JUSTC

Article

http://justc.ustc.edu.cn

Received: May 10, 2022; Accepted: July 10, 2022

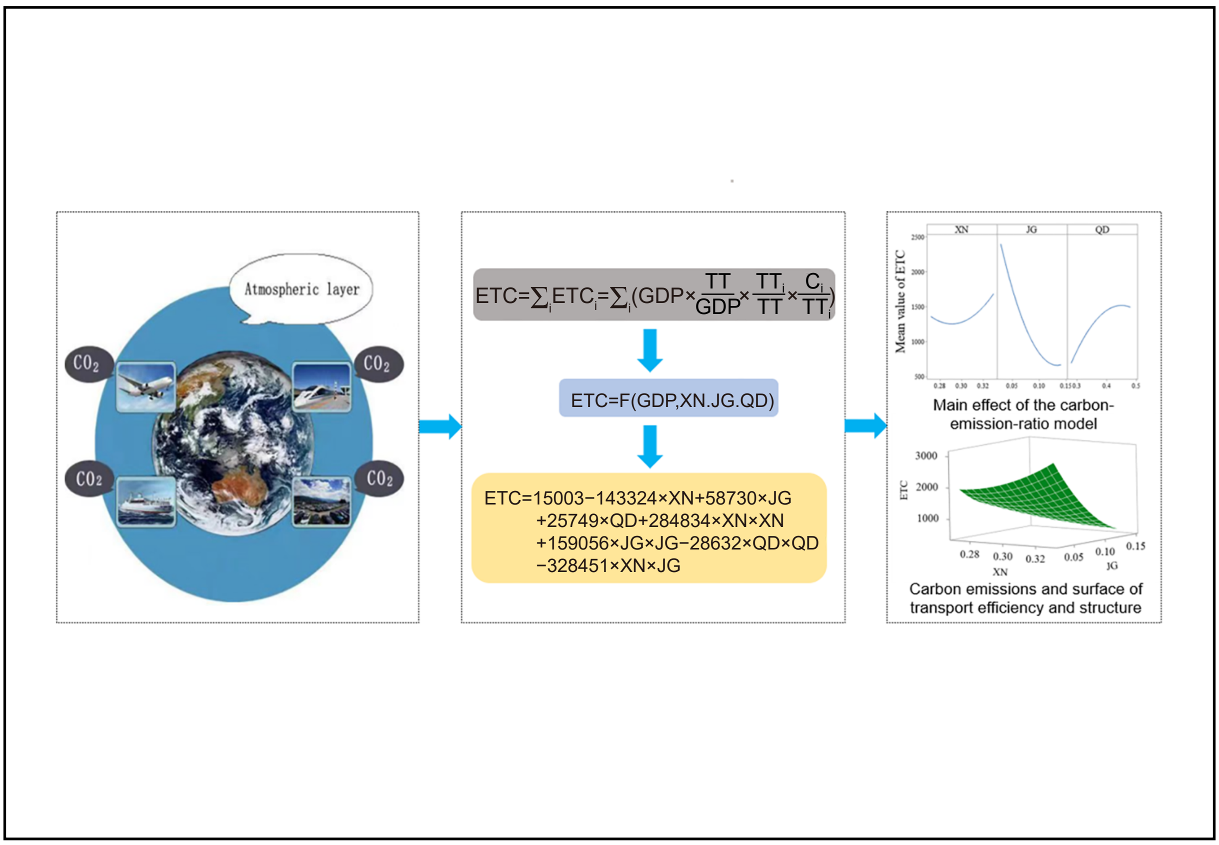
Empirical analysis of influencing factors of carbon emissions in transportation industry in Fujian Province, China

Mingchun Zhong[1], Linzhi Que[2], and Guofu Lian[2] ✉

[1]School of Economics and Trade, Fujian Jiangxia University, Fuzhou 350108, China;
[2]School of Mechanical and Automotive Engineering, Fujian University of Technology, Fuzhou 350118, China

✉Correspondence: Guofu Lian, E-mail: gflian@mail.ustc.edu.cn

Graphical abstract



Key factors decomposed by LMDI to study carbon emissions in the transportation industry.

Public summary

■ The variance analysis was used to investigate the influence factors of carbon emissions in the transportation industry in Fujian Province.

■ A mathematical regression model of carbon emissions was established by the stepwise method to reveal the influence of the transportation industry on carbon emissions and the interaction mechanism of various factors on carbon emissions.

■ This paper focuses on innovative energy-saving and emission-reduction technologies for transportation efficiency and provides suggestions to promote the green and low-carbon development of the transportation industry.

