The Road Freight Industry Green Research Based on Big Data of Heavy-Duty Trucks Operation

Xinzi Wang, Nanxi Zhao, Junzhong Tang*, and Lian Chen

Research Institute of Highway Ministry of Transport, Beijing, 100088, China.
Xinzi Wang and Nanxi Zhao contributed equally to this paper

*Corresponding author:jz.tang@rioh.cn

Abstract. Transportation is one of the key areas for energy consumption and greenhouse gas emissions (GHG emissions). Road freight transportation is the core part in CO_2 emissions but difficult to calculate due to strong liquidity characteristics. Based on the dynamic data of heavy-duty trucks Global Positioning System (GPS), this research adopts big data processing and establishes road freight market green index model that reflects the road freight green development. Also, the paper do the case study to analyze the green development of road freight across different provinces, providing quantitative support for energy reduction and emission reduction of road freight market.

Keywords: Transport, road freight, CO_2 emissions, green index, GIS, dynamic operation data analysis, heavy-duty trucks.

1 Introduction

Transportation is one of the key areas for energy consumption and greenhouse gas emissions (GHG emissions), where 7.5% of carbon emissions coming from. Road freight transportation is the core part for carbon reduction in China due to the low proportion of truck motor vehicles with relatively high contribution to pollutant emissions. Among them, heavy-duty trucks generate a large amount of pollution during the transportation, which are the key targets for air pollution prevention and control in China. According to the China Mobile Source Environmental Management Annual Report, the freight vehicles account for 9.5% of motor vehicles, but emit 65% CO2 and 85% NOX. Also, the number of heavy-duty trucks are less than 3% of motor vehicles, but nitrogen oxide and particulate matter emissions account for 69% and 48% of the total motor vehicle emissions, and CO2 emissions account for nearly 40% [1]. To achieve the carbon reduction task in the transportation, it is necessary to understand the current situation of carbon emissions in road freight market, which is the focus.

The road freight market has low concentration and strong liquidity characteristics, the calculation of carbon emissions face many problems, such as inaccurate data and difficulty in covering a large area, etc. With the development of Internet of Things

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(IoT), emerging third-party vehicle related applications has more information and data of vehicle fuel consumption and carbon emissions. Based on the data availability, the analysis of road freight market become possible.

Preliminary, authors have established a “1+4” road freight industry index system based on the operation data of road heavy-duty trucks through relevant research [2], which includes Truck Moving Index (TMI), Scale Index, Efficiency Index, Price index. Meanwhile, according to the Wang et al. (2023) [3], the preliminary calculation method for estimation of road freight industry carbon emissions based on dynamic data of heavy-duty trucks was established. This paper will further clean and analyze dynamic data operation data of heavy-duty trucks, and refine each province carbon emissions. Besides, a green index will be established based on the output of carbon emissions, including monthly and annual carbon emission green index, national weighted carbon emission green index, carbon emission green index for different vehicle models, and other calculation models, which further improve “1+4” road freight industry index system and provides strong support for research on the Transportation Low Carbon Development Index.

2 Literature Reviews

Dynamically grasping the level of green transportation development can provide important decision-making support for scientific promotion of green transportation development. The comprehensive evaluation of green transportation is the link between the theory and practice of green transportation, and has become an effective tool for quantifying the development level of urban green transportation. Scholars have conducted rich research on the comprehensive evaluation indicators and methods of green transportation.

