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Environmental Pollution Caused by the Transportation Industry and Influencing Factors of Carbon Emission: A Case Study of Jiangxi Province, China

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ABSTRACT

With the accelerating industrialization and urbanization in China, the energy consumption of the transportation industry in the country is increasing quickly, and its proportion to the total social energy consumption is significantly growing. The transportation industry is a main source of carbon emission in urban areas. The unreasonable structure of energy consumption, the low proportion of new-energy use, and low energy utilization influence the energy-saving and emission reduction in the transportation industry. Thus, in this work, the influencing factors of transportation-induced carbon emission were estimated to analyze the environmental pollution caused by the transportation industry further. Regression analysis was performed on the environmental pollution caused by the transportation industry and the influencing factors of carbon emission in Jiangxi Province, China. Subsequently, a random STIRPAT model was constructed, and the influencing factors of carbon emission from the transportation industry in Jiangxi Province from 2007 to 2017 were analyzed through the partial least squares (PLS) method. Regression results based on the PLS method were relatively ideal. Increases in gross domestic product per capita, population size, passenger person kilometers, rotation freight transport kilometers, and the number of car ownerships can intensify transportation-induced carbon emission. This emission is increased when transportation energy intensity declines, but can be significantly inhibited by increased energy prices. The conclusions of this study can provide references for the continuous optimization of the energy use structure in the transportation industry, saving of energy resources, reduction of greenhouse gas and pollutant emission, and acceleration of low carbonization in the transportation industry.

INTRODUCTION

Energy is an important pillar of economic and social development. Energy development and utilization promote economic development and progress. Recently, the transportation industry has become a major consumer of energy and the main source of CO_2 and pollutant emissions in the world. With the accelerating urbanization and industrialization in China, the energy consumption of the transportation industry in the country is increasing. Transportation industry has been ranked second in energy consumption for several successive years, only next to industrial energy consumption. Energy is an essential production element in national economic development, and it is the vein of national economies. As a fundamental industry that supports economic development, the transportation industry highly depends on energy. However, it can fully support national economies and drive the development of all industries in social economies only with sufficient energy supply. With the continuous large-scale energy consumption in the transportation industry, traffic pollution (including the quantity, concentration, and duration of the smoke, dust, and harmful gases emitted by vehicles) not only has exceeded the self-cleaning capacity of the atmospheric environment under natural states but also produces noises that are outside of the regulated range, thus exposing people and other creatures to pollution damages. Traffic pollution can be influenced by various factors of vehicles, such as traveling density, vehicle modes, fuel, operating state of vehicles, road conditions, and local physical geographic environments. Traffic pollution changes continuously at different moments and in various seasons.

Jiangxi is an important province with a large population in central China and has remarkable geological advantages in transportation. The transportation industry has rapidly developed. Figure 1 shows that rotation freight transport kilometers (RFTKs) were 228.549 billion tons/km in 2008 and 452.863 billion tons/km in 2018, showing an annual growth rate of 9.8%. This observation fully reflects the rapid development of the transportation industry in Jiangxi Province. The number of vehicles increased continuously during this rapid development, thereby significantly intensifying the traffic pollution in Jiangxi Province. The secondary photochemical smog formed by nitric oxides emitted by vehicles and the secondary pollution formed by ozone, particulates, and dust has become irreversible and severe regional and seasonable environment pollution problems in Jiangxi Province.

