

Assessment and Analysis on the Structure Status and CO₂ Emissions from Freight Transport in China

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Abstract. With the booming freight industry in China in recent years, the freight volume has presented a growing trend, but the accompanied motor vehicle pollution emission becomes increasingly prominent. For the purpose of green development in freight industry, China is taking active measures to reduce emissions. Among them, the structural emission reduction enjoys the greatest potential in energy conservation and emission reduction in the transportation industry in the future. Its key is to adjust the current unreasonable transportation structure in China, and promote the transfer of freight transport from road to rail and water through the development of multimodal transport. Therefore, systematically finding out the structural characteristics of China's freight industry and sorting out the problems existing in the freight structure can provide technical support for promoting the structural emission reduction of the freight industry and building an intensive, efficient and green cargo transportation system. This study systematically analyzed the overall development and structural characteristics of China's freight transportation, calculated the current situation and characteristics of CO₂ emissions in China's freight transportation sector, summarized and analyzed the main problems facing energy conservation and emission reduction in China's freight transportation sector, and put forward countermeasures and suggestions.

1 Introduction

The goal of carbon emission peaking and the vision of carbon neutrality are major strategic decisions made by the Party Central Committee and the State Council in light of the overall situation at home and abroad. They are far-reaching and significant, demonstrating China's firm determination and responsibility as a major power to actively respond to climate change and take a green and low-carbon development path. On September 22 2020, President Xi Jinping solemnly declared at the general debate of the 75th Session of the United Nations General Assembly that "China will increase its intended nationally determined contribution, adopt more effective policies and measures, strive to peak its carbon dioxide emission by 2030, and strive to achieve carbon neutralization by 2060". Again, President Xi Jinping declared the vision of carbon neutralization in Climate Ambition Summit in December 12, 2020, and further proclaimed that "by 2030, China will reduce its CO₂ emissions per unit of GDP by more than 65 percent as compared with 2005". *The Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035* clearly points out that "green production and lifestyle should be widely formed, with stable but reduced carbon emissions after the carbon emission peaking".

Transportation is a key sector to deal with climate change, and the carbon emission peaking and deep emission reduction in the transportation sector are of great significance for the whole society to achieve carbon emission peaking and carbon neutralization. Among them, the promotion of carbon emission reduction in the freight transport sector is extremely important. China's economy has experienced rapid development since the Reform and Opening-up, with remarkable achievements in transportation industry. The freight volume in China has presented a growing trend in recent years. In 2020, the total freight volume in China was up to 47.3 billion tons, in which road freight volume dominated the freight transportation industry, accounting for 72.3%. The CO₂ emissions in transportation industry took up about 10% of the total emissions in 2019 in China, of which road transport (including private cars) accounted for more than 86%. Besides, automobile exhaust in transportation industry is also one of the major atmospheric pollution sources. Road freight transport in China is mainly provided by diesel trucks. According to statistics, diesel trucks take up only about 11.1% of vehicle population in China, while NO_x emissions account for 78% of total vehicle emissions and particulate matter emissions up to 89.9%. The motor vehicle polluting emission accompanied with the booming of freight transport industry in China is increasingly prominent.

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To promote the energy conservation and emission reduction in the freight industry, the first step is to understand the development of freight industry and the current status of CO₂ emissions from the freight industry in China, and identify the main problems of energy conservation and emission reduction in the freight industry, so as to lay a good foundation for further research on structural emission reduction development strategies.

The remaining part of this paper is organized as follows: Section 2 clarifies the overall situation and structural characteristics of freight development in China. Section 3 calculates the CO₂ emissions and analyses the characteristics of freight transport sector in China. Section 4 analysis on main problems in energy conservation and emission reduction and puts forward the main countermeasures for China's freight emission reduction.

2 Overview of Freight Development in China

2.1 Freight volume and freight turnover of China

Since the Reform and Opening-up, the freight transport has grown rapidly along with the ultra-fast growth of China's economy. China's GDP increased by 9.2 times from 2001 to 2020, and the freight volume and freight turnover increased by 3.4 times and 4.2 times respectively, reaching 47.3 billion tons and 20.2068 trillion tonne-km respectively in 2020. The growth of freight volume and freight turnover in China is generally divided into two stages. The first stage is rapid growth period from 2001 to 2012, with the average growth rate of freight volume and freight turnover as 10% and 12% respectively; the second stage is fluctuation and slow growth period from 2013 to 2020, with the average growth rate of freight volume and freight turnover of about 2%^[1], as shown in Fig. 1 and Fig. 2.

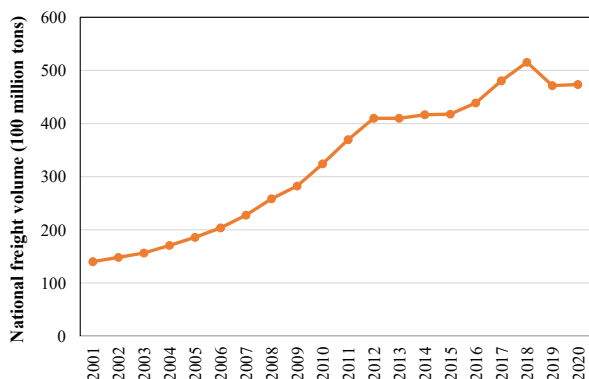


Fig. 1. Trends in Freight Volume in China from 2001 to 2020

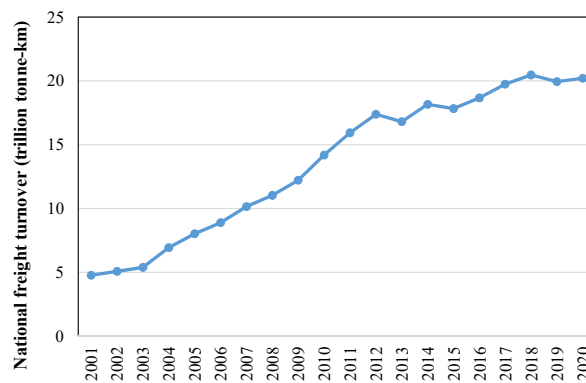


Fig. 2. Trends in Freight Turnover in China from 2001 to 2020

2.2 Transportation infrastructure

After the Reform and Opening-up, China's comprehensive transport infrastructure has gained long-term progress and formed a comprehensive transport network with "ten-vertical and ten-horizontal" comprehensive transport channel as the main framework. It basically covers cities with a population of more than 200,000 and connects China's major economic zones and economic belts. The present development of comprehensive transport infrastructure in China is shown in the Fig. 3. The trends in number of airports in China from 2010 to 2020 is shown in Fig. 4. The indicators have increased significantly compared with those in 1980, as shown in Tab. 1.

Tab. 1. Development of Comprehensive Transport Infrastructure.

Year	1980	2020	Growth multiple from 1980 to 2020	Average growth from 1980 to 2020
Railway operating mileage (10,000km)	5.3	14.6	2.8	4.4%
Road traffic mileage (10,000km)	88.8	519.8	5.9	12.1%
Expressway network mileage (10,000km)	0	16.1	-	-
Inland waterway mileage (10,000km)	10.9	12.77	1.2	0.4%
Civil transport airport (nr.)	79	241	3.1	5.1%
Civil aviation route mileage (10,000km)	19.5	946	48.5	118.8%
Oil and gas pipeline mileage (10,000km)	0.9	13.42	14.9	34.8%

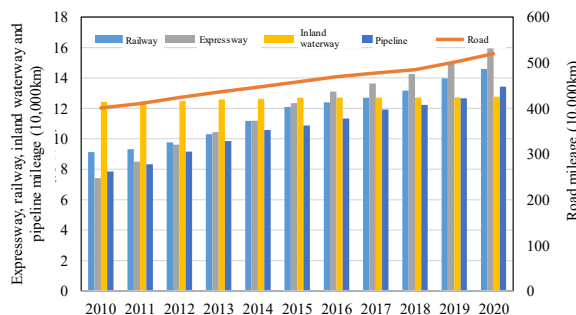


Fig. 3. Development of Comprehensive Transport Infrastructure in China from 2010 to 2020

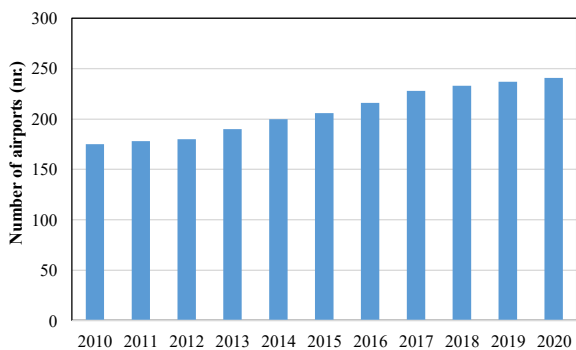


Fig. 4. Trends in Number of Airports in China from 2010 to 2020

2.3 Present Structure of Freight Transport in China

In general, the freight volume in China witnesses a rapid growth, in which road transport still accounts for more than half of the volume. In 2020, our freight volume reached 47.3 billion tons, with an increase of 1.4 times over 2010. Among them, the road transport accounts for the largest proportion, and the road freight volume increases from 24.4 billion tons to 34.2 billion tons, accounting for 72.4% in 2020. The water freight volume presents an upward trend. In 2020, the water freight volume reached 7.6 billion tons, accounting for 16.1%, being the second largest freight mode in China. The rail freight volume increases from 3.6 billion tons in 2010 to 4.5 billion tons in 2020, accounting for 9.4% of the total freight volume. The air freight volume owns the smallest proportion, accounting for about 0.01%. Fig. 5 shows a gradual upward trend from 2010 to 2020, and the freight volume of civil aviation was 6.77 million tons in 2020^[1].

After years of development, China's freight transport structure has changed dramatically, as shown in Fig.6. With the coverage of ocean transport and international air freight, the proportion of rail transport volume in the total freight volume has decreased from 43.6% in 1978 to 9.4% in 2020, and proportion of freight turnover decreased from 43.4% to 15.0%. In the same period, the proportion of road freight volume increased from 33.72% to 72.4%, and the proportion of freight turnover increased from 2.2% to 29.8%. The proportion of water freight volume has increased obviously since 1980, increasing from 7.8% to 16.1% in 2020. Due to the long distance of water transport (including ocean transport), the freight turnover accounted for a relatively high proportion, i.e., 52.4%, in 2020. The proportion of freight volume and freight turnover of pipeline and civil aviation transportation is relatively small, and has basically increased since 1995. In 2020, the proportion of freight volume and freight turnover of pipeline and civil aviation transportation was about 2%.

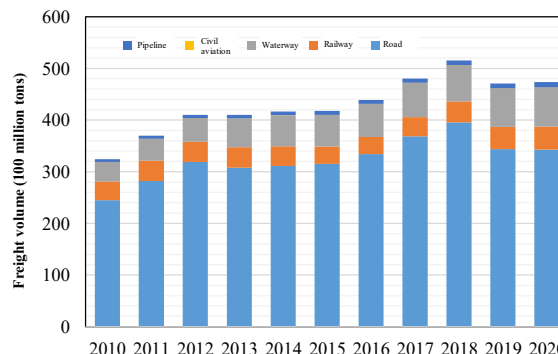


Fig. 5. Trends in Freight Volume by Mode in China from 2010 to 2020

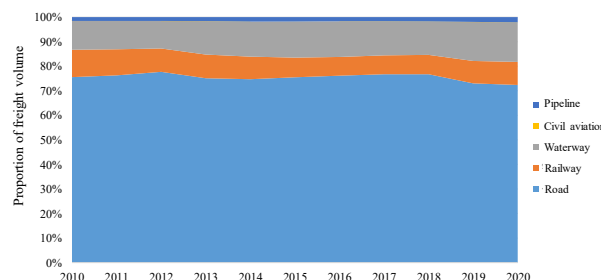


Fig. 6. Changes in Freight Volume Structure by Mode in China from 2010 to 2020

3 CO₂ Emissions from Freight Transport in China

3.1 Accounting Method for CO₂ Emissions

To comprehensively calculate the CO₂ emissions of products or organizational activities, three different but related carbon emissions calculation methods are generally used at present, including the input-output analysis method, life cycle assessment (LCA) method and the hybrid life cycle assessment method^[2].

3.1.1 Input-output analysis method

The input-output analysis method is a method to arrange the input (purchase) sources and output (sales) destinations of a series of internal departments within a certain period of time into a crisscross input-output table, establish a mathematical model based on it, calculate the consumption coefficient, and carry out economic analysis and forecasting accordingly. The main content of the input-output analysis method includes compiling input-output tables, establishing corresponding linear algebraic equation systems, comprehensively analyzing and determining the intricate connections between various sectors of the national economy, and analyzing important macroeconomic proportional relationships and industrial structure and other basic issues. By combining the data on CO₂ emissions of products or various organizational departments, the input-output analysis method can be used to calculate the CO₂ emissions caused by all departments to produce products or provide services for end consumers in the entire production chain. The calculation formula is as follows:

$$C = c \cdot (I - A)^{-1} \cdot Y \quad (1)$$

In the formula, C is the direct or indirect CO₂ emissions caused by all departments to meet the final demand Y; c is the direct emission coefficient matrix, where the element represents the direct CO₂ emissions per unit of monetary output of a certain department or organization; I is the unit matrix; A is the direct consumption coefficient matrix; and Y is the final demand vector of the organization or department.

In the carbon emissions assessment based on the input-output analysis method, only the average emission intensity data of departments or organizations are used, so it is not suitable for analyzing the microscopic system specific to a certain product, but suitable for the horizontal comparison of carbon footprints between departments or of the carbon footprints of similar factors between different departments. At present, many scholars have calculated the carbon footprint of China [3,4], Australia [5], the USA [6] and other countries and regions based on the theory of input-output analysis.

3.1.2 Life cycle assessment method

The definition of LCA has been studied by international organizations such as the International Organization for Standardization (ISO), the Society of Environmental Toxicology and Chemistry (SETAC), and the United Nations Environment Programme (UNEP). The most widely accepted definition is the definition of ISO, that is, life cycle assessment refers to the compilation and assessment of the inputs, outputs and their potential environmental impacts in the life cycle of a product system. The object of LCA research is the product system, which can be a product, a process or a service. The content of the research includes five stages of raw material collection, manufacturing, transportation, use, and final disposal, that is, the whole life cycle "from cradle to grave". The quantitative assessment of product carbon emissions is to establish a product life cycle inventory (LCI), then characterize the data classified as global warming during the product life cycle, and finally calculate the carbon emission results of the product. Therefore, the quantitative assessment of carbon emissions of the product based on the theory of life cycle assessment can be carried out by reference to the standard ISO 14040/ISO 14044.

Contrary to input-output analysis method, the life cycle assessment method is a bottom-up method for carbon footprint calculation, which has the advantages of pertinence and delicacy in its analysis results, and is suitable for carbon footprint accounting of micro-systems such as specific products. At present, scholars at home and abroad have used this method to calculate electromechanical products, automobiles or their partial systems, and home appliances. Shi Xiaoqing et al. used the LCA method to analyze the emission reduction potential of electric vehicles and its influencing factors [7]. Levasseur et al. used the LCA method to estimate the electricity carbon footprint of Quebec (Québec) [8]. Based on detailed household survey data, Peng et al. proposed

an LCA framework for quantifying household carbon footprint [9].

3.1.3 Hybrid life cycle assessment method

To combine the advantages of both the input-output analysis method and the LCA method, some scholars have proposed and developed the hybrid life cycle assessment (Hybrid LCA) method. This method integrates the input-output analysis method and the LCA method into the same analysis framework of carbon emissions assessment, which has become a research hotspot in recent years. The calculation formula of the Hybrid LCA method is as follows:

$$B = \begin{bmatrix} b & 0 \\ 0 & b \end{bmatrix} \begin{bmatrix} A & M \\ L & I - A \end{bmatrix}^{-1} \begin{bmatrix} k \\ 0 \end{bmatrix} \quad (2)$$

In the formula, B is the direct or indirect CO₂ emissions of the analysis object; b is the direct emission coefficient matrix of the micro system; A is the technology matrix, which represents the input and output of the analysis object at all stages of the life cycle; I is the identity matrix, L represents the input from the macroeconomic system to the micro system where the analysis object is located, and this matrix is associated with a specific sector in the input-output table; M represents the input from the micro system where the analysis is located to the macroeconomic system; and k is the external demand vector. As the input and output of the analysis object at all stages of the life cycle can be represented by the technology matrix A, the connection between the specific process of the micro system (such as a specific product) and the macroeconomic sector (or organization) can be described in a unified framework.

Due to the high theoretical requirements of the Hybrid LCA method for researchers in practice, the researches on carbon footprint calculation using this method are fewer than those using the LCA method and the input-output analysis method, but a rapid development has been seen in recent years. Norwegian researcher Larson used this method to assess and calculate the carbon footprint of Trondheim, a city of Norwegian [10]. Jiang et al. used the Hybrid LCA method to estimate the carbon emissions during road use, maintenance and restoration [11]. Feng Chao et al. conducted a study on the CO₂ emissions of private electric vehicles based on the Hybrid LCA method [12]. Li Xiaohuan et al. used the Hybrid LCA method to calculate the CO₂ emissions from cassava-based ethanol production in China [13]. This method not only retains the advantages of strong pertinence and delicacy of the LCA method, but also avoids truncation errors, and it can maximize the use of the existing input-output table, thus reducing the human and material resources in carbon footprint accounting, which is suitable for the carbon emission analysis of various macro and micro systems.

3.2 Accounting Method for CO₂ Emissions from Freight Transport in China

Boundary: The accounting boundary for CO₂ emissions from freight transport is the carbon dioxide emissions generated from the combustion of fossil fuels during the

transportation of freight vehicles, and international shipping and aviation are not included in the scope of accounting.

Method: Referring to the mainstream CO₂ emissions accounting methods at home and abroad, this study adopts the input-output method to calculate the fossil energy consumed by the freight industry, and calculate the CO₂ emissions from freight transport in combination with the emission coefficient method. That is, the total amount of energy consumed by the freight industry is calculated first, and then the CO₂ emissions is calculated based on the statistical average of the gas emissions from the production of a unit of product.

According to China's freight statistics basis, based on the Input-Output Table of the National Bureau of Statistics for All Subsectors, Statistical Bulletin on the Development of the Transportation Industry, Railway Statistical Bulletin, Statistical Bulletin on the Development of the Civil Aviation Industry, the Statistical Report System for Energy Consumption of Road, Water Transport and Ports and other related data, different measurement and calculation methods are adopted for road transport, water transport, rail transport and air transport. For road transport, a "bottom-up" method based on activity levels and emission factors is adopted, that is, accounting is carried out through the truck population, mileage and carbon emission factor, taking into account the socio-economic and energy structures and the technological level. For water transport, rail transport and air transport, a "top-down" method is adopted, that is, accounting is carried out through the freight turnover, consumption per unit of turnover and the carbon emission factor. The specific measurement and calculation method is as follows:

(1) Road transport. In addition to commercial trucks, there are also a large number of non-commercial trucks in road transport. Therefore, the CO₂ emissions from motor vehicles in road transport are mainly accounted for, measured and calculated, and predicted based on the measurement and calculation of the vehicle population, mileage, energy consumption intensity in this study, and the carbon emission factor as shown in Formula 3;

$$E = \sum P_{i,j,k} \times VMT_{i,j,k} \times EF_j \quad (3)$$

In the formula, E is the emissions, ton; i is the vehicle model; j is the type of fuel; k is the year of the first registration date; P is the population of vehicles; VMT is the average annual mileage, km/year; and EF is the emission factor.

(2) Water transport, rail transport and air transport. Measurement and calculation is carried out based on the turnover, unit energy consumption and the carbon emission factor as shown in Formula 4 and Formula 5.

$$E = \sum Y_j \times EF_j \quad (4)$$

$$Y_j = Z_j \times F_j \times 10^{-3} \quad (5)$$

In the formula, E is the emissions, ton; j is the type of fuel; Y_j is the consumption of the jth fuel in tons; Z_j is the turnover completed by transportation equipment using the jth fuel, tonne-km; F_j is the unit energy consumption, kg/ton-km; and EF_j is the emission factor of the jth fuel.

3.3 Assessment on CO₂ Emissions from Freight Transport in China

Based on the accounting method for CO₂ emissions from freight transport in Section 3.2, the existing CO₂ emissions from freight transport of China in 2019 were measured and calculated. In 2019, China's total carbon dioxide emissions from freight transport were 704 million tons. Among them, road freight is the key area of carbon emissions, reaching 614 million tons, accounting for up to 87.2%; water transport accounted for 10.5%; due to the high degree of electrification of rail transport, carbon emissions from railway freight accounted for only 1.2%; due to its small scale, carbon emissions from air freight accounted for a relatively low proportion of 1.1%, as shown in Fig. 7.

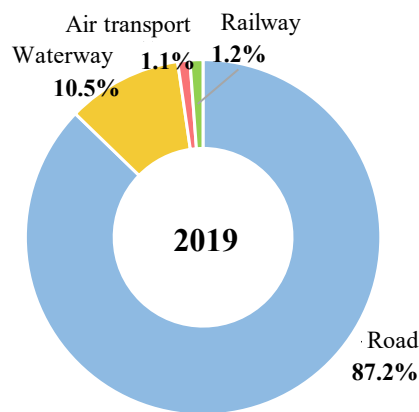


Fig. 7. Proportion of CO₂ Emissions from All Freight Transport Industries of China in 2019

4 Main Problems and suggestions for Energy Saving and Emission Reduction of Freight Transport in China

4.1 Problems of Energy Saving and Emission Reduction from Freight Transport in China

4.1.1 Freight transport structure still needs to be further optimized

Driven by the Three-Year Action Plan for Promoting the Adjustment of Transport Structure (2018-2020), the adjustment of China's freight transport structure has achieved initial results, but the proportion of rail freight volume is still low, the proportion of road freight volume for bulk cargos is still high, and that of rail-water intermodal transport for containers is still too low. After analysis, there are still obstacles mainly in the following aspects:

First, an inevitable cycle is needed for the cultivation of rail transport and market development. At present, the imperfect collection and distribution system of the railway network and the poor connection of "Last Mile" have become important factors restricting the growth of rail freight volume and the acceleration of "Road-to-rail Transport".

Second, a reasonable price comparison relationship between road and rail transport has not yet been formed. On the whole, the rate of road freight is still significantly lower than that of rail freight and the "Upside Down" problem still exists widely, so the advantage of the road freight rate will be further highlighted when the preferential policies on rail freight rate are canceled in the future.

Third, the market-oriented reform of rail freight lags behind and cannot meet the modern freight transport demand. Due to the natural monopoly of rail transport, its linkage with road and water transport is subject to the organization and operation rules of rail transport, and even the transport demand of cargo owners must be determined according to the supply capacity of rail transport enterprises, which cannot be fully guaranteed.

4.1.2 The efficiency of freight transport still needs to be further improved

First, the overall level of multimodal transport development is not high. Various modes of freight transport are poorly connected, and the unified standards for the connection of rail, road, water, and air transport need to be further improved; the full-chain and integrated multimodal freight service capabilities that adapt to the development of modern logistics are poor, and the "First and Last Mile" problems are prominent.

Second, the drop-and-pull transport has not yet been fully developed. Since the launch of the first batch of pilot work for drop-and-hook transport in November 2010, the scale of drop-and-hook transport has seen a continuous expansion, and more and more enterprises have joined the ranks of drop-and-hook transport, which has effectively promoted the expansion of China's drop-and-hook transport market. However, China's drop-and-pull transport enterprises still face major difficulties such as high institutional costs for transport, difficult to coordinate due to separated management of all sectors, and high transport costs. Logistics enterprises are taxed repeatedly, making the tax burden on enterprises heavy.

4.2 Main Countermeasures for Energy Saving and Emission Reduction of Freight Transport in China

4.2.1 Countermeasures to optimize the freight transport structure

Further step up the efforts in the adjustment of transport structure; based on solving the "Last Mile" problem of rail transport, with promoting the formation of a reasonable price comparison relationship between road and rail transport as the core, with the construction of demonstration areas for transport structure adjustment and the establishment of green transport demonstration enterprises as the key points. It is recommended to start from the construction of railway infrastructure, bulk cargo transport in ports, bulk cargo transport for industrial and mining enterprises, transport of urban production and

living materials, multimodal transport, and establishment of green transport demonstrations.

4.2.2 Countermeasures to strengthen the management of energy saving and emission reduction in freight transport

The first is to propose strategies and paths for further accelerating the development of multimodal transport. The second is to further improve the management assurance system of the freight industry in terms of organizational guarantees, comprehensive encouragement and support policies, and the improvement of the credit system of the freight transport industry. The third is to propose the countermeasures to improve the internal efficiency of road, rail and water freight systems. The fourth is to put forward measures to further promote the development of urban freight distribution.

5 Conclusions

5.1 A method for calculating carbon emissions from freight transportation in China was established

This study referred to the calculation methods of carbon emissions in China and abroad, and established the calculation model of China's freight carbon emissions. Different measurement methods were used for road transport, water transport, rail transport and air transport, and the total CO₂ emissions of China's freight transport in 2019 were estimated to be 700 million tons.

5.2 The problems of emission reduction and energy conservation in freight transportation in China were systematically analyzed

By combing the development status of China's freight transport, this study found two problems in the emission reduction of China's freight transport structure, namely, the freight structure needed to be optimized and the freight efficiency needed to be improved. The freight structure still needs to complement the advantages of railway and road transport; In terms of freight efficiency, there is still a need to strengthen multimodal transport development and drop-and-pull transport.

5.3 The main countermeasures of energy conservation and emission reduction in China's freight transportation were put forward

In view of the above problems, this study put forward the countermeasures of China's freight emission reduction. Including further strengthening the transport structure adjustment work, to solve the problem of railway "last kilometer"; Further accelerate the multimodal transport development strategy and path research; Study the countermeasures to improve the internal efficiency of highway, railway and waterway freight system;

Formulate carbon emission management standards and policy systems for freight vehicles.

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