Citation: Zhong M C, Que L Z, Lian G F. Empirical analysis of influencing factors of carbon emissions in transportation industry in Fujian Province, China. *JUSTC*, **2023**, 53(1): 6. DOI: 10.52396/JUSTC-2022-0079

JUSTC

Article

http://justc.ustc.edu.cn

Received: May 10, 2022; Accepted: July 10, 2022

Empirical analysis of influencing factors of carbon emissions in transportation industry in Fujian Province, China

Mingchun Zhong[1], Linzhi Que[2], and Guofu Lian[2] ✉

[1]School of Economics and Trade, Fujian Jiangxia University, Fuzhou 350108, China;
[2]School of Mechanical and Automotive Engineering, Fujian University of Technology, Fuzhou 350118, China

✉Correspondence: Guofu Lian, E-mail: gflian@mail.ustc.edu.cn

Cite This: *JUSTC*, **2023**, 53(1): 6 (7pp)   **Read Online**

Abstract: The transportation industry has become an important source of carbon emissions with rapid economic development and the acceleration of urbanization. Identifying the key factors of carbon emissions is crucial for energy conservation, emission reduction and green development in the transportation industry. Here, variance analysis was used to study the influencing factors of carbon emissions in the transportation industry in Fujian Province, China. The results showed that transportation efficiency have the most significant impact on carbon emissions, followed by carbon emission intensity in transportation, and then the transportation structure. Meanwhile, there was a significant interaction between transportation efficiency and structure. Therefore, innovative energy-saving and emission-reduction technologies for transportation efficiency should be studied as the focus for the green and low-carbon development of the transportation industry.

Keywords: transportation industry; carbon emissions; low-carbon transportation; influencing factors

CLC number: X511   **Document code:** A

1 Introduction

The transportation industry, as a basic, leading, and strategic industry in the national economy, is vital for controlling carbon emissions with economic development[1]. The transportation industry has become the second-largest source of global carbon emissions due to its high dependence on petrochemical resources, accounting for approximately 50% and 25% of the world's oil consumption and carbon emissions, respectively[2]. The total carbon emissions of the transportation industry account for approximately 15% of the national terminal emissions in China. The average growth rate, the fastest-growing field in carbon emissions, remained above 5% from 2013 to 2019. As the largest greenhouse gas emitting country, China has been playing an active role in reducing emissions[3]. In September 2020, China proposed to strive to achieve carbon peaking in 2030 and carbon neutrality in 2060. Therefore, there is a long way to go in addressing climate change, energy conservation and emission reduction in the future[4].

As an economically developed province along the southeast coast, the transportation infrastructure of Fujian Province has been increasingly improved in recent years. The national expressway network in Fujian has been basically completed, and three vertical and eight horizontal high-speed railway networks have been formed. The province's total highway mileage exceeded 110000 km, of which the highway mileage exceeded 6000 km by the end of 2021, and the comprehensive road-network density ranked third in China (the data came from the official website of the Fujian Provincial Department of Transportation). Meanwhile, passenger turnover by railways, highways, water transportation, and aviation increased from 24.765 billion person-kilometers in 1995 to 119.003 billion person-kilometers in 2019 (an increase of 4.81 times) with economic development. Freight turnover increased from 60.861 billion ton-kilometers in 1995 to 829.663 billion ton-kilometers in 2019, an increase of 13.63 times.

The situation of energy consumption and carbon emissions become not optimistic with the rapid development of the transportation industry. Fujian is the first national demonstration zone for ecological civilization. Although its ecological construction has been at the forefront in China for many years, there are still many shortcomings in energy savings and emission (carbon) reduction. Therefore, the carbon emission level of the transportation industry in Fujian Province should be scientifically measured to explore the change law of the carbon emission quantity and speed up the identification of the influencing factors of carbon emissions [5–6]. Formulating effective green transportation policies and promoting a high-quality economy in Fujian are of great practical significance.

The transportation industry, as an important source of carbon emissions, is still in accelerated development[7–8], which makes carbon emissions in transportation a hot spot in academic circles. Scholars have studied the relationship between the transportation industry and carbon emissions[9–11], carbon emission efficiency[12–14], and scenario predictions of carbon emissions[15–17]. These studies have provided scientific decision-making support for relevant departments to manage transportation carbon emissions. However, more studies focus on the influencing factors of carbon emissions in the transportation industry.

The factor-decomposition model has been widely used in carbon emissions in the transportation industry since 2000 due to its low technical difficulty and strong persuasiveness[18–19]. Wu et al.[20] decomposed and analyzed the changes in energy-consumption carbon emissions in transportation in Shanghai from population, per capita GDP, transportation-carbon-emission intensity, energy intensity and structure in 2012. Zhuang and Xia[21] conducted an empirical analysis of the contribution rate of transportation carbon emissions in Guangdong Province in 2017 from the transportation development level, transportation structure, number of private cars, and energy intensity based on the LMDI method. Guo and Meng[22] used the LMDI decomposition method to decompose the carbon emission factors into the transportation energy structure, economic development level, energy intensity, industrialization, etc., through an empirical study which is performed on transportation carbon emissions in the Beijing-Tianjin-Hebei region in 2019. Yu et al.[7] analyzed the changes in carbon emissions between different modes of transportation in China's transportation industry based on the LMDI method. Solaymani[23] used the same method to compare the influencing factors of carbon emissions in seven major transportation carbon-emitting countries in 2019.

In summary, the decomposition research of transportation carbon emission factors based on LMDI involves various levels, such as cities or provinces, regions, and countries. Most scholars are accustomed to incorporating macroscopic factors of general significance into their research. Wu et al.[20] selected per capita GDP and population to reflect the level of economic development. Guo and Meng[22] selected two factors, the economic development level and industrialization, while Zhuang and Xia[21] fully considered the role of the growing scale of private cars in carbon emissions. Yu et al.[7] and Solaymani[23] analyzed the carbon emissions of the transportation industry and compared the carbon emissions of different transportation modes and different countries, respectively. The application research of LMDI is becoming increasingly mature, but some deficiencies in factor decomposition exist: when macro factors such as economic level, population size, industrialization, and other macro factors are chosen to explain the carbon emissions of specific industries, it is not conducive to providing precise carbon emission reduction measures for specific industries [6].