EARLIER STUDIES

Many in-depth studies on traffic pollution and the influencing factors of carbon emission have been reported worldwide. Transportation energy consumption is becoming a major source of total energy consumption for economic and social development in different countries. Air pollutants and greenhouse gas emissions brought by the excessive primary energy consumption of the transportation industry need to be controlled. Concerning traffic pollution, Duke et al. (1995) believed that vehicle repair, vehicle refueling, vehicle cleaning, and activities on paved roads and vehicle storage areas may cause water pollution in transportation the department. Rondinelli et al. (2000) stated that the influences of the transportation industry on the natural environment (e.g., air, water, and land resources) are becoming increasingly complicated and proposed some reasonable measures to prevent environmental pollution and natural resource degradation caused by the transportation industry. Mao et al. (2012) argued that the transportation industry in China has become a primary CO_2 emission source, which induces a large number of regional atmosphere pollutants. He believed that taxing for CO_2 emission might be an effective policy tool. Shrivastava et al. (2013) believed that most cities in India are experiencing extremely high levels of air pollution and found that transportation contributes largely to environmental pollution. Finally, an evaluation model for traffic pollutant emissions and effective measures for reducing traffic pollution have been proposed. Anenberg et al. (2019) believed that emissions from the transportation sector are the main cause of air pollution, which is a major contributor to global environmental health risks. Zhou et al. (2018) concluded that the rapid growth of transportation energy consumption and CO_2 emission brings considerable challenges to the energy demands and environmental problems in China. With respect to the influencing factors of transportation-induced carbon emission, Zhang et al. (2011) studied the influencing factors of the transportation energy consumption in China during 1980-2006 by using the LMDI method and found that the continuous growth of traffic turnover is the principal influencing factor. Energy intensity reduction caused by technological progress inhibits the growth of transportation energy consumption. Krautzberger et al. (2012) applied the Malmquist-Luenberger index of productivity model and compared the development of CO_2 productivity in the commercial transportation industry in Europe during 1995-2006. He found that the transportation industry's sensitivity to carbon emissions changed significantly in most European countries, and the average productivity efficiency declined to some extent. Chung et al. (2013) studied transportation-induced carbon emissions in China from 2003 to 2009 and found that the high growth rate of diesel consumption in freight transportation was the main contributor to the overall energy consumption growth. Tiwari et al. (2013) investigated the causes of energy consumption changes in the transportation industry in India and found that

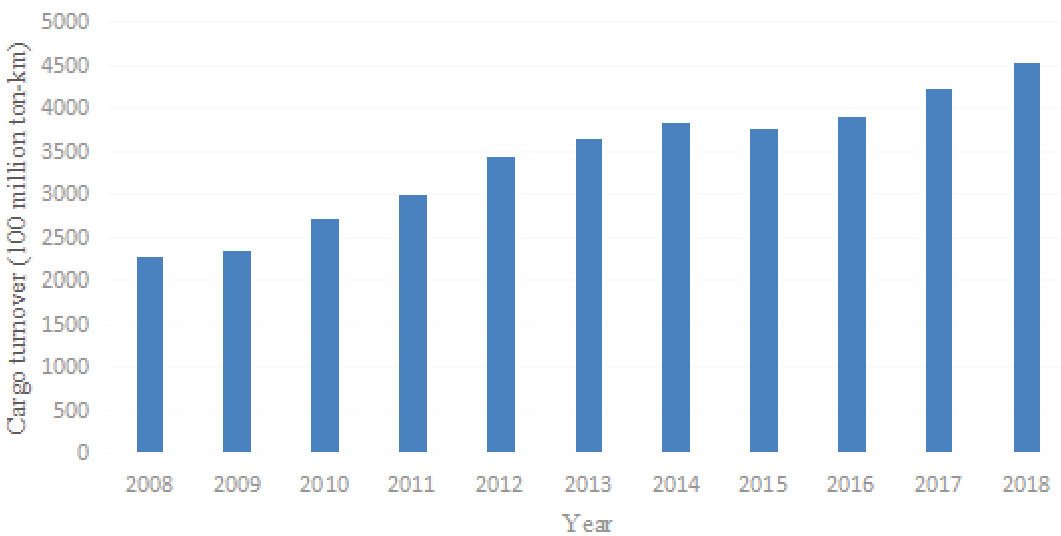

Fig. 1: RFTKs in Jiangxi Province from 2008 to 2018.
(Data source: Statistical Yearbook of Jiangxi (2009-2019))

