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Analysis of Carbon Emissions from Road Transport in China

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Abstract

China is one of the world's largest energy consumers, accounting for about 31.11% of global CO□ emissions [1]. While the industrial sector dominates final energy consumption, the transport sector is also a major source, with road transport accounting for the largest share of both total freight volume and emissions [2]. Road freight transport serves as the backbone of domestic logistics but remains highly dependent on fossil fuels, making it a critical target for CO□ reduction. In 2020, the Chinese government announced its goals of achieving carbon peaking by 2030 and carbon neutrality by 2060, designating the decarbonization of the transport sector as a national priority under the "dual-carbon" policy framework [3]. Achieving these goals requires a fuel transition in road transport—from diesel to natural gas and electricity—together with improvements in energy efficiency and optimization of the transport structure.

This study focuses on China's road transport sector and quantitatively analyzes CO□ emissions based on freight transport activity and fuel composition. Using the freight turnover-based method [4], which applies emission factors differentiated by fuel type, the study evaluates emission reduction effects under various fuel transition scenarios. Linear regression is applied to road freight transport data from 2015 to 2024 to project future values and estimate transport activity and emissions for 2025–2030. This analysis aims to quantitatively reveal structural changes in emission patterns and assess the progress of decarbonization over time.

Keywords: Road freight transport; CO□ emissions; Freight turnover-based method; Scenario analysis; Fuel transition; Decarbonization; China

1. Research Methodology

1.1 Emission Estimation Model Based on the Freight-Turnover-Based Method

The freight-turnover-based method proposed in this study calculates CO□ emissions as the product of the scale of freight transport activity and its corresponding emission intensity. In other words, the environmental impact generated during the transport process depends on the transported freight volume and distance, and is further determined by the emission characteristics of each fuel type. Therefore, by multiplying the emission factor per unit of freight transport by the actual freight turnover, the total carbon emissions from transport activity can be quantitatively derived. Based on this concept, the estimation model is expressed as follows:

$$E = A \times \frac{EF}{1000}$$

where Erepresents CO□ emissions from transport (tCO□e), Adenotes freight turnover (t·km), and EF is the fuel-specific emission factor (kgCO□e/t·km). Division by 1000 converts emission factors from kilograms to tons. In this equation, freight turnover Acaptures the physical scale of logistics operations, whereas the emission factor EF reflects fuel characteristics and energy-use efficiency. Their product yields the total emissions associated with the transport mode under consideration.

The emission factors adopted in this study are based on the "Recommended Emission

Factors for Freight Transport" published by Zero Carbon Lab (ZEROLab) [5]. This dataset is compiled using China's road-transport energy statistics and vehicle-operation characteristics, and calculates life-cycle emissions—including fuel production, transportation, and consumption—through a Life Cycle Assessment (LCA). The values are provided for major energy types such as diesel, gasoline, natural gas, and battery-electric vehicles, and are categorized by gross vehicle weight classes (heavy-duty, medium-duty, light-duty, and mini-vehicles), with units expressed as kgCO□e/t·km.

In this study, Well-to-Wheel (WTW) emission factors are employed, covering the entire chain from fuel extraction to vehicle operation [6]. Compared with Tank-to-Wheel (TTW), which only considers emissions during fuel consumption, WTW provides a more comprehensive representation of emissions and enhances the validity of the estimation.

1.2 Scenario Design Based on Fuel Composition

Comprehensive statistical data on road freight transport volume (t·km) disaggregated by fuel type are not available in China. Therefore, to assess how changes in fuel composition may influence total sectoral CO□ emissions, this study employs a scenario analysis approach. Scenario analysis is a method widely used in the fields of energy and environmental studies, in which multiple hypothetical conditions are established based on existing data and policy targets, and comparative analysis is performed by varying key parameters—in this study, the fuel composition ratio.

Drawing on data from the International Council on Clean Transportation (ICCT), Wood Mackenzie, and Reuters [7][8][9], this study establishes three representative scenarios. Total emissions E_{total} are calculated by multiplying total freight turnover A_{total} by the weighted sum of the fuel composition ratio s_i and the fuel-specific emission factor EF_i:

$$E_{\text{total}} = A_{\text{total}} \times \sum_i (s_i \times EF_i)$$

Baseline Scenario

According to the ICCT (2024) report [7], sales shares of heavy-duty trucks in China in 2024 were approximately 57% diesel, 29% natural gas, and 13% battery-electric vehicles (8). Based on these proportions, the Baseline Scenario assumes the following fuel composition: 60% diesel, 5% gasoline, 25% natural gas, and 10% battery-electric vehicles. Under this fuel structure, total CO□ emissions are estimated.

Transition Scenario

Analyses by ICCT (2024b) and Wood Mackenzie [8] indicate rapid market expansion of LNG trucks and electric trucks, suggesting ongoing structural changes in fuel use. Accordingly, the Transition Scenario assumes 45% diesel, 5% gasoline, 30% natural gas, and 20% battery-electric vehicles, and calculates the resulting total CO□ emissions following partial fuel transition.

Low-Carbon Scenario

Based on Reuters (2025) data, sales of electric heavy-duty trucks in China may reach approximately 50% of new vehicle sales by 2028 [9]. Reflecting this trend, the Low-Carbon Scenario assumes 30% diesel, 5% gasoline, 25% natural gas, and 40% battery-electric vehicles, and estimates long-term emissions under this advanced transition pathway.

This study calculates a weighted average emission intensity to incorporate fuel composition into the analysis. The weighted average emission intensity is a composite indicator representing the overall carbon efficiency of transport activities in which multiple fuel types are used. Because CO□ emissions per unit of freight transport differ by fuel type, a single fuel-specific emission factor cannot accurately represent the sector as a whole. Therefore, each fuel-specific emission factor EF_i is multiplied by its corresponding fuel composition ratio s_i, and the sum yields a representative value for the entire sector. This measure represents the carbon emission intensity of the road freight transport sector as shaped by its fuel composition.

In this study, this weighted value is defined as the average emission intensity (EF_{ave}), which serves as a key analytical indicator:

$$EF_{ave} = \sum_i (s_i \times EF_i)$$

1.3 Projection of Future Freight Transport Activity Using Linear Regression Analysis

To quantitatively assess the future trajectory of road freight transport activity, this study conducts a linear regression analysis using observed data from 2015 to 2024. Specifically, total freight turnover A_{total}(unit: million t·km) is used as the dependent variable, and calendar year as the independent variable. A best-fit regression curve is obtained through the ordinary least squares method, and the resulting regression equation is used to project freight transport volumes for the period 2025–2030. The derived regression model is expressed as follows:

$$y = 160{,}667x - 3.0 \times 10^8$$

where $y$represents the projected freight turnover (million t·km), and $x$denotes the calendar year. The regression coefficient (160,667) indicates the average annual increase in freight turnover, suggesting that road freight transport has been growing at an annual rate of approximately 2–2.5%. The coefficient of determination R^2exceeds 0.85, indicating a high degree of model fit.

Based on this regression model, freight transport volumes for 2025–2030 are extrapolated, and future CO□ emissions under each scenario are computed by multiplying these projected values by the corresponding average emission intensity EF_{ave}. It should be noted, however, that this analysis relies on a linear trend and represents a short-term projection model. Nonlinear factors such as policy shifts or structural economic transitions are not incorporated. Therefore, the estimated values should be interpreted as a baseline trend for medium-term outlooks.

2. Calculation Results

In order to estimate CO□ emissions from road freight transport in China, this study applies the freight-turnover-based method. The calculation model is expressed as follows:

$$E = A_{total} \times \sum_i (s_i \times EF_i)$$

where Erepresents total emissions (tCO□e), A_{total}denotes total freight turnover (t·km), $s_i$is the fuel composition ratio under each scenario, and $EF_i$is the fuel-specific emission factor for each fuel type (kgCO□e/t·km).

