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Original Paper

Summary of Carbon Emission Statistics and Measurement of Transportation Industry

LI Zhen[1*], MA Qian-qian[2], WANG Li-xuan[2] & ZHANG Lei[2]

[1] Transport Environmental Protection and Low Carbon Technology Research Institute, Xi'an Highway Research Institute Co., Ltd., Xi'an, China

[2] Shaanxi Provincial Transport Environmental Monitoring Center, Xi'an, China

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Abstract

Transportation is a critical area for China to achieve its goal of carbon neutrality. A successful national climate plan and the overall development of a strong transportation nation are tied to achieving the carbon peak and carbon neutrality in transportation. This study first sorts out the statistical boundaries and methods of carbon emissions. Secondly, it introduces the measurement methods of carbon emissions in the transportation industry, including the emission factor method and the full life cycle method. Thirdly, the research on influencing factors of carbon emissions in the transportation industry is reviewed from four aspects: economy, transportation industry itself, technology, and others, and relevant research on carbon emission prediction methods in the transportation industry is summarized. Finally, the limitations of existing research are analyzed, and future research on carbon emissions statistics and measurement in the transportation industry is prospected.

Keywords

transportation carbon emission statistics, carbon emission measurement, carbon emission influencing factors research, carbon emission forecast

1. Introduction

In accordance with China's energy and resource endowment, we will stick to the first and then break, undertake carbon peak action step by step, further push the energy revolution, and actively participate in the global governance of climate change, according to the Party's 20th report. The transportation sector, a high-emission sector in contemporary civilization, has a significant and far-reaching impact on all facets of human life and serves as the backbone of human society. Globally, the transportation industry accounts for one third of the global energy consumption, and has become the second largest energy consuming industry, second only to industry. As a result, its reduction in carbon emissions will significantly aid in the transition of humanity to a more sustainable way of life. Since the concept of low carbon economy was proposed, domestic and foreign, academic circles have carried out research on low carbon economy, with research on carbon emissions becoming the focus, and research results continuously emerging. The research contents mainly include carbon emission statistics, calculation and decomposition methods, influencing factors of carbon emission, carbon emission prediction, etc.

On the basis of analyzing the transportation industry, this paper, the author discusses the research, and looks forward to the future development of the research content, in order to serve as a resource for future study on carbon emissions.

2. Research on Carbon Emission Statistics of Transportation Industry

2.1 Combing of Carbon Emission Statistical Boundaries

The international carbon emission statistics are mainly conducted around the preparation of national greenhouse gas inventories. In 1994, China, as a non Annex Party (i.e., developing and least developed countries), acceded to the United Nations Framework Convention on Climate Change, our country needs to information bulletin or update report every two years, mainly report greenhouse enterprise emissions and absorption. The international transportation industry is divided into air, road, railway, water and other five parts. The accounting scope includes direct carbon dioxide emissions from all mobile sources in the respective fields, covering all operational and non-operational traffic sources, excluding infrastructure.

At the state level, in August 2021, the leading Group of carbon neutrality established a working group on carbon emission statistical accounting, to be responsible for organizing and coordinating the carbon emission statistical accounting of nationwide and various industries. In general, the National Bureau of Statistics uses the energy balance sheet to determine the carbon emissions of different industries. But according to the national economic classification, transportation, storage, and postal services fall into one category. It is divided into eight categories: road transport, water transport, railway transport, air transport, pipeline transportation, multimodal transport and transportation agency, loading, unloading, handling and storage, and postal service. The statistical range covers carbon dioxide emissions from mobile and supply sources.

At the industry level, the carbon emission of the operating vehicles is the main indicator of the industry. The accounting border, which excludes indirect carbon dioxide emissions, is the direct carbon dioxide emissions produced by the competent authorities' permission and filing and commercial passenger and cargo transportation. Commercial road passenger transport includes line passenger transport and tourist chartered buses; commercial road freight includes freight vehicles with total quality above 4.5 tons and road transport certificate; commercial water transport includes inland river and coastal ships, which is completely consistent with the statistical scope of a set of networked direct reporting system. The pairs of carbon emission statistical boundaries at different levels are shown in Table 1:

Table 1. Comparison of Carbon Emission Statistical Boundaries of Various Requirements