In addition to the choice of influencing factors, the LMDI (logarithmic mean Divisia index) itself has some limitations. For example, the LMDI model cannot contain relative and absolute factors simultaneously, and decomposition depends on the relationships between decomposed factors. To address these shortcomings, some scholars have used the GDIM (generalized Divisia index model) to study the influencing factors of carbon emissions in the transportation industry [24]. Some studies have repeated interpretations in selecting influencing factors, which are prone to multicollinearity[6].

Therefore, econometric analysis methods have more advantages in studying carbon emissions in transportation[6]. Xu[25] and Lin[26] used quantile econometric models to decompose carbon emissions from transportation in China. In addition, various methods have been combined to study the influencing factors of transportation carbon emissions [27]. With the development of spatial-measurement research methods, there are an increasing number of studies on the spatiotemporal characteristics or spatial correlation of carbon emissions. Li et al.[28] combined the LMDI and geostatistical trend surface method to analyze the influencing factors and spatial distribution patterns of transportation energy consumption and carbon emissions in Henan Province. Zeng et al.[29] used the GWR model to study the spatial heterogeneity of factors affecting carbon emissions in provincial transportation. Lyu[30] analyzed the spatial heterogeneity and correlation of the influencing factors of automobile-transportation carbon emissions in the Beijing-Tianjin-Hebei region.

The research on carbon emissions has been continuously deepened with the increasing maturity of the decomposition method of carbon emission factors and the increasing diversification of research methods, and many beneficial explorations have been made for precisely managing carbon emissions. However, there is no in-depth research on the influences of factors and their interactions on carbon emissions, and the mitigation strategy of transportation carbon emissions still lacks a perfect theoretical basis. Therefore, this work used the LMDI factor decomposition model and variance analysis method to study the influencing factors of carbon emissions of transportation in Fujian Province. The changing law was revealed to provide a reference for reducing carbon emissions of transportation.

2 Research design and data sources

2.1 Carbon emission calculation method

At present, the methods for calculating carbon emissions from energy consumption include the macromethods of the upbottom input and output and the micromethods of bottom-up process analysis. The bottom-up method needs to measure carbon emissions through the number of different vehicles in a specific area, the amount of mileage, and the energy consumption per mileage. In addition to difficult operations, the data are difficult to obtain. Relatively, the upbottom method only needs to obtain different energy consumption values and their respective standard coal conversion coefficients and carbon emission coefficients to calculate carbon emissions, which is relatively simple. Therefore, the work adopted the updown estimation method as Eq. (1) in the IPCC Guidelines for National Greenhouse Gas Inventories.

$$\mathrm{ETC}=\sum_{i}^{7}(\mathrm{ETC})=\sum_{i}^{7}\mathrm{COE}_i\times\mathrm{ISC}_i\times\mathrm{IEC}_i\times\frac{44}{12},\qquad(1)$$

where ETC (emission of total CO_2) is the carbon emission; COE_i (consumption of energy) is the consumption of the ith energy; ISC_i (index of standard coal) is the standard coal conversion coefficient of the ith energy; IEC_i (index of energy consumption) is the carbon emission coefficient of the ith energy; and the molecular weights of CO_2 and carbon are 44 and 12, respectively. The standard coal conversion coefficients and carbon emission coefficients of various energy sources adopt IPCC standards[27] (see Table 1).

2.2 Identification of factors affecting carbon emissions

Carbon emissions involve many influencing factors. The

DOI: 10.52396/JUSTC-2022-0079
JUSTC, 2023, 53(1): 6

Table 1. Standard coal conversion factors and carbon emission factors for various energy sources.

Energy type	Standard coal conversion factor (kg)	Carbon emission factor	Energy type	Standard coal conversion factor (kg)	Carbon emission factor
Crude oil	1.429	0.585	Kerosene	1.471	0.571
Gasoline	1.471	0.401	Coke	0.971	0.855
Fuel oil	1.429	0.618	Raw coal	0.714	0.756
Diesel	1.457	0.592	Natural gas	12.148	0.448

factor-decomposition model with rigorous mathematical-logic relationships can be used for variable selections[6]. At present, there are many data processing methods related to the decomposition of carbon emission factors. IDA (index decomposition analysis) and SDA (structural decomposition analysis) are commonly used methods. The LMDI in IDA has thorough residual decomposition and excellent elasticity due to using the exponential average weight equation. Therefore, the LMDI was used to decompose the carbon emissions of the transportation industry in the work (see Eq. (2)).

$$\mathrm{ETC} = \sum \mathrm{ETC}_i = \sum_i \left(\mathrm{GDP} \times \frac{\mathrm{TT}}{\mathrm{GDP}} \times \frac{\mathrm{TT}_i}{\mathrm{TT}} \times \frac{\mathrm{ETC}_i}{\mathrm{TT}_i} \right), \quad (2)$$

where ETC represents the total carbon emissions of transportation; GDP is the economic development level; TT is the total turnover of freight transportation; TT_i is the freight turnover of the ith transportation mode; and ETC_i is the carbon emissions of the ith transportation mode quantity. Based on the above LMDI model, the functional forms of carbon emissions of transportation are obtained: $\mathrm{ETC} = f(\mathrm{GDP}, \mathrm{XN}, \mathrm{JG}, \mathrm{QD})$. The economic development level (GDP), transportation efficiency (XN), transportation structure (JG), and carbon emissions intensity in transportation (QD) are important influencing factors of the carbon emissions of transportation.

