IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

The evaluation methodology on carbon emissions of passenger cars based on travel characteristics

To cite this article: Zhenyu Li *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **227** 062001

The evaluation methodology on carbon emissions of passenger cars based on travel characteristics

Zhenyu Li[1], Kai Liao and Chao Li

China Urban Sustainable Transport Research Center, China Academy of Transportation Sciences, Beijing 100029, P. R. China.

[1] Email: zhenyulee123@163.com

Abstract. In recent years, with the rapid growth of economy, China's urbanization and urban transport are undergoing a rapid development, resulting in a large amount of travels. But at the same time, due to "blowout" growth of passenger cars, a series of serious social problems occurred, such as traffic congestion and fast increase in Carbon Dioxide emissions, which posed a great challenge to the sustainable development of urban transport in China. Studies on the evaluation methodology of Carbon Dioxide emissions based on travel characteristics are to be conducted to effectively improve the evaluation accuracy of emission quantification of passenger cars, and find out the place and source of Carbon Dioxide emissions, so as to further promote accurate emission reduction. This paper first analyzes the main characteristics of Carbon Dioxide emissions of passenger cars in China, optimizes the evaluation methodology of Carbon Dioxide emissions of passenger cars from the perspectives of scoping, road grading and classification evaluation, and conducts a test on Carbon Dioxide emission factors in some cities. The paper also takes Harbin city as an example to evaluate its Carbon Dioxide emissions of passenger cars from 2014 to 2016, so as to testify the feasibility of the methodology.

1. Introduction

Over the past ten years, with the rapid development of China's social economy, the process of urbanization has been rapidly advanced and the vehicle stock has been increased rapidly. By the end of 2016, the vehicle stock in China had reached 295 million, of which two-thirds were passenger cars. The rapid development of passenger cars also brought about a series of serious social problems, such as traffic congestion and rapid increase of Carbon Dioxide emissions. In the "thirteenth Five-Year" period, China need to reach a 18% reduction of Carbon Dioxide emissions per unit of GDP in 2020 as compared with in 2015 and the fuel economy of new passenger cars need to reach 5L/100km[1]. China is facing a huge task of energy saving and emission reduction. Currently, the ownership of passenger cars in China has entered a period of rapid growth. According to the *Special Planning of Transport Science and Technology Innovation in the "thirteenth Five-Year" Period*, it is expected that the ownership of passenger cars in 2020 will reach about 300 million, with the gasoline and diesel consumption rising to 350 million tons and oil demands reaching 590 million tons. In the Paris Agreement of 2015, China pledged to peak Carbon Dioxide emissions by 2030 and strived for an early realization. The transportation industry is facing great pressures and challenges. Passenger cars are undoubtedly the biggest sources of Carbon Dioxide emissions among urban transport. However, due to the scattered management, complex influencing factors and poor statistic basis, the evaluation accuracy of Carbon Dioxide emissions of passenger cars is not enough. Therefore, it is of great significance to explore the evaluation methodology of Carbon Dioxide emissions from passenger cars based on travel characteristics for promoting the low carbon development of urban transport.

2. Main characteristics of passenger car carbon emissions

2.1. Rapid growth and huge emissions
Nowadays, passenger cars in China showed the main characteristics of "three highs". The first high refers to high ownership. In 2016, the total ownership of passenger cars in China reached 146 million, ranking the second in the world after the USA. The second high refers to high growth speed. The growth of ownership was over 10% in the past ten years. The third high refers to high usage frequency. Passenger cars were used in daily commutes, tours, relatives and friends visiting and shopping, with long average driving travel and high utilization. These caused a rapid rise of Carbon Dioxide emissions of passenger cars. However, as compared with other developed countries and cities, China is still in the early stage of motorization, and the per capita possession of passenger cars is still in a low level. In order to reduce congestion, several cities including Beijing, Shanghai and Guiyang have already adopted some transport demand measures to reduce congestion and emissions. China's passenger car transport is still in a strong development potential in the future [2].

