Empirical study on carbon emission measurement and influencing factors of urban traffic based on "Population-Economy-Environment"

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Abstract. Economic growth, urban expansion, traffic dependence, and urban lifestyle have caused a large amount of energy consumption and greenhouse gas emissions in cities. The issue of urban greenhouse gas emissions has become a global focus and a research hotspot. This paper analysed the causality of driving factors and identified the key elements such as urban population, economy, energy and motor vehicles through system dynamics (SD) and econometric model. Then, it conducted empirical analysis and explored the impact of factors on urban transportation carbon emissions taking Beijing as an example. The research results showed that in addition to energy consumption, other factors were positively correlated with traffic carbon emissions. It believed that in order to control urban traffic carbon emissions, we must control the urban population, economy and the number of vehicles rationally. With the optimization of energy structure, the structural adjustment of traffic energy consumption is conducive to energy conservation and emission reduction in the transportation industry, and the decoupling of the total energy consumption of traffic and the carbon emissions from transportation.

1. Introduction

IEA statistics showed that the global transport of CO₂ emissions accounts for about 25% of the total global emissions, and that of developed countries is about 30% [1]. The carbon emissions of the transportation industry have increased by 21% in the past 10 years in the EU [2]. The proportion of carbon emission in transportation industry is about 10% in China, and the growth is very significant. Therefore, exploring the mechanism of urban transportation carbon emissions and conducting empirical analysis has become a key and research hotspot for energy conservation and emission reduction in the transportation industry. Li Zhipeng [3] encouraged new energy and hybrid cars. Wang Yongxuan et al. [4] analysed the significant differences in population and per capita GDP changes on transport carbon emissions in economically more developed regions levels. Lv Qian et al. [5] showed that per capita GDP, energy intensity, tertiary industry share, and public transport are important drivers of carbon emissions. Li Lingjie et al. [6] believed that there are significant differences in the degree of impact on carbon emissions among the three levels of development: low, middle, and high-development. This article is going to analyse the “population-economy-energy” driving factor and mechanism of action on transport carbon emissions, and conducts empirical analysis.
2. SD causality analysis of transportation energy consumption and carbon emissions

2.1. Methods and subsystems
Urban transportation carbon emissions are a complex and dynamic system, and there are close dynamic causal relationships with factors such as urbanization, population, economy, public transport, private cars, and transportation energy consumption. Therefore, SD is suitable for dynamic simulation. The subsystem includes Population and economic subsystem, Public transport and Private Car subsystems, Energy consumption subsystems.

2.2. Cause and effect diagram
As an important part of economic life, urban transportation is a complex system composed of population and economy, public transportation and private cars, transportation energy consumption and carbon emissions.

2.2.1. Subsystem of Population and Economic. The development of urban economy has promoted the growth of per capita income and increased the attractiveness of the city. With the migration of the population more than moving out, it has promoted the further concentration of urban population [7]. Urban economic development, per capita disposable income, population growth, etc., have contributed to the growth in demand for transportation (in Figure 1).

![Figure 1. Causality diagram of urban population](image1)

![Figure 2. Subsystem of Public Transport and Private Car](image2)

2.2.2. Subsystem of Public Transport and Private Car. As the level of per capita purchases has increased, the demand for private cars has increased drastically, but car taxes, oil prices, and traffic restrictions have restrictions on private cars. The increase in private car ownership has enabled shared travel. From one aspect, it helps improve per capita income, ease traffic pressure, and reduce travel per person (in Figure 2).

2.2.3. Energy consumption subsystems. From the view of transportation demand, the growth of urban economic development, urban population gathering, and per capita disposable income have increased people's requirements for the quantity and quality of transportation. The urban transportation modes that cause traffic carbon emissions mainly include public transportation (buses, taxis), subway and private car traffic, resulting in an increase in the total amount of traffic energy consumption, making the transportation of carbon emissions increased rapidly, due to environmental policy control, negative feedback on the economic development of the city[8] (in Figure 3).
2.3. The factors affecting urban transportation carbon emissions

The increase in carbon emissions has been promoted. Therefore, urban population-economy-energy-vehicle ownership has led to the rapid growth of carbon emissions in the transportation industry. Empirical studies have been conducted on the four factors of urban population-economic-energy-vehicle ownership, and carbon emissions have been measured based on transportation energy consumption, and the actual factor analysis is conducive to the energy saving and emission reduction of the transportation industry and the sustainable development of green transportation.