Hsu et al. (2016) [4] constructed a green index to evaluate the accessibility of green transportation networks and conducted simulation experiments using Monte Carlo simulation. Based on the connotation of green transportation. Yang et al. (2017) [5] proposed four evaluation indicators, including infrastructure level and green travel, by analyzing the concept and connotation of green transportation. Wang et al. (2018) [6] designed a comprehensive industry green transportation evaluation index system from the perspectives of energy conservation, carbon reduction, and ecological protection. Wen et al. (2017) [7] selected evaluation indicators with a focus on medium-sized cities and applied the cloud element model to evaluate and analyze the level of green transportation development in Heyuan City. Wang et al. (2020) [8] selected evaluation indicators based on the characteristics of the current traffic situation in valley-cities, and applied the entropy weight grey correlation model to conduct a case study on the development level of green transportation in Lanzhou City. Ouyang et al. (2017) [9] constructed the China Green Transportation Development Index consisting of "3-8-21" three-level indicator system from the dimensions of industry green development, public green travel, and government green governance. They proposed using the comprehensive index method to calculate the green transportation development index through index weighting. Li et al. (2021) [10] selected indicators from transportation infrastructure, public transportation service quality, and environmental impact, and established a green transportation evaluation index system. They used a combination of principal component analysis and weight method to obtain comprehensive weights of the indicators, and applied grey correlation model and cloud element model to comprehensively evaluate the development level of green transportation in Nanjing. Xi (2021) [11] constructed a green transportation evaluation index system that combines 23 quantitative and qualitative indicators, with green travel level, green supporting level, and green management level as the criterion layer. Using the material element extension method as the evaluation method, a case study was conducted to verify the development level of green transportation in the pilot area of Jinan City. Dong (2018), Liu (2020), and Gao (2022) [12] - [14] respectively used the DPSIR (Driving Force Pressure State Impact Response) model to construct an evaluation index system for urban green transportation development, which includes one target layer, five criterion layers, and multiple indicator layers, and the specificity of the method was verified through case analysis. Peng et al. (2023) [15] established an evaluation index system of low-carbon transportation development in Zhejiang Province from low-carbon transportation development, transportation energy consumption emissions, and transportation low-carbon management.

Generally, the academic researches are mainly focus on urban green transportation parts, and the evaluation dimensions are mostly based on the overall development of the industry or from the perspective of human travel behavior. The insufficient attention paid to the green development of the road freight industry is the research gap. Therefore, this article mainly focuses on the carbon emissions of road freight transportation and indicatively uses dynamic data of heavy-duty truck operation to establish a green transportation index.

3 The Model of Road Freight Green System

3.1 Model Develop

The unified transportation carbon emission calculation system has not formed in the road freight industry. The commonly used estimating methods include "top-down", "bottom-up", full life-cycle, carbon footprint consumption patterns and etc. Through analyzing the dynamic trajectory operation data of heavy-duty trucks, the output of operation time, speed and trucks quantity can be obtained. Based on the previous research [2-3] [16], the carbon emissions of each province could be estimated.

$$Emission\ (E) = \sum_{i,\ j} F_{i,j} \times M_{i,j} \times L_{i,j} \times EF_i \tag{1}$$

$$\mathrm{EF}\left(\frac{\mathrm{kg}}{\mathrm{TI}}\right) = \text{Carbon content per unit calorific value}\left(\frac{\mathrm{Ton}}{\mathrm{GJ}}\right) \times 1000 \times \text{Oxidation rate} \times 44/12 \times 1000 \tag{2}$$

-i stands for the type of fuel consumed by trucks, e.g., diesel, gasoline, natural gas, etc; j stands for the deadweight tonnage of the vehicle.

-F stands for the unit consumption of vehicle type j using fuel per 100 KM.

-M stands for the number of vehicles of type j.

-L stands for the average annual mileage of type j using the fuel i.

-EF is the CO2 emission factor for the fuel.

The road freight green index model are based on the carbon emissions estimation. The specific calculation model are as follows.

Annual Road Freight Green Index for Each Province.
Set the first week 2021 are the base period $GI_1^k = 100$, adjusted every three years, and the index value of n week is calculated as follow:

$$GI_n^k = \frac{E_n^k}{E_1^k} \times 100 \tag{3}$$

$$GI_{year}^k = \frac{\sum_n^{k=1,2,3\ldots} GI}{12} \tag{4}$$

(4) represents the road freight green index of province/city, and month;

-n is the monthly value, $n = 1,2,3,\ldots$,representing January 2021, February 2022, March 2022, etc; k corresponding to each province/city in the country,$k = 1,2,3,\ldots$

Monthly Road Freight Green Index of the Country.
There is a significant difference of road freight volume and carbon emissions between different provinces and cities. The simple average weight may lead to significance errors, therefore, it is necessary to set different weights for different provinces and cities to obtain the national monthly index. In this paper, the weight setting is determined by the proportion of freight volume in the base year, as shown in the table 1 below. The weight value is adjusted annually based on the road freight volume.

Table 1. Weight setting for each province.