2.3 Analysis of influencing factors and selection of indices

2.3.1 Economic development level

The transportation industry has been thought of as the “blood” of the national economy. When the technical level remains unchanged, economic development inevitably accelerates the transportation turnover rate and the economic scale, which increases the energy consumption and carbon emissions of the transportation industry. Therefore, a linear correlation exists between the level of economic development and transportation turnover, which will be further verified. The economic development level was measured by the gross regional production. The regional gross output values over the years were comparable after excluding the impact of price fluctuations. The nominal GDPs of the past years were deflated to obtain the constant price of the gross regional production (real gross regional production).

2.3.2 Transportation efficiency

Transportation efficiency generally refers to the capability and efficiency of existing transportation equipment under specific transportation conditions. The index can be used to evaluate the costs of logistics or distribution enterprises. Generally, the greater the transportation efficiency is, the higher the transportation efficiency, and vice versa. Transportation efficiency, indicating transportation turnover per unit of the gross regional product, was obtained by dividing total transportation turnover by the gross regional product in the work. The passenger turnover of the same transportation mode (100 million people/km) is multiplied by the conversion coefficient to obtain freight turnover in transportation (100 million tons/km). Then, transportation freight turnover is added to derive the total transportation turnover.

2.3.3 Transportation structure

As the transportation industry is highly dependent on petrochemical energy, the development of the transportation industry is bound to accelerate energy consumption and generate more carbon emissions. At present, transportation mainly includes railways, roads, water transportation, and aviation. Significant differences exist in the energy consumption and carbon emissions of different transportation modes. According to the statistics of the transportation department, the carbon emission intensity of highways, waterways (cruise ships), and civil aviation is 7.1, 47.7, and 19.1 times that of railways, respectively. In terms of freight, the carbon emission intensity of highways, waterways, and civil aviation is 9.5, 1.9, and 88.2 times that of railways, respectively[6]. Rail transport is the least carbon-intensive for both passenger and freight transport. Although the carbon emission intensity of freight transport by waterways is not large, that of passengers (cruises) is very large, 47.7 times that of railways. The transportation structure was measured by the proportion of passenger and cargo turnover in railway transportation in the work.

2.3.4 Carbon emission intensity of transportation

The carbon emission intensity of transportation is obtained by dividing the total carbon emissions of the transportation industry by total passenger and freight turnover in transportation, representing the carbon emissions per unit turnover. The index can reflect the overall technical level of the transportation industry. A higher transportation technology level is more conducive to the intensive use of energy resources, which reduces the carbon emissions per unit turnover. In addition, different energy sources have different emission factors. Therefore, carbon emission intensity is closely related to the energy structure, and increasing the proportion of low-carbon energy can reduce carbon emission intensity.

2.4 Variance analysis

ANOVA is a hypothesis testing method proposed by Fisher. The experimental data are analyzed to test whether multiple normal population means with equal variance are equal and judge whether the influences of each factor on the experimental index are significant. The work used variance analysis

DOI: 10.52396/JUSTC-2022-0079
JUSTC, **2023**, 53(1): 6

to study the carbon emissions and influencing factors of the transportation industry in Fujian Province from 2003 to 2019. A multivariate quadratic regression model[30] was established based on carbon emission data to determine the impacts of transportation efficiency, carbon emission intensity and transportation structure on carbon emissions. Innovative technologies for carbon emission reduction were proposed for the green and low-carbon development of the transportation industry.

2.5 Data sources

The transportation industry in the work refers to the transportation, warehousing, post and telecommunication industries defined in the China Statistical Yearbook after 1991. The relevant data come from the energy balance sheets of the Fujian Statistical Yearbook and China Energy Statistical Yearbook from 2003 to 2019. The reasons for data selection are as follows. ① The transportation industry did not include the data of the warehousing industry before 1990, and the statistical caliber before and after 1990 was inconsistent; therefore, the sample data before 1990 were excluded. ② The related indices of 1998–2002, 2020, and 2021 were missing, and the carbon emissions of transportation could not be estimated (only the carbon emissions data of 1999 were estimated); thus, the data for these years were not included in the samples. At present, the transportation industry mainly includes 8 types of energy, e.g., gasoline, fuel oils, kerosene, diesel oils, crude oils, natural gases, raw coal and cokes (CO_2 from the electricity and heat industry was not considered because electricity and heat did not directly emit CO_2). Carbon emissions were calculated according to the IPCC upbottom method (see Table 2 for the specific processing method of the data).