	Commercial mobile source	Commercial fixed source	Non-commercial mobile source	Non-commercial fixed source
International requirements	√(Direct emission source)		√(Direct emission source)	
National requirements	√(Direct emission source)			
Industry requirements	√(Inactive)			

2.2 Combing of Carbon Emission Statistics Methods

Internationally, statistical methods generally follow the idea of conducting energy consumption statistics first, and then dividing the result by the emission factor to get the overall carbon emissions. Transportation energy consumption in the United States is a full-caliber statistics, including operational and non-operational statistics. According to the American Transportation Energy Data Manual jointly compiled by the Ministry of Energy, the Department of Transportation, the Department of Environment and Oak Ridge National Laboratory0. Figure 1 shows the statistical framework of road transport energy consumption in the United States.

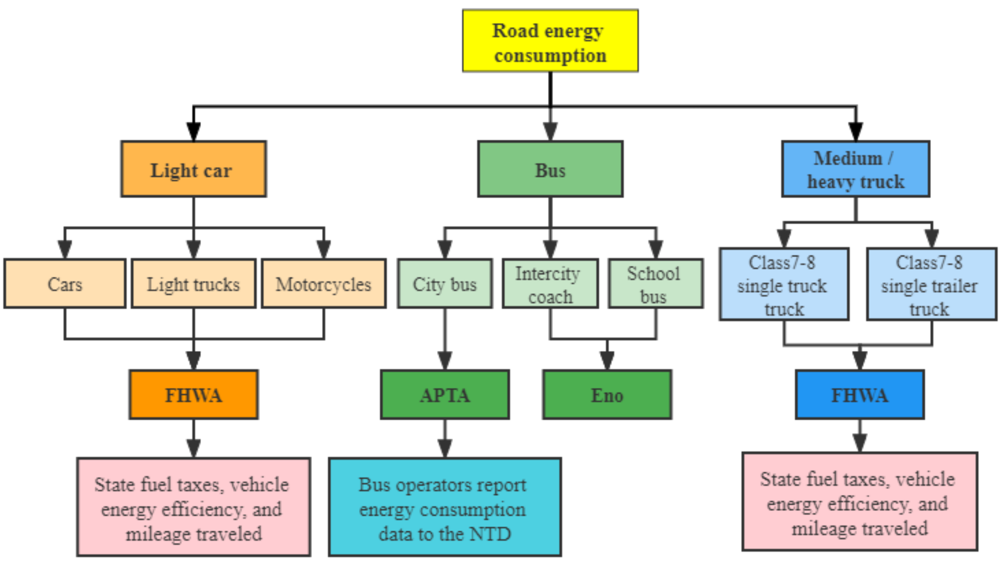

Figure 1. Statistical Framework

The EU and the UK adopt the combination of two methods, the EU adopts the road cargo transportation method and the military and civilian living energy consumption method, and the UK adopts the road cargo transportation method and the local energy consumption measurement.

Table 2. The EU and the UK on Carbon Emissions Statistics Methods

	The EU		The UK	
Statistical method	Road cargo transportation method (including energy consumption)	Methods of household energy consumption	Road cargo transportation method (including energy consumption)	Local energy consumption calculation
Statistical department	Eurostat	Eurostat	Ministry of communications	The UK Department of Commercial Energy and Industrial Strategy commissioned Ricardo Energy & Environment
Statistical project	Eurostat published the Methods for Road Cargo Transport	Special investigations, administrative records, online monitoring, and modeling	Continuous investigation of road freight transport	Use use of UK domestic database
Survey statistics	Basic enterprise information, basic vehicle information, transportation information, goods information.	Data of household energy consumption	Trucks registered in the UK with total mass (HGVs) exceeding 3.5 tons	Data estimation and processing: only covering gasoline and diesel consumption
Acquisition time	Annually	Annually	Throughout the year	Annually
Merit	Comprehensive calculation of two or more methods, to avoid the limitations and constraints brought by one method		Effectively avoid seasonal fluctuations	Use the database statistics to calculate and reduce the cost

	of the survey

The Ministry of Land and Transportation, the Ministry of Environment, and the National Environmental Research Institute of Japan have jointly compiled the “Handbook of Energy and Economic Statistics in Japan”, and established a statistical survey plan for transportation energy consumption.