The latter term, $\sum_i (s_i \times EF_i)$, represents the weighted average of fuel-specific emission factors, calculated by multiplying each fuel-specific emission factor $EF_i$by its corresponding fuel composition ratio s_i. This value is the weighted average emission intensity, which characterizes the average carbon emission intensity of the entire transport sector. Even when emission characteristics differ across fuel types, incorporating fuel composition allows for a representative sector-wide emission intensity to be derived.

The fuel-specific emission factors adopted in this study are the WTW (Well-to-Wheel) emission values provided by Zero Carbon Lab (ZEROLab). These values cover the entire life cycle of fuels—from extraction and production to transportation and end use—thus enabling comprehensive evaluation of lifecycle emissions. The adopted values are presented in Table 1, and the fuel composition ratios $s_i$for each scenario in Table 2.

The study period covers 2015 to 2024. Total freight turnover (A_{total}) is based on publicly available data from the Ministry of Transport of China and the National Bureau of Statistics, expressed in units of "million t·km" (Table 3).

Table 1. Emission Factors by Fuel Type (EF_i)

Fuel Type	Emission Factor (EFi) ($kgCO_2e/t{\cdot}km$)
Diesel truck	0.2157
Gasoline truck	0.2251
Natural gas truck	0.2478
Pure electric truck	0.1278

Table 2. Scenario Settings for Fuel Composition Ratios (s_i)

Scenario (Si)	Diesel truck	Gasoline truck	Natural gas truck	Pure electric truck
① Baseline Scenario	0.6	0.05	0.25	0.1
② Transition Scenario	0.45	0.05	0.3	0.2
③ Low-carbon Scenario	0.3	0.05	0.25	0.4

Table 3. Annual Trends in Road Freight Transport Volume in China (A_{total})

Year	Road Freight Transport Volume (A_{total}) (million t·km)
2015	5,795,572.45
2016	6,108,009.68
2017	6,677,151.59
2018	7,124,921.19
2019	5,963,639.15
2020	6,017,184.52
2021	6,908,765.32
2022	6,895,803.75
2023	7,395,021.40
2024	7,684,753.00

The weighted average emission intensity (EF_{ave}) under the three scenarios is calculated as follows:

$$EF_{ave} = \sum_i (s_i \times EF_i)$$

where s_i denotes the fuel composition ratio for each fuel type, and EF_i represents the corresponding fuel-specific emission factor (kgCO□e/t·km). This formulation enables the estimation of an average carbon emission intensity that reflects the actual fuel composition within each scenario.

Table 4. Calculation Results of Weighted Average Emission Factors by Scenario (EF_{ave})

Scenario	Calculation Formula	Result (EFave) ($kgCO_2e/t{\cdot}km$)
① Baseline Scenario	(0.6×0.2157+0.05×0.2251+0.25×0.2478+0.10×0.1278)	0.215405
② Transition Scenario	(0.45×0.2157+0.05×0.2251+0.30×0.2478+0.20×0.1278)	0.20822
③ Low-carbon Scenario	(0.30×0.2157+0.05×0.2251+0.25×0.2478+0.40×0.1278)	0.189035

Based on the above calculation results, the contribution of each fuel type to total emissions in the Baseline Scenario was calculated.

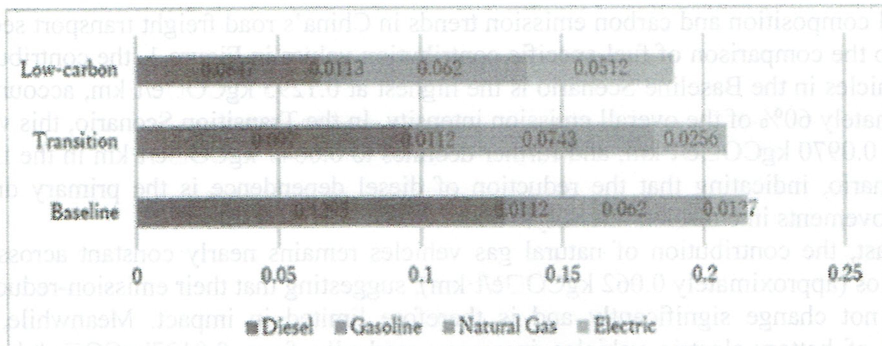

Figure 1. Comparison of emission contributions by fuel type under each scenario (kg CO□e / t·km)

A linear regression analysis using the ordinary least squares method was conducted on the road freight transport data from 2015 to 2024 shown in Table 3. As a result, the regression equation representing the annual trend in freight transport volume was obtained as follows:

$$y = 160{,}667x - 3.0 \times 10^8$$

where $y$denotes the projected freight turnover (million t·km), and $x$represents the calendar year. The regression coefficient of 160,667 indicates the average annual increase in freight transport volume.

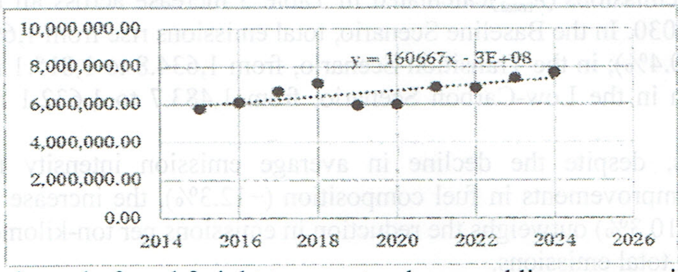

Figure 2. Annual trend of road freight transport volume and linear approximation curve in China (2015–2024)

Using this regression equation, the total transport volume (Atotal) for the years 2025 to 2030 was estimated. The results are presented in Table 5.

Table 5. Estimated road freight transport volume and CO□ emissions for 2025–2030 based on regression analysis

Transport Volume (A_{total}) (million t·km)	Emissions under Baseline Scenario (E_{total}) (million t CO_2 e)	Emissions under Transition Scenario (million t CO_2e)	Emissions under Low-carbon Scenario (million t CO_2e)
7,845,000	1690.1	1634.8	1483.7
8,006,000	1725.3	1670.9	1513.3
8,167,000	1760.6	1707	1543
8,328,000	1795.9	1743	1572.7
8,489,000	1831.2	1779.1	1602.4
8,650,000	1866.5	1815.1	1632.1

3. Results and Analysis References

3.1 Analysis Based on the Calculation Results

The calculation results (Figures 1 and 2; Table 5) quantitatively clarify the relationship between fuel composition and carbon emission trends in China's road freight transport sector. According to the comparison of fuel-specific contribution values in Figure 1, the contribution of diesel vehicles in the Baseline Scenario is the highest at 0.1295 kgCO□e/t·km, accounting for approximately 60% of the overall emission intensity. In the Transition Scenario, this value decreases to 0.0970 kgCO□e/t·km, and further declines to 0.0647 kgCO□e/t·km in the Low-Carbon Scenario, indicating that the reduction of diesel dependence is the primary driver behind improvements in emission intensity.

In contrast, the contribution of natural gas vehicles remains nearly constant across the three scenarios (approximately 0.062 kgCO□e/t·km), suggesting that their emission-reduction effect does not change significantly and is therefore limited in impact. Meanwhile, the contribution of battery-electric vehicles increases markedly from 0.0127kgCO□e/t·km to 0.0256kgCO□e/t·km and then to 0.0512 kgCO□e/t·km—approximately a fourfold increase—demonstrating that the expansion of electrification contributes most significantly to the reduction of average emission intensity(EF_{ave}). As shown in Table 4, the average emission intensity decreases from the current 0.215405 kgCO□e/t·km to 0.189035 kgCO□e/t·km under the Low-Carbon Scenario, a reduction of approximately 12.3%.

Next, as illustrated in Figure 2, road freight transport volume (A_{total}) increased by approximately 2% annually from 2015 to 2024 according to the regression equation $y = 160{,}667x - 3 \times 10^{8}$. Based on this trend, the projected values for 2025–2030 increase from 7,845,000 to 8,650,000 million t·km (+10.3%). With this growth in transport activity as the basis, the total emissions (E_{total})calculated in Table 5 increase across all three scenarios between 2025 and 2030. In the Baseline Scenario, total emissions rise from 1,690.1 to 1,866.5 million tCO□e (+10.4%); in the Transition Scenario, from 1,634.8 to 1,815.1 million tCO□e (+11.0%); and even in the Low-Carbon Scenario, from 1,483.7 to 1,632.1 million tCO□e (+10.0%).

In other words, despite the decline in average emission intensity resulting from electrification and improvements in fuel composition (−12.3%), the increase in road freight transport activity (+10.3%) outweighs the reduction in emissions per ton-kilometer, leading to continued growth in total emissions.

3.2 Interpretation of the Results

The above findings indicate that the carbon emission structure of China's road freight transport sector remains dominated by diesel consumption, and that the progress of electrification is the key factor in reducing carbon emission intensity. Although the average emission intensity (EF_{ave})decreases to 0.1890 kgCO□e/t·km under the Low-Carbon Scenario, total emissions continue to rise due to increasing transport activity. This suggests that improvements in fuel composition alone are insufficient for achieving a peak in transport-sector emissions before 2030, and that both demand-side management and structural transformation of the transport system must be promoted simultaneously.

As shown in Table 3 and Figure 2, road freight transport volume in China increased at an annual average rate of approximately 2% from 2015 to 2024, and the regression-based projections indicate that it will expand to approximately 8,650,000 million t·km by 2030. In other words, transport activity (A_{total})is expected to continue increasing as freight demand grows alongside economic development.

Given this situation, it becomes clear that, in order to reduce total emissions in 2030 to a level lower than at present, it is necessary not only to improve the fuel mix, as suggested by the scenarios, but also to substantially reduce the emission intensity per unit of transport activity compared with the current level. Specifically, assuming that total freight transport demand increases from 7,845,000 million t·km to 8,650,000 million t·km by 2030—an increase of approximately 10.3%—the average emission intensity would need to be reduced below the current level of 0.215405 kgCO□e/t·km merely to maintain total emissions at the present level (1,690.1 million tCO□e). Moreover, as the previous analysis indicates, achieving the 2030 target requires an emission intensity significantly lower than the current value. Examination of the minimum threshold for meeting this target reveals that the average emission intensity must be controlled at approximately 0.195 kgCO□e/t·km. This required level constitutes a "minimum threshold for realizing the emission peak," derived through back-casting from the analytical process. It should, therefore, be understood not as a future projection but as a conceptual scenario that specifies the indispensable conditions for achieving the target. If this scenario is regarded as an "ultra-low-carbon scenario," then a fuel mix consisting of roughly 30% diesel vehicles, 20–25% natural gas vehicles, and 45–50% electric vehicles would make it possible to attain this emission intensity, suggesting that achieving the 2030 emission peak is theoretically feasible. These findings indicate that, for the road freight transport sector to stabilize its emissions by 2030, a level of electrification and fuel decarbonization exceeding that of the current low-carbon scenario is essential.

4. Conclusion

In summary, the findings of this study clearly demonstrate that achieving decarbonization in China's road freight transport sector under the dual-carbon policy framework cannot be accomplished through fuel transition alone. Instead, it is essential to simultaneously advance a multifaceted set of measures, including transport-structure reform, improvements in operational efficiency, and the expanded use of renewable energy. The current Low-Carbon Scenario represents only a phase of "mitigating the upward trend in emissions," and achieving a genuine carbon peak will require more proactive expansion of electrification as well as stronger institutional and policy support.

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