3 Empirical analysis

Multicollinearity existed between the economic development level and the transportation efficiency according to the qualitative analysis of the relationship between the economic development level and transportation turnover. This was because transportation efficiency was obtained by dividing transportation turnover by gross regional production. Variance inflation factors (VIF) were used to judge the multicollinearity of the influencing factors. The results showed that the VIF of the economic development level (gross regional production) was 13.29445. According the usual practice, once if VIF>10, it means there is serious multicollinearity existing in the model. Moreover, the index of XN can explain the carbon emissions of the transportation industry more precisely than that of GDP, which is a macroeconomic factor. Therefore, the GDP index was excluded to ensure the reliability of the statistical analysis. The previous carbon emission calculation methods and selection of indices were used to obtain the carbon emissions and influencing factors of the transportation industry in Fujian Province from 2003 to 2019 (see Table 3).

A mathematical regression model is established (see Eq. (3)) by the step-by-step regression modeling analysis of the data. Table 4 shows the corresponding variance analysis.

$$\begin{aligned}\mathrm{ETC} = {} & 15003 - 143324\times\mathrm{XN} + 58730\times\mathrm{JG} + 25749\times\mathrm{QD} + \\ & 284834\times\mathrm{XN}\times\mathrm{XN} + 159056\times\mathrm{JG}\times\mathrm{JG} - \\ & 28632\times\mathrm{QD}\times\mathrm{QD} - 328451\times\mathrm{XN}\times\mathrm{JG}.\end{aligned} \tag{3}$$

Table 4 shows that the p value of the carbon emission regression model is < 0.001, indicating that the selected model has high accuracy. Model R^2 is 0.9917, close to 1. The model can predict the errors in the experimental values by comparing the difference (0.0159 < 0.2) between adjusted and predicted R^2 in the table. Transportation efficiency has the most significant impact on carbon emissions by comparing the P value of each input variable, followed by carbon emission intensity and transportation structure. In addition, a significant interaction exists between transportation efficiency and transport structure.

Fig. 1 shows that carbon emissions first decrease and then increase with increased transportation efficiency and decrease with the increased transportation structure. The emissions first increase and then decrease with the increased carbon emission intensity in transportation. The reasons are as follows.

(Ⅰ) Carbon emissions decrease slightly at the early stage with improved transportation and increase at the later stage, which is related to the rapid increase in passenger turnover at the early stage. China has accelerated the modernization of railways in an all-around way since 2003 and has improved transportation technologies and equipment with remarkable results to improve transportation capacity. The annual passenger traffic in Fujian Province increased from 38.619 billion

Table 2. Index selection and data description for the transportation industry.

Variable symbols	Indices	Index description and treatment
ETC	Carbon emissions	$\mathrm{ETC}=\sum_{i}^{7}(\mathrm{ETC})=\sum_{i}^{7}\mathrm{COE}_i\times\mathrm{ISC}_i\times\mathrm{IEC}_i\times\frac{44}{12}$
GDP	Economic development level	According to the Fujian Statistical Yearbook and China Energy Statistical Yearbook, price effects are excluded to ensure comparability. The constant GDP is obtained by deflating the base period (1995).
JG	Transportation structure	It is obtained from the total passenger and cargo turnover of railroad/total passenger and cargo turnover of transportation. First, the passenger turnover must be converted into freight turnover according to the conversion factor; the total passenger and freight turnover of transportation is calculated by summing up the passenger and freight turnover of different modes of transportation.
XN	Transportation efficiency	Total passenger and cargo turnover of transportation/regional GDP (TT/GDP)
QD	Carbon emission intensity in transportation	Calculated from total transportation carbon emissions/total transportation passenger and cargo turnover (ETC/TT)

Table 3. Carbon emissions and influencing factors of the transportation industry in Fujian Province from 2003–2019.

Vintage	ETC	XN	JG	QD
2003	530.728	0.312	0.140	0.354
2004	749.162	0.318	0.138	0.439
2005	713.958	0.318	0.115	0.375
2006	760.450	0.328	0.098	0.336
2007	898.500	0.313	0.093	0.362
2008	1254.465	0.308	0.083	0.454
2009	1371.046	0.284	0.071	0.479
2010	1517.743	0.293	0.063	0.451
2011	1595.833	0.295	0.058	0.420
2012	1653.716	0.299	0.051	0.386
2013	1662.220	0.271	0.048	0.385
2014	1787.377	0.296	0.040	0.345
2015	1870.619	0.303	0.033	0.323
2016	1982.322	0.310	0.031	0.310
2017	2085.990	0.317	0.030	0.294
2018	2223.266	0.328	0.028	0.280
2019	2399.384	0.329	0.032	0.280

Table 4. Variance analysis.

Project	Source	DF	Adj SS	Adj MS	F value	p value
ETC	Regression	7	5238746	748392	153.54	<0.001
	XN	1	49416	49416	10.14	0.011
	JG	1	19875	19875	4.08	0.074
	QD	1	29726	29726	6.10	0.036
	XN·XN	1	61360	61360	12.59	0.006
	JG·JG	1	216389	216389	44.39	<0.001
	QD·QD	1	24325	24325	4.99	0.052
	XN·JG	1	56618	56618	11.62	0.008
	Error	9	43869	4874	–	–
	Total	16	5282615	–	–	–
	R^2			99.17%		
	R^2(adj)			98.52%		
	R^2(pred)			96.93%		

person-kilometers in 2003 to 119.003 billion person-kilometers in 2019, an increase of 4.8 times. The completion and operation of public transportation infrastructures represented by bullet trains and G-series high-speed trains has optimized the transportation structure, which decreases carbon emissions. Freight turnover has a greater positive effect on carbon emissions in the long run, and that in Fujian Province is larger with a faster growth rate. Therefore, traffic efficiency has a more significant positive effect on carbon emissions.

