Original Research Article

Characteristics of transportation carbon emissions in China from 2018 to 2022

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Abstract: The transportation sector is a major contributor to global carbon emissions, making its low-carbon transition essential for achieving China's carbon neutrality objectives. Utilizing the IPCC emission model, this study quantitatively evaluates trends in energy consumption and carbon emissions in China's transportation sector over the past five years. The findings indicate that gasoline and diesel remained the dominant energy sources from 2018 to 2022, while electricity and natural gas consumption exhibited sustained growth, with electricity consumption increasing by 27%. Total carbon emissions demonstrated a declining trajectory, decreasing by 6.1%. Gasoline and diesel continued to account for approximately 60% of total carbon emissions, although the proportion of emissions from electricity and natural gas rose by 5%. Meanwhile, GDP increased by 31%, and carbon emission intensity declined by 22%, reflecting advancements in energy efficiency and emissions mitigation technologies. Despite the positive outcomes of low-carbon policies and technological innovations, short-term economic fluctuations may pose challenges to sustaining emission reductions.

Keywords: Transportation sector; Energy consumption; Carbon emissions; Carbon intensity

1. Introduction

Global climate change poses a significant challenge to the sustainable development of humanity. To address this issue, China announced its carbon peaking and carbon neutrality goals in 2020, aiming to achieve carbon peaking by 2030 and carbon neutrality by 2060[1-6]. The transportation sector, as the third-largest source of carbon emissions after industry and buildings, plays a crucial role in achieving these targets[4].

Accurate measurement of carbon emissions in the transportation sector and a scientific assessment of emission reduction potentials are critical foundations for developing targeted carbon reduction strategies and advancing deep decarbonization efforts [2]. Currently, international methods for measuring transportation carbon emissions include the actual measurement method, emission factor method[5], mass balance method, life cycle analysis, and input-output analysis. Among these, the emission factor method is widely adopted due to its advantages in data requirements,[7] applicability, and ease of operation. This method can be categorized into two approaches: the top-down method, based on macro-level statistics, and the bottom-up method, based on micro-level behaviors. Each approach has its strengths and limitations. The top-down method is easy to calculate but less precise, while the bottom-up method requires extensive data but provides greater accuracy[1].

Although carbon emissions in the transportation sector have become a prominent research focus, there is a lack of publicly available systematic statistics specifically for China's transportation sector . Current estimates primarily rely on data from international organizations based on China's energy consumption. For example, the International Energy Agency (IEA) estimated that the transportation sector contributed approximately 901 million metric tons of CO_2 emissions in 2019, representing 9.12% of the nation's total emissions. However, variations in data sources, boundary definitions, and emission factor methodologies among studies have led to significant discrepancies in estimates. This highlights the need for more comprehensive and standardized data to accurately assess the carbon emissions profile of China's transportation sector.

This paper analyzes energy consumption data from China's transportation sector (2018–2022) using the IPCC method to examine carbon emission characteristics. It investigates changes in the energy structure, total carbon emissions, and contribution ratios across different years. Additionally, the study explores the relationship between carbon emissions and economic development by assessing carbon emissions per unit of GDP (carbon emission intensity), offering a theoretical foundation for the transportation sector's decarbonization strategies.

2. Data and methodology

The measurement scope of this paper is the transportation, warehousing and postal sector in the China Statistical Yearbook, and carbon emissions refer to carbon dioxide (CO_2) emissions. The carbon emission calculation method adopts the emission factor method recommended in the IPCC 2006 Guidelines for National Greenhouse Gas Inventories, in which the carbon emissions from fossil fuels are calculated as in equation (1).

$$\mathrm{CF} = \sum_{i=1}^{6} \mathrm{FC}_i \times \mathrm{ALC}_i \times \mathrm{C}_i \times \mathrm{R}_i \times \frac{44}{12} \tag{1}$$

Where CF denotes transportation carbon emissions from fossil fuel consumption (kg CO_2); i denotes fuel type, including six fossil fuels: coal, gasoline, kerosene, diesel, fuel oil, and natural gas; FC denotes fossil fuel consumption (kg); ALC denotes net calorific value of energy (kJ/kg); C denotes carbon content (t/TJ); and R denotes carbon oxidation rate (%).

Carbon emissions from electricity are calculated as in equation (2).

$$\mathrm{CE} = \mathrm{EC} \times \mathrm{EF} \tag{2}$$

Where CE denotes transportation carbon emissions from electricity consumption (kg CO_2); EC denotes electricity consumption (kW· h); EF denotes electricity carbon emission factor (kg CO_2/kW· h).

