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A Study on the Driving Factors of Carbon Emissions from China's Transportation Sector

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KEYWORDS

Transportation carbon emissions;

Driving factors; SPSS;

Stepwise regression method

ABSTRACT

The deep decarbonization of the transportation sector is of decisive significance for China to achieve its "dual carbon" strategic goals. The formulation of a scientific emission reduction path relies on the precise quantitative analysis of the driving factors of carbon emissions growth. This study systematically combed through China's macroeconomic, social and infrastructure data from 2004 to 2023, and selected 11 potential driving factors covering four dimensions: economic scale, industrial structure, population and society, and infrastructure. By using SPSS statistical software and comprehensively applying methods such as correlation analysis, curve estimation and multiple linear stepwise regression, a multi-factor prediction model for the turnover volume of each sub-sector of passenger and freight transportation was constructed for the first time in a systematic manner. The empirical results show that the output value of the secondary industry is the most stable core economic variable driving freight demand (especially railway and waterway transportation); the urbanization rate has a significant positive impact on freight (railway and air) and air passenger turnover volume, revealing the deep transportation demand brought about by spatial structure changes; port throughput, as an indicator of an outward-oriented economy and trade activity, is closely related to road freight and air passenger demand. This study identified and quantified the key macro drivers of transportation carbon emissions from the root cause of demand, not only providing a reliable quantitative tool for transportation demand prediction, but also offering solid empirical evidence and decision-making references for achieving source reduction through top-level design such as optimizing industrial layout, adjusting economic structure and guiding urbanization models.

INTRODUCTION

Under the urgent global agenda to address climate change and China's solemn commitment to peak carbon emissions by 2030 and achieve carbon neutrality by 2060, the green and low-carbon transformation of the transportation industry, as one of the fastest-growing sectors in energy consumption and carbon emissions, has become a national strategic focus. According to statistics, the carbon dioxide emissions from China's transportation sector have surged from 248 million tons in 2000 to 885.4 million tons in 2021, accounting for a continuously increasing proportion of the country's total carbon emissions[1]. Although the substitution paths of terminal technologies such as electric vehicles and hydrogen energy have attracted much attention, if the intrinsic driving force of transportation demand growth is ignored, the emission reduction effect of any technological route may be offset by the overall growth. Therefore, a thorough analysis and quantification of the underlying driving factors that affect transportation carbon emissions is a prerequisite for achieving deep decarbonization of the transportation system.

Existing research has yielded fruitful results in areas such as transportation carbon emission accounting[2-4], scenario forecasting[5-7], and emission reduction costs [8-13], widely adopting "top-down" or "bottom-up" approaches. However, there remains a notable gap in the systematic identification and quantitative attribution analysis of key drivers connecting the macro socioeconomic system with

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micro-level transportation emissions, particularly through rigorous statistical models for comprehensive multi-variable analysis. Most studies have only engaged in qualitative discussions or simple correlations, lacking measurements of net effects under the interference of multiple collinear factors.

In light of this, based on the Energy-Economy-Environment (3E) systems theory framework, this study views transportation carbon emissions as an outcome driven by the socioeconomic system. Utilizing the SPSS statistical analysis software, standardized statistical processing and modeling analysis were conducted on multidimensional panel data, aiming to achieve the following objectives: (1) identify key driving factors influencing the turnover of various transportation sectors from a pool of candidate variables; (2) establish quantitative forecasting models based on these key driving factors; and (3) interpret the underlying drivers of transportation carbon emissions growth from the demand-side perspective, thereby providing scientific support for formulating forward-looking and systematic emission reduction policies.

1.Research Methodology and Data Processing

This study adopts a "bottom-up" analytical paradigm. Transportation carbon emissions originate directly from the fuel consumption of various transport vehicles, which is jointly determined by the level of transportation activity (turnover of transportation sectors) and energy intensity. Among these, energy intensity is primarily influenced by technological progress, while the activity level is deeply constrained by the macro socioeconomic environment. Therefore, identifying and forecasting the activity level forms the basis for carbon emission prediction.

1.1.Variable Selection and Data Sources

Drawing on relevant domestic and international studies [14-22] and considering data availability, continuity, and representativeness, this study preliminarily selected 11 driving factors that may influence transportation turnover volume. These factors cover four major dimensions: Economic Scale Dimension: Gross Domestic Product (GDP), GDP per capita. Industrial Structure Dimension: Output value of the primary industry, secondary industry, tertiary industry, and the transportation sector. Population & Society Dimension: Total population, household consumption level, urbanization rate. Infrastructure Dimension: Railway operating mileage, cargo throughput of major coastal ports.