(Ⅱ) The proportion of railway passenger and freight turnover selected for the transportation structure in the work indicates that China has now formed a railway transportation network dominated by bullet trains and high-speed rails with

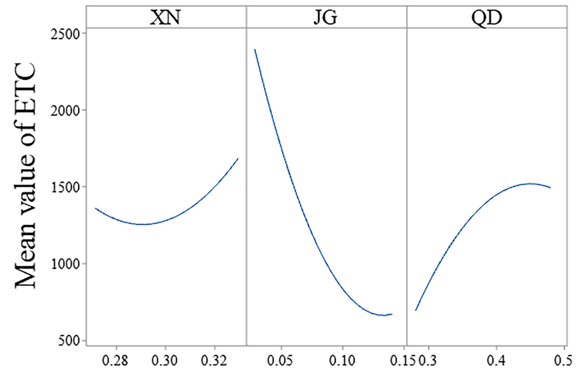


Fig. 1. Main effect of the carbon-emission-ratio model.

the low carbon emissions of railway transportation. Therefore, the transportation structure is negatively correlated with carbon emissions. Transportation structures have low significance to carbon emissions, which may be related to changes in transportation structures. The transportation structure of Fujian Province (the proportion of railway-transportation passenger and freight turnover) decreases from 20.4% in 1995 to 3.2% in 2020. On the other hand, Fujian Province has opened the Wenzhou-Fuzhou, Hefei-Fuzhou, Fuzhou-Xiamen, Xiamen-Shenzhen, and other high-speed rail lines, basically forming a relatively complete railway network extending in all directions. The construction of bullet trains and G-series high-speed trains has been stable, and the carbon emissions in railway transportation are small, so the transportation structures have a small impact on carbon emissions.

(Ⅲ) In theory, there should be a positive correlation between the carbon emission intensity of transportation and carbon emissions. The reason why carbon emissions increase rapidly and decline at a certain point is that the pressure on carbon emissions brought about by increased carbon intensity has forced the relevant departments to adopt stricter environmental control policies. Meanwhile, the technical level of energy conservation and emission reduction is improved by increasing investment in research and development and encouraging scientific and technological innovations. Thus, carbon emissions decrease after increasing to a certain point. The reasons are defined as follows.

① Fujian Provincial Government has formulated and promulgated the *Fujian Ecological Functional Zoning, Decision on Promoting the Construction of Ecological Civilization, Special Plan of Fujian Province's "Twelfth Five-Year Plan" for Environmental Protection and Ecological Construction*, etc., at the institutional level since 2010. ② In terms of performance appraisal, Fujian Province has canceled the single GDP appraisal system for 34 counties and cities and implemented the performance appraisal method of giving priority to ecological protection and agriculture since 2014. ③ In terms of the transportation infrastructure, Fujian Province has successively opened many trains and railway lines since 2009, forming an increasingly perfect railway network. The transportation structure and green and low-carbon transportation have been promoted. ④ In terms of developing the new energy vehicle industry, the number of new energy vehicles in Fujian has grown rapidly. According to data from March

DOI: 10.52396/JUSTC-2022-0079
JUSTC, **2023**, 53(1): 6

2021, 14000 new-energy vehicles (NEV) were registered in the first quarter, accounting for 7.62% of the total vehicle registrations. In addition, Fujian Province also issued the Fujian Province New Energy Vehicle Industry Development Plan (2017–2020) to support the development of the NEV industry.

Fig. 2 shows that carbon emissions increase with increased traffic efficiency and decreased transportation structure. Increased transport efficiency indicates the increased transport turnover per unit of the gross regional product. The reduced transportation structure means a decreased proportion of railway passenger and freight turnover in total transportation turnover. Increased turnover in transportation means improved transportation at the same economic development level, which consumes more petrochemical energy in turn. Meanwhile, bullet trains and G-series high-speed trains have the smallest carbon emissions among the major modes of transportation. Therefore, the combined effect of improved transportation efficiency and reduced transportation structure inevitably generates more carbon emissions.

4 Conclusions

This paper estimates the scale of carbon emission in the transportation industry in Fujian province by using the IPCC method, and then conduct an empirical research on carbon emission in the transportation industry by combining the LMDI and variance analysis. Based on the single-factor variance analysis of the influencing factors of carbon emissions in the transportation industry in Fujian Province, the constructed model had high accuracy and could predict the errors in the experimental values. Transportation efficiency had the most significant impact on carbon emissions, followed by carbon emission intensity and then transportation structure. Meanwhile, there is a significant interaction between transportation efficiency and structure. The green and low-carbon development of the transportation industry should focus on energy conservation and emission reduction on transportation efficiency (calculated from transportation passenger and cargo turnover/gross regional production). With the unchanged economic development level (gross regional production), the larger the traffic passenger and freight turnover, the higher the traffic efficiency, and vice versa. Passenger and freight turnover reflected the vitality of the economy in a sense. Therefore, CO_2 generated in the process of traffic turnover, instead of the passenger and freight turnover of transportation, should be reduced.

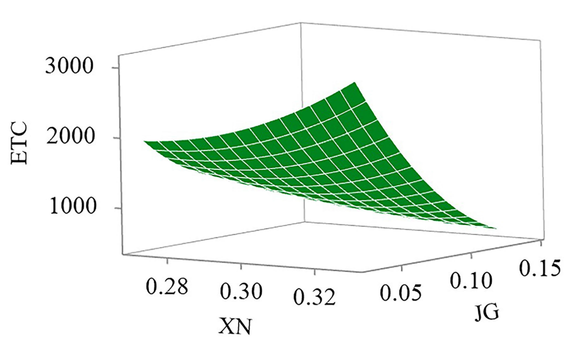


Fig. 2. Carbon emissions and surface of transport efficiency and structure.

The specific measures mainly include the following aspects:

(Ⅰ) Continue to optimize the traffic structure. The transportation structure represented by the proportion of railway passengers and freight turnover has no significant effect on carbon emissions. The carbon emission scale of railway transportation is relatively small, but it does not mean that the structural optimization of transportation modes is not important for carbon emissions. According to official statistics in 2019, the total carbon emissions in China's transportation sector were approximately 1.1 billion tons, of which roads accounted for 74%, water transport accounted for 8%, railways accounted for 8%, and aviation accounted for approximately 10%. Therefore, reducing the proportion of road transportation is still quite necessary. In terms of freight transportation, the scale and intensity of carbon emissions in the process of transportation turnover should be reduced as much as possible by utilizing road-to-railway and road-to-waterway.

(Ⅱ) Vigorously develop smart transportation. Information technology is used to create a smart transportation platform, which improves the precise matching of supply and demand and reduces the unoccupied ratio, empty-loading ratio, and vacancy ratio of transportation. Transportation is improved to minimize inefficient transportation turnover. Technologies such as big data can be fully utilized to reduce the "three ratios" of road freight. Improving the transportation system can reduce the energy consumption and carbon emissions generated in the process of vehicle transportation turnover. It is estimated that if the idling rate of vehicles in China is reduced from 45% to 25%, 147.2 billion kilometers of ineffective mileage can be reduced every year, and 69.51 million tons of carbon emissions can be reduced.

(Ⅲ) Promote the low-carbon transformation of transportation equipment. The carbon emission reduction of transportation equipment is closely related to the carbon emission intensity in transportation turnover. At present, the green and low-carbon transformation of transportation has become a major development trend in the world under the background of global climate change. The Netherlands, Spain, Germany, and other countries have proposed realizing the electrification of all passenger vehicles before 2030, 2040, and 2050, respectively; the United States proposed increasing the sales ratio of new energy vehicles to 50% by 2030. Therefore, corresponding financial and legal policies should be formulated to support the development of the NEV industry. R&D investment should be increased to innovate carbon emission reductions. Energy alternatives are sought—gradually promoting the application of new or clean energy such as electricity, biodiesel, hydrogen, and natural gases in transportation.

(Ⅳ) Gradually raise vehicle emission standards. Vehicle emission standards can control energy consumption and carbon emissions in transportation turnover. It is estimated that the United States has reduced fuel consumption by 40% and carbon emissions by 50% since it enacted the world's strictest vehicle emission standards in 2011. According to the standards, the United States will reduce greenhouse gas emissions by 770 million tons of carbon dioxide by 2030. The possibility for China is provided to gradually improve vehicle emission standards with the continuous and rapid development of science and technology. At present, there is still a certain gap between the technical level of automobile manufacturing in China and developed countries, and there is room for improving vehicle emission standards. China has the most populous emerging market, with great potential for automobile growth. Therefore, it is of great significance to continuously improve vehicle emission standards to reduce carbon emissions in transportation turnover.

Furthermore, the research method has a certain reference value for the impacts of carbon emissions in the transportation industry in other provinces and even the whole country.

Acknowledgements

This work was supported by the 2020 Major Project of Education and Teaching Reform in Undergraduate Colleges and Universities in Fujian Province (FBJG20200042).

Conflict of interest

The authors declare that they have no conflict of interest.

Biographies

Mingchun Zhong is an Associate Professor at Fujian Jiangxia University. He received his Ph.D. degree in Economics from Fujian Normal University in 2010. His research interests focus on environmental economics and industrial economics.

Guofu Lian is a Professor at Fujian University of Technology. He received his Ph.D. degree in Engineering from the University of Science and Technology of China in 2011. His research interests focus on additive manufacturing and industrial economics.

