] used the STIRPAT model to predict carbon emissions in Chongqing. They found that improving clean energy technology could effectively reduce carbon emissions, Liu et al. (2018) [8] used the STIRPAT model and system dynamics model to study the driving factors of China's carbon emissions, emission peak, and environmental Kuznetz curve (EKC) hypothesis. Regarding the carbon emission prediction of the Yangtze River Economic Belt (YREB), Huang et al. (2018) [5] divided the YREB into three regions: the east, the central, and the west. Chen et al. (2018) [4] mainly used scenario analysis to predict carbon emissions from the perspective of global night light data.

3 Model Design

3.1 Carbon Emission Measurement Method

Considering the authority and universality, the invention adopts the method provided by the Intergovernmental Panel on Climate Change (IPCC) in 2006 for the national greenhouse gas inventory guidelines designated by the United Nations Framework Convention on Climate Change and the Kyoto Protocol, namely the IPCC (2006 Inventory

Table 1. Carbon emission accounting parameters of various energy sources

Energy type	NCV (kJ/kg; kJ/m^3)	CEF (kg/GJ)	COF (%)	δ (kg/kg; kg/m^3)
Raw coal	20908	26.37	94	1.90
Cleaned coal	26344	27.40	94	2.49
Other coal washing	10454	27.40	94	0.99
Briquette	17761	33.60	90	1.97
Coke	28435	29.50	93	2.86
Coking coal furnace gas	16726	12.10	98	0.73
Other gas	15054	12.10	98	0.65
Crude oil	41816	20.10	98	3.02
Gasoline	43070	18.90	98	2.93
Kerosene	43070	19.60	98	3.03
Diesel oil	42652	20.20	98	3.10
Fuel oil	41816	21.10	98	3.17
Liquefied petroleum gas	50179	17.20	98	3.13
Refinery dry gas	45998	18.20	98	3.01
Natural gas	38931	15.30	99	2.16

Guidelines) method to measure the carbon emissions. The specific calculation formula is as follows:

$$CO_2 = \sum\nolimits_i E_i \times \delta_i = \sum\nolimits_i E_i \times NCV_i \times CEF_i \times COF_i \times \frac{44}{12} \tag{1}$$

where is carbon dioxide emissions, CO_2 is the type of energy; E is energy consumption, NCV is the average low calorific value. CEF is the carbon emission coefficient, representing the carbon content per heat unit. 44/12 is the carbon oxidation factor, which represents the carbon oxidation rate when energy is burned; 44/12 is the ratio of carbon dioxide to carbon chemical molecular weight, and δ is energy's carbon dioxide emission factor. The carbon dioxide emission coefficient of each energy is shown in Table 1.

3.2 Carbon Emission Decomposition Method

Based on LMDI decomposition technology, the change of carbon emissions is decomposed. The basic model is as follows:

$$C = \sum\nolimits_i C_i = \sum\nolimits_i \frac{C_i}{E_i} \times \frac{E_i}{E} \times \frac{E}{Y} \times \frac{Y}{N} \times N \tag{2}$$

where: C is carbon emissions, C_i is the carbon emissions of one kind of energy, E is the total energy consumption, E_i is the consumption of one kind of energy, Y is regional

GDP, and N is regional population. The five terms on the right side of the equation are: C_i/E_i represents the carbon emission of one unit of i energy, namely, the carbon emission coefficient of the i energy, E_i/E is the proportion of energy consumed by the i energy, represents the energy structure, E/Y represents energy consumption per unit of output, namely energy intensity, Y/N is GDP per capita, representing the level of economic development, And N is the population size.