3. Empirical analysis of carbon emissions measurement and impact factors based on energy consumption

3.1. The energy consumption structure of the transportation industry is gradually optimized

The type of transportation energy consumption in Beijing mainly includes coal, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas, natural gas, liquefied natural gas, thermal power, and electricity. The Beijing Statistical Yearbook for 2016 and previous years includes various types of energy consumption in the transportation industry[9]. There is no LNG consumption in the statistics, but in the 2017 yearbook, liquefied natural gas is newly added. For structural comparisons, LNG is converted to natural gas based on conversion factors. In order to compare the standardization of energy consumption, the standard conversion factor in the 2013 China Energy Statistical Yearbook was used to convert to standard coal (in Table 1). The conversion factors for various energy sources were 0.7143, 0.9714, 1.4714, 1.4714, 1.4571, 1.4286, respectively. 1.33, 1.7572, 0.0341 and 0.1229.

![Figure 5](image_url)

**Figure 5.** Changes in total energy consumption (10,000 tce) and its structure (%) of the transport industry in Beijing

In the dynamic changes in transportation energy consumption over the years, kerosene is the most consumed energy for transportation, accounting for more than 50% of the energy consumption of transportation. Followed by diesel, gasoline, diesel and gasoline accounted for about 20% of the
energy consumption of transportation. The consumption of natural gas and electricity has risen rapidly and currently accounts for about 10%. In particular, the promotion and application of new energy vehicles (hybrids, natural gas, electric vehicles, etc.) throughout the country have replaced diesel oil to a certain degree, which has reduced the growth in transportation energy consumption and reduced the energy consumption of transportation in China.

3.2. Style and spacing calculation method of carbon emissions in the transportation industry

Based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, the 2011 Provincial Guidelines for the Preparation of Provincial Greenhouse Gas Inventories, and other data, the calculations are based on energy consumption types and emission factors. The model is:

\[ C_i = \sum E_{it} \times f_i \times g \]

Among them, \( C \), \( E \), \( f \), \( g \) are carbon emissions, energy consumption, emission factors, and gasification coefficients (coefficient of conversion between carbon and carbon dioxide, respectively, \( g = \frac{44}{12} \)); \( i \) is energy types, including coal, gasoline, kerosene, diesel, fuel oil, and liquefied petroleum gas, natural gas, thermal power, and electricity. The carbon emission factors for them are 0.51826, 0.79774, 0.82307, 0.84434, 0.86467, 0.84582, 0.58969, 0, and 0, respectively[10].

3.3. Empirical analysis of key factors affecting carbon emission in transportation industry

The explained variable is the carbon emission (denoted by \( y \)), which is the direct carbon emission of traffic in Beijing, and excludes the direct emissions of indirect emissions such as heat and electricity. The explanatory variables are population, economic, energy, and vehicle ownership (represented by \( x_1 \), \( x_2 \), \( x_3 \), and \( x_4 \), respectively), which reflect the population, economic, energy, and motor vehicle growth in the study area (in Table 1).

Table 1. Historical Changes in Carbon Emissions and Key Factors in Beijing

| Year | Population (million people) | Economy (100 million yuan) | Energy consumption (10,000 tons of standard coal) | Motor vehicles (10,000 vehicles) | Traffic carbon emissions (10,000 tons of CO₂) |
|------|-----------------------------|-----------------------------|-----------------------------------------------|---------------------------------|---------------------------------------------|
| 2005 | 1538                        | 7141.4                      | 246.1                                         | 563.39                          | 1008.9513                                   |
| 2006 | 1601                        | 8312.6                      | 717.6                                         | 275.4                           | 1265.7607                                   |
| 2007 | 1676                        | 10071.9                     | 840.8                                         | 277.8                           | 1460.8004                                   |
| 2008 | 1771                        | 11392                       | 993.9                                         | 318.1                           | 1674.0685                                   |
| 2009 | 1860                        | 12419                       | 1025.2                                        | 401.9                           | 1746.6632                                   |
| 2010 | 1961.9                      | 14441.6                     | 1104.8                                        | 480.9                           | 1883.1702                                   |
| 2011 | 2018.6                      | 16627.9                     | 1185.9                                        | 498.3                           | 1898.8315                                   |
| 2012 | 2069.3                      | 18350.1                     | 1235.1                                        | 520                             | 2041.3453                                   |
| 2013 | 2114.8                      | 20330.1                     | 1145.5                                        | 543.7                           | 2042.8783                                   |
| 2014 | 2151.6                      | 21944.1                     | 1204.2                                        | 559.1                           | 2164.0451                                   |
| 2015 | 2170.5                      | 23685.7                     | 1249.4                                        | 561.9                           | 2212.9594                                   |
| 2016 | 2172.9                      | 25669.10                    | 1312.7                                        | 571.70                          | 2361.8362                                   |
| 2017 | 2172.9                      | 28014.9                     | 1386.8                                        | 590.9                           | 2495.3625                                   |

Source of data: Calculated from "Statistical Yearbook of Beijing" and "Yearbook of Energy Statistics" over the years.