References

[1] Danielis R, Scorrano M, Giansoldati M. Decarbonising transport in Europe: Trends, goals, policies and passenger car scenarios. *Research in Transportation Economics,* **2022**, *91*: 101068.
[2] Balat M, Balat H. Recent trends in global production and utilization of bio-ethanol fuel. *Applied Energy,* **2009**, *86*: 2273–2282.
[3] Liu Z, Guan D B, Wei W, et al. Reduced carbon emission estimates from fossil fuel combustion and cement production in China. *Nature,* **2015**, *524* (7565): 335–338.
[4] Xu B Y, Wang T J, Li S, et al. Assessment of the impact of "dual-carbon" goal on future changes in air pollution and climate in China. *Chinese Science Bulletin,* **2022**, *67*: 784–794.
[5] Liu J, Li S, Ji Q. Regional differences and driving factors analysis of carbon emission intensity from transport sector in China. *Energy,* **2021**, *224*: 120178.
[6] Wang J T, Ma X M. Influencing factors of carbon emissions from transportation in China: Empirical analysis based on two-level econometrics method. *Acta Scientiarum Naturalium Universitatis Pekinensis,* **2021**, *57* (6): 1133–1142.
[7] Yu J, DA Y B, Bin Q Y. Analysis of carbon emission changes in China' s transportation industry based on LMDI decomposition method. *China Journal of Highway and Transport,* **2015**, *28* (10): 112–119.
[8] Wang L B, Zhang Y. Factors decomposition and scenario prediction of energy-related CO_2 emissions in China. *Electric Power Construction,* **2021** (9): 1–9.
[9] Alshehry A S, Belloumi M. Study of the environmental Kuznets curve for transport carbon dioxide emissions in Saudi Arabia. *Renewable and Sustainable Energy Reviews,* **2017**, *75*: 1339–1347.
[10] Han X, Xu Y, Kumar A, et al. Decoupling analysis of transportation carbon emissions and economic growth in China. *Environmental Progress & Sustainable Energy,* **2018**, *37* (5): 1696–1704.
[11] Li Yi, Du Q, Lu X R, et al. Relationship between the development and CO_2 emissions of transport sector in China. *Transportation Research Part D,* **2019**, *74*: 1–14.
[12] Ru C S, Zhang S, Yuan C W. China' s transportation economy development and carbon environmental efficiency evaluation. *China Journal of Highway and Transport,* **2019**, *32* (1): 154–161.
[13] Yuan C W, Zhang S, Jiao P, et al. Temporal and spatial variation and influencing factors research on total factor efficiency for transportation carbon emissions in China. *Resources Science,* **2017**, *39* (4): 687–697.
[14] Lu J F, Fu H, Wang X X. Research on the impact of regional transportation emissions efficiency factors. *Journal of Transportation Systems Engineering and Information Technology,* **2016**, *16* (2): 25–30.
[15] Ma H, Sun W, Wang S, et al. Structural contribution and scenario simulation of highway passenger transit carbon emissions in the Beijing-Tianjin-Hebei metropolitan region, China. *Resources Conservation and Recycling,* **2019**, *140*: 209–215.
[16] Xu L, Chen N, Chen Z. Will China make a difference in its carbon intensity reduction targets by 2020 and 2030? *Applied Energy,* **2017**, *203* (10): 847–882.
[17] Li Z, Li Y, Shao S. Analysis of influencing factors and trend forecast of carbon emission from energy consumption in China based on expanded STIRPAT model. *Energies,* **2019**, *12* (16): 3054.
[18] Chen L, Wang J H, He T, et al. Forecast study of regional transportation carbon emissions based on SVR. *Journal of Transportation Systems Engineering and Information Technology,* **2018**, *18* (2): 13–19.
[19] Ang B W. LMDI decomposition approach: A guide for implementation. *Energy Policy,* **2015**, *86*: 233–238.
[20] Wu K Y, He C H, Wang G X, et al. Measurement and decomposition analysis on carbon emissions of transportation industry in Shanghai. *Economic Geography,* **2012**, *32* (11): 45–50.
[21] Zhuang Y, Xia B. Estimation of CO_2 emissions from the transport sector in Guangdong Province, China and analysis of factors affecting emissions. *Research of Environmental Sciences,* **2017**, *30* (7): 1154–1162.
[22] Guo M, Meng J. Exploring the driving factors of carbon dioxide emission from transport sector in Beijing-Tianjin-Hebei region. *Journal of Cleaner Production,* **2019**, *226*: 692–705.
[23] Solaymani S. CO_2 emissions patterns in 7 top carbon emitter economies: The case of transport sector. *Energy,* **2019**, *168*: 989–1001.
[24] Zhang C, Zhang W, Luo W, et al. Analysis of influencing factors of carbon emissions in China' s logistics industry: A GDIM-based indicator decomposition. *Energies,* **2021**, *14*: 5742.
[25] Xu B, Lin B. Investigating the differences in CO_2 emissions in the transport sector across Chinese provinces: Evidence from a quantile regression model. *Journal of Cleaner Production,* **2018**, *175*: 109–122.
[26] Lin B, Benjamin N I. Influencing factors on carbon emissions in China transport industry: A new evidence from quantile regression analysis. *Journal of Cleaner Production,* **2017**, *150*: 175–187.
[27] Zhang G X, Su Z X. Analysis of influencing factors and scenario prediction of transportation carbon emissions in the Yellow River Basin. *Management Review,* **2020**, *32* (12): 283–294.
[28] Li X Y, Li D. Driving factors and spatial pattern analysis of the transportation carbon emission in Henan Province. *Journal of Lanzhou University: Natural Sciences,* **2019**, *55* (4): 430–435.
[29] Zeng X Y, Qiu R Z, Lin D T, et al. Spatio-temporal heterogeneity of transportation carbon emissions and its influencing factors in China. *China Environmental Science,* **2020**, *40* (10): 4304–4313.
[30] Lyu Q. Study on the driving factors of vehicle transport carbon emissions in Beijing-Tianjin-Hebei region. *China Environmental Science,* **2022**, *38* (10): 3689–3697.

DOI: 10.52396/JUSTC-2022-0079
JUSTC, **2023**, 53(1): 6