2.2. Various and complicated factors
There are many influencing factors for Carbon Dioxide emissions of passenger cars, including vehicle factors (age, type of fuel, vehicle emission standards, I/M and vehicle technical status, etc.), weather conditions, traffic conditions, road conditions (expressway, main road, secondary road, and branch road) and driving behaviors. The reasons are also very complicated [3].

2.3. Weak statistical service
From the government point of view, passenger car transport involves several departments, including transportation, public security, environmental protection and municipal administration, etc. The management is rather segmented both at the national level and at the local level. The responsible division in most cities is not clear, with serious mutual prevarication phenomenon. The industry statistical work is very weak, for example, most vehicles have no GPS positioning equipment, and lack of corresponding management information platform, and statistical data and operating data limited the application of evaluation methodology for Carbon Dioxide emission quantification.

3. Determination of evaluation methodology and key factors
The methods of "top-down" and "bottom-up" are usually used for evaluating transport Carbon Dioxide emissions. The top-down method is used to calculate carbon emissions based on the fuel consumption of a special transportation mode, while the bottom-up method focuses on a transport vehicle, which calculates carbon emissions according to characteristics of its traffic activities and the corresponding emission factors. The top-down method is mostly used on buses and taxi as these two modes have good fuel consumption data in China [4, 5]. The bottom-up method is mostly used on passenger cars and motorcycles as there are limited statistic data. And the basic bottom-up method is to conduct calculations by using indicators including ownership, travelling kilometer and fuel economy. The shortcomings are too simple and limited accuracy of Carbon Dioxide emission evaluation. See the formula (1) .

$$Q = \sum_{i,j}\left(d_{i,j} \cdot S_{i,j} \cdot \varepsilon_{i,j} \cdot EF_{i,j}\right) \quad (1)$$

In the formula (1), i refers to different transport modes， j refers to different fuel types， Q refers to Carbon Dioxide emissions, d refers to average traveling kilometer， S refers to vehicle stock, ε refers to average fuel economy, EF refers to Carbon Dioxide emission factors.

3.1. Evaluation method
Compared with top-down method, the bottom-up method can conduct deeper evaluation analyses including causes, structure and distribution of Carbon emissions and then formulate emission inventory. Advanced monitoring is mostly based on this method of assessment. Therefore, with the city data availability as the basis, combined with the main factors affecting the carbon emissions of passenger cars, this paper optimizes a new methodology of medium scale carbon emission assessment of passenger cars. See from formula (2) to formula (5). This method is used to calculate carbon emissions of passenger cars based on the real transport activity level and emission factors under different driving conditions. It considers more influencing factors as far as possible, so the evaluation accuracy is highly improved, which can not only improve the accuracy, but solve the problem of higher cost by using micro scale evaluation method. So it is more in line with the general requirements of most cities in China.

$$Q_T = Q_h + Q_c \tag{2}$$

In the formula (2), Q_T refers to total Carbon Dioxide emissions of passenger cars, Q_h refers to Carbon Dioxide emissions of passenger cars under thermal operation, Q_c refers to Carbon Dioxide emissions of passenger cars under cold start.

$$Q_h = \sum_{i,j}\left(VKT_{i,j} \cdot EF_{i,j}^{h}\right) \tag{3}$$

In the formula (3), i refers to transport modes, j refers to fuel types, Q_h refers to Carbon Dioxide emissions of passenger cars under thermal operation, VKT refers to Vehicle Kilometre Travelled, EF^h refers to emission factors under thermal operation.

$$VKT_k = VF_k \cdot DIS_k^{sam} \tag{4}$$

In the formula (4), VKT refers to vehicle kilometer traveled, VF refers to vehicle fleet model, DIS refers to traveling distance of k vehicle type among transport demand models or through sampling surveys.

$$Q_c = N \cdot EF^c \tag{5}$$

In the formula (5), Q_c refers to Carbon Dioxide emissions of passenger cars under cold start. N refers to the number of cold start, which relates to fleet annual average traveling kilometer, time distribution, parking time distribution. EF^c refers to cold start emission factors, which is decided by vehicle types, air temperature and humidity.

