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Urban Transportation Carbon Efficiency and ESG Performance: An AQI-Based Empirical Analysis in China

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Abstract: This study, based on the environmental protection (E) dimension of the ESG framework, quantifies urban environmental performance using the proportion of days with good air quality (AQI). It further investigates the impact of carbon efficiency in urban transportation on this performance. An OLS regression model was employed on panel data from ten major cities spanning 2019 to 2023 for empirical analysis. The results reveal a significant negative relationship between per capita transportation carbon emissions and urban environmental performance, suggesting that reducing transportation carbon intensity is an effective strategy to improve air quality and enhance ESG outcomes. These findings offer empirical support and practical guidance for city planners to integrate ESG objectives into transportation policies and to design coordinated emission reduction measures.

Keywords: urban transportation carbon efficiency; air quality index (AQI); environmental protection; ESG

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1. Introduction

Amid accelerating global urbanization, urban transportation systems face unprecedented challenges. Traffic congestion, environmental pollution, and energy consumption have become critical constraints on sustainable urban development. The transportation sector is a major source of global carbon emissions and urban air pollution, with vehicular emissions releasing substantial amounts of particulate matter (PM2.5), nitrogen oxides (NOx), and other harmful pollutants that adversely affect public health and urban livability. Concurrently, the ESG (Environmental, Social, and Governance) framework has gained widespread recognition as a key metric for assessing sustainable development, reflecting the growing consensus that long-term value creation should be evaluated through environmental stewardship, social responsibility, and sound governance [1].

Within the transportation sector, implementing ESG principles is crucial for driving green transformation. The Environmental (E) dimension, in particular, plays a central role in promoting sustainable mobility. Its importance lies not only in reducing emissions and energy consumption but also in protecting ecosystems throughout the entire life cycle of transportation systems, from infrastructure construction to vehicle operation and disposal. Accurately measuring and managing the environmental footprint of urban mobility is therefore a cornerstone of sustainable urban development [2]. However, a persistent challenge remains in quantifying transportation environmental performance in a manner that can be directly linked to measurable outcomes.

This study addresses this challenge by focusing on a precise and policy-relevant indicator: urban air quality. It proposes that the carbon efficiency of a city's transportation system-measured as per capita transportation CO_2 emissions-is intrinsically associated with ambient air quality, which directly influences residents' well-being. By empirically examining the relationship between transportation carbon efficiency and air quality within the ESG framework, this research aims to provide actionable insights for city planners seeking to integrate sustainable mobility strategies with broader environmental and public health objectives [3]. The findings are particularly relevant for rapidly urbanizing regions pursuing ambitious carbon reduction goals while managing urban growth.

2. Literature Review

China has been actively engaging in global environmental and climate governance, demonstrating a strong commitment to achieving its dual-carbon objectives, which include peaking carbon emissions by 2030 and attaining carbon neutrality by 2060. This ambitious agenda coincides with rapid urbanization, which has accelerated the development of urban transportation infrastructure. As a consequence, the transportation sector has emerged as a major contributor to urban carbon emissions, with its complex and dynamic emission patterns presenting significant challenges for effective carbon reduction. At the city level, the factors that drive transportation emissions exhibit notable spatiotemporal variability, reflecting differences in urban density, industrial composition, infrastructure planning, and mobility patterns [4]. These emissions mechanisms evolve dynamically across different periods and spatial scales, highlighting the need for context-specific strategies in urban environmental management.

Urban air quality is increasingly recognized as a critical indicator of environmental performance and a key component of sustainable urban development. The Air Quality Index (AQI), in particular, has gained attention as a comprehensive, policy-relevant metric because it captures the overall exposure of residents to pollutants, rather than merely quantifying emission levels. Metrics such as the number of days with good ambient air quality, combined with transportation-related CO_2 emissions, provide valuable insights into the effectiveness of environmental policies and the efficiency of urban mobility systems. Evidence suggests that deficiencies in transportation emission management can significantly affect urban air quality, especially in densely populated megacities, where high traffic volumes exacerbate pollution levels [5].

The role of policy-driven technological innovation, such as the promotion of electric vehicles and low-emission transportation modes, has been highlighted as an effective mechanism for reducing urban air pollution. Such initiatives not only contribute to emission reduction but also enhance broader environmental, social, and governance (ESG) outcomes, reflecting the growing integration of sustainability considerations into corporate and municipal decision-making. Despite these advances, empirical research applying statistical models like Ordinary Least Squares (OLS) to examine the relationship between transportation emissions and urban environmental performance remains relatively limited, leaving a gap in our understanding of the underlying mechanisms [6].

Recent literature in environmental economics has emphasized that the AQI should not be viewed merely as an outcome of pollution, but rather as a welfare-linked performance indicator that reflects residents' exposure risk, public health implications, and the effectiveness of regulatory interventions. Notably, the incorporation of per capita transportation CO_2 emission intensity into empirical studies has been limited, creating an important gap in the assessment of urban transportation environmental efficiency. Addressing this gap is crucial for developing evidence-based policies and targeted interventions aimed at improving air quality, optimizing urban transportation planning, and advancing sustainable urban development in the context of rapid urbanization.

3. Methodology

This study employs an empirical research approach, using balanced panel data from ten major Chinese cities-Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu, Hangzhou, Wuhan, Xi'an, Nanjing, and Tianjin-over the five-year period from 2019 to 2023. This period is strategically selected to capture a critical phase in China's implementation of its dual-carbon goals, while also encompassing the unique variations in transportation and economic activity induced by the COVID-19 pandemic and the subsequent recovery. This dataset provides a comprehensive basis for analyzing the interplay between urban transportation carbon emissions and environmental performance, a key component of the Environmental (E) dimension within the ESG framework [7].

Urban environmental performance is quantified using the Air Quality Index (AQI), a widely recognized and policy-relevant metric. The dependent variable is defined as the annual ratio of days with "Good" air quality (Air_Quality_Days_Ratio), providing a direct measure of outcomes relevant to citizen well-being and regulatory effectiveness. This approach extends beyond merely quantifying emission outputs, emphasizing the actual environmental quality experienced by urban residents. By employing a multivariate regression framework, the study aims to isolate the specific impact of transportation decarbonization on this key performance indicator, thereby offering insights into how green transportation initiatives tangibly enhance a city's ESG profile. This methodology addresses a notable gap in existing research by directly linking urban transportation efficiency with measurable ESG outcomes at the city level.

(1) Data Sources and Variable Definitions

The study draws data from authoritative databases.

1) **Dependent Variable:** Urban environmental performance (Air_Quality_Days_Ratio), measured as the annual proportion of days with "Good" air quality. Data were obtained from municipal ecology and environment bureaus as well as official city government websites.
2) **Core Independent Variable:** Per capita transportation carbon emissions (transport_CO2). This variable is calculated by estimating the transportation share of total city CO_2 emissions, based on total city CO_2 from the CEADs database and a benchmark value of 10% derived from authoritative reports, including the China National Greenhouse Gas Inventory, China Energy Statistical Yearbook, China Transportation Statistical Yearbook, and the Chinese Academy of Sciences' report on transportation carbon emission inventories. The transportation CO_2 emissions are then divided by the city's permanent resident population to obtain per capita values.
3) **Control Variables:** To account for other factors influencing urban environmental performance, the model incorporates:
   a) **gdp_per_capita:** Per capita GDP
   b) **urbanization_Rate:** Urbanization level
   c) **population:** Permanent resident population (in millions)
   d) **green_Transport_Investment:** Calculated using the allocation method: Green Transportation Investment = Transportation Expenditure from the city's General Public Budget Final Account Report × Assumed proportion allocated to green transportation projects.

Transportation expenditure data were obtained from city government websites and official budget reports. According to the City Business Charm Ranking released by Yicai's 'New First-Tier Cities Institute' in 2024, Beijing, Shanghai, Guangzhou, and Shenzhen are classified as First-Tier Cities, while the remaining cities are considered New First-Tier. The allocation ratio (α) is approximately 0.35 for First-Tier Cities and 0.25 for New First-Tier Cities, reflecting the higher share of investment in rail transit in larger cities [8].

(2) Model Specification

To test the hypotheses, this study constructs the following Ordinary Least Squares (OLS) multiple linear regression model:

$$\mathrm{AirQualityDaysRatio}_{i,t} = \beta_0 + \beta_1 TransportCO2_{i,t} + \beta_2 GDPPerCapita_{i,t} + \beta_3 Population_{i,t} + \beta_4 UrbanizationRate_{i,t} + \beta_5 GreenTransportInvestmen_{i,t} + \varepsilon$$

In this model, β_0 represents the intercept, while β_1 through β_5 denote the regression coefficients corresponding to the respective independent variables, and ε captures the random error term [9]. The model is designed to accurately isolate the net effect of per capita transportation carbon emissions on urban environmental quality, while controlling for factors such as economic level, population scale, stage of urban development, and policy-related investment [10]. The coefficient β_1, associated with the core independent variable transport_CO2, is expected to be significantly negative, indicating that higher transportation carbon emissions are linked to poorer ambient air quality (As shown in Table 1).

Table 1. Variables and Descriptions.

Variables	Descriptions	Source
Air_Quality_Days_Ratio	ESG or green development performance proxy - defined as the proportion of days with "Excellent or Good" AQI in a year	Official websites of municipal ecological environment bureaus (e.g., Beijing, Shanghai, Guangzhou, Chengdu, etc.)
transport_CO2	Per capita transport-related CO_2 emissions (total city CO_2 × assumed 10% transport share ÷ permanent population)	CEADs (Carbon Emission Accounts & Datasets for China); National greenhouse gas inventory reports
gdp_per_capita	GDP divided by permanent population	Municipal Statistical Yearbooks
urbanization_Rate	Permanent urban population ÷ total population	Municipal Statistical Yearbooks
population	Total permanent resident population (in millions)	Municipal Statistical Yearbooks
green_Transport_Investment	Annual public investment in green / low-carbon transport infrastructure projects	Municipal public budget reports; "Yicai New First-Tier Cities Report 2024" & Green Transportation and Low-Carbon City Financing Research Report 2017,for benchmark ratios

4. Results and Discussion

(1) Descriptive Statistics

As presented in the table below, the mean value of transport_CO2 is 0.72, with a standard deviation of 0.52. The mean of Air_Quality_Days_Ratio is 81.02, with a standard deviation of 9.98. For gdp_per_capita, the mean is 144,807.14, with a standard deviation of 35,677.09. The mean urbanization_Rate is 85.70, with a standard deviation of 5.89. The mean population is 1,301.32 million, with a standard deviation of 488.35. Finally, the mean green_Transport_Investment is 35.36, with a standard deviation of 36.16 (As shown in Table 2).

Table 2. Descriptive statistics.

	N	Min	Max	m	SD
transport_CO2	50	.132	1.618	.72507	.428887

Air_Quality_Days_Ratio	50	53.900	97.800	81.02000	9.980287
gdp_per_capita	50	79181.000	203489.000	144807.14000	35677.091575
urbanization_Rate	50	74.410	99.820	85.70440	5.889312
population	50	526.000	2488.000	1301.32000	488.350720
green_Transport_Investment	50	3.278	119.490	35.36392	36.157000

(2) Correlation Analysis

Correlation analysis is a statistical technique used to examine the relationships between two or more variables, providing insight into both the strength and direction of these associations. In this study, SPSS version 26 was employed to perform the analysis, assessing the correlations among the selected variables.

Generally, the closer the absolute value of a correlation coefficient is to 1, the stronger the association between the variables. In this study, coefficients below 0.3 are interpreted as indicating a weak or negligible correlation, values between 0.3 and 0.6 represent a moderate correlation, and coefficients above 0.6 are considered strong. A positive coefficient indicates a direct relationship between variables, whereas a negative coefficient reflects an inverse relationship [11,12].

The results, presented in the table below, reveal that Air_Quality_Days_Ratio is significantly negatively correlated with transport_CO2 ($r = -0.193$, $p < 0.05$). In contrast, Air_Quality_Days_Ratio exhibits significant positive correlations with gdp_per_capita ($r = 0.578$, $p < 0.05$) and urbanization_Rate ($r = 0.624$, $p < 0.05$), suggesting that higher economic development and urbanization levels are associated with better urban air quality (As shown in Table 3).

Table 3. Correlation table.

	transport_CO2	**Air_Quality_Days_Ratio**	**gdp_per_capita**	**urbanization_Rate**	**population**	**green_Transport_Investment**
transport_CO2	1	-.193	.212	-.054	-.365**	.007
Air_Quality_Days_Ratio	-.193	1	.578**	.624**	.165	.242
gdp_per_capita	.212	.578**	1	.703**	-.027	.583**
urbanization_Rate	-.054	.624**	.703**	1	.006	.484**
population	-.365**	.165	-.027	.006	1	.414**
green_Transport_Investment	.007	.242	.583**	.484**	.414**	1

(3) Regression Analysis

To assess the impact of transport_CO2 on Air_Quality_Days_Ratio, a hierarchical regression analysis was performed. In this model, transport_CO2 served as the independent variable, Air_Quality_Days_Ratio as the dependent variable, and gdp_per_capita, urbanization_Rate, population, and green_Transport_Investment were included as control variables.

The results indicate that, after accounting for the effects of gdp_per_capita, urbanization_Rate, population, and green_Transport_Investment, transport_CO2 remains a significant predictor of Air_Quality_Days_Ratio ($F = 11.628$, $P < 0.05$). Collectively, the variables in the model explain 56.9% of the variance in the dependent variable, as shown in Table 4.

Table 4. OLS regression.

	(1)	**(2)**
(Variables)	-13.459(-.738)	-.422(-.022)
gdp_per_capita	.000 (3.137) **	.000(3.541) ***
urbanization_Rate	.804(3.313) **	.674(2.693) **
population	.007(2.963) **	.006(2.187) ***
green_Transport_Investment	-.118(-2.895) **	-.111(-2.762) **
transport_CO2		-4.462(-1.672) **
R^2	.542	.569
F	13.307	11.628
p	0.000	0.000

5. Conclusion and Policy Implications

This study empirically investigated the relationship between per capita transportation carbon emissions and urban environmental performance, measured by air quality, using an econometric modeling approach. Analysis of panel data from ten major Chinese cities between 2019 and 2023 revealed a significant negative correlation between per capita transportation carbon emissions (transport_CO2) and the proportion of days with good air quality (Air_Quality_Days_Ratio). This finding underscores the critical importance of promoting a low-carbon transition in the transportation sector as a means to enhance the environmental dimension of urban ESG performance. Additionally, the results indicate that economic development, as measured by per capita GDP, and the degree of urbanization exert significant positive effects on air quality, whereas the environmental benefits of green transportation investment at the current stage require further realization.

Based on these findings, several policy implications are proposed:

First, strengthen top-level planning for transportation carbon reduction. Urban managers should recognize reducing per capita transportation carbon emissions as a central strategy for achieving the dual-carbon goals and improving ESG performance. This objective should be explicitly incorporated into urban green transportation development plans and integrated into performance assessment frameworks.

Second, implement comprehensive policy packages that balance structural and technological measures. While continued investment in new energy vehicles and related infrastructure remains essential, greater emphasis should be placed on optimizing urban travel patterns and increasing the public transportation share. Structural interventions aimed at reducing transportation demand can complement technological initiatives, jointly lowering carbon emissions at their source.

Third, enhance the precision and efficiency of green investment. The findings suggest that merely increasing investment volume does not automatically yield environmental improvements. It is therefore necessary to optimize the allocation and operational effectiveness of green transportation projects, establishing mechanisms for precision investment and impact evaluation guided by measurable outcomes in carbon reduction and air quality enhancement.

A limitation of this study lies in the estimation of transportation carbon emissions based on fixed proportions, without differentiating the effects of specific transportation policies, such as driving restrictions or congestion charges. Future research could incorporate more accurate, real-time transportation emission data and adopt comparative case study approaches to examine the implementation pathways and synergistic effects of diverse policy instruments. Such analyses would provide more actionable guidance for the green and low-carbon transformation of urban transportation systems.

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