Furthermore, the total carbon emissions are decomposed into carbon emission intensity effect (I), energy structure effect (S), energy intensity effect (E), economic development effect (G) and population size effect (N). For example, Eq. (3).

$$C = \sum_i C_i = \sum_i \frac{C_i}{E_i} \times \frac{E_i}{E} \times \frac{E}{Y} \times \frac{Y}{N} \times N = \sum_i I_i S_i EGN \tag{3}$$

According to Formula (1), the change in carbon emissions from year to year can be expressed as:

$$\begin{aligned} \Delta C = C^{t+1} - C^t &= \sum_i I_i^{t+1} S_i^{t+1} E^{t+1} G^{t+1} N^{t+1} - \sum_i I_i^t S_i^t E^t G^t N^t \\ &= \Delta C_I + \Delta C_S + \Delta C_E + \Delta C_G + \Delta C_N \end{aligned} \tag{4}$$

where: ΔC_I is the carbon emission intensity effect, ΔC_S is the effect of energy structure, ΔC_E is energy intensity effect, ΔC_G is the effect of economic development, ΔC_N is the effect of population size.

Using the LMDI decomposition technology, the LMDI effect formula of each decomposition factor in Formula (3) from year to year is:

$$\Delta C_I = \sum_i^m L\left(C_i^{t+1},\ C_i^t\right) \ln\left(\frac{I^{t+1}}{I_t}\right) \tag{5}$$

$$\Delta C_S = \sum_i^m L\left(C_i^{t+1},\ C_i^t\right) \ln\left(\frac{S^{t+1}}{S_t}\right) \tag{6}$$

$$\Delta C_E = \sum_i^m L\left(C_i^{t+1},\ C_i^t\right) \ln\left(\frac{E^{t+1}}{E_t}\right) \tag{7}$$

$$\Delta C_G = \sum_i^m L\left(C_i^{t+1},\ C_i^t\right) \ln\left(\frac{G^{t+1}}{G_t}\right) \tag{8}$$

$$\Delta C_N = \sum_i^m L\left(C_i^{t+1},\ C_i^t\right) \ln\left(\frac{N^{t+1}}{N_t}\right) \tag{9}$$

Of which, $L\left(C_i^{t+1},\ C_i^t\right) = \left(C_i^{t+1} - C_i^t\right) / \left(\ln C_i^{t+1} - \ln C_i^t\right)$.

3.3 Carbon Emission Prediction Methods

The STIRPAT model has been widely used by scholars in the study of environmental impact, and its basic expression formula is I = aPbAcTde. Among them, I represents the degree of environmental pressure, a represents the model coefficient, P represents the demographic factor, A represents the economic factor, T represents the technical factor, and e is the error term. The model has a random expansion, which can be used to evaluate the impact of various factors on the environment. Each index can reflect the non-proportional impact of each factor on the environment. After taking the logarithm of the basic Formula, the specific Formula is obtained as follows.

$$\mathrm{lnI} = \mathrm{lna} + \mathrm{blnP} + \mathrm{clnA} + \mathrm{dlnT} + \mathrm{lne} \tag{10}$$

Combined with the results of LMDI decomposition and existing research, this paper will add energy structure factors based on population, economic development level, and technology factors in the model and industrial structure factors. It should also be noted that energy intensity is consumed per unit of output, which can reflect production efficiency and technology. Therefore, this paper will measure the technical factors by energy intensity (EE). The model's energy structure and industrial structure factors will be measured by the proportion of coal in energy consumption (ES) and the proportion of the added value of the secondary industry in regional GDP (IS), respectively. The STIRPAT model is extended as follows:

$$\mathrm{lnI} = \mathrm{lna} + \mathrm{blnN} + \mathrm{clnG} + \mathrm{dlnEE} + \mathrm{flnESI} + \mathrm{glnIS} + \mathrm{lne} \tag{11}$$

where a, b, c, d, f and g are the coefficients of each index term, and e is the error term.

3.4 Variable Description and Data Source

This paper takes Fujian Province as the research object and takes the period from 2003 to 2020 as the sample interval. The data sources are China Energy Statistical Yearbook and China Statistical Yearbook. The missing data are supplemented by the linear interpolation method and the ARIMA model. Among them, the GDP was calculated at the constant price in 2003, and all kinds of energy were converted into standard coal according to the conversion factor to calculate the energy consumption. The definitions and calculation methods of relevant variables are shown in Table 2.