3.2. Key parameters
The carbon emissions and fuel consumption of passenger cars are positively related to the level of traffic activities, that is to say, the vehicle kilometer traveled. VKT data can be derived from traffic demand models or through urban traffic surveys. In the city with traffic demand model, the traffic flow data of passenger cars on the road is calculated through deriving data including the traveler's travel time distribution, travel destination, trip mode and traffic route selection from the model. At present, only a few cities (such as Beijing, Shenzhen, Shanghai, etc.) can meet with the conditions of traffic demand model in China, and most of cities need to carry out traffic survey. This paper targets at these cities to explore the feasibility and effectiveness of the evaluation methodology.

3.3. Vehicle kilometre data

3.3.1. Vehicle fleet. The establishment of vehicle fleet model is the basic condition for carbon emission assessment. Many literature shows that the main factors affecting car emissions include displacement, vehicle age, emission standards and fuel types. Considering the actual situation in China and by referring to international experiences on analysis clustering, this paper classifies passenger cars into four dimensions, namely the age of the vehicle (1-15 year), engine displacement (<=1.0 L, 1.0-1.4 L, 1.4-2.0 L and >2.0L), the fuel categories and emission standards (China 0, I, II, III, IV, etc.), so as to determine the fleet model architecture, and collect the relevant data according to the architecture of this model.

3.3.2. Transport activity level. Traffic state and urban road conditions are closely related. According to the national standard of GB 50220-1995, the urban road is divided into expressway, trunk road, secondary road and branch road [6]. According to the actual conditions of each road level, the level of traffic activity is classified. The main indictor is vehicle average speed in different road grades. The level of activity under the road grades is shown in Table 1. Through this classification, the relationship between traffic activity and urban infrastructure can be better connected.

Table 1. Traffic Activity Level Classification (Unit: km/h).

Road activity level	Unimpeded	Basically unimpeded	slight congestion	moderate congestion	serious congestion
Expressway	$V^a>65$	$50<V\leq65$	$35<V\leq50$	$20<V\leq35$	$V\leq20$
Trunk road	$V>40$	$30<V\leq40$	$20<V\leq30$	$15<V\leq20$	$V\leq15$
Secondary road and branch road	$V>35$	$25<V\leq35$	$15<V\leq25$	$10<V\leq15$	$V\leq10$

[a]V refers to vehicle average speed.

3.3.3. Traffic volume survey. There is no enough statistical data regarding the travel distribution of different types of passenger cars under different traffic conditions in the downtown area. Generally, minimum sample size needs to be determined firstly based on statistical principles, see formula (6). Sample surveys are carried out through field interviews and telephone interviews. An economic, effective and feasible investigation method is identified through analysis and research.

$$n \geq \frac{N}{1+\frac{(N-1)\cdot\epsilon^2}{z^2\cdot P\cdot(1-P)}} \tag{6}$$

In the formula (6), n refers to minimum sample size, N refers to the total number of vehicles, ε refers to the most allowed error (5%), z refers to confidence interval (95%，z=1.96), P refers to subtype count.

During the survey, the first is to take a sample of average annual kilometer of different types of passenger cars in the downtown area. The questionnaire should include the age of the vehicle, displacement, fuel type and annual trip kilometer in the downtown area, etc.

Secondly, road monitoring points are set up to obtain the driving ratio of passenger cars in different road types and road activity level. Each road type should select at least 3 monitoring points. The specific method and steps are as follows:

Step 1, with the help of road video monitoring equipment or manual measurement, the traffic volume and average speed of each monitoring point in 2 hours are obtained.

Step 2, according to the average speed of each monitoring point in different periods and the road section traffic activity level classification (see Table 1), the road activity level of each monitoring point in different periods is determined.

Step 3, for a certain type of road, the sum of traffic flows of a certain road activity level in each monitoring points in different periods and the percentage of the sum of traffic flows of a corresponding road activity level to the total traffic flow all day long of the corresponding road type in each monitoring point are calculated. The percentage is equivalently considered to the proportion of small and medium vehicles running at the level of the road activity level in this road type.