changes in energy consumption are attributed to the growth of freight volume, structural change or mode transformation, and energy intensity. Xu et al. (2015) applied the vector autoregression model to analyze the influencing factors of transportation-induced CO_2 emission in China and found that energy efficiency plays a dominant role in CO_2 emission reduction. Moreover, the large-scale use of private cars, the continuous growth of RFTK, and accelerating urbanization can significantly influence the growth of CO_2 emission in the transportation industry. Fan et al. (2016) analyzed the influencing factors of transportation-induced carbon emission in Beijing based on the extended Kaya identical equation and concluded that economic growth, energy intensity, and population size are major positive driving factors of such emission. Lin et al. (2017) investigated the influences of gross domestic product (GDP) per capita, energy intensity, carbon intensity, and total population in China's transportation industry on CO_2 emission from 1980 to 2010 through quantile analysis and found that GDP, energy intensity, and carbon intensity affect carbon emission more than urbanization. Based on Beijing-Tianjin-Hebei panel data during 1995-2016, Guo et al. (2019) analyzed the driving factors of CO_2 emission in the transportation industry. Guo found that transportation energy intensity and economic effect are the major causes of increased CO_2 emission, whereas energy structural effect is the main reason for reduced CO_2 emission in the transportation industry. Most scholars emphasized the national level of transportation-induced carbon emission and preferred to use the factor decomposition method to analyze basic indexes, such as economy, population, energy intensity, and car ownership. A case study of Jiangxi Province centered at RPK, RFTK, and energy price was conducted to provide policy suggestions for energy saving and emission reduction and for realizing green sustainable development in the transportation industry.

MODEL CONSTRUCTION AND DATA SOURCE

STIRPAT Model

Environmental deterioration is generally the collaborative consequence of demographic factors, economic development, and technological development. In the 1970s, the IPAT equation was produced to study the action mechanism among demographic development, wealth, technological progress, and the environment. To overcome the shortcomings of the IPAT equation, Dietz et al. (1994) constructed a random STIRPAT model of the IPAT equation. This model involves a randomness variable in addition to the original variables of the IPAT model, thus enabling superior empirical analysis. Thus, an extensible random environmental effect assessment model was formed. The detailed STIRPAT model can be expressed as formula (1):

$$I_i = aP_i^b A_i^c T_i^d \varepsilon_i \qquad \ldots(1)$$

Where, I_i denotes the environmental factors; P_i denotes the demographic factors; A_i is the affluence degree; I_i is the technological level; b, c, and d are the parameters that have to be estimated; and ε_i is a random error term. This model assumes that ecological environmental pressure is accompanied by the combined influences of population size, affluence degree, and technological level. The model formula is expressed as an exponential function; however, it is generally transformed into logarithmic form for convenient operation in practical studies, thereby not only potentially eliminating the possible heteroscedasticity problem but also possibly estimating parameters through linear regression. After the natural logarithms, the model is rewritten as formula (2):

$$LnI_i = a + bLnP_i + cLnA_i + dLnT_i + \varepsilon_i \qquad \ldots(2)$$

On the basis of the concept of elastic coefficient, the regression coefficient of the equation reflects the elastic relationship between dependent and independent variables. It reflects changes in the dependent variables for each 1% change in an independent variable when other independent variables are fixed. The STIRPAT model still maintains the original product structure of the IPAT equation. Population, affluence, and technology are still decisive factors that influence the environment. Meanwhile, the STIRPAT model accepts unit root test and allows the decomposition of environmental and technological factors. For the flexibility of the STIRPAT model, relevant variables can be added into the original model in accordance with the research goal. The extended relevant factors are included into the STIRPAT model in this study on the basis of development changes in the transportation industry in Jiangxi Province and current traffic pressure. The influence degrees of economic level, population size, energy intensity, RPK, RFTK, energy price, and the number of car ownerships on carbon emission are analyzed thoroughly. The expanded model can be expressed as formula (3):

$$\ln C_i = a + b_1(\ln GDP_i) + b_2(\ln POP_i) + b_3(\ln ENE_i)$$
$$b_4(\ln PAS_i) + b_5(\ln FRE_i) + b_6(\ln PRI_i) + b_7(\ln VEC_i) + \varepsilon_i \qquad (3)$$

Where, C_i denotes the environmental influences and is expressed by transportation-induced carbon emission in Jiangxi Province. *GDP* refers to the GDP per capita. *POP* is the popularization size. *ENE* is the energy intensity. *PAS* is RPK and *FRE* is RFTK. *PRI* is the energy price. *VEC* is the number of car ownerships, and ε_i is a random error.

Generally, population change, social and economic development, and technological innovation are connected, influenced, and constrained mutually. Therefore, time series data involving these three factors often have multiple collinearity problems. Multiple collinearities can not only increase the variance of parameter estimation but also exclude important explanatory variables from the model, thus ignoring the meaning of the significance test of variables. Therefore, a regression analysis based on partial least squares (PLS) is conducted. This regression analysis integrates the characteristics of multiple linear regression, principal component analysis, and typical correlation analysis. PLS can screen and extract principal components that influence dependent variables mostly in the system and recognize valid information in the regression process.