Row No.	Provinces	Weight	Provinces	Weight
1	Heilongjiang	1.08%	Shandong	7.44%
2	Jilin	1.22%	Qinghai	0.36%
3	Liaoning	3.90%	the Xinjiang Uygur Autonomous Region	1.39%
4	Beijing	0.59%	Gansu	1.78%
5	Tianjin	0.88%	Shaanxi	3.14%
6	Shanxi	2.93%	the Ningxia Hui Autonomous Region	0.96%
7	Inner Mongolia Autonomous Region	3.39%	Tibet Autonomous Region	0.12%
8	Hebei	5.81%	Guizhou	2.28%

9	Shanghai	1.35%	Chongqing	3.10%
10	Fujian	2.83%	Yunnan	3.30%
11	Jiangxi	4.63%	Sichuan	4.38%
12	Jiangsu	4.77%	Hainan	0.19%
13	Zhejiang	5.46%	Hubei	4.12%
14	Anhui	6.62%	Guangxi	4.32%
15	Hunan	5.07%	Henan	5.79%
16	Guangdong	6.83%		

Annual Road Freight Green Index of Different Vehicle Types and Fuel Types.

$$ATGI_n^k = \frac{E_n^{i,j}}{E_1^{i,j}} \times 100 \quad (5)$$

- $ATGI_n^k$ represents the annual road freight green index of the country;
- n is the monthly value, representing 2021, 2022, 2023, etc;

The national annual road freight green index can be subdivided into different vehicle types and fuel types as follows:

$$ATGI_n^k = \frac{\sum_n^{i,j} \boldsymbol{E}}{\sum_1^{i,j} \boldsymbol{E}} \times 100 \quad (6)$$

3.2 Data Source

The data mainly include two parts: fuel consumption distribution data and dynamic data of heavy-duty trucks. The fuel consumption data are mainly from questionnaires to a heavy-duty trucks drivers from different service platforms, industry associations, key freight enterprises, and other freight enterprises, which collected more than 450. The information are collected as shown in the table 2 below. Effective sample data is cleaned, organized, analyzed, etc. to estimate carbon emissions and calculate index.

Table 2. Fuel consumption data of road freight vehicles.

	Data set	Main Fields
1	Basic information	Service life, driving experience, vehicle types, vehicle brand, fuel type, truck emission standards, total mass, comprehensive fuel consumption of vehicles, operating range and route, main types of goods, etc.
2	Vehicle usage information	Actual fuel consumption per 100KM, monthly actual fuel consumption, monthly driving mileage, etc
3	Freight rate and cost	Monthly total freight rate, monthly net income, fuel costs, tolls, etc

The dynamic data of heavy-duty trucks is mainly based on the real-time operation of over 7 million 12 ton and above heavy-duty trucks on the public platform. The dynamic operation information of freight vehicles is collected through GPS, including vehicle speed, operating time, vehicle tonnage, fuel type, and other data. Combined with standard fuel consumption, the distribution of vehicle fuel consumption for different vehicle models and fuel types is formed.

4 Results Analysis

4.1 Analysis of Carbon Emission Results

From different regions, Eastern China region has the largest carbon emissions in 2022, accounting for 37.2% of the total road freight carbon emissions, followed by Northern China and Central South China, accounting for 23.7% and 18.5% respectively as shown in Figure 1 and 2. Through analysis, these regions have more carbon emissions mainly due to two reasons. Firstly, Northern and Eastern China are active areas of freight vehicles in the economic circles, with over 40% active freight capacity totally. Secondly, freight vehicle registration areas are concentrated in economically developed regions such as Eastern China, Central South, and Northern China, accounting for 36.2%, 19.4%, and 18.2%, respectively. Overall, the national carbon emissions are showing a decreasing trend from east to west.

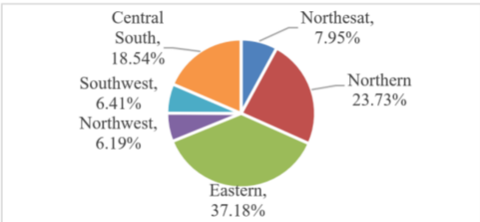

Fig. 1. The proportion of carbon emissions from different vehicle models in different regions.

Fig. 2. Distribution of carbon emissions in 2022.

From different provinces, carbon emissions show a gradually decreasing trend from east to west, which is basically consistent with the changes in active heavy-duty trucks operation as shown in Figure 3. The top five provinces (cities) are Hebei, Shandong, Henan, Anhui, and Jiangsu, accounting for 13.7%, 13.5%, 8.21%, 6.2%, and 6.1%. They are mainly concentrated in areas with more freight activities such as Northern China, Eastern China, and Central South China. The last five are mainly concentrated in the underdeveloped areas, including Gansu, Guizhou, Hainan, Qinghai and Tibet, accounting for less than 1% in total.

Fig. 3. GPS positioning map of heavy-duty trucks.

4.2 Analysis of Road Freight Green Index Results

From 2021 to 2022, the overall operation of the road freight green index was relatively stable, showing a high degree of consistency with the operational characteristics of the road freight industry in Figure 4. In the first quarter, the index showed a "V" shape and gradually rebounded after the low point in February; April and May are the month of rapid growth in the supply side, usually reaching its peak in May, and the green index also reaches its peak. In June, the supply of the road freight market declined, and the index also experienced a small fluctuation decline. It gradually stabilized after September.

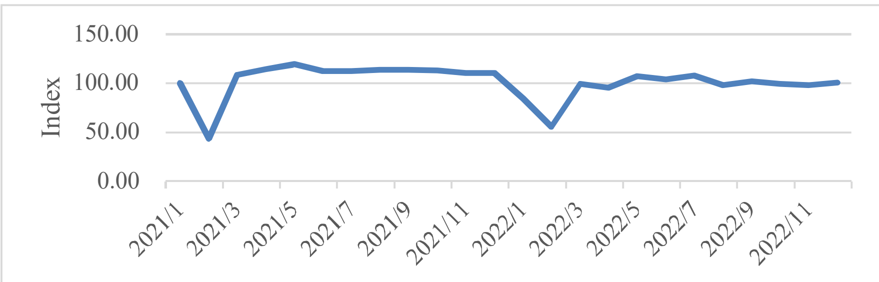

Fig. 4. Changes in the road freight Index from 2021 to 2022.

From the perspective of different regions, the index in Northeast China fluctuates greatly, and the overall level of the index in 2021 is slightly higher than 2022 (Figure 5-10). At the beginning of 2022, due to the impact of the epidemic, some areas in Northeast China, such as Jilin, resulting in weaker trucks mobility and less carbon emissions, which reflected on the index a downward trend; Except for the impact of the Spring Festival in February, the overall operation of the index in Northern China is relatively stable. Among them, Hebei has a higher level of green index, while Tianjin and Shanxi have a lower level; In the Eastern China, the overall operation of the index is relatively stable, but in 2022, due to the impact of the epidemic, the operation of road freight in Shanghai and Fujian fluctuated greatly, resulting in severe fluctuations in the index; Northwest region has less trucks activities, the operation conditions fluctuate more violently coupled with the oil prices rise and the epidemic, such as Xinjiang Uygur Autonomous Region and the Ningxia Hui Autonomous Region. The overall operation in southwest China is relatively stable, and the index fluctuates greatly in Tibet Autonomous Region due to less truck activities; The overall operation of the central and southern regions is stable, which has more significant impact during holiday periods.

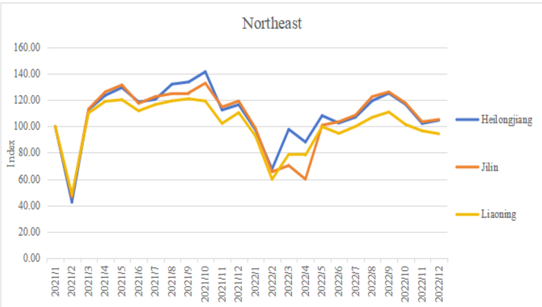

Fig. 5. Changes in road freight green index in Northeast region

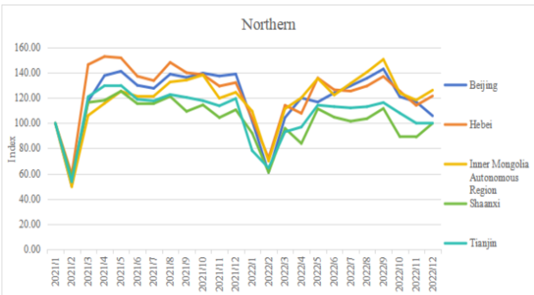

Fig. 6. Changes in road freight green index in Northern region

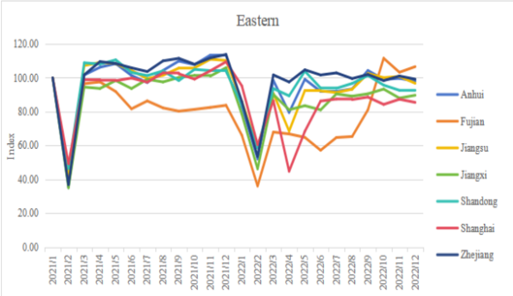

Fig. 7. Changes in road freight green index in Eastern region

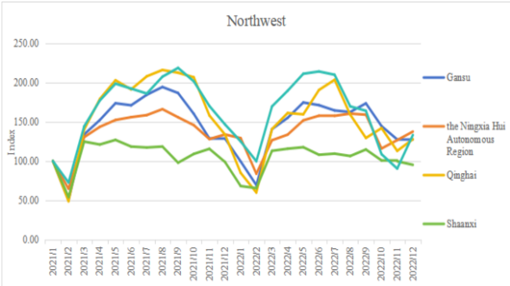

Fig. 8. Changes in road freight green index in Northwest region

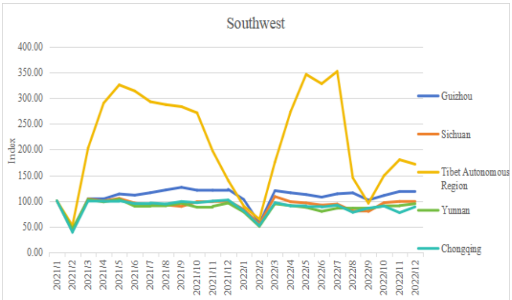

Fig. 9. Changes in road freight green index in Southwest region

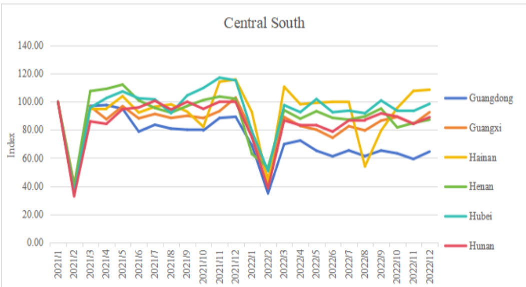

Fig. 10. Changes in road freight green index in Central South region

4.3 Reliability Analysis

The paper select road freight volume and road freight turnover to verify the index reliability as shown in Figure 11. It can been seen that the index has good consistency with the changes in road freight volume and road freight turnover, with the correlation coefficients are 0.981 and 0.932, respectively.

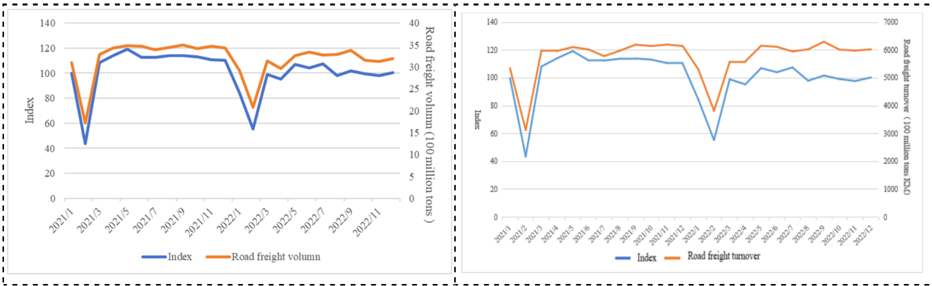

Fig. 11. Reliability analysis

5 Conclusion

Transportation is an important industry that supports the national economy development, and is one of the industries with the fastest growth rates in energy consumption and carbon emissions. This research establishes road freight green index model based on the carbon emissions of heavy-duty trucks, and calculates the results. The results show that the carbon emissions and index are various between regions. Therefore, various regions should tailor their transportation carbon reduction targets to local conditions. In the future study, this research consider carbon emissions as the main indicator to establish road fright green index, the further study could consider other factors such as renewable energy vehicles application rate and etc., to enrich system.

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