Step 4, the total passenger car kilometers in different road types are calculated, that is, the total length of the road type multiply the average total traffic flow at each monitoring point of the road type, and then getting the driving ratio of passenger cars in different road types.

With the results of step 3 and step 4, in the whole urban road network, the driving ratio of passenger cars at a certain road activity level of a certain road type throughout the year is obtained.

By combining the annual average travel kilometer of different types of passenger cars in the city limits and the driving ratio of passenger cars in different types of roads and road activity levels, the average travel kilometer of different types of passenger cars in different types of roads and road activity level can be obtained.

Under the condition of defined classified integration degree and corresponding emission factors, the accuracy of "bottom-up" also depends on the number of samples and the number of road monitoring points, which will affect the data accuracy. A survey conducted with definite sample size could meet the assessment requirements. Under the relevant conditions, buses and taxi can also be calculated by using the bottom-up method and verified with the top-down method, and be consistent with the system error of car accounting results.

3.3.4. Emission factors based on vehicle kilometre.s The fuel consumption of passenger cars is related to engine speed and operation condition. This paper carried out an actual observation in the cities (Beijing, Harbin) and established a dynamic relationship among the engine speed, operating power and fuel consumption. The PHEM model is adopted to determine emission factors of passenger cars and the local vehicle emission factor database is established.

Considering the factors such as the road types (expressway, trunk road, secondary road and branch road) and road activity level (unimpeded, basic unimpeded, mild congestion, moderate congestion and severe congestion), through the test, the local Carbon Dioxide emission factor database of car can be established, as shown in Figure 1. It can be seen from it that if the road condition is good, the road activity level is higher, and the emission factor is low, with the increase of congestion level, the emission factors of unit kilometre is significantly increased [7, 8, 9, 10].

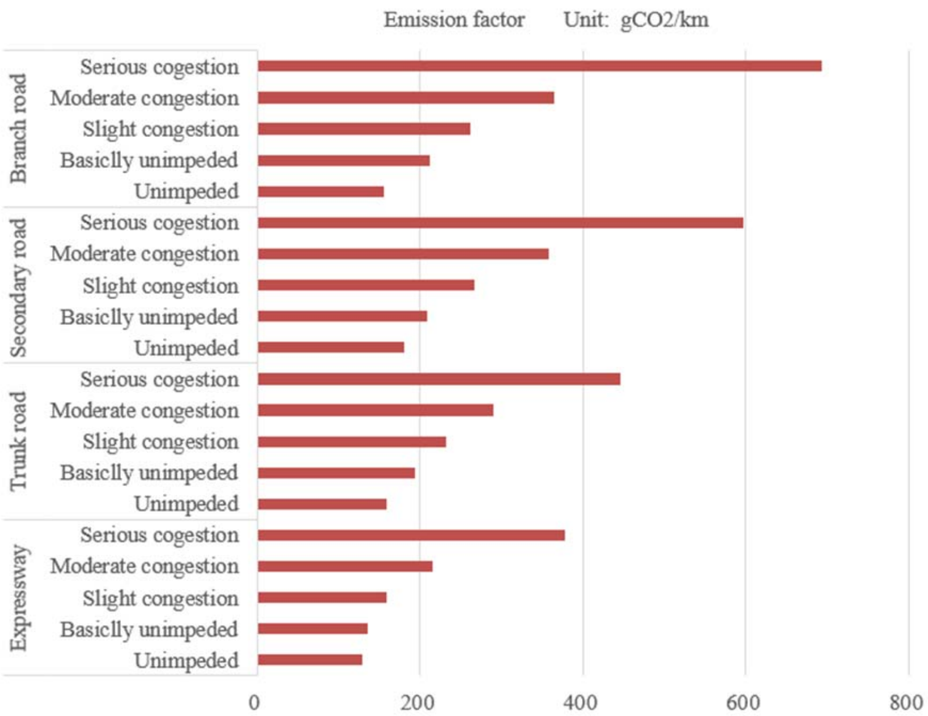

Figure 1. Carbon Dioxide emission factors of 1.4-2.0L China IV passenger cars under different road types and road activity levels.

4. Case study

Harbin is a capital city in the northeast of China. The urban transport in Harbin is developing rapidly, and the city is carrying out national "Public Transit Metropolis" construction currently. In 2010, the city of Harbin had 469 thousand passenger cars, and by 2016, it increased to 1.30 million, with an average annual growth rate of 18.46%. In 2010, the per capita GDP of Harbin was 36,961 Yuan, and grew to 63,445 Yuan in 2016, with an average annual growth rate of 9.42%. The average annual growth rate of passenger cars is nearly twice as much as the average annual growth rate of per capita GDP, which shows that the desire of Harbin residents to buy passenger cars is very strong [11].

By using the above defined evaluation methodology and self-determined evaluation model, the calculation of emissions of passenger cars in Harbin downtown area from 2014 to 2016 is done, and emissions from public transport and taxi were calculated by using the top-down method, see the results in Figure 2. There are 2 thousand samples selected for surveying in Harbin. Among the different transport modes, the Carbon Dioxide emissions of passenger cars is the largest, and the average proportion of carbon emissions in urban transport is 77.5%.

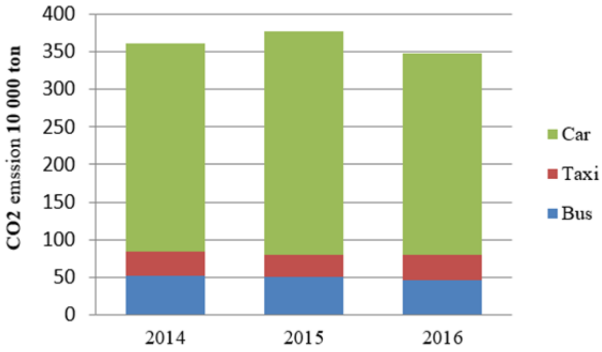

Figure 2. Urban Transport Carbon Dioxide Emissions in Harbin.

In the cold city Harbin, Carbon Dioxide emissions from passenger cars are mostly from hot running, but the moment emission intensity of cold start is much higher than that of hot running, which cannot be ignored. Combined with temperature, humidity and average travel distance, the cold start Carbon Dioxide emissions of passenger cars is calculated, accounting for about 5% of the total emissions of passenger cars in Harbin, as shown in Figure 3.

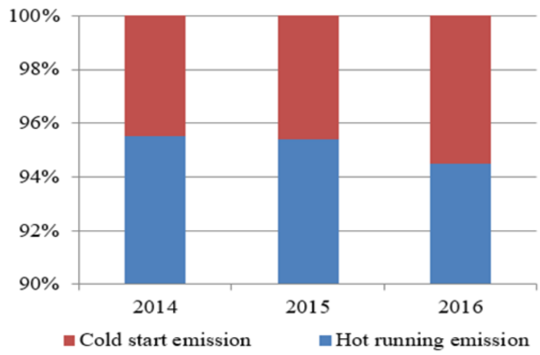

Figure 3. Proportion of hot emissions and cold start emissions of passenger cars in Harbin.

From the point of view of displacement, passenger car emissions of 1.4L-2.0L, accounting for more than half of total carbon emissions, as shown in Figure 4. For emissions standards of passenger cars, the largest emissions are in China IV and China V, and the proportion increased year by year, they accounted for 87.6% of the total emissions in 2016, as shown in Figure 5.

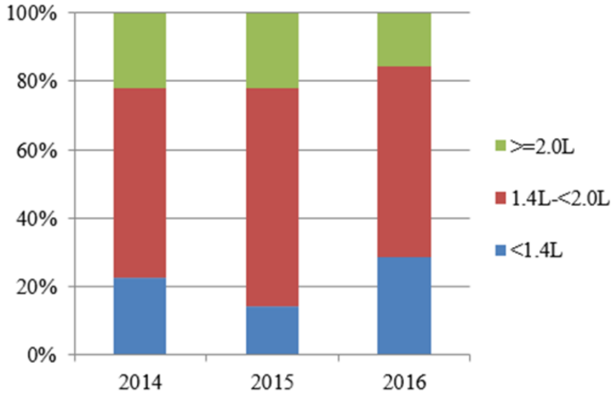

Figure 4. Proportion of different volumes of passenger car emissions in Harbin.