Carbon intensity is calculated as in equation (3).

$$I = \frac{\mathrm{H_t}}{\mathrm{K_t}} \tag{3}$$

Where *I* is the carbon emission intensity (t/10^4 CNY); Ht is the carbon emission (t); Kt is the total value of GDP in each year (10^4 CNY).

Energy consumption data, population data, and GDP data of various types were obtained from the China Statistical Yearbook; the net heating value and carbon content of various types of energy were adopted from the IPCC reference values, and the oxidation rate was adopted from the IPCC default value of 100%. The carbon emission factor for electricity was taken from the CO_2 Emission Factor for Electricity in 2021 issued by the Ministry of Ecology and Environment and the National Bureau of Statistics, and the value of 0.5568 kg CO_2/(kW·h) was taken. The density of natural gas takes the value of 0.775 kg/m^3.

3. Results

3.1. Transportation energy consumption and carbon emissions

Gasoline and diesel remain the primary energy sources. Meanwhile, coal and kerosene consumption has continued to decline, with coal consumption dropping by 70% and kerosene by 48% between 2018 and 2022. In contrast, the consumption of fuel oil, natural gas, and electricity has increased over the same period, rising by 20%, 18%, and 27%, respectively.

total carbon emissions from transportation decreased from 862.78 Mt in 2018 to 810.41 Mt in 2022, reflecting an overall decline of 52.37 Mt or 6.1%. During the same period, the population increased by 6.34 million, while per capital carbon emissions fell from 0.61 to 0.57 t/person. This indicates that population growth did not significantly heighten carbon emissions pressure. The declining trend underscores the effectiveness of policy measures and technological advancements in curbing transportation-related emissions. However, the anomalous increase in carbon emissions in 2021 is likely linked to the economic rebound and heightened transportation activity following the pandemic.

3.2. The contribution of carbon emission

The energy structure of transportation carbon emissions exhibits a clear divergence trend. Carbon emissions from four energy sources (gasoline, diesel, kerosene, and electricity) account for approximately 85% of total carbon emissions, with diesel and gasoline contributing about 38% and 21.9%, respectively. Emissions from kerosene have been steadily decreasing, while those from electricity and natural gas have shown an increasing trend. This shift reflects the growing adoption of new energy technologies and a gradual reduction in dependence on traditional fossil fuels.

4. Discussion

From 2018 to 2022, the energy mix of transportation carbon emissions has undergone partly changes. While gasoline and diesel continue to dominate, the use of kerosene has steadily declined, and the consumption of electricity and natural gas has increased annually. This shift reflects a gradual transition toward cleaner energy sources in the transportation sector, driven by the promotion of new energy technologies and the widespread adoption of new energy vehicles.

Between 2018 and 2022, the transportation sector successfully reduced its carbon emissions by 6.1%. In 2019, the total carbon emissions in this study were 849 Mt, compared to 901 Mt according to the International Energy Agency (IEA), and 732 Mt according to the China Subsectoral Accounting Carbon Emission Inventory published in the China Carbon Accounting Databases (CEADs). The discrepancy with the IEA data may arise from differences in data sources and the selection of emission factors. Additionally, the energy consumption data from CEADs differ slightly from those in this study, as their carbon emission estimations may account for electricity as a secondary energy source, which was not included in the transportation emissions in this paper.

Economic growth has increased by 31%, while carbon intensity has decreased by 22%, indicating significant advancements in emissions reduction technologies and energy efficiency within the transportation sector. Previous studies have analyzed the relationship between urban road transport carbon emissions and factors such as urbanization, economic development, technological progress, and population growth in China. These studies found that transport energy intensity is a key driver of emission reductions, while population size and per capita GDP are the primary contributors to increased emissions[3]. In this study, the decline in per capita carbon emissions suggests that population growth has not imposed excessive pressure on carbon emissions. Moreover, the reduction in carbon emission intensity reflects a “decoupling” trend between economic growth and carbon emissions, driven by the combined effects of economic restructuring, technological advancements, and supportive policies.

However, the anomalous rise in carbon emissions in 2021 may be attributed to economic recovery and the resurgence of transportation activities following the pandemic. This highlights the influence of short-term economic fluctuations on the carbon emission trajectory. Consequently, maintaining the downward trend in emissions amid economic fluctuations remains a significant challenge for the transportation sector.

5. Conclusion

Analysis of data from 2018 to 2022 shows that the transportation sector has achieved remarkable results in carbon emission control. While the economy grows, the total carbon emissions and carbon emission intensity show a downward trend, indicating the initial success of low-carbon transformation. However, short-term economic fluctuations may have some impact on carbon emission control, and the use of traditional energy sources still dominates. Therefore, the promotion of new energy vehicles and the use of clean energy should be strengthened in the future, as well as the optimization of the energy structure to promote the deep decarbonization of the transport sector and ensure long-term emission reduction.

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