A Study on Transportation Carbon Emissions Based on the IPCC Method: a Case Study of Chongqing City

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Abstract:The carbon emissions from transportation have an undeniable impact on global climate change. This article focuses on the central urban area of Chongqing City as the research area and uses IPCC's reference method to calculate the carbon emissions from transportation in Chongqing from 2016 to 2020. The study estimated the carbon emissions from transportation vehicles in terms of fossil fuels and electricity, and analyzed the relationship between the carbon emissions of transportation vehicles powered by fossil fuels and electricity respectively. The study found that the carbon emissions from transportation in Chongqing increased during the study period, with gasoline and diesel vehicles accounting for the majority of emissions. In addition, this article also analyzed the role of promoting electric vehicles and achieving electrified transportation in reducing carbon emissions from transportation vehicles, which was found to be an effective way. Therefore, this article suggests that efforts should be made to promote and develop electric vehicles, while encouraging and promoting the achievement of electrified transportation to achieve the goal of reducing carbon emissions from transportation vehicles.

Keywords: IPCC Reference Approach; Transportation Carbon Emissions; Low-carbon Travel; Carbon Footprint Calculation.

1. Introduction

"The 14th Five-Year Plan" is a critical period and window for China to peak carbon emissions. Currently, the public transportation sector in China faces enormous pressure to reduce emissions. The transportation sector accounts for about 10.4% of China's total carbon emissions, with urban road transportation accounting for over 85% of the country's transportation carbon emissions. This makes it the absolute mainstay and focus of emission reduction efforts. In the future, due to the continued rapid growth of China's national economy and transportation, and the lack of fundamental changes in the technological level and energy structure of transportation development, carbon emissions from the transportation sector will continue to increase, creating a severe situation with great pressure to reduce emissions. Analyzing the travel behavior and characteristics of city residents is essential for scientific urban planning and transportation management, as they constitute a significant part of the urban mobility system. Public transportation is an important support for ensuring smooth and green urban transportation, accurately grasping residents' travel behavior characteristics and demand is key.

In Chongqing City, public transportation relies on high-density and low-efficiency conventional ground buses to support the entire urban transportation system. However, due to the unfavorable urban terrain for walking and cycling, there is a high demand for public transportation, but the low capacity of single buses results in low efficiency and high density, causing inconvenience to residents' travel. This article focuses on the central urban area of Chongqing City, using the IPCC's reference method to calculate the city's transportation carbon emissions from 2016 to 2020. It analyzes the relationship between fossil fuel-powered vehicles and electric-powered vehicles' carbon emissions and finds that promoting electric vehicles and achieving electrified transportation are effective ways to reduce carbon emissions from transportation.

1.1 Overview of the Study Area

This thesis selects the central urban area of Chongqing as the study area, located in the middle and west of Chongqing City between 106°3'E-106°8'E and 29°3'N-29°8'N. It is situated at the confluence of the Yangtze River and Jialing River, with four mountain ranges including Mingyue Mountain, Tongluo Mountain, Zhongliang Mountain, and Jinyun Mountain parallelly distributed from north to south. This has created a unique landscape pattern of "two rivers, four banks, and three valleys" and an urban form of "one core, one axis, and five cities". The natural geographical conditions of abundant mountains and rivers have laid the foundation for the development of a "multi-center and group-based" urban spatial structure. The development needs of the city in different historical periods have also promoted the strengthening of this spatial pattern. The central urban area includes nine districts under the jurisdiction of Yuzhong District, Dadukou District, Jiangbei District, Shapingba District, Jiulongpo District, Nanan District, Beibei District, Yubei District, and Bana District, as well as two functional areas, Liangjiang New Area and Chongqing High-tech Zone.

In 2020, the rail transit network in the central urban area gradually became operational, with a total mileage of 343.3 kilometers, 2062 operating vehicles, and a passenger volume of 839.75 million. Chongqing's operating vehicles reached 10,843 (including 8,923 buses and 1,920 taxis), operating 694 routes, and its passenger flow scale ranks fourth in the country, with conventional public transportation operating efficiency ranking among the top in the country.