DATA SOURCE

Time series data in Jiangxi Province during 2007-2017 were selected. Data about energy use and energy intensity in the calculation were collected from the China Energy Statistical Yearbook. During carbon emission estimation, the carbon emission coefficients of different energy sources were the carbon emission coefficient adopted by the Energy Research Institute of National Development and Reform Commission. Per capita consumption level was transformed into the constant price in 2007. Data about population size, RPK, RFTK, and the number of car ownerships were selected from the *Statistical Yearbook of Jiangxi* during 2008-2018. Energy price data were obtained from the *Price Yearbook of China*.

RESULT ANALYSIS

PLS regression results were calculated using the SIMCA-P software (demo version 11.5). Table 1 lists the results.

Table 1: PLS regression results.

Variable	Nonstandardized coefficient	Standardization coefficient
C_i	−23.041	4.685
GDP	1.654	0.178
POP	3.158	0.194
ENE	−0.629	−0.287
PAS	0.541	0.125
FRE	0.875	0.116
PRI	−3.871	−0.268
VEC	0.784	0.381
$R^2X(cum)$	0.845	-
$R^2Y(cum)$	0.821	-
$Q^2(cum)$	0.904	-

Table 1 indicates that $R^2X(cum)$, $R^2Y(cum)$, and $Q^2(cum)$ are indicators of the fitting degree of the extracted principal components, and all values are higher than 0.8, indicating that PLS regression results are relatively ideal. Economic factors are the most important factors that influence transportation-induced carbon emission in Jiangxi Province. Economic growth increases transportation-induced carbon emission in Jiangxi Province, and every 1% growth of GDP per capita may increase transportation-induced carbon emission by 1.654%. Jiangxi Province has been exhibiting rapid economic growth since 2008. In particular, economic development has increased residential income after the implementation of the "central China" development, thereby promoting an increase in consumption level and changes in lifestyle and travel modes. Products consumed by residents produce abundant CO_2 emission in the transportation link. The economy of Jiangxi Province will maintain a stable and high growth rate over a long period in the future, which may increase transportation-induced carbon emission to an excessive extent. Population growth also significantly increases carbon emission. Every 1% increase in population size may result in 3.158% growth transportation-induced carbon emission in Jiangxi Province. Recently, the population size of Jiangxi Province has been increasing quickly because the province has been undertaking industries from coastal regions, and the processing and manufacturing industries have been attracting abundant employees. Population growth in Jiangxi Province may lead to increased energy demands and traffic pressure in cities and may accelerate population mobility. As a result, transportation-induced carbon emission continues to increase. Transportation-induced carbon emission increases with the reduction of energy intensity. The increase in transportation-induced carbon emission is the collaborative consequence of multiple factors. On the one hand, increased carbon emission caused by demographic changes and economic development offsets the reduced carbon emission brought by technological progress. On the other hand, energy consumption can be saved by the increased energy utilization after technological progress, accompanied by increased demands for new energy sources, due to the rebounding effect. The collaborative consequence is manifested by increased carbon emission upon technological developments. As the industrial upgrade in Jiangxi Province continues in the future, technological progress still has a large development space. The transportation-induced carbon emission increases with RPK, which is related to the economic development level in Jiangxi Province. Large-scale spatial migration of the population exists in Jiangxi Province due to accelerating urbanization. In particular, the perfecting of traffic infrastructures, such as the Shanghai–Kunming railway and highways, has brought significant growth in passenger capacity to Jiangxi Province and facilitated economic development and energy consumption, resulting in the continuous growth of carbon emission. The increase in RFTK increases transportation-induced carbon emission. RFTK can influence transportation-induced carbon emission more than RPK. With evident geological traffic advantages, Jiangxi Province has an exerted effort to develop a modern logistics industry. Freight transportation considerably depends on railways and shipways. The favorable railway and shipping transportation conditions in Jiangxi Province establish a good foundation for the development of this modern logistics industry. Transportation-induced carbon emission in Jiangxi Province is decreased by 3.871% for every 1% increase in energy price, showing a significant inhibition effect. Energy price growth forces some transportation enterprises to reduce activities, thus decreasing carbon emission. Private cars are convenient for the travel of residents. The proportion of passengers in public transportation declines with an increased number of car ownerships, thus further increasing transportation-induced carbon emission.

POLICY SUGGESTIONS

Strengthening formulation and implementation of tax policy for traffic pollution: Tax policy for pollution is a compulsory environmental policy formulated by the government. For traffic pollution, a certain tax will be collected from vehicles with excessive emissions or under environmental standards. The collected taxes will be applied to improve environmental quality. According to the preset of the Pigou Institute, external marginal cost is internalized into the private cost to stimulate dischargers to lower emissions and pollution discharge amounts. The charging system for traffic pollutant emission will be implemented to vehicle users of households, individuals, and organizations. Traffic pollutant emission charges for each vehicle shall be calculated from the total annual pollutant emission of traffic loads in Jiangxi Province. Vehicle users shall pay for pollutant emission during the annual inspection, thus inhibiting the use frequency of vehicles. Guiding and encouraging people to use vehicles with small emission capacity and encouraging enterprises to produce vehicles with small emission capacity are important measures for saving energy and reducing emissions because vehicles with small emission capacity have small weights, small oil consumption, and relieved environmental pollution.

Accelerating development of low-energy consumption transportation mode: Considerable effort shall be exerted to promote high economic growth in Jiangxi Province. Currently, the proportions of transportation mode and energy consumption of highways in Jiangxi Province are significantly higher than those of other transportation modes. Government shall accelerate the construction of a comprehensive energy-saving traffic system and fully develop relative advantages of different transportation modes through the overall planning of the comprehensive traffic system. A reasonably balanced development of different transportation modes with considerations for the natural geological environment and economic development status will be promoted in Jiangxi Province. Moreover, the connection and information levels of infrastructure in the comprehensive traffic system shall be improved to realize the fast transshipment of passengers and freight and increase transportation service quality and efficiency. Investment and support for railway, ship, and tube transportation shall be increased. Jiangxi Province shall increase the proportion of transportation modes with low single consumption and guide bulk cargo to energy-saving environmentally friendly transportation modes. The attractions of the railway to freight transportation and the railway transportation service quality of passengers and freight shall be improved. The advantages of speed and comfort of high-speed railway relative to highways shall be developed.

Increasing technological innovation level in the transportation industry: Jiangxi Province shall accelerate the improvement of transportation tools and the development of clean energy sources. Outdated vehicles with high energy consumption will be eliminated, and the development of transportation vehicles toward large-sized and diesel consumption types will be guided. In addition, the province shall promote the development of new-energy vehicles, increase the fast charging technology of electric vehicles, and improve the cruising power of batteries. Subsidies to electric vehicles shall be increased, and the competitive edges of new-energy vehicles relative to traditional vehicles will be strengthened. Railway transportation shall promote the use of electric locomotives, gradually decrease the proportion of diesel locomotives, and reduce dependence on petroleum products. Substantive efforts shall be made to promote the update of old ships and develop ships toward large and professional types. The province shall popularize clean-energy products (new electric cars). Nowadays, the energy supply shortage is severe, and pollution is intense. The government shall formulate relevant regulations to develop and use new energy sources and the developed tail gas purification devices. The government requests car owners to install this device. On the basis of the overall transportation industry, the current situation of pollutant emission (traffic pollution shall be classified independently in general surveys of secondary pollution) shall be analyzed. Moreover, emission reduction technologies shall be developed, demonstrated, and popularized. Studies on monitoring pollutant emission reduction and verification technologies shall be conducted. Jiangxi Province must formulate and adjust national emission standards and price policies in favor of emission reduction to increase the proportion of railway transportation. It should likewise implement relevant industrial pollution control technological standards and norms.

Increasing public consciousness in transportation-related environmental protection: The government shall increase publicity and public consciousness about environmental protection through television, broadcast, WeChat, MicroBlog, network media, newspapers, forums, and brochures, especially in rural areas. These efforts can guide the public to abandon bad habits of carelessly throwing waste and spitting in public areas. They can also advocate afforestation, energy saving, emission reduction, and recycling (e.g., focusing on the classification and recycling of household wastes, reasonable processing of waste straws, reducing the use of white waste bags, advocating vehicles with small emission capacity, using public transportation, and reducing the use of pesticides). Environmental protection education shall be offered in schools, and environmental protection curriculums should be established. Government affairs related to transportation-related environmental protection shall be open to the public to increase information transparency. The public shall be motivated to supