



Understanding the carbon emissions status and emissions reduction effect of China's transportation industry: dual perspectives of the early and late stages of the economic "new normal"

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Abstract

Since China has entered the economic "new normal," China's industries pay more attention to green and low-carbon development. However, the transportation industry is still one of the three industries with high carbon emissions at present. Based on this, this paper first constructed two scenarios for the early and late stages of economic "new normal." Furthermore, using the extended structural decomposition model, input–output method, and energy consumption method, this paper studied the carbon emissions status and emissions reduction effect of China's transportation industries in the early and late stages of economic "new normal." The results showed as follows. (1) Compared with the early stage of economic "new normal," the energy intensity of transportation industries and optimization of energy consumption structure played a better role in emissions reduction after entering the economic "new normal." However, the input structure effect reflecting generalized technological progress did not play a significant role. (2) Compared with the early stage of economic "new normal," low-carbon energy such as liquefied petroleum gas, natural gas, and liquefied natural gas played a more significant role in the energy structure effect with the emissions reduction effect showing an obvious enhancement trend over time after entering the economic "new normal." (3) In the early or late stage of economic "new normal," the final demand effect was the main driving factor for the growth of CO₂ emissions in the transportation industry. Meanwhile, compared with the early stage of economic "new normal," the final demand effect had a stronger driving effect in the late stage of economic "new normal." In these two periods, the second industry and the third industry were the main contributors to the final demand effect. This paper provided a basic theoretical analysis basis for carbon emission control of transportation industry under the "new normal" of the Chinese economy, and also provided a realistic guidance path for the transportation industry to carry out more accurate emission reduction from the level of energy varieties on the demand side and industry on the demand side.

Keywords Transportation · Economic "new normal," Carbon emissions · Emissions reduction

Introduction

Since the twenty-first century, the global economy stable development has stimulated the growth of energy demand, and CO₂ from excessive energy consumption has accelerated global warming (Jiang et al. 2019; Sun et al. 2020; Yu et al. 2020). Carbon emissions caused by fossil fuels account for more than 58% of the total emissions and are the main source of global carbon emissions (Sun et al. 2021; Adebayo et al. 2021). However, the transportation industry, mainly consuming fossil energy, belongs to the high energy consumption industry at present (Chang et al. 2013). In line with the statistics of the International Energy Association, the transportation industry has turned into the second largest CO₂ emission industry worldwide by 2018, accounting for a

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quarter of the world's CO₂ emissions. Also in 2018, 9.17% of China's CO₂ came from transportation industries, which indicates that the transportation industry has become one of the three high CO₂ emission industries in China (Chang et al. 2013). Therefore, controlling the swift growth of CO₂ from the transportation industry is the link that cannot be ignored for China to achieve carbon peak and carbon neutralization.

On December 10, 2013, the concept of economic “new normal” was first proposed by China's President Xi Jinping at the Central Economic Work Conference. The conference revealed that the economic growth of China has changed from high speed to medium high speed (Liu, 2016), and emphasized that the resource and environment constraints of future economic development would be further strengthened. It injected a strong political impetus into promoting domestic climate governance. Based on the above domestic and foreign environments, promoting a new mode of green development of industries has turned into an inevitable choice for sustainable development and protection of the global ecological environment under the economic “new normal” (Jiang et al. 2020). The transportation industry is one of the three high carbon emission industries in China. The comparative analysis of CO₂ emission current situation and emission reduction influencing factors of China's transportation industries in the early and late stages of the economic “new normal” has theoretical and practical value for the transportation industry to carry out more efficient and accurate low-carbon development in the post “new normal” period.

The existing research on carbon emission of the transportation industry can be summarized from the perspectives, methods, and contents of the research. In terms of research perspective (Wang et al. 2020), the existing literature is mainly studied from the following two directions. Firstly, from the perspective of energy consumption, some studies analyzed transportation utility indirectly. For example, Chai et al. (2016) explored the correlation between CO₂ and energy consumption from the transportation industry of China. Huang et al. (2019) discussed the relationship between energy utilization technology and CO₂ in the transportation industry. Secondly, some studies regarded the transportation industry as an intermediate input to analyze the CO₂ emissions. For instance, Wang et al. (2018) analyzed the linkage between carbon emissions of transportation utility and GDP per capita in China. Lv et al. (2019) tested the relationship between the CO₂ emissions of the aviation industry and urbanization. In terms of research methods, the literature about CO₂ in the transportation sector mainly focuses on qualitative research of various factors (Wang et al. 2018; Chai et al. 2016; Huang et al. 2019). Comparatively, there are few literatures on quantitative research about carbon emission of the transportation industry. Moreover, decomposition

models, such as DEA (data envelopment analysis) and LMDI (Logarithmic Mean Divisia Index), are mainly used in the quantitative study of carbon emissions from the transportation industry. Chang et al. (2013) applied DEA to analyze the environmental efficiency of the transportation industries of China. Wu et al (2016) adopted DEA to evaluate and analyze the environmental and energy performance of the transportation industry of China. Zhang et al. (2020) used an extended DEA to evaluate and analyze the energy-related CO₂ emissions efficiency of the transportation industry of China. Wang et al. (2011) adopted LMDI to analyze the CO₂ emissions of the transportation utility of China. Quan et al. (2020) used LMDI to study the influencing factors of CO₂ emissions in China's logistics industry. Yu et al. (2020) studied China's aircraft-related CO₂ emissions. In terms of research content, the research on CO₂ emissions of transportation utility mainly focuses on CO₂ emission efficiency evaluation and the analysis on influencing factors of CO₂ emission increase (Feng et al. 2020; Lin et al. 2019). Alataş (2021) found that environmental technologies have a statistically insignificant positive effect on CO₂ emissions from the transport sector of the EU15 countries. Liu et al. (2021) employed the extended STIRPAT and GTWR models to reveal the influence of driving factors on carbon emission intensity from spatial–temporal perspectives. Zhao et al. (2022) studied the effect of smart transportation on CO₂ emissions in China by employing spatial econometric models. They found that smart transportation significantly reduces carbon dioxide emissions from transport.

According to the analysis of existing CO₂ emission literature of transportation industries, the following three points can be drawn. First, from the research perspective, few pieces of literature unified the supply-side and the demand-side of transportation industries through input–output analysis theory. This study can more comprehensively study the CO₂ emission and emissions reduction of transportation industries. Second, in the terms of research methods, few kinds of literature were used to extend structural decomposition analysis (SDA) and input–output analysis to study CO₂ emissions in the transportation industry of China. An obvious advantage of this method is that it can analyze the influence of demand fluctuation of various industries on CO₂ emissions of transportation industries, which is not available in the IDA (Index Decomposition Analysis) model (Hoekstra and Van den Bergh 2003). Thirdly, from the research content, few literatures have evaluated the carbon emission characteristics and emissions reduction effects of the transportation industry of China after the economic “new normal.” In addition, there is almost no literature to comparatively analyze the CO₂ emission status and reduction effect of the transportation industry before and after the economic “new normal.”