4 Empirical Analysis

4.1 Overview of Carbon Emissions in Fujian Province

With the rapid economic and social development of Fujian province, the demand for energy consumption is also increasing, which brings about an increase in carbon emissions in the whole province. The total energy consumption increased from 27.585 million tons of standard coal in 2003 to 95.8743 million tons of standard coal in 2020, an increase of 3.48 times. At the same time, the total carbon emission increased from 82.7771 million tons in 2003 to 288.742 million tons in 2020, an increase of 3.49 times. As shown in Fig. 1, carbon emissions can be divided into two growth stages: the period from 2003 to 2011 is the first stage, with a relatively fast growth rate; The period from 2011 to 2020 is the second stage, which shows a gradual slowdown in growth. The rising trend of carbon emissions is synchronized with the economic development of Fujian province.

Table 2. Definitions of variables

Variable	Index	Definition
Carbon emission	C	Carbon emissions from various types of energy use (see Table 1 for energy types)
Energy consumption	E	All kinds of energy are converted into standard coal according to the conversion coefficient
Level of economic development	G	Regional GDP/ total population, GDP in 2003 as the base period
Population size	N	Total population
Energy structure	ES	Certain energy consumption/total energy consumption
Energy intensity	EE	Energy consumption/GDP, GDP is flat in 2003
Industrial structure	IS	Secondary industry added value/GDP

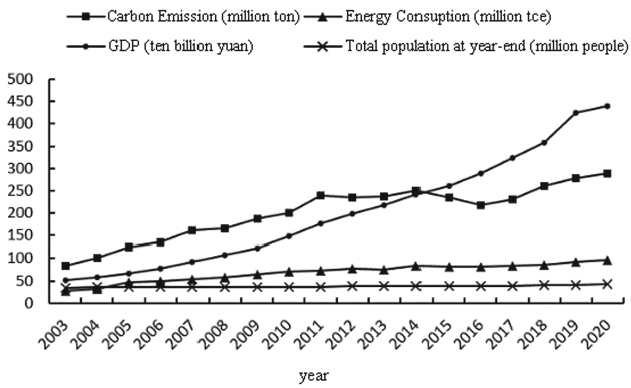

Fig. 1. Carbon emissions, energy consumption, GDP and population in Fujian Province from 2003 to 2020

4.2 Influencing Factors and Decomposition of Carbon Emissions in Fujian Province

The impact on carbon emissions in Fujian Province includes the annual change of carbon emissions and the cumulative change of carbon emissions based on 2003, and the results are shown in Table 3.

The total carbon emissions in Fujian Province increased from 82.7771 million tons of carbon in 2003 to 288.742 million tons of carbon in 2020, with an average annual growth rate of 12.12%. It can be seen from Table 2 that from 2003 to 2020. The economic scale effect caused the carbon emission to increase by 317.58 million t carbon, and the carbon intensity effect caused the carbon emission to increase by 36.68 million t carbon. The change in population-scale caused the carbon emission to increase by 28.01 million t carbon, with a total increase of 382.27 million t carbon. The change in energy structure and intensity led to the improvement of terminal energy efficiency, which reduced the carbon emissions by 17.867 million t carbon. Therefore, the net carbon emissions increase in Fujian Province from 2003 to 2020 was 203.61 million t carbon.

The decomposition of driving factors of carbon emissions in Fujian Province from 2003 to 2020 is shown in Fig. 2. It can be seen from Table 2 and Fig. 2 that from 2003 to 2020, changes in energy intensity and energy structure had an overall inhibitory effect on carbon emissions, reducing carbon emissions by 179 million tons, indicating that changes in energy intensity and energy structure had a negative driving effect on carbon emissions in Fujian Province. However, economic growth led to an increase of 318 million t in carbon emissions, and the contribution share of the economic scale effect was as high as 156%. The change in carbon emission intensity led to an increase of 37 million t of carbon emissions, and the contribution share of the carbon emission intensity effect was 18%. Population size led to an increase of 28 million t in carbon emissions, with a contribution share of 13.8%. This shows that economic growth is the main driving factor for the increase in carbon emissions in Fujian Province.

Table 3. Factor decomposition analysis of the incremental effect of carbon emissions in Fujian

Year	Total effect	Carbon emission intensity effect ΔC_I	Energy structure effect ΔC_S	Energy intensity effect ΔC_E	Economic development effect ΔC_G	Population size effect ΔC_N
2003–2004	17.16	6.43	-1.03	2.95	8.12	0.70
2004–2005	41.52	-21.12	10.38	29.07	22.32	0.87
2005–2006	53.49	-19.76	9.93	23.20	38.42	1.70
2006–2007	77.14	-9.82	7.09	12.83	64.41	2.62
2007–2008	84.17	-12.02	6.95	2.47	83.35	3.43
2008–2009	105.31	-13.68	10.92	-0.53	104.12	4.48
2009–2010	118.47	-10.90	6.40	-14.02	129.97	7.03
2010–2011	155.52	9.49	2.73	-33.10	167.59	8.80
2011–2012	151.25	0.52	3.01	-43.42	181.36	9.79
2012–2013	151.96	13.98	-8.13	-59.84	195.14	10.81
2013–2014	166.22	20.67	-18.56	-63.73	215.41	12.43
2014–2015	151.38	11.27	-15.05	-75.62	217.55	13.23
2015–2016	131.27	-2.79	-15.63	-85.28	221.07	13.91
2016–2017	149.15	13.25	-23.49	-99.28	242.97	15.70
2017–2018	180.17	32.35	-27.70	-119.87	277.26	18.14
2018–2019	198.26	36.86	-30.34	-141.74	313.36	20.11
2019–2020	203.61	36.68	-35.47	-143.20	317.58	28.01

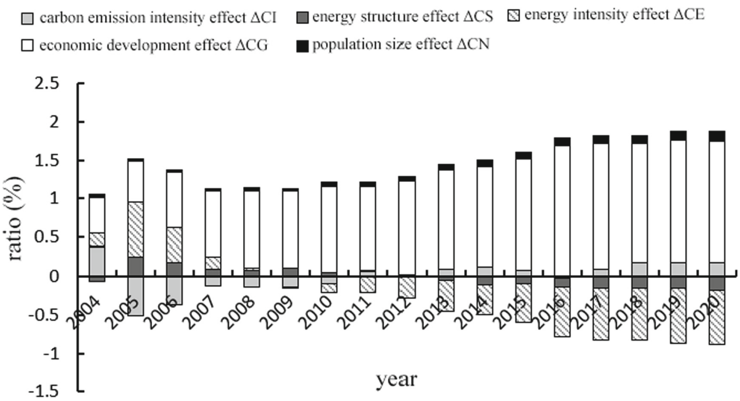

Fig. 2. Decomposition of driving factors of carbon emissions in Fujian Province from 2003 to 2020

In contrast, the impact of carbon emission intensity adjustment is small, followed by the impact of population change. In summary, the economic scale effect, carbon intensity effect, and population scale effect on carbon emissions change were positive, and the effects of energy intensity and energy structure effect were adverse. The economic scale effect's positive driving effect and the energy intensity effect's negative inhibitory effect were significant. In contrast, the effect of the population scale effect was weak.

From the perspective of the total effect of carbon emissions in Fujian Province over the years, the overall carbon emissions showed an upward trend from 2003 to 2011, while the carbon emissions showed a significant fluctuation from 2011 to 2016, with an apparent downward trend. Since 2006, the carbon emissions in Fujian Province have been increasing yearly, while the growth rate has been slowing down year by year.

From the economic development effect perspective, the continuous expansion of the economic scale is the decisive factor for the growth of carbon emissions in Fujian Province. Since 2003, the proportion of carbon emissions caused by the economic scale effect has been stable at more than 40%. Since 2010, the proportion of carbon emissions has contributed to more than 100%, which is closely related to the rapid economic development of Fujian province. From 2003 to 2020, the GDP of Fujian province increased by 8.39 times, while carbon emissions increased by 3.49 times duringthe same period. Rapid economic development stimulates energy consumption, resulting in an increase in carbon emissions year by year. Per capita GDP is a comprehensive measure of a country or region's per capita production and service capacity, reflecting economic growth and people's quality of life. Energy is an essential element of production and supports economic development.

In contrast, economic development with the secondary industry as the leading industry will exacerbate energy consumption and increase carbon emissions. Therefore, China's economic development is often accompanied by the growth of carbon emissions. Among the driving factors of carbon emissions in Fujian Province, rapid economic development is the most important driving force for the growth of carbon emissions.

The energy intensity effect has a significant adverse effect on the overall change of carbon emissions in Fujian province, indicating that Fujian province has improved energy efficiency and promoted carbon emission reduction through the adoption of new technologies. Energy intensity is a unit to measure the input-output characteristics of the energy system, and the unit of GDP energy consumption reflects the overall efficiency of energy and economic activities. In theory, the reduction of energy intensity indicates an improvement in energy efficiency, usually caused by technological progress. If other factors remain constant, the decline in energy intensity will have a negative impact on carbon emissions.

The effect of energy structure on carbon emissions in Fujian Province was relatively weak and showed a negative impact on the whole, but this negative growth did not show a trend of gradual amplification. This shows that the energy structure optimization in Fujian Province has achieved some results, but there has yet to be a breakthrough change. It can be seen from Table 2 that the energy structure effect has played a negative role in inhibiting the growth of carbon emissions in Fujian province since 2013, which is related to the continuous optimization of the energy structure in Fujian province.

From the perspective of population effect, the population size of Fujian province increased from 35.02 million to 41.61 million from 2003 to 2020, with a total increase of 28 million t in carbon emissions. This shows that with the increase in population size, the carbon emissions of Fujian province also increased. Population size has a positive driving effect on carbon emissions. The reason may be that China's urbanization increases with the growth of population, which has a significant impact on carbon emissions. Urbanization is the main factor driving the growth of cement demand for large-scale urban and transportation infrastructure construction, which may lead to more carbon emissions. In addition, the increasing population leads to an increased demand for energy consumption, which leads to carbon emissions.

Through the LMDI decomposition model, the carbon emissions in Fujian province are decomposed into carbon emission intensity, energy structure, energy intensity, economic development, and population scale effect. The decomposition results show that the total carbon emissions in Fujian province show an increasing trend. Among them, economic growth and energy intensity significantly impacted carbon emissions. Economic development, carbon intensity, and population growth drove carbon emissions positively; Energy intensity and structure change negatively drove carbon emissions.

4.3 Prediction and Analysis of Carbon Emissions in Fujian Province

The fitting of STIRPAT model.

In this paper, the least square method is used to fit the multiple linear regression of Model (11) to check the collinearity of the model. The results show that the adjustment of the model is 0.98, and the F value is 154.612. However, the VIF of several independent variables is greater than 10, indicating multicollinearity among the variables. This indicates that the model parameters are unstable, the predictive power is reduced, and the regression results are unstable. In order to eliminate the influence of collinearity, this paper conducts ridge regression on the model. It obtains ridge traces of each variable under different parameters K, as shown in Fig. 3.

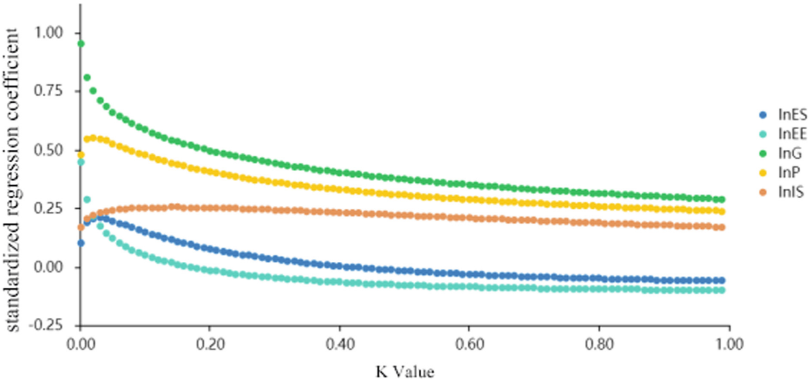

Fig. 3. Ridge trace diagram

From the ridge trace plot, we can see that when the value of K is 0.01, the standardized regression coefficient of the independent variable tends to be stable. Therefore, take K = 0.01, rerun ridge regression, and the adjusted value is 0.98. The F test is significant (F = 145.320, p = 0.000 < 0.05), and the T-test of each variable is significant. Therefore, the model regression Eq. (12) is obtained by fitting the results of the composite test requirements:

$$lnI = -26.386 + 4.016lnN + 0.559lnG + 0.392lnEE + 0.311lnES + 2.166lnIS \quad (12)$$

Scenario analysis prediction.

Based on the development rules and changes of different influencing factors in Fujian Province in recent years, three scenarios were determined: baseline, low-carbon, and high-speed. In each scenario, the variables involved in demographic, economic, and technological factors affecting carbon emissions were set to predict the future development trend of carbon emissions in Fujian Province, and the carbon peak and carbon neutral forecasts of carbon emissions were carried out.

(1) The baseline scenario

In the base scenario, the current development model of population, economy, and technology is maintained, economic development and increasing residents' income are the main driving factors, and emission reduction strategies to cope with climate change are actively adopted. The trend of population development follows the evolution characteristics of the current population size and structure; The trend of economic development is set according to the national economic development goals; The situation of technological change maintains the current rate and trend of technological progress.

Demographic factors. From 2003 to 2020, the average growth rate of the population in Fujian province was 1.02%. The growth rate of the population in different years of the investigation period was 0.91% from 2005 to 2010, 0.79% from 2010 to 2015, and 1.68% from 2015 to 2020. The Population Development Plan of Fujian Province (2016–2030) points out the practical problem of low-speed growth of the total population. It puts forward the goal of a continuous increase in the total population. It is estimated that the total population of Fujian province will reach about 41 million in 2020 and about 41.5 million in 2030. Data show that the total population of Fujian province reached 41.61 million at the end of 2020, reaching the planning target, so it is expected that the population of Fujian province will reach about 42.12 million in 2030. Considering the current situation of low-speed growth of the total population under the social environment, the forecast range of population growth rate will be between 0.1% and 0.9%, and the growth rate will slowly decline and rise.

Energy intensity. In 2020, the total energy consumption of Fujian province will increase by 48.5% compared with 2012, with an average annual growth rate of 4.5%, 3.4 percentage points lower than the average annual GDP growth rate in the same period. During the 12th and 13th Five-Year Plan periods, the province's energy consumption per 10,000 yuan of GDP decreased by 16.3% and 15.2%, respectively, exceeding the planned target by 0.3 and 0.2 percentage points. From 2003 to 2020, the energy intensity of Fujian province showed a weakening trend year by year, with an average annual growth rate of -4.66%. The less energy consumption per unit GDP, the more conducive to the decoupling of economic development level and energy consumption. The annual energy intensity is predicted to decrease gradually by 0.01%.

Energy structure. According to the Special Plan for Energy Development of Fujian Province during the 14th Five-Year Plan Period, the energy structure should be further optimized, and the total energy production capacity of Fujian province will reach 54 million tons of standard coal by 2025. In 2025, the energy consumption structure of Fujian province will be 48.2% coal, 18.2% oil, 6.2% natural gas, and 27.4% non-fossil energy. The proportion of coal in energy consumption will decrease from 48.3% in 2020 to 48.2%, while the proportion of clean energy will increase from 28.1% to 33.6%. In order to meet the target of the 13th Five-Year Plan, the share of coal in energy consumption will be reduced by 0.1%, so the growth rate of coal energy will be set at - 0.08%. Considering the realization of the 3060 targets, it is expected that by 2060, under the carbon-neutral state, coal energy will be withdrawn entirely from China's energy structure, with solar energy (solar energy) accounting for 47%. Wind energy accounts for 31%, occupying the top two places in China's energy structure. Therefore, the proportion of coal energy in Fujian province is expected to be tiny or zero in 2060, and its growth rate will gradually decrease by 0.3% every year after 2035.

Industrial structure. From the perspective of industrial structure, Fujian province has changed from a "secondary and tertiary" industrial structure to a "tertiary and tertiary" industrial structure. In 2016, the ratio of the three industries in Fujian Province was 7.24:49.59:43.16, and in 2020, the ratio was 6.22:46.3:47.47. The ratio of secondary and tertiary industries is equal, and the electronic information industry, petrochemical industry, and machinery industry are the three leading industries in Fujian Province. According to the "14th Five-Year Plan" of Fujian Province, the economic structure will be optimized by 2025, and the proportion of the added value of the service industry will reach more than 50%. Therefore, it is predicted that the growth rate of the secondary industry will be 1.6% in 2020–2025. The proportion of the added value of the secondary industry in Fujian Province increased gradually from 2003 to 2012 and then decreased slightly after reaching 52% in 2013 and 2014. According to the data, the secondary industry in Fujian province showed a trend of first rising and then falling. It is predicted that the proportion of the secondary industry will decrease from 50% in 2025 to 33% in 2060.

GDP per capita. According to the target of the 14th Five-Year Plan of Fujian Province, the per capita regional GDP will grow by 5.4% annually by 2025. It is inferred that the per capita regional GDP will reach 92,000 yuan/person in 2025, so the average annual growth rate of per capita GDP in 2021–2025 will be 9%, 7%, 5%, and 4%. As mentioned in the previous decomposition analysis, the economic development level significantly impacts the CO_2 emissions of Fujian Province, and the economic development speed will slow down when emission reduction measures are taken. However, Fujian province has a solid industrial foundation and a vibrant private economy. The economic aggregate, per capita GDP, and financial strength of Fujian Province are uneven in the national ranking. With less than 3% of the national GDP, the economic output still has potential, so the parameter is set to 9%, and the per capita GDP growth rate will start to decline after 2035.

(2) Low-carbon scenario

In the low-carbon scenario, population growth rates, per capita GDP, energy intensity, industrial structure, and energy structure will increase by 0.01%, 0.05%, 0.06%, 0.1%, and 0.06%, respectively, respectively, compared with the baseline scenario. In the low-carbon scenario, the proportion of the secondary industry is forecast to decrease from 50% in 2025 to 30% in 2060.

(3) High-speed scenario

In the low-carbon scenario, population growth rates, per capita GDP, energy intensity, and energy structure will increase by 0.01%, 0.05%, 0.06%, 0.08%, and 0.06%, respectively, compared with the low-carbon scenario. In the low-carbon scenario, the proportion of the secondary industry is predicted to decrease from 50% in 2025 to 26% in 2060.

Forecast results and analysis of carbon emissions.

According to the three scenarios set and combined with the STIRPAT model, the carbon emission trend of Fujian Province from 2021 to 2060 is predicted. According to the prediction results, the overall industrial carbon emissions prediction curve under various scenarios is drawn, as shown in Fig. 4.

As Fujian enters the later stage of industrialization, economic growth will not increase carbon emissions, that is, the environmental Kuznetz curve of economic growth and carbon emissions (inverted U-shaped). Therefore, under the high-speed development scenario, Fujian will achieve the carbon peak earliest. The low-speed development scenario is a low-GDP grown-high-carbon development model. With slow economic and social development, slow technological upgrading, reduced energy consumption, and low population growth, which will face high energy intensity and heavy energy structure, it takes work to control carbon emissions fundamentally. In the baseline development scenario, the time and quantity of carbon peak are between the high-speed and low-speed development scenarios. It can be seen that the high-speed development scenario is the most suitable development model for Fujian, which can not only achieve rapid economic and

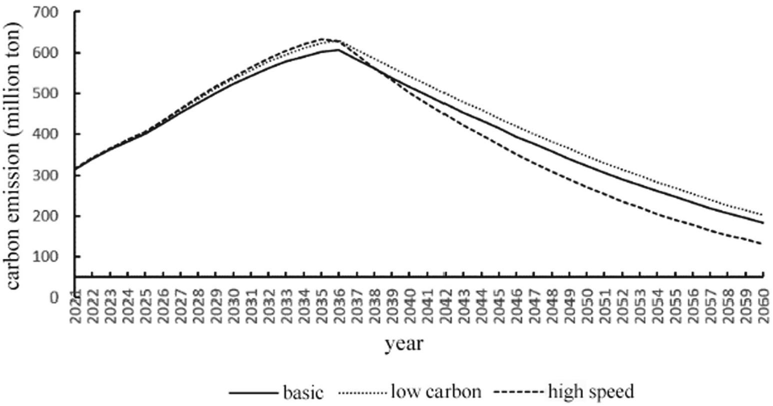

Fig. 4. Carbon emission trends under different scenarios in Fujian Province

social development but also reduce energy intensity through the development of low-carbon technology and continue to save energy and reduce emissions, to achieve carbon peak and carbon neutrality as soon as possible.

5 Research Conclusions and Policy Recommendations

The LMDI decomposition method was used to decompose the driving factors of carbon emission change in Fujian Province. On this basis, the STIRPAT model was used to predict the peak and peak time of carbon emission in Fujian Province from 2021 to 2060, and the following conclusions were drawn:

During the study period, the economic development effect was the primary factor for the increase of carbon emissions, and the changes in energy structure and intensity were the essential factors in inhibiting the increase of carbon emissions. The contribution rate of energy intensity to the change of carbon emissions in Fujian Province was negative, and the decline rate of its cumulative contribution rate increased after 2015. Among the other factors, carbon emission intensity and population growth promoted carbon emissions, but the contribution rate was low. The cumulative contribution rate of the population factor to carbon emissions in Fujian province was 13.76%, and the emission increased by 28.01 million tons.

Based on the decomposition of the driving factors of carbon emissions, we set three scenarios: baseline, low-speed and high-speed scenarios. The high-speed scenario is optimal for achieving carbon neutrality and peak carbon emissions in Fujian province. Under this scenario, carbon emissions in Fujian province will peak in 2035, providing a path for carbon emission reduction in Fujian province.

Based on the above research results, the following countermeasures are proposed:

Energy structure and energy consumption intensity are essential factors in inhibiting the increase of carbon emissions. Carbon intensity is an important indicator to measure the peak of carbon emissions, and the reduction of carbon intensity depends on the adjustment of industrial structure and energy structure. It is challenging to change China's energy structure in the short term. Therefore, it is necessary to improve energy efficiency, promote clean energy production and electrification of energy consumption, actively promote technological progress and innovation, and improve energy efficiency and reduce energy intensity in Fujian Province. We should strictly control the total amount of fossil energy, increase the proportion of non-fossil energy, weaken the situation of fossil energy consumption led by coal, and reduce the energy intensity of Fujian province.

The per capita GDP and carbon emission intensity effect have a significant role in promoting carbon emissions. However, Fujian province still maintains rapid growth, and there is still much room for economic growth, which means that carbon emissions will continue to increase. Therefore, under the premise of ensuring inevitable economic growth, Fujian province should improve the efficiency of clean energy use, focus on supporting Fujian province to carry out green manufacturing demonstrations, strengthen the innovation of green science and technology, and drive the green and low-carbon development of the Yangtze River Economic Belt with science and technology.

Scenario prediction analysis shows that the high-speed model is the optimal scenario to achieve the emission reduction target in Fujian province. Under this scenario, the carbon emissions of Fujian province will reach a peak in 2035. Therefore, continuously reducing the intensity of carbon emissions is essential for Fujian to reach the peak of carbon emissions as soon as possible. Meanwhile, it is essential to promote the development of clean energy, promote the cross-provincial consumption of clean energy, establish a green brand of high-quality production capacity, promote the extension of a green industry chain, build an inter-regional information technology exchange platform in the Yangtze River Economic Belt, optimize and adjust the layout of service industries, and promote the development of clean energy. To promote the transformation of energy production and consumption to clean and low-carbon, promote the green and sustainable development of enterprises, industries, and society, and provide an optimal path for energy conservation, emission reduction, and high-quality development in Fujian province.

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