Table 3. Traffic Energy Consumption Statistics and Survey Scheme in Japan

Investigation name	Automobile fuel consumption survey	Motor transport statistical survey	Shipping statistical survey	Air transport statistical survey
System of selection	Random choice			Full sample
Investigation method	Mail survey Online survey other	Email investigation Online survey	Mail survey Online survey other	Email investigation Online survey
Fuel consumption survey begins in the first year	1960		1981	
Survey cycle	Monthly	Monthly	Monthly; Private ship: 1 year	Monthly
Access to data is available for the year	2010-2021	2000-2020	2005-2021	2006-2021

In China, the National Bureau of Statistics regards transportation, warehousing, and postal services as a major category, using a balance sheet and top-down accounting. The Ministry of Ecology and Environment internally calculates the total carbon emissions from mobile sources across the country, mainly using the inventory method. It obtains the vehicle inventory in various regions from the Emission Source Statistical Investigation System, obtains the accumulated driving mileage from the Technical Specifications for the Collection and Transmission of Regular Inspection Information on Vehicle Emissions, and obtains the unit consumption per 100 kilometers by relying on the remote monitoring platform for heavy vehicle emissions.

3. Research on Carbon Emission Measurement Methods for Transportation Industry

Data of carbon dioxide emissions is not directly published by the state or the official. Using collected indicator data to calculate traffic carbon dioxide emissions is crucial for research on traffic carbon emissions. At present, the research method of carbon emission measurement by Chinese and foreign scholars has entered a mature stage. Some related measurement methods can be used to carbon emission measurement in the transportation field.

Summarize the research results of most scholars, it is found that there are two main methods to measure the carbon emission: the emission factor method and the whole life cycle method. The emission factor method is divided into "top-down" method (also known as the end-consumption side calculation method) and "bottom-up" method.

3.1 Emission Factor Method

The Intergovernmental Panel on Climate Change (IPCC)'s first method for estimating carbon emissions was the emission factor method, which is presently popular. The fundamental concept is to create activity data and emission factors for each emission source in accordance with the list of carbon emission sources, and then use the result of these calculations to determine the project's carbon emissions. The IPCC report's default values for the emission factors (i.e., reference values based on global averages) can be used, or the emission factors can be created independently. Activity data is one of them, and it primarily comes from pertinent national statistical data, census and survey data from emission sources, monitoring data, etc. Currently, based on the emission factor method, many countries have proposed carbon emission calculators to provide a user oriented method for estimating carbon emissions. From one side, it is shown that the emission factor method has become the mainstream of carbon emission estimation methods today.

3.1.1 The "Top-Down" Approach

According to the energy consumption statistics of the transportation sector multiplied by the fuel carbon emission coefficient, the "top-down" approach calculates traffic carbon emissions. This method is the traditional carbon emission measurement method, and is applicable to the carbon emission measurement of the whole industry or other segments. The "top-down" method can obtain data through the energy statistical yearbook. However, due to the fact that transportation, warehousing, and postal services are considered as one industry in China's energy terminal consumption statistics, it is difficult to split according to the business scope of the transportation management department, and it is not possible to accurately obtain the energy consumption of different modes of transportation.

Wu Cuifang et al. (2015) adopted the "top-down" carbon emission calculation method. According to the data of IPCC National Greenhouse Gas List Guide, they calculated the traffic carbon dioxide emission of Gansu Province from 2000 to 2013, and made the trend analysis on the total traffic carbon emission, per capita carbon emission, carbon emission structure of transportation energy and carbon emission and carbon emission intensity. Zhang Taoxin and Zeng Aozhi (2013) using the "top-down" method of energy consumption data of transportation industry and calculate transportation $C0_2$

emissions, the transportation energy consumption of $C0_2$ emissions decomposed into direct emissions and indirect emissions, the former is produced by fossil energy consumption, the latter is generated by heat and power consumption, calculate two types of emissions coefficient, two parts of carbon emissions add the total traffic carbon emissions. Liu Yanhui et al. (2022) calculated the total carbon emissions generated by the transportation industry in Hubei Province from 2000 to 2019 through the “top-bottom” method. They then incorporated the energy structure and the industrial structure based on Kaya’s equation, combined with the situation of Hubei Province, and decomposed them by the LMDI decomposition method.

3.1.2 The “Bottom-up” Approach

The “bottom-up” approach is based on the idea of “activity-transportation mode proportion—density—fuel consumption” proposed by Schipper et al. (2000). On the basis of the conversion coefficient and conversion formula of energy to carbon emissions, the total fuel consumption is calculated by the vehicle mileage, ownership and energy consumption of various modes of transportation to be studied in the national or regional transportation sector, and then multiplied by the C02 emission coefficient of energy to obtain the carbon emission of the transportation sector. “Bottom-up” method due to all kinds of data scattered in different departments, enterprises, data access has certain difficulty, but based on the perfect cross-sectoral coordination mechanism can realize all kinds of data collection, and can accurately reflect the different modes of transportation in the urban carbon dioxide emissions contribution, facilitate transportation management guide to carry out targeted reduction measures.

The number of vehicles, mileage, energy consumption patterns, and carbon emission factors of each energy mode were used by Chen Fei et al. (2009) to compute Shanghai’s carbon emissions from 2000 to 2007. Ning Xiaoju et al. (2014) employed the “bottom-up” calculation approach and indicators including the number of vehicles, annual miles, fuel consumption per kilometer, fuel density, and net heating value of fuel consumed to determine the traffic-related carbon emissions of Zhengzhou residents. Liu Shuang et al. (2015) calculated the carbon emission of Beijing traffic through the total-structure method and the “bottom-up” method respectively, and analyzed the proportion of traffic travel under different scenarios by using the optimization model of urban passenger transport structure. Xia et al. (2020) estimated the carbon emissions of daily travel in Hangzhou, and proposed a bottom-up method of carbon emission reduction in urban transportation.

3.2 Full-Life-Cycle Method

The full life cycle method refers to the computation of the total carbon emissions produced over the course of the manufacture, use, and disposal of all types of vehicles. It can fully reflect the energy consumption of the whole life cycle of various vehicles, but the data needs encompass multi-disciplines, multiple links and multiple departments, and the computation is more complex and the inaccuracy is considerable.

Xiu-yuan zhang (2014) research on energy consumption of urban passenger transport system throughout the entire life cycle, including the construction stage, the operation stage, the maintenance stage, the recycling stage, including vehicles, infrastructure and fuel consumption three aspects, and considering the whole process consumption and bear the whole consumption, with life cycle model method analysis and evaluation. Guided by the theory of full life cycle, Fanghai et al. (2021) adopted the inventory analysis method and emission coefficient method to build the calculation model of carbon emission during the highway construction period and calculate the carbon emission of the road surface during the construction period of Panxing Expressway in Guizhou.

The merits and demerits of three methods for calculating carbon emissions from transportation are compared in Table 4. The "bottom up" method is now the most popular way for computing carbon dioxide emissions in the transportation industry based on the benefits and drawbacks of various methodologies.

Table 4. Comparison of different Carbon Emission Measurement Methods

Method	Characteristic	Merit	Shortcoming	Operating frequency
Top-down method	Traffic carbon emissions are calculated using the transportation industry's total energy consumption	Data is easy to obtain with high accuracy	(1) Unable to reflect the carbon emissions of various transportation modes (2) Transportation, storage and postal service as an industry statistic, it is difficult to split according to the scope of the management part	Generally frequent
Bottom-up method	The trip requirements for various means of transportation are taken into account when calculating traffic carbon emissions	It can reflect various transportation modes' contributions to carbon emissions accurately and direct focused emission reduction measures	There are more data requirements, scattered in different departments, enterprises, etc., so it is difficult to obtain	The most frequent
Full life cycle method	The energy consumption of various vehicles across their entire life	It can accurately indicate how much energy different vehicles use over	Data requirements involve multi-disciplines, multi-links and multi-departments, and the	The least frequent

	cycles, from creation to destruction, is used to compute traffic carbon emissions	their entire life cycles	calculation is more complex and the error is relatively large

4. Research on Carbon Emission Forecast of Transportation Industry

4.1 Research on Influencing Factors of Carbon Emissions in the Transportation Industry

The study of the factors that influence carbon emissions in the transportation industry is a hot topic in the field of transportation carbon emissions research, it is an open, nonlinear complex system. By summarizing relevant literature on factors affecting transportation carbon emissions, it is found that factor decomposition method is a commonly used analysis method, including the construction of Kaya identity, log-average dean decomposition (LMDI), population, affluence and technology (STIRPAT) model, extended STIRPAT model, etc., Summary, the main influences of previous scholars based on the decomposition methods include: economic development level, the transportation industry itself factors, technical level and other factors. At the same time, traffic factors also include traffic activity volume, transportation structure, transportation development level, the proportion of buses, private car ownership, transportation energy consumption structure and other index dimensions. Other factors, such as population density, have a complex impact on traffic carbon emissions, it can affect the carbon emissions of traffic by affecting the first three factors. Table 5 combs the relevant studies according to the different influencing factors.

Table 5. Investigate the Factors that Influence Carbon Emissions in the Transportation Industry

Influencing factor	Concrete content	Correlation studies
Economic development	Economic development is the main driving factor of transportation carbon emissions	(Schipper et a1., 2000; Zheng Changde et al., 2011; W. W. Wang et a1., 2011; Jia Jianwen, 2020; Huang Yi et al., 2021; Liu Yanhui, 2022)
	Economic growth and traffic carbon emissions are correlated in an inverted “U” pattern	(Stefanski, (2009); Gao Biao et al., 2013; Yin Peng et al., 2016)
The transportation industry itself	The effect of traffic volume on carbon emissions	(Zhu Changzheng, 2015; Wu Cuifang, et al., 2015)
	The impact of transportation structure on traffic carbon emissions	(Wei et al, 2013; Zhang Taoxin and Zeng Zaozhi, 2013; Yu Jie et al., 2015; Tian Chunlin et al., 2022; Li Yanhong et al., 2022)

	Transportation intensity	(W. W. Wang et a1., 2011; Yu Jie et al., 2015; Wang Lixuan et al., 2022)
Technical level	The improvement of energy-saving technology can drive the reduction of the energy intensity and improve the energy efficiency	(Zhao Min et al., 2009; Zhang Taoxin, 2012; Tianyi Wang et a1., 2012; Xie Shouhong et al., 2016)
Other	The relationship between factors such as population and car ownership and traffic carbon emissions	(Su, et al., 2011; Wang, et al., 2022)

4.2 Research on the Prediction Method of Carbon Emission in the Transportation Industry

On the basis of carbon emission measurement and research on the variables that affect carbon emissions in the transportation industry, domestic and foreign scholars have mainly focused on the prediction of carbon emission, carried out a lot of research, and obtained some practical results in both theory and practice. Summarizing the research results at home and abroad, it is found that the main prediction methods include model construction, regression analysis and scenario analysis. Table 6 sorts out the merits and drawbacks of these three methods and correlated studies.

Table 6. Research on Carbon Emission Prediction Method in Transportation Industry

Prediction technique	Concrete content	Merits and drawbacks	Correlation studies
Build a model	Extending the STIRPAT model	The prediction results are less accurate and cannot reflect the actual situation of the future change trend of regional traffic carbon emissions.	(Ji Jianyue et al., 2012; Dong Jiankang et al., 2014; Elkafoury A, 2016; Zhang Guoxing et al., 2020)
	Gray system prediction (GM (1,1)) model	It can deal with complex systems well, which has the advantage of accurate prediction with a small amount of sample data, and can overcome the deficiencies in classical mathematics and statistical mathematics	(Liu Hongyuan and Chen Lulu, et al., 2014,2015; Zhang Jianyi, et al., Luan Ziqing, 2019)
	BP neural network	It has good nonlinear mapping ability, strong self-learning and adaptive ability, and strong fault tolerance, but when solving the highly	(Pan Xiu, 2018)

		nonlinear problem, the operation results are easy to fall into the local minimum rather than the global minimum, and the factors considered by the model in the prediction process are not comprehensive enough	
	Support vector regressor (SVR) model	For finite sample research, the global optimal solution can be obtained theoretically, the complexity of the sample dimension, thus achieving optimal results in the function approximation and the regression prediction	(Hu Maofeng, 2021; Gao Jinhe, 2022)
Regression analysis	Construct a linear regression equation for the prediction of future traffic carbon emissions	Although the general multiple linear regression prediction model effectively overcomes the defects of non-normal random error term, heteroscedasticity, and regression equation limitation, the regression coefficient of this prediction model is hard to explain, which affects the accuracy of the prediction results	(Marcotullio, 2007; Liu Jiencui, 2011; Zhu Changzheng, 2022)
Scenario analysis	By setting up different scenarios to predict transport carbon emissions	It is extensive, comprehensive, comprehensive and timely, but the application process is relatively complex, and the division of scenarios is influenced by the traditional mode and human factors	(Kousoulidou et al., 2008; Qu Yanmin et al., 2010; Yang Qi et al.; 2014; Li et al., 2016; Zhu Changzheng, 2022)

5. Summary and Research Outlook

5.1 Summary

According to the above collection and collation of the existing relevant literature of the transportation industry at home and abroad, it has been discovered that research on the carbon emissions of the transportation industry at home and abroad has yielded phased results, focusing primarily on the calculation, influencing factors, and trend prediction of transportation carbon emissions. However, through the review of relevant literature, it is found that there are still some deficiencies in previous research, and some problems that have not been solved and need to be studied:

(1) The institute of transportation industry carbon emissions involves many influencing factors. Most of the existing studies have analyzed the macro or micro influencing factors separately, and few of the two

are applied to the research of carbon emission in the transportation industry.

(2) Currently, researchers studying the factors that affect carbon emissions in the transportation sector tend to deconstruct these factors on a national or provincial level as their primary spatial scale, identify the key influencing factors, and offer recommendations for emission reduction in accordance with their findings. Such studies do not only lack the analysis of the dynamic trends of carbon emission influencing factors in the transportation industry, but also analyze the spatial heterogeneity of influencing factors in various provinces.

(3) In the transportation carbon emissions forecast, most scholars choose to use scenario analysis, but the use of scenario analysis process is complex, the division of the scene by the traditional pattern and human factors, and if there is greater uncertainty, some scenarios may not be enough reality, eventually get the prediction results will lack of objectivity and reliability.

5.2 Research Outlook

Transportation is a complex giant system. Transportation carbon emission involves many fields, links, industries and departments. Carbon dioxide emissions from transportation must be calculated with the cooperation of all parties in society. In order to further promote China to take the lead in achieving carbon peak and carbon neutrality, and scientifically quantify carbon dioxide emissions in the transportation field, the following prospects are proposed for China’s transportation “carbon reduction” work:

The first is to introduce guidelines for carbon emission from the transportation industry to clarify the calculation methods and scope boundaries. At present, China still lacks a set of standardized guidance and unified standards for carbon emission calculation in the field of transportation. It is suggested to clarify the boundary of carbon emission scope in industry, construction, transportation and other fields at the national level, issue guidelines for carbon emission calculation in the field of transportation, and clarify the calculation boundary, caliber and data sources. By issuing a set of unified standards and norms and scientific and effective traffic carbon emission calculation methods, local governments are guided to carry out the quantification, assessment and assessment of traffic carbon emission.

The second is to form a set of technical guidelines to guide the construction of urban scale transportation carbon emission inventory models. Traffic carbon emission inventory models have been widely used abroad, but in China, except for cities such as Beijing, Shanghai, and Shenzhen, where traffic carbon emission inventory models are being constructed, most urban traffic carbon emission inventories are still in the initial stage. In addition, considering China’s national conditions, foreign transportation carbon emission inventory models cannot be completely copied and copied, and a set of technical guidelines should be formed to guide the construction of transportation carbon dioxide emission factor inventory models at the urban scale in China.

The third is to establish a traffic carbon dioxide emission related data collection and integration platform. The data required for the calculation of transportation carbon dioxide emissions are scattered among different government departments, industries, and enterprises. Data acquisition is the key to the accurate calculation of transportation carbon emissions. By building a traffic carbon emission data collection and integration platform, data acquisition issues are clarified, and multi-source data flows related to traffic carbon emission are gathered to provide support for accurate calculation of regional traffic carbon emissions.

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