In order to eliminate dimensionality, influence of oversized data, and generate data gorges while improving the convergence speed in data analysis, the data is first standardized. Build a multiple regression model with a linear regression model with \( k \) explanatory variables:

\[ y_t = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + \beta_3 x_{3t} + \mu_t \quad (t = 1, 2, ..., T) \] (1)
In equation (1), it is the coefficient, \( t \) represents the time, \( T \) represents the number of samples, \( n \) is the number of independent variables (\( n=4 \)), and \( \mu \) is the disturbance term (the part used to show that the change of \( y \) is not explained by \( x \)).

### Table 2. Regression Analysis Results

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|----------|-------------|------------|-------------|-------|
| C        | 0.017015    | 0.037996   | 0.447821    | 0.6707|
| X1       | 0.260888    | 0.461966   | 0.564735    | 0.5927|
| X2       | 0.379474    | 0.156790   | 2.420264    | 0.0518|
| X3       | -0.157935   | 0.276784   | -0.570606   | 0.5898|
| X4       | 0.474491    | 0.175541   | 2.703023    | 0.0354|

\[ R^2 = 98.8\%, DW = 1.937, F = 127.36 \]

\( R^2 = 98.8\% \), it can be judged that the model is well-fitting and statistically significant. Every one percentage point increase in population, economy, energy, and motor vehicle ownership will lead to a 0.261, 0.379, -0.158, and 0.474 percentage point increase in carbon emissions from the transportation industry. It reveals the positive correlation between population, economic and motor vehicle ownership and the growth of transportation carbon emissions, while energy consumption is negatively correlated with transportation carbon emissions. This is due to the fact that transportation carbon emissions are calculated from energy consumption, but energy consumption in the structure, heat and electricity are zero emissions during the operation of motor vehicles, and the proportion of electricity is growing. Therefore, the energy consumption of transportation is negatively correlated with the carbon emissions from transportation. It shows that the optimization of traffic energy consumption structure has a certain role in promoting traffic reduction, and the application of transportation new energy has a great contribution to green transportation, especially the national energy-saving emission reduction.

To analyze the relationship between independent variables and traffic carbon emissions further, analyze the causality between \( x \) and \( y \).

### Table 3. Granger Causality Tests among X1, X2, X3, X4 and Y

| Null Hypothesis                  | Obs | F-Statistic | Prob. | outcomes |
|----------------------------------|-----|-------------|-------|----------|
| Y does not Granger Cause X1      | 10  | 1.62502     | 0.0085| accept   |
| X1 does not Granger Cause Y      | 14.3389 | 0.2859     | accept|
| Y does not Granger Cause X2      | 10  | 0.16425     | 0.0737| accept   |
| X2 does not Granger Cause Y      | 4.59682 | 0.8529     | refuse|
| Y does not Granger Cause X3      | 10  | 13.6712     | 0.0094| accept   |
| X3 does not Granger Cause Y      | 3.38484 | 0.1176     | refuse|
| Y does not Granger Cause X4      | 10  | 8.68084     | 0.0236| accept   |
| X4 does not Granger Cause Y      | 3.37888 | 0.1179     | refuse|

Table 3 is F statistic and its probability significance level at the null hypothesis. The research results show that under the confidence level of 95%, the lag of 2, the transportation variables and carbon emissions are granger reasons, in the development of transportation industry, the growth of population,
economy contribution to the CO₂ from traffic with time lag. While the energy consumption from traffic is not obvious to contribute to the CO₂ from traffic with time lag.

4. Conclusions
The coupled effects of urban population, economy, energy, and motor vehicles have enabled the rapid growth of carbon emissions in urban transportation. Research indicates:
1) Through the SD causality analysis, identify the key factors affecting urban transportation carbon emissions, including population, economy, energy consumption and motor vehicle ownership. Explaining that to control urban transport carbon emissions, we must rationally control the urban population, economy, energy consumption and the number of motor vehicles.
2) Energy consumption is negatively related to transportation carbon emissions, and other factors are positively related. The control of urban transportation carbon emissions must be based on the total population, economic aggregates, and motor vehicle travel volume. Adjusting the industrial structure and the number of motor vehicle trips can effectively achieve low-carbon urban traffic.
3) In the gradual optimization of energy structure, the promotion and application of new energy transportation, electricity and heat in the transportation industry, the proportion of energy consumption has increased rapidly, and direct emissions are zero, optimization of traffic energy consumption structure is conducive to energy-saving emission reduction in the transportation industry, promote total traffic energy consumption is decoupled from traffic carbon emissions.

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