In response to the above problems, based on the input–output analysis theory, combining the supply and demand aspects of transportation utility, and then applies the extended SDA, input–output analysis, and energy consumption method, the paper analyzes the CO₂ emission situation and the emissions reduction effect of the transportation industry before and after the “new normal” for China’s economy. This study can not only draw the results of low-carbon development of the transportation industry after entering the “new normal” compared with that before the “new normal” for China’s economy. Meanwhile, it can also objectively point out the problems existing in the low-CO₂ development of transportation industries after the economic “new normal,” which provides the direction and theoretical basis for the accurate low-carbon development of transportation industries in this period.

The marginal contribution of this paper is mainly reflected in the following three aspects. Firstly, based on the national conditions of China’s new economic normal, this paper constructs two scenarios in the early and late periods of the new economic normal, and compares and analyzes the CO₂ emissions and CO₂ emission structure characteristics of China’s transportation industry in the two scenarios. Secondly, from the perspective of input–output analysis, the quantitative influence degree of the four factors on the carbon emission change of China’s transportation industry in two scenarios is compared and analyzed, which provides a basic theoretical analysis basis for more effective CO₂ emission control of the transportation industry in the later period of the “new normal.” Thirdly, the existing standard structure decomposition model is extended to refine the analysis of the effect of each energy in the energy structure effect and the effect of each industry in the final demand effect, providing a realistic guidance path for the transportation industry to carry out emission reduction more accurately from the demand-side energy varieties and the demand-side industry level under the “new normal” economic situation. The follow-up arrangements for this paper are as follows. The theoretical analysis and scenario setting are discussed in the “[Theoretical basis and scenario design](#)” section. The “[Data source and model construction](#)” section details data sources and model construction. There are empirical results and analysis in the “[Empirical results and analysis](#)” section and the “[Discussion](#)” section provides research conclusions and enlightenment.

Theoretical basis and scenario design

Theoretical basis

The theoretical basis of this paper mainly includes three parts: the method of energy consumption, the analysis of input–output, and the analysis of structural decomposition.

The method of energy consumption

This method is one of the three mainstream methods for measuring carbon emissions (Schipper et al. 1996, 2001). Moreover, this method has the following advantages: convenient operation and accurate results (Sumabat et al. 2016). Therefore, this study chooses the method of energy consumption to calculate the carbon emissions from the terminal energy combustion in the transportation industry. Firstly, we manually collected and sorted out the terminal energy consumption of transportation utility in each year. Secondly, we obtained the carbon emissions coefficients of specific energy combustion for terminal consumption by consulting the literature (Huang et al. 2019). Finally, we get the CO₂ emission of transportation industries according to the terminal energy consumption data of the transportation utility and the CO₂ emission coefficient of each energy source.

The analysis of input–output

The method of input–output analysis is used to study the balance relations among all sectors of the national economy (Su et al. 2017; Zhu et al. 2012; Xie, 2014). On the basis of the general equilibrium assumption, the correlation of products from each sector is expressed as a set of equations. After that, according to the characteristics of the statistical data, a chessboard balance table or a matrix is made to express the overall situation of the balance of product supply and demand in various sectors of the national economy. As one of the 42 intermediate input sectors, the transportation industry participates in the production activities of the national economy to meet the demand of various products or activities for transportation (Magazzino and Mele, 2020). By using the above input–output analysis, the paper integrates direct carbon emissions from supply and indirect carbon emissions from the demand of transportation industries. It is conducive to a more comprehensive study on carbon emissions and emissions reduction for the transportation industry.

The analysis of structural decomposition analysis

At present, the two most widely used methods for scientific evaluation and quantitative analysis of carbon emission

factors are SDA and IDA. Among them, the index decomposition analysis model refers to the form of data aggregation being used for analyzing the direct impact of changes in demographic factors, economic factors, structural factors, and other factors of carbon emissions (Ang, 1995). The structural decomposition analysis model is based on the classic input and output theory (Rose and Casler, 1996; Casler and Rose, 1998). The research data of the structural decomposition analysis model is more complete and the analysis is more detailed. This method can make up for the fact that the index decomposition model cannot study the extent to which carbon emissions growth is affected by final demand (Su and Ang, 2012; Peters et al. 2007; Minx et al. 2011).

Therefore, the structural decomposition analysis is used to explore the CO₂ emissions from the transportation utility of China. In this paper, we not only analyze the effects of energy structure, the effects of energy intensity, the effects of input structure, and the impacts of final demand on transportation CO₂ emissions. Moreover, the structure decomposition analysis model is extended to further study the role of each industry in final demand and the role of each type of energy source in the effect of energy structure.

Scenario design

This paper takes 2012 as the demarcation point for the economy of China to enter the economic “new normal,” which is jointly determined by the following three reasons. First, through consulting the literature on the “new normal” for China’s economy (Li et al. 2019; Xu and Qi, 2017; Zhu et al. 2018; Pan, 2016), we found that the official government did not have a clear response to the time when China’s economy entered the “new normal.” It just gave the most typical feature of the economic “new normal,” that is, the economic growth rate transforms from high speed (above 9%) to medium–high speed (below 8%). Among them, China’s economic growth rate was over 9% before 2012, and 7.4% in 2012. Second, the economic “new normal” was first proposed in 2013 (Liu, 2016). Third, considering the discontinuity of China’s input–output table data, the data of the input–output table closest to 2013 is the one for 2012.

Based on the above analysis, and considering that China’s input–output table for 2017 is the latest table, this paper sets 2012–2017 as the “new normal” period for China’s economy, and defines it as scenario 2. In addition, the comparative analysis of the effects of different scenarios needs to unify the time interval of the two scenarios, and also takes into account the availability of China’s input–output table data. Therefore, this paper sets 2007–2012 as the period when the economy of China has not reached the “new normal.” Table 1 shows the details of the two scenarios.

Table 1 Scenario design

Scenario name	Scenario description
Scenario I	2007–2012 is set as the period when China has not entered the economic “new normal,” which is defined as scenario I
Scenario II	2012–2017 is set as the period when China enters the economic “new normal,” which is defined as scenario II

Data source and model construction

Data source

The core data in this study mainly comes from the following three parts, namely, the input–output table data of China for 2007, 2010, 2012, 2015, and 2017; the terminal energy consumption data of the transportation sector in China Energy Statistical Yearbook in 2008, 2011, 2013, 2016, and 2018; the direct carbon emission factor; the carbon emission coefficient; and conversion coefficient of every kind of energy source. It is worth noting that China’s input–output table has 42 departments. To simplify the final research results, 42 departments were merged into 9 departments (Jiang et al. 2019; Yu et al. 2021) as shown in Fig. 1.

Model

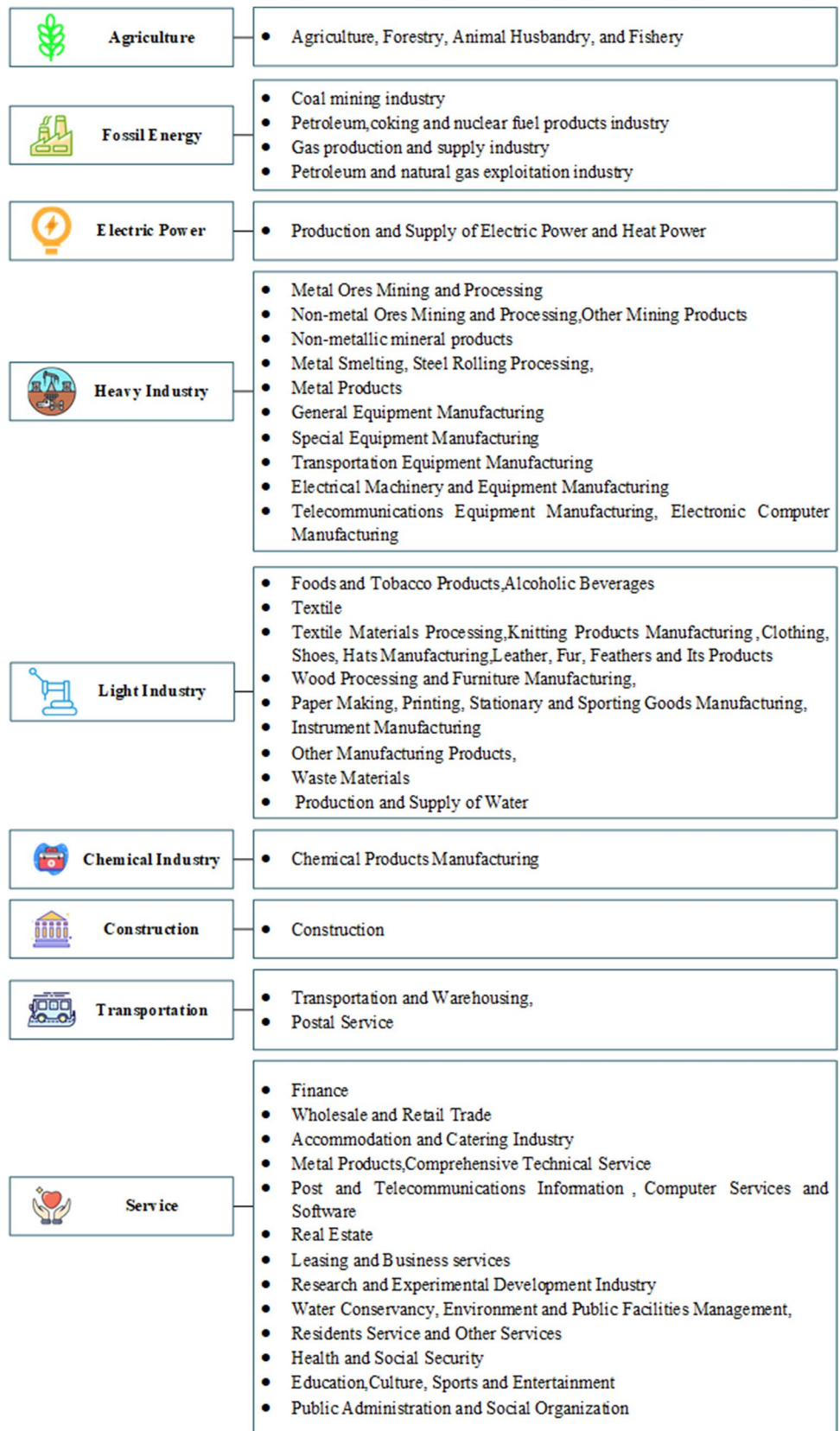
The model in this paper includes two aspects. First, apply the energy consumption method to calculate CO₂ emissions from transportation utility, and analyze the structural characteristics of CO₂ emissions from transportation industries. Second, use the analysis of input–output and the analysis of structural decomposition to decompose the rising of transportation utility CO₂ emissions, obtain changes in CO₂ emissions increase among four effects; based on the expansion of the structural decomposition analysis model, the role of various energy sources in the energy consumption structure and the role of different industries in the final demand effect are analyzed in detail (Yang et al. 2021).

Energy consumption method

Assuming that the terminal consumption of the i energy on the supply-side of the transportation sector is E_i , and the CO₂ emission coefficient of the i energy is f_i , the CO₂ emissions from the i energy CE_i can be calculated as follows.

$$CE_i = E_i \times f_i \quad (1)$$

Fig. 1 The department classification



Assuming that the transportation industry consumes h types of energy sources, the total energy CO₂ emissions from transportation industries CE can be measured as below.

$$CE = \sum_i^h CE_i = \sum_i^h E_i \times f_i \tag{2}$$

The proportion of CO₂ emissions from energy i in the total energy CO₂ emissions of transportation industries SC_i can be measured as follows.

$$SC_i = \frac{CE_i}{CE} = \frac{E_i \times f_i}{\sum_i^h E_i \times f_i} \tag{3}$$

Input–output method

The method of input–output was founded by the famous mathematical economist Leontief in the 1930s. It is a widely used mathematical economics analysis method (Yu et al. 2021; Andrés et al. 2021; Tabatabaie and Murthy, 2021). The economic significance of A_{ij} is the number of products from the j department consumed by the i department for unit output.

$$A = [A_{ij}], A_{ij} = \frac{X_{ij}}{X_j} \tag{4}$$

$$\begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_i \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & \dots & A_{1j} \\ A_{21} & A_{22} & \dots & A_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ A_{i1} & A_{i2} & \dots & A_{ij} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_i \end{pmatrix} + \begin{pmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_i \end{pmatrix} \tag{5}$$

$$AX + Y = X \tag{6}$$

$$X = (I - A)^{-1}Y \tag{7}$$

In the above equation, $X = [X_j]$ is the matrix of total output in the input–output model; $Y = [Y_j]$ is the matrix of final demand; A is the direct consumption coefficient matrix; $L = (I - A)^{-1}$ is the Leontief inverse matrix.

Structural decomposition analysis model

In the production activities of the national economy, the transportation industry, as one of the 42 intermediate departments, is closely related to the production of China’s national economy. When the transportation industry is consumed by various industries as an intermediate input, although the process does not directly produce carbon emissions, it will lead to implied carbon emissions. The transportation industry, as an intermediate input commodity, consumes fossil energy and produces carbon emissions in the production

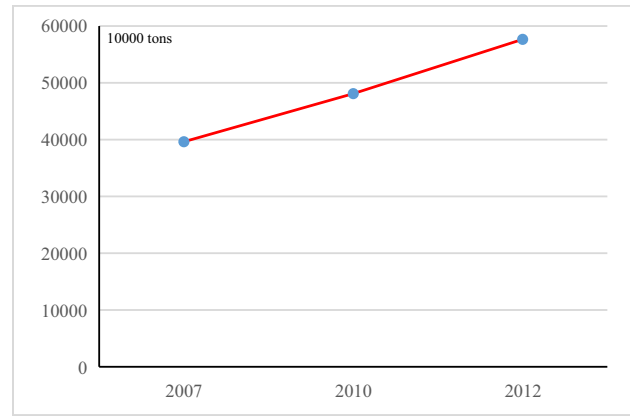


Fig. 2 Carbon emissions from transportation industries under scenario I

process. Therefore, the carbon emission directly generated by the transportation industry consuming fossil energy is the implicit carbon emission that is consumed as intermediate input.

Due to the large differences between the fossil energy consumption units in the transportation industry, this article uniformly converts fossil energy consumption into standard coal.

$$C_k = E_k \times e_k \tag{8}$$

$$S = \begin{pmatrix} \frac{C_{11}}{\sum_{i=1}^m C_{1i}} & \frac{C_{12}}{\sum_{i=1}^m C_{1i}} & \dots & \frac{C_{1n}}{\sum_{i=1}^m C_{1i}} \\ \frac{C_{21}}{\sum_{i=1}^m C_{2i}} & \frac{C_{22}}{\sum_{i=1}^m C_{2i}} & \dots & \frac{C_{2n}}{\sum_{i=1}^m C_{2i}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{C_{n1}}{\sum_{i=1}^m C_{ni}} & \frac{C_{n2}}{\sum_{i=1}^m C_{ni}} & \dots & \frac{C_{nn}}{\sum_{i=1}^m C_{ni}} \end{pmatrix} I_{n \times n} = \begin{pmatrix} \frac{\sum_{i=1}^m C_{1i}}{X_1} & 0 & \dots & 0 \\ 0 & \frac{\sum_{i=1}^m C_{2i}}{X_2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \frac{\sum_{i=1}^m C_{ni}}{X_n} \end{pmatrix} \tag{9}$$

where e_k is the conversion coefficient of fossil energy of the k ; C_k represents the amount of fossil energy converted into standard coal by the k fossil energy; $S = [s_{ik}]$ is the

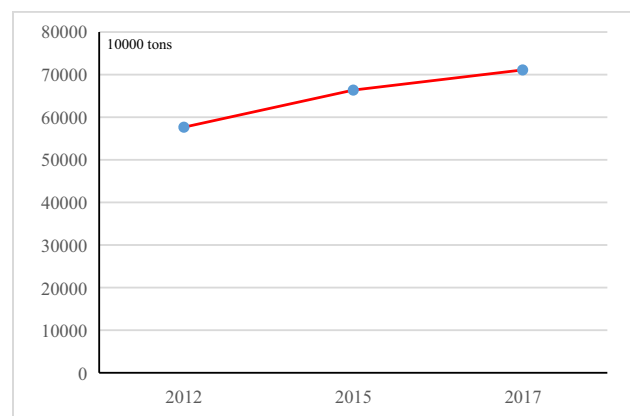


Fig. 3 Carbon emissions from transportation industries under scenario II

energy structure matrix of the transportation industry; $I_{n \times n}$ is the energy intensity matrix. Then, the CO₂ emissions CE of the k fossil energy consumed by transportation and public utilities can be calculated using the following formula:

$$CE = FSILY \tag{10}$$

where let $F = [f_k]$ be the matrix of CO₂ emission coefficient. Let L be the Leontief inverse matrix. The growth of CO₂ emissions ΔCE can be calculated as below.

$$\Delta CE = FS_t I_t L_t Y_t - FS_{t-1} I_{t-1} L_{t-1} Y_{t-1} = \Delta E_s + \Delta E_I + \Delta E_L + \Delta E_Y \tag{11}$$

$$\begin{aligned} \Delta E_h = & \frac{1}{2} \underbrace{(F_t I_t L_t Y_t - F_{t-1} I_{t-1} L_{t-1} Y_{t-1}) \Delta S}_{\text{energy structure effect}} + \frac{1}{2} \underbrace{(F_t S_t L_t Y_t - F_{t-1} S_{t-1} L_{t-1} Y_{t-1}) \Delta I}_{\text{energy intensity effect}} \\ & + \frac{1}{2} \underbrace{(F_t S_t I_t Y_t - F_{t-1} S_{t-1} I_{t-1} Y_{t-1}) \Delta L}_{\text{input structure effect}} + \frac{1}{2} \underbrace{(F_t S_t I_t L_t - F_{t-1} S_{t-1} I_{t-1} L_{t-1}) \Delta Y}_{\text{final demand effect}} \end{aligned} \tag{12}$$

$$\Delta E_s = \frac{1}{2} (F_t I_t Y_t - F_{t-1} I_{t-1} Y_{t-1}) \tag{13}$$

$$\Delta E_I = \frac{1}{2} (F_t S_t Y_t - F_{t-1} S_{t-1} Y_{t-1}) \tag{14}$$

$$\Delta E_L = \frac{1}{2} (F_t S_t I_t - F_{t-1} S_{t-1} I_{t-1}) \tag{15}$$

$$\Delta E_Y = \frac{1}{2} (F_t S_t I_t L_t - F_{t-1} S_{t-1} I_{t-1} L_{t-1}) \tag{16}$$

The structural decomposition analysis model usually has four forms. The main difference is the processing results of the cross terms. The two-pole decomposition method has relatively small errors among various decomposition methods. Therefore, this paper uses a two-pole decomposition method to decompose factors. In addition, we extend the structure decomposition model to further study the effect of various energy sources in the energy consumption structure, every kind of industry in the effect of final demand.

$$PE_k = \Delta E_s \times \frac{\Delta C_k}{\sum_m \Delta C_k} \tag{17}$$

$$PDF_j = \Delta E_Y \times \frac{\Delta Y_j}{\sum_i \Delta Y_j} \tag{18}$$

where PE_k is the k energy's energy structure effect in the transportation industry; PDF_j is the role of the j industry in the final demand effect.

Empirical results and analysis

Carbon emissions analysis and the characteristics of carbon emission structure under two scenarios

The calculation results of transportation carbon emissions under scenario I and scenario II are shown in Fig. 2 and Fig. 3.

Based on the results in Fig. 2, from 2007 to 2012 (before China entering the economic “new normal”), carbon emissions from transportation industries showed a continuous upward trend. However, the growth rate of CO₂ emis-

sions showed a slow downward trend. Specifically, under scenario I, the growth rate of CO₂ emissions was 21.37% in 2007–2010 and 19.87% in 2010–2012, and the average annual growth rate was 9.1% in 2007–2012.

According to the results in Fig. 3, from 2012 to 2017 (after China turn into the economic “new normal”), the CO₂ emissions of transportation industries still showed a growing trend. However, the growth rate trend is still declining slowly. Specifically, under scenario II, the carbon emission growth rate of transportation industries was 15.11% in 2012–2015 and 7.13% in 2015–2017, and the average annual growth rate was 4.66% in 2012–2017.

By comparing the research results in Fig. 2 and Fig. 3, we can conclude that, although the CO₂ emissions from transportation industries still maintain a growth trend in the two scenarios; the growth rate of transportation utility CO₂ emissions under scenario II is significantly lower than that under scenario I. In other words, compared with before China entering the “new normal” of the economy, the growth of CO₂ emissions of transportation industries has been more effectively controlled after the Chinese economy entering the economic “new normal.”

The CO₂ emission structure characteristics of the transportation industry under scenario I and scenario II are shown in Table 2 and Table 3.

According to Table 2, we can draw the following conclusions. Under scenario I, the percentage of high carbon energy consumption, such as fuel oil and energy-related CO₂ emissions of the transportation industry, has a decreasing trend, while the proportion of low carbon consumption, such as liquefied natural gas and energy-related CO₂ emissions, shows an upward direction and trend. The reason for

Table 2 CO₂ emission structure of the transportation industry under scenario I

Kinds of energy	2007	2010	2012
Raw coal	3.937106%	3.069354%	2.450600%
Cleaned coal	0.146142%	0.059292%	0.060338%
Other washed coal	0.031364%	0.025875%	0.020007%
Coke	0.004223%	0.000759%	0.000475%
Gasoline	21.022404%	20.089722%	19.624577%
Kerosene	8.830161%	10.308493%	9.598233%
Diesel oil	54.187993%	55.976385%	58.800509%
Fuel oil	11.352380%	8.927487%	7.768784%
LPG	0.430745%	0.386037%	0.350418%
Natural gas	0.057483%	0.361933%	0.452718%
LNG	0.000000%	0.794663%	0.873340%

Table 3 CO₂ emission structure of the transportation industry under scenario II

Kinds of energy	2012	2015	2017
Raw coal	2.450600%	1.672756%	1.119117%
Cleaned coal	0.060338%	0.035154%	0.000000%
Other washed coal	0.020007%	0.026653%	0.025696%
Coke	0.000475%	0.013845%	0.025718%
Gasoline	19.624577%	24.106700%	24.163552%
Kerosene	9.598233%	11.687870%	13.820911%
Diesel oil	58.800509%	53.159178%	50.023695%
fuel oil	7.768784%	7.020160%	8.063359%
LPG	0.350418%	0.476996%	0.546592%
Natural gas	0.452718%	0.627400%	0.673816%
LNG	0.873340%	1.173289%	1.537544%

this result is the improvement of the energy consumption structure in the energy supply of the transportation industry from 2007 to 2012. Specifically, in the energy consumption structure of the transportation industry from 2007 to 2012, the proportion of high-carbon energy on the supply side declined, while the proportion of low-carbon energy rose.

According to Table 3, we can draw the following conclusions. Under scenario II, the percentage of high-carbon energy in the energy-related CO₂ emissions of the industry of transportation industry showed a decreasing trend, while the proportion of low-carbon energy in the

carbon emissions of the transportation utility showed a rising trend. This is due to the improvement of the energy consumption structure in the energy supply of the transportation industry of China from 2012 to 2017. Specifically, in the energy consumption structure of 2012–2017, the proportion of high-carbon energy on the supply-side of the transportation was reduced, while the proportion of low-carbon energy increased.

By comparing the results of Table 2 and Table 3, we can draw conclusions that although the changing trend of CO₂ emission structure of China's transportation industry under scenario I and scenario II is consistent on the whole, that is, the proportion of CO₂ emission of high carbon energy has been reduced and that of low carbon energy rising. However, the degree of decline or rise was different. Specifically, compared with scenario I, high-carbon energy's proportion in the carbon emissions of the transportation industry under scenario II decreased faster, while the proportion of the carbon emissions of the low-carbon energy rose faster. This can be better explained. Since China has turned into the economic "new normal," the government of China has paid more attention to the quality of economic development, actively encouraged and promoted the low-carbon transformation of the industry, and further optimized the supply-side energy consumption structure of the transportation utility, which led to the above phenomenon.

Analysis of influencing factors of carbon emission growth from transportation industry under two scenarios

Through the above input–output method and structural decomposition model, we can clarify how the four factors under scenarios I and II affect the growth of energy-related carbon emissions in the transportation industry. The results are shown in Table 4 and Table 5.

From the perspective of time evolution, the three points below can be obtained by analyzing Table 4. First, from 2007 to 2010, FDE, ISE, and ESE promoted the rising of transportation industry carbon emissions. Specifically, ESE played a weaker role in boosting the growth of CO₂ emissions from the transportation industry of China, while ISE and FDE are more conducive to the increase of carbon emissions in the transportation industry. However, energy intensity effect had an inhibitory effect on the rising of transportation industry

Table 4 The influence of four factors on the rising of energy-related carbon emissions from the transportation industry under scenario I

Effects(unit:10,000 tons)	Energy structure effect (ESE)	Energy intensity effect (EIE)	Input structure effect (ISE)	Final demand effect (FDE)
2007–2010	181.3328077	−6418.569471	5097.153033	8753.907762
2010–2012	−210.9935978	−195.5730817	−6940.240903	15,239.40317
2007–2012	8.960178906	−7473.969472	−451.4809225	23,317.37328

Table 5 The influence of four factors on the rising of energy-related carbon emissions from the transportation industry under scenario II

Effects (unit:10,000 tons)	ESE	EIE	ISE	FDE
2012–2015	− 537.0405254	− 11,233.08442	5950.512329	12,911.34498
2015–2017	− 713.4342258	5406.590224	− 6961.734643	27,764.26135
2012–2017	− 1362.491745	− 9099.403273	1982.976586	40,802.5168

carbon emissions. Second, FDE promoted the rising of carbon emissions from the transportation industry from 2010 to 2012, while ISE, ESE, and EIE inhibited the increasing of carbon emissions from the transportation industry. Among them, ISE had a stronger inhibitory effect on the rising of transportation industry carbon emissions, while ESE and EIE had weaker inhibitory effects on the rising of transportation industry carbon emissions. Third, from 2007 to 2012, FDE and ESE promoted the rising of transportation industry carbon emissions. Among them, FDE had made greater contributions to promoting the rising of carbon emissions from China’s transportation industry, while ESE had made smaller contributions to promoting the rising of carbon emissions from China’s transportation industry. However, EIE and ISE had inhibitory effects on the rising of transportation industry carbon emissions. Among them, energy intensity effect had a stronger inhibitory effect on the rising of carbon emissions from the transportation industry, while ISE had a weaker inhibitory effect on the rising of transportation industry carbon emissions.

From the perspective of time evolution, the following three points can be drawn by analyzing Table 5. First, from 2012 to 2015, FDE and ISE promoted the rising of transportation industry carbon emissions. Specifically, FDE can significantly increase carbon emissions in the transportation industry, while ISE has a lesser role in promoting CO₂ emissions in the transportation industry. However, EIE and ESE inhibited the growth of carbon emissions. Among them, the inhibitory effect of EIE on the rising of transportation industry carbon emissions was stronger, while the inhibitory

effect of ESE on the rising of carbon emissions was weaker. Second, FDE and EIE promoted the rising of transportation industry carbon emissions from 2015 to 2017. Among them, FDE played a stronger role in promoting the rising of transportation industry CO₂ emissions, while EIE plays a weaker role in improving CO₂ emissions in the transportation industry. However, ESE and ISE inhibited the rising of transportation industry carbon emissions. Among them, ISE had a stronger inhibitory effect on the rising of transportation industry carbon emissions, while ESE cannot significantly curb the increase in carbon emissions from the transportation industry. Third, from 2012 to 2017, FDE and ISE promoted the rising of transportation industry carbon emissions. Among them, FDE can significantly increase carbon emissions in the transportation industry, while ISE cannot promote a significant increase in carbon emissions in the transportation industry. However, EIE and ESE inhibited the rising of transportation industry carbon emissions. Among them, EIE can significantly reduce the growth of carbon emissions in my country’s transportation industry, while ESE has a weak restraint on the increasing CO₂ emissions from the transportation industry.

Analysis of the influence of changes in the specific energy consumption structure on the growth of carbon emission growth from the transportation industry under the two scenarios

Table 6 calculates the energy consumption structure of transportation utilities, from 2007 to 2017. Table 7 and Table 8

Table 6 The proportion of energy consumption structure in the transportation industry from 2007 to 2017

Kinds of energy	2007	2010	2012	2015	2017
Raw coal	3.937106%	3.069354%	2.450600%	1.672756%	1.119117%
Cleaned coal	0.146142%	0.059292%	0.060338%	0.035154%	0.000000%
Other washed coal	0.031364%	0.025875%	0.020007%	0.026653%	0.025696%
Coke	0.004223%	0.000759%	0.000475%	0.013845%	0.025718%
Gasoline	21.022404%	20.089722%	19.624577%	24.106700%	24.163552%
Kerosene	8.830161%	10.308493%	9.598233%	11.687870%	13.820911%
Diesel oil	54.187993%	55.976385%	58.800509%	53.159178%	50.023695%
Fuel oil	11.352380%	8.927487%	7.768784%	7.020160%	8.063359%
LPG	0.430745%	0.386037%	0.350418%	0.476996%	0.546592%
Natural gas	0.057483%	0.361933%	0.452718%	0.627400%	0.673816%
LNG	0.000000%	0.794663%	0.873340%	1.173289%	1.537544%

Table 7 The impact of changes in the energy structure on the rising of CO₂ emissions from China's transportation industry under scenario I

Kinds of energy	2007–2010	2010–2012	2007–2012
Raw coal	-1.116348538	0.882323303	-0.045852119
Cleaned coal	-0.459708579	-0.102755552	-0.008466499
Other washed coal	0.000320195	0.018618629	-0.000408553
Coke	-0.018731947	0.001369228	-0.000469147
Gasoline	29.14807126	-37.89201884	1.529141415
Kerosene	31.08566992	-12.85948445	1.015131142
Diesel oil	112.6659339	-151.1952984	6.016312245
Fuel oil	-4.055215537	-3.845492465	-0.009009579
LPG	0.36363881	-0.416422207	0.017818672
Natural gas	3.790123551	-2.281976031	0.139726738
LNG	9.929059541	-3.302461011	0.30625459

Table 8 The impact of changes in the energy structure on the growth of CO₂ emissions from China's transportation industry under scenario II

Kinds of energy	2012–2015	2015–2017	2012–2017
Raw coal	11.27875801	28.62213218	37.78783639
Cleaned coal	0.501842216	2.496829395	2.5041202
Other washed coal	-0.336705233	-0.077786547	-0.605707294
Coke	-0.357443524	-0.89134784	-1.186977744
Gasoline	-287.0789855	-176.9816618	-590.8612123
Kerosene	-132.6385814	-301.831536	-421.0034765
Diesel oil	-79.74193363	-40.6427785	-158.3948687
Fuel oil	-9.965775957	-145.4890796	-114.232427
LPG	-7.787123223	-11.97393818	-20.85191933
Natural gas	-10.89890427	-10.74907151	-25.14244261
LNG	-20.01567288	-55.91598733	-70.50467002

calculate the role of various types of energy sources in the energy structure effect under scenario I, scenario II.

Through the analysis of Table 6, we find that from 2007 to 2017, in the supply-side energy consumption structure of the transportation utility, low-carbon energy shows a rising trend, while high-carbon energy is on the decline. It can be inferred that the effect of energy structure on carbon emission reduction is due to the continuous optimization of energy consumption structure on the supply side. The main reason for this situation is the growth of the percentage of low-carbon energy consumption, the fall in the percentage of high-carbon energy consumption.

As shown in Table 7, based on the perspective of energy structure, different energy sources have great differences in restraining and promoting carbon emissions from China's transportation industry, during 2007–2012. Specifically, within the research interval, the main factor in optimizing

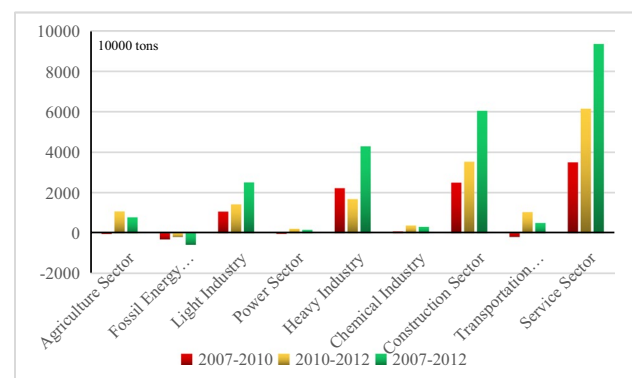
the energy consumption structure of the transportation industry is the decline in the percentage of high-carbon energy consumption. Based on the perspective of time evolution, the emission reduction effect of energy consumption structure optimization in China's transportation industry shows a rising trend over time.

As shown in Table 8, in terms of energy structure, the positive or negative impacts of different energy sources on the rise of carbon emissions in the transportation sector are different at different stages from 2012 to 2017. Specifically, within the research interval, the increase of low-carbon energy consumption structure, such as LNG, gasoline, is a main driving force to optimize the energy consumption structure of the transportation industry and play the role of emission reduction. The following conclusions are drawn based on the time evolution. As time went by, the emissions reduction effect of optimizing the transportation industry energy consumption structure showed an increasing trend.

Analysis of the impact of changes in transportation demand of each industry on the rising of carbon emission growth from the transportation industry under the two scenarios

Figure 4 and Fig. 5 show the impact of volatility in transportation demand of various industries on the growth of CO₂ emissions of the transportation industry under scenario 1 and scenario 2 from 2007 to 2017.

According to the analysis of Fig. 4 and Fig. 5, it can be seen that the fluctuation of industry demand from 2007 to 2017 has different promoting impacts on the rise of fossil energy carbon emissions. Specifically, from 2007 to 2012, the final demand effects of light and heavy industries, service industries, and construction industries have a significant role in promoting the increase in carbon emissions of the transportation industry. From 2010 to 2015, heavy and light

**Fig. 4** The impact of changes in transportation demand in various industries on the rising of transportation industry CO₂ emissions of China under scenario I

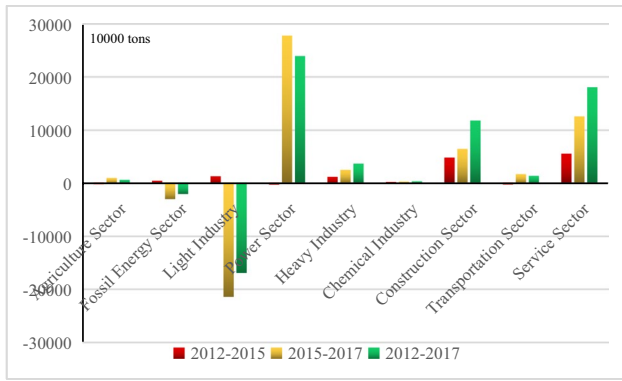


Fig. 5 The impact of changes in transportation demand of various industries on the rising of transportation industry CO₂ emissions of China under scenario II

industry, service, and construction industries have a strong role in accelerating the rising of transportation industry carbon emissions in the final demand effect. From 2015 to 2017, the service industry and construction industry have a strong role in improving the increase in carbon emissions of the transportation industry in the final demand effect. Based on the above analysis, we can conclude that the main factors influencing final demand are ranked as follows: secondary industry, tertiary industry, and primary industry.

Discussion

This paper can be discussed based on the four aspects of the above research results.

Discuss the carbon emissions and carbon emissions structure characteristics of the industry of transportation under the two scenarios

Since the first few years of the twenty-first century, China’s economy has maintained a steady growth rate. The average growth rate of China’s GDP was 10.22% from 2007 to 2012; from 2012 to 2017, the average growth rate of China’s GDP was 7.31%. Due to the significant positive correlation between the growth of economy and the consumption of energy (Shahbaz et al. 2013), economic growth will also be significantly positively correlated with the CO₂ emissions from energy consumption. Meanwhile, in various industries, the demand for transportation has been boosted by the steady growth of China’s economy (Magazzino and Mele, 2020), which leads to a growth of demand for energy consumption in the transportation industry. Thus, the energy CO₂ emissions of the transportation industry showed an increasing trend in the research range. In addition, compared with the early stage of the “new normal” of China’s economy, the

growth rate of carbon emissions from China’s transportation industry reduced significantly in the late stage of the “new normal.” Furthermore, according to a series of energy consumption policies from 2007 to 2017, it can be concluded that the Chinese government proposes to continue to control the structure of high-carbon energy consumption and increase the consumption structure of low-carbon energy continuously. This also explained well that in the research interval, the carbon emission structure of the industry of transportation has a downward trend in the percentage of high-carbon energy carbon emissions and an upward trend in the proportion of carbon emissions in low-carbon energy.

Discuss influencing factors of a rising of transportation industry CO₂ emissions under the two scenarios

In 2012, after China began to enter the economic “new normal,” the energy consumption structure optimization and energy intensity of the transportation industry played a better role in emissions reduction than that in the early phase of the “new normal” of the economy. This also can be well explained. Compared with the early phase of the economic “new normal,” the Chinese government further optimized the energy consumption structure of the industry of transportation after 2012 (Yu et al. 2021), especially significantly raised the proportion of low-carbon energy in the energy consumption structure of the industry of transportation. As a result, the energy structure effect can reduce carbon emission of China’s transportation industry more effectively (Feng et al. 2020). In addition, on the basis of calculating the energy intensity of the transportation industry of China in 2007, 2010, 2012, 2015, and 2017, we find that the energy intensity presented a downward trend (Huang et al. 2019), and the energy intensity decreases more after the economic “new normal.” This is also a good explanation for the emissions reduction effect of energy intensity after the economic “new normal.” Of course, it should be noted that in the late phase of the “new normal” of the economy, the input structure effect did not exert a significant reduction effect. Since the input structure effect represents the generalized technological progress, in the future, there is still a large space for the transportation industry of China to reduce emissions through energy-saving technological progress and production technology innovation.

Discuss the effects of volatility in specific energy consumption structure on CO₂ emissions in the transportation industry under two scenarios

After China began to enter the economic “new normal,” low-carbon energy such as liquefied petroleum gas, liquefied natural gas, and natural gas had a more significant

effect on reducing emissions in the energy structure effect than that in the early phase of the “new normal” of economy with the emissions reduction effect showing an obvious increasing trend over time. This also can be well explained. By reviewing the energy consumption yearbook and relevant policies of the transportation industry within the research range, we can conclude that compared with 2012, the growth rate of low-carbon energy consumption in the transportation industry was 183.54%, 217.1%, and 192.35% in 2017. In addition, in the text of the 11th Five-Year Plan for China’s Energy Development, natural gas as a low-carbon energy source is required to increase by 1.8%. According to the Outline of China’s 12th Five-Year Energy Development Plan, compared with 2010, the proportion of natural gas in primary energy consumption was planned to increase to 7.5% in 2015. Of course, we can also see that it is still far from achieving the goal of fully optimizing the transportation industry energy consumption structure, subsequently. Therefore, we need to focus on the energy sources that are not obviously optimized, such as fuel oil and raw coal.

Discuss the impact of fluctuations of transportation demand of every kind of industry on the rising of transportation industry carbon emissions under the two scenarios

Although in the early and late stages of the economic “new normal,” the final demand effect is the main factor driving the increase of carbon emissions in the transportation industry; the final demand effect in the late stage of the economic “new normal” has a stronger promoting effect on the growth of carbon emissions than in early stage of the economic “new normal.” This is due to the increase in the transportation demand scale of various industries on the demand side, which is consistent with Yu et al. (2021). In the early and late stages of the “new normal” of the economy, the secondary industry and the tertiary industry are the main contributors to the final demand effect. This also can be well explained. Firstly, based on the angle of industrial structure, the proportions of the secondary industry, tertiary industry, and primary industry in the national economy are arranged from the largest to the smallest. Secondly, based on the analysis of the transportation demand of various industries, the raw materials on the supply-side of the secondary industry and the physical commodities on the production-side need to be transported by the transportation industry, while these demands of the tertiary industry and the primary industry are relatively small (Chai et al. 2016). Meanwhile, the high carbonization of the transportation industry means that there is still a high energy input in the transportation industry of China

after the economic “new normal.” With the improvement of energy efficiency, the driving effect of final demand on the increase in CO₂ emissions of the transportation industry will be suppressed to a certain extent, and the proportion of low-carbon energy consumption of China’s transportation industry in the future.

Research conclusions and policy implications

Since China has entered the economic “new normal,” China’s industries attach importance to low-carbon development. However, the transportation industry is still one of the three high CO₂ emissions industries in China at present. Based on this, this paper first constructed two scenarios of China’s economic “new normal” in the early and late stages. Furthermore, using the extended structural decomposition model, input–output method, and energy consumption method, this paper studied the carbon emissions status and emissions reduction effect of China’s transportation industries in the early and late stages of economic “new normal.”

This paper has the following conclusions. (1) Compared with the early stage of the economic “new normal,” the transportation industry carbon emissions still maintained an upward trend with the growth rate obviously slowing down after entering the economic “new normal.” The conclusion directly reflects that the extensive development mode of China’s transportation industry has been initially and effectively controlled. (2) Compared with the early phase of the “new normal” of economy, optimizing the energy consumption structure and energy intensity of transportation and public utilities will have a beneficial impact on emission reduction after entering the economic “new normal.” However, the input structure effect reflecting generalized technological progress had no significant influence on emissions reduction. Therefore, the generalized technological progress reflected by the input structure effect still has a large optimization space in the transportation industry. (3) Compared with the early stage of the economic “new normal,” low-carbon energy played a more significant role in the energy structure effect of the transportation industry with the emissions reduction effect showing an obvious enhancement trend over time after entering the economic “new normal.” (4) In the early or late phase of the “new normal” of the economy, the final demand effect was the key factor for the rising of the transportation industry’s CO₂ emissions. Meanwhile, comparing the early phase of “new normal” of the economy, the final demand effect has an obvious promoting effect in the later period of the “new normal.” The second industry and

the third industry were the main contributors to the final demand effect in these two periods.

The policy suggestions can be provided as follows. (1) Because the effect of energy structure and the effect of energy intensity were both the major restraining factors for the rising of transportation industry carbon emissions after the economic “new normal,” high carbon energy consumption still accounts for a large proportion on the supply-side, and the energy intensity of the transportation industry was still high at this stage. Therefore, the transportation industry of China needs to insist on optimizing energy consumption structure and improving energy utilization efficiency in the future. (2) In addition, the input structure effect did not inhibit on the rising of transportation industry carbon emissions after the economic “new normal.” Therefore, in the later phase of the “new normal” of the economy, the energy utilization technology of transportation utility is an important factor to effectively curb CO₂ emissions in the long term. (3) In the late phase of the “new normal” of the economy, as for energy structure effect, the liquefied petroleum gas, gasoline, natural gas, and liquefied natural gas played a major role in emissions reduction. The proportion of these energy sources in energy consumption in the transportation industry needs to be further steadily improved in the later period. Meanwhile, high-carbon energy sources, for example, raw coal and clean coal do not play a significant role in reducing emissions in the energy structure. The emission reduction effect of high-carbon energy, such as raw coal and clean coal through energy structure effect is not obvious. Therefore, in the later stage of optimizing the energy consumption structure of the transportation industry, policymakers should not ignore these energy sources that are not obvious in the earlier stage. (4) In the late phase of the “new normal” of the economy, the final demand effect was still the major driving factor to promote the rising of transportation industry carbon emissions. And the secondary industry and the tertiary industry are the main factors affecting the final demand effect. Therefore, based on the demand side of the transportation industry, the government should take the initiative to promote green transportation such as low-carbon travel and focus on the development of the secondary and tertiary industries.

Author contribution Tangyang Jiang has contributed to idea conceptualization of the study, design, literature search, analysis, and conclusion, and reviewed edited manuscript and approved the submission. Bo Yang conceptualizes the study, design, analysis, and conclusion, and reviewed the edited manuscript and approved the final submission. Yang Yu has contributed to analysis and conclusion, and reviewed edited manuscript and approved the submission.

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Data availability The data is accessible from the corresponding author upon request.

Declarations

Ethics approval The study obtained ethical approval from School of Internet, Anhui University, Hefei, 230039, China; School of Economics, Hainan University, Haikou, 570228, China; Institute of Open Economy, Hainan province, Haikou, 570228, China.

Consent to participate Not applicable.

Consent for publication The authors have provided consent to publish this work.

Competing interests The authors declare no competing interests.

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