The historical data for all driving factors, as well as passenger and freight turnover volumes, span the period from 2004 to 2023. The baseline data are sourced from the *China Statistical Yearbook*, *China Transport Statistical Yearbook*, *China Ports Yearbook*, and the official database of the National Bureau of Statistics.

1.2.SPSS Analysis Methods

The entire research process is conducted using SPSS, with the main analytical methods including:

Normality Tests and Correlation Analysis:The Shapiro-Wilk (S-W) test is employed to assess the distribution pattern of the data. Based on the results, either Pearson or Spearman correlation coefficients are selected to preliminarily evaluate the strength of association between each driving factor and the turnover of each sector.

Forecasting of Driving Factors (Curve Estimation):To obtain future values for the driving factors, the "Curve Estimation" function in SPSS is utilized. Each driving factor is treated as the dependent variable and fitted against the time variable (year) using various functional forms (linear, logarithmic, quadratic, exponential, etc.). The optimal forecasting model is selected based on the highest R^2 value.

Core Model: Multiple Linear Stepwise Regression: This is the core of the research. Using the turnover of each transportation sub-sector as the dependent variable and the screened driving factors as independent variables, a stepwise regression method is applied to construct the forecasting model. This method automatically introduces and removes variables, effectively addressing multicollinearity issues, ultimately yielding a parsimonious and statistically significant model. The model's explanatory power is evaluated using the Adjusted R^2, its overall significance is tested via Analysis of Variance (ANOVA), the independence of residuals is assessed using the Durbin-Watson (D-W) statistic, and multicollinearity is diagnosed using the Variance Inflation Factor (VIF).

2.Empirical Results and Analysis

2.1.Data Foundation Tests and Correlation Analysis

Before conducting regression analysis, normality tests were performed on all variables. Taking freight railway turnover and its driving factors as an example, the Shapiro-Wilk test results indicated that the significance levels for most variables were greater than 0.05, suggesting they follow a normal distribution, with only a few variables such as "Population" being exceptions. This provides a basis for subsequently employing Pearson correlation analysis as the primary method.

Pearson/Spearman correlation analysis indicates (Table 1) that all pre-selected driving factors show significant correlations with freight railway turnover at the 0.01 level, with the absolute values of correlation coefficients mostly exceeding 0.8. This demonstrates that the preliminary variable selection is reasonable and provides a solid foundation for further in-depth regression analysis.

Variable	Railway Freight Turnover		Coefficient Type
	Significance (2-tailed)	Correlation Coefficient	
GDP	<0.001	.853**	K-S
GDP per Capita	<0.001	.857**	K-S
Population	<0.001	.774**	S-W
Household Consumption	<0.001	.834**	K-S
Primary Industry Output Value	<0.001	.864**	K-S
Secondary Industry Output Value	<0.001	.876**	K-S
Tertiary Industry Output Value	<0.001	.835**	K-S
Transportation Industry Output Value	<0.001	.847**	K-S
Urbanization Rate	<0.001	.820**	K-S
Railway Operating Mileage	<0.001	.797**	K-S
Port Cargo Throughput	<0.001	.833**	K-S

Table.1. Correlation Test between Driving Factors and Freight Railway Turnover

2.2. Identification of Key Driving Factors and Model Construction Based on Stepwise Regression

Taking freight railway turnover as an example, the SPSS stepwise regression process ultimately retained four variables, forming Model 4 (Table 2). The adjusted R-squared for this model is as high as 0.956, meaning the selected four variables explain 95.6% of the variation in freight railway turnover, indicating an excellent goodness-of-fit. The Durbin-Watson (D-W) value is 1.644, close to 2, suggesting no autocorrelation among the residuals. The ANOVA test shows an F-value of 105.223 ($p < .001$) for the model, indicating that the model as a whole is highly significant.

Model	R	R^2	Adjusted R^2	Standard Error
4	.983[d]	.966	.956	968.31953

Table.2. Summary of the Stepwise Regression Model for Freight Railway Turnover

The output value of the secondary industry and the urbanization rate are the core growth drivers: Their positive coefficients indicate that the deepening industrialization process and the rising urbanization level are the strongest macroeconomic forces driving the demand for railway freight. For every 100 million yuan increase in the output value of the secondary industry, railway freight turnover is expected to increase by 0.081 hundred million ton-kilometers.