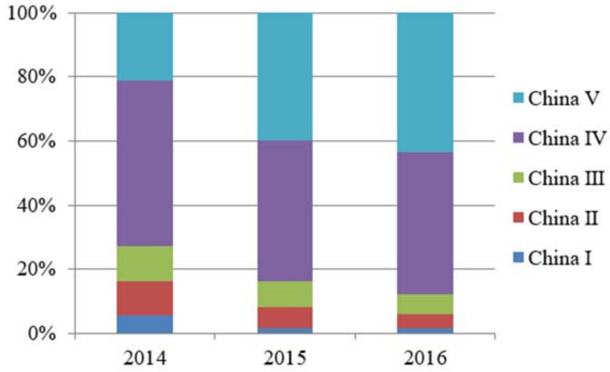

Figure 5. Emission standards of passenger car emissions in Harbin.

5. Conclusions

Through case study, the methodology is a practical methodology for evaluating urban traffic carbon emission at the medium scale level, which can quantify the emissions for the main transport characteristics including different road types, emission vehicles, running phase. It is one of the milestones for capacity building in transport and climate change. And the evaluation accuracy is improved greatly and it can be used to give important supporting for policy decision in both municipal government and urban transport government. Based on this, the methodology combined with GIS data can be improved to show time and spatial distribution of carbon emission in the next phase, and some big data such as internet rental taxi data can be used to calculate VKT with more accuracy.

And if the methodology can be used well, considering the current development situation in China and the traffic emission assessment researches, based on the experiences of developed countries, efforts must be made to speed up the capacity building of urban transport to respond to climate change and to strengthen the traffic emission assessment on passenger cars in the whole country.

Firstly, strengthen statistics of energy consumption and Carbon Dioxide emissions of urban transport industry. Due to the lack of statistical indicators like energy consumption and emissions, a national long term mechanism for urban transport emissions monitoring has not been established. Relevant statistical indicators should be increased from the legal level as soon as possible, such as increasing "Carbon Dioxide emissions" index of different modes of transport and strengthening the quality of urban transport energy consumption statistical data, to ensure a comprehensive and reliable statistical data and provide a powerful guarantee for urban transport emissions monitoring.

Secondly, establish a cross sector data sharing mechanism. Different Data of passenger cars is scattered in different departments, such as public security, transportation, environmental protection, etc. It is of no significance for a city to do a separate analysis on a single transport mode. Overall consideration, planning and arrangement must be carried out. So all relevant departments should fully tap the existing data, mutual exchange needed data and avoid duplication of work. It is recommended to establish an "inter agency data sharing mechanism" involving departments of transport, public security, environmental protection and planning and to make statistical data open to the whole society. Investment should be made to strengthen the construction of maintenance of urban transport demand model.

Thirdly, establish passenger car carbon emission monitoring platform. Speed up the innovation of science and technology and adopt new technical tools including big data, cloud computing and "Internet plus", to broaden the coverage of data resources, improve data accuracy and timeliness, to achieve real-time monitoring, analysis and forecast of carbon emissions of a variety of transportation modes, and in future expand to real-time monitoring on pollutants.

By strengthening the study on traffic emission assessment, assessment can also be carried out on Carbon Dioxide reduction results of key policies or measures, such as establishing a low emission zone, congestion and emission reduction zone, green travel zone, so as to provide more references for scientific decision-making.

Acknowledgment
This paper was supported by CDM “Low carbon development policy of urban transport for small and medium sized cities” (Project No. 2014090); World Bank Global Environment Facility “Congestion Alleviation and Emission Reduction in Mega Cities "(No. TF014206-CN).

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