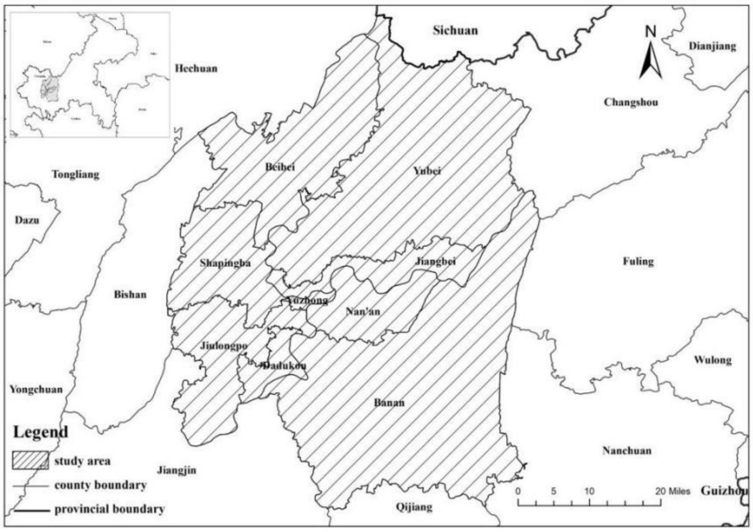


Figure 1 Location of the Research Area in Chongqing Downtown

1.2 Selection of Research Data

This study, based on the provincial energy balance sheet, uses IPCC reference methods to calculate Chongqing's carbon emissions from 2016 to 2020. Subsequently, through relevant allocation principles, the city's carbon emissions are allocated to various central urban areas. The study uses the transportation energy consumption data in the energy balance sheet for calculations. The carbon content of fossil fuels, carbon oxidation rate, and power carbon emissions are all from the "Provincial Greenhouse Gas Inventory Compilation Guide (Trial)", while fossil fuel consumption data, power consumption data, and average low heating value of energy are from the "China Energy Statistical Yearbook". The relevant data on transportation, warehousing, and postal industries in the statistical yearbook are severely lacking, so this study uses the third industry output indicators of various central urban areas as the allocation indicators for the transportation industry.

2. Development of Traffic Carbon Emission Models and Calculation of Carbon Emissions

2.1 Research on Traffic Carbon Emissions at Home and Abroad

Regarding the study of traffic carbon emission calculation and prediction models, there are mainly two methods for accounting traffic carbon emissions: "fuel-based" calculation method and "distance-based" calculation method. Based on the standard for urban size classification in China, Zhang et al.[1] selected resident travel survey data from sample cities and analyzed and evaluated the quantitative effects of various improvement measures using per capita carbon emission characteristics. Zhuang et al. [2] estimated the carbon emissions from Guangdong's transportation sector using the methods provided by IPCC in the greenhouse gas inventory guidelines, and applied the LMDI decomposition method to analyze the factors contributing to carbon emissions in Guangdong's transportation sector. The second method is "distance-based" calculation. Zhao et al. [3] quantitatively calculated the carbon emissions of residents' commuting before and after the opening of the subway in Zhengzhou by using a distance-based calculation method and combining with the policy evaluation model of EU TREMOVE2.4. Based on the calculation method mentioned above, a model can be established for predicting carbon emissions. For example, Xu et al. [4] utilized big data resources from buses to establish a "speed-energy consumption-carbon emission intensity curve" model and evaluation method. Based on the STIRPAT model, Gao et al. [5] established a predictive model and obtained a GA-SVM model that is more suitable for predicting carbon emissions from urban transportation by building a training set.

Foreign scholars have studied the influencing factors of transportation carbon emissions. Yuan et al. [6] constructed a linear regression model using the natural logarithm values of 7 correlation indicators, including urban population, urban area, and commuting spatial radius. They calculated that the significant influencing factors of one-way commuting distance and peak vehicle speed on workdays have a significant linear relationship with urban carbon emissions. Wang et al. [7] calculated transportation carbon emissions using panel data from 286 cities and pointed out that per capita GDP, vehicle ownership, and highway mileage have significant positive effects on transportation carbon emissions in the study area. In terms of computational methodology, Sun et al. [8] utilized a three-dimensional grey relational analysis model to study the population, GDP, tertiary industry, energy structure, and logistics scale, based on the carbon emission accounting method of the Intergovernmental Panel on Climate Change (IPCC). They calculated the transportation carbon emissions of low-carbon pilot and non-pilot provinces in China from 2010 to 2019. Li et al. [9] used grey model, triple exponential smoothing, and a combined model of grey triple exponential smoothing to predict transportation CO2 emissions. Ma et al. [10] used the Tapio model and the Logarithmic Mean Divisia Index (LMDI) method to investigate the decoupling relationship and influencing factors between economic development and carbon emissions from tourism transportation.

In summary, the calculation method based on fuel consumption is more accurate, while the distance-based calculation is subject to significant errors due to factors such as vehicle type, passenger capacity, and road congestion. As data on the mileage of various types of vehicles and their fuel consumption per unit distance are not easily obtainable in China, and fuel consumption data and calculation parameters are more readily available, this paper uses the "fuel-based" method to estimate per capita carbon emissions from transportation.

2.2 Calculation Method for Carbon Emissions from Transportation in Chongqing

We calculate the carbon emissions from transportation vehicles that use fossil fuels for energy assistance by using the consumption of gasoline, diesel, and natural gas in each year's energy balance table. The calculation formula is shown as equation (1):

$$GR = \sum_{i=1}^{n} CO_i \times ACVE_i \times C_i \times R_i \times \frac{44}{12} \qquad (1)$$

In the equation: GR represents the amount of carbon emissions from transportation generated by the consumption of fossil fuels; i represents the type of fuel, including gasoline, diesel, natural gas, and three types of fossil fuels used; CO represents the consumption of fossil fuels; ACVE represents the average calorific value of energy; C represents carbon content; R represents carbon oxidation rate.

We use the electricity consumption data from energy balance sheets of various years to calculate the carbon emissions of electrically-assisted transportation vehicles, using the formula (2).

$$CE = EC \times E \qquad (2)$$

In the equation: CE represents the carbon emissions from traffic generated by power consumption; EC represents the amount of power consumption; E represents the carbon emission factor for electricity.

On the basis of calculating the carbon emissions of Chongqing city, they are allocated to various districts according to certain distribution principles. The specific allocation formula is as follows:

$$FP_{\text{city}} = FP_{pronvince} \bullet W \qquad (3)$$

FP_{city} refers to the energy consumption in the urban area; $FP_{\text{pronvince}}$ refers to the total energy consumption in Chongqing;

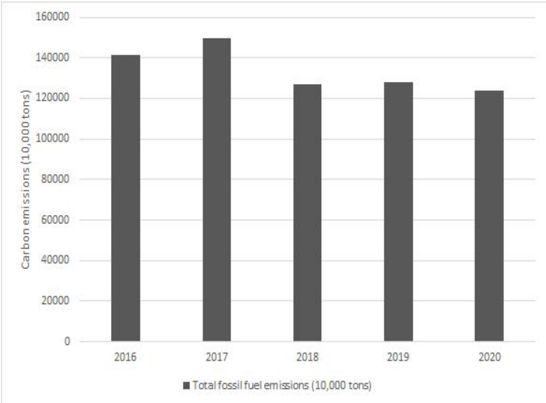
W denotes the corresponding allocation coefficient.

Table 1: Parameters Required for Calculating Carbon Emissions from Fossil Fuels

Types of fuel i	Energy lower heating value ACVE(KJ/kg)	Carbon content C(t/TJ)	Carbon oxidation rate (R)
Gasoline	43070	18.9	0.98
diesel	42652	20.2	0.98
natural gas	38931	15.32	0.99

Table 2. Carbon emissions from electricity in Chongqing.

Province	The carbon emissions of electric power E (kg CO2/kWh))
Chongqing	0.801



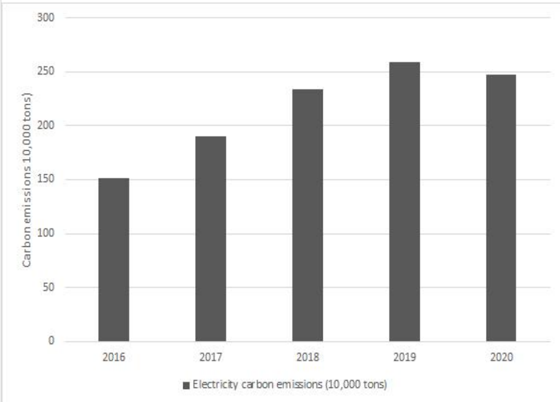


Figure 2 shows the changes in carbon emissions of transportation vehicles powered by fossil fuels and electricity supply from 2016 to 2020 in Chongqing.

2.3 Calculation Results

Analysis of carbon emissions from transportation in the central urban area of Chongqing reveals that vehicles in the region are powered by fossil fuels or electricity. The proportion of carbon emissions from each district remained stable between 2016 and 2020 with no significant fluctuations. Among them, Jiangbei, Yubei, Yuzhong, and Jiulongpo districts are the main areas, while the remaining districts develop around their dispersed "ring-shaped" support structure.

Table 3 displays the carbon emissions of transportation vehicles powered by fossil fuels in the central urban area of Chongqing from 2016 to 2020. (10,000 tons)

Urban areas	2016	2017	2018	2019	2020
Yuzhong	16974.19	18667.17	13869.55	12021.23	11528.06
Dadukou	1788.51	3020.88	1789.39	1570.43	1409.66
Jiangbei	9410.70	11728.08	9139.81	9723.31	9768.38
Shapingba	7405.03	8601.88	6869.56	6714.50	6449.87
Jiulongpo	9999.50	11376.43	8867.14	9622.52	9120.13
Nan’an	5115.83	6763.77	5263.99	4814.47	4731.13
Beibei	2510.63	3968.06	2919.19	2855.82	2878.59
Yubei	8752.03	11474.24	10535.63	12853.50	12450.43
Banan	4930.43	7214.14	5205.99	4925.04	4323.20

Table 4 shows the carbon emissions of transportation vehicles

using electricity supply in the central urban area of Chongqing from 2016 to 2020.(10,000 tons)

Urban areas	2016	2017	2018	2019	2020
Yuzhong	18.14	18.85	18.85	16.54	16.54
Dadukou	1.91	3.05	3.05	2.13	2.13
Jiangbei	10.06	11.84	11.84	10.90	10.90
Shapingba	7.92	8.69	8.69	8.19	8.19
Jiulongpo	10.69	11.49	11.49	10.57	10.57
Nan'an	5.47	6.83	6.83	6.28	6.28
Beibei	2.68	4.01	4.01	3.48	3.48
Yubei	9.36	11.59	11.59	12.56	12.56
Banan	5.27	7.28	7.28	6.21	6.21

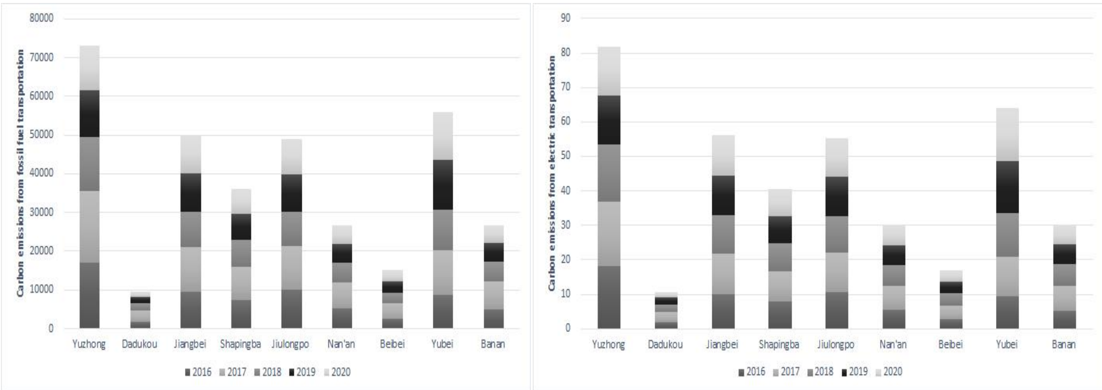


Figure 3 illustrates the carbon emissions of transportation vehicles powered by fossil fuel and electricity supply from 2016 to 2020 in the central urban area of Chongqing.

As shown in Figure 2, an analysis of carbon emissions from vehicles using fossil fuels for energy supply in Chongqing's central urban area revealed a slow decrease from 141.47 million tonnes in 2016 to 124.00 million tonnes in 2020 (Table 3), with the carbon emission intensity showing a gradual increase until peaking in 2017 and then slowly decreasing. This is mainly due to changes in the central urban area's economic development model and the successful implementation of energy-saving and emission reduction policies. An analysis of carbon emissions from vehicles using electricity for energy supply in Chongqing's central urban area showed a slow increase from 151.23 million tonnes in 2016 to 247.67 million tonnes in 2020 (Table 4), with the carbon emission intensity showing a gradual increase as well. This is because, during the city's development process, with industrial upgrading and technological improvement, the number of vehicles using electric power is increasing.

3. Conclusion and Future Outlook

This study used the IPCC's reference method to calculate carbon emissions in Chongqing from 2016-2020, and allocated them to each central urban area based on relevant allocation principles. The study found that Yuzhong District and Yubei District had the highest carbon emissions, while Dadukou District had the lowest. Furthermore, carbon emissions from electricity supply were significantly lower than those from fossil fuels. Overall, taking into account economic development levels and population mobility, the study's conclusions are consistent with reality.

However, this study has some limitations. Firstly, it only considered carbon emissions from transportation, without a comprehensive assessment of other environmental and social impacts. Secondly, the study only simulated the situation for the next few years, lacking predictions and analysis of long-term trends. Finally, our research only focused on reducing carbon emissions from fossil fuel-powered transportation to electrified transportation, without exploring the potential and effects of other sustainable transportation modes.

In the future, we will further improve research methods and data sources, considering both carbon emissions and other environmental and social impacts of transportation. We will also expand the scope of our research to explore the potential and effects of other sustainable transportation modes, in order to provide more comprehensive and in-depth research support for future sustainable transportation and urban planning.

References

[1] Zhang C, Jia FJ. Characteristics of carbon emissions from urban transportation based on residents' trips and strategies for energy conservation and emission reduction[J]. Transportation and Shipping, 2020, 36(03): 76-79.

[2] Zhuang Y, Xia B. Carbon emissions accounting and influencing factor analysis of transportation in Guangdong Province [J]. Environmental Science Research, 2017, 30(07): 1154-1162.

[3] Zhao RQ, Fan H, Zhang ZJ, et al. The impact of urban subway on commuting carbon emissions of residents along the line: A case study of Zhengzhou City [J]. Regional Research and Development, 2021,40(02):151-155+161.

[4] Xu L, Wang L, Liu Y, et al. Calculation model of energy consumption and carbon emissions for buses based on multi-source data [J]. Transportation Systems Engineering and Information, 2020,20(03):174-181.

[5] Gao JH, Huang WL, Jiang HP. Comparative analysis of multiple models for predicting urban transportation carbon emissions [J]. Journal of Chongqing Jiaotong University (Natural Science). 2020, 39(07): 33-39.

[6] Yuan RJ and Zhao LQ. Analyze the Impact Mechanism of Urban Planning on Traffic Carbon Emissions Based on Big Data[J]. Journal of Civil Engineering and Urban Planning, 2022, 4(4).

[7] Wang T, Zhang K, Liu KL, Ding KK, Qin WW. Spatial Heterogeneity and Scale Effects of Transportation Carbon Emission-Influencing Factors—An Empirical Analysis Based on 286 Cities in China[J]. International Journal of Environmental Research and Public Health,2023,20(3).

[8] Sun YM, Liu SX, Li L. Grey Correlation Analysis of Transportation Carbon Emissions under the Background of Carbon Peak and Carbon Neutrality[J]. Energies,2022,15(9).

[9] Li YM, Li TT, Lu SS. Forecast of urban traffic carbon emission and analysis of influencing factors[J]. Energy Efficiency,2021,14(8).

[10] Ma HQ, Liu JL, Xi JC. Decoupling and decomposition analysis of carbon emissions in Beijing’s tourism traffic[J]. Environment, Development and Sustainability, 2021,24(4).