The complex effects of population and railway operating mileage: Their negative coefficients may be related to multicollinearity among variables in the model and long-term structural changes. A possible explanation is that as population growth slows and the railway network becomes increasingly well-developed, the transportation efficiency per unit of operating mileage has improved, or substitution effects have emerged within the comprehensive transportation system, necessitating integrated analysis with other modes of transport.

3. Summary of Driving Factor Models for Each Transportation Sector

Using the same method, other passenger and freight subsectors were analyzed to obtain a series of key driver models, which are summarized in Table 3. The results show that the dominant driving factors vary significantly across different transportation sectors, reflecting different dimensions of economic activities.

Department	Branch	Fitting formula
Freight transport	Road	y=21100.812+0.171L-8228.589k
	Railway	y=367541.343+0.081f-3228.138k-3.154c+1919.86i
	Water	y=31088.501+0.198f
	Pipeline	y=-1002.001+0.007L
	Air	y=-273.002+8.392i

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Passenger transport	Road	y=31981.123+0.041L-4534.178k
	Railway	y=3909.719-0.619e+0.041L+0.339h
	Water	y=66.262-0.003e
	Air	y=-1710.358-0.361e+0.035L+2.058d-0.052a

Table 3. Summary of Key Driving Factors and Regression Models for Turnover in Passenger and Freight Sectors

In the table:
a: GDP
c: Population
d: Resident Consumption
e: Output Value of the Primary Industry
f: Output Value of the Secondary Industry
h: Output Value of the Transportation Industry
i: Urbanization Ratio
k: Railway Operating Mileage
L: Port Cargo Throughput
The results indicate:

1.Dominance of Industrial Structure: The output value of the secondary industry is not only the core driver for railway freight but also the sole significant driving factor for waterway freight. This clearly corroborates China's role as the "world's factory," highlighting the high synchronization between the cross-regional and import/export logistics of bulk raw materials and finished products with the development of heavy and chemical industries.

2.Comprehensive Impact of Urbanization: The urbanization rate drives not only railway freight but also serves as a key factor for aviation freight, reflecting the increasing demand for timeliness in logistics of high-value-added, lightweight products as cities develop. Simultaneously, it is one of the main drivers for aviation passenger transport, indicating frequent business and personnel exchanges between urban agglomerations.

3.Pull Effect of Trade and Consumption: Port cargo throughput, as a barometer of international trade, significantly influences road freight, railway passenger transport, and aviation passenger transport. This underscores the passenger and freight flow patterns shaped by both the export-oriented economy and internal consumption upgrading. The level of resident consumption has become a key explanatory variable for railway and aviation passenger transport, signaling rising demands for travel quality in a consumer-driven society.

4.Regulatory Role of Infrastructure: Railway operating mileage shows a negative correlation in the road freight model, possibly reflecting the substitution effect of an improved railway network on medium- to long-distance road freight flows. This demonstrates the inherent potential for optimizing the transportation structure.

Conclusion

Through systematic SPSS statistical analysis, this study has successfully identified and quantified the multi-dimensional key driving factors influencing China's transportation activity levels—the underlying source of carbon emissions. The main conclusions are as follows:

1. Driving factors exhibit clear sectoral heterogeneity: Different transportation sectors correspond to distinct dominant socioeconomic drivers. Freight sectors are closely tied to the industrialization process (secondary industry), while passenger sectors are more strongly linked to the upgrading of household consumption, trade activity, and urbanization-driven lifestyles.

2. The economic growth model defines the baseline for transportation carbon emissions: A development model dominated by the secondary industry inevitably entails rigid growth in the demand for bulk cargo transportation. This is the deep-seated structural reason behind the current high levels of transportation carbon emissions, particularly from freight.

3. Urbanization is a long-term growth driver: Urbanization not only directly stimulates passenger demand but also indirectly drives demand for time-sensitive freight by reshaping industrial layouts and consumption patterns. Its influence on transportation carbon emissions is therefore comprehensive and enduring.

This study primarily focuses on the identification of macro-level driving factors. In the future, the predicted activity levels from the model could be further integrated with energy-environment models such as LEAP. This integration could be used to quantify carbon emission pathways under different socioeconomic development scenarios and to evaluate the mitigation potential and cost-effectiveness of demand-side management policies, thereby constructing a more comprehensive decision-support system for transportation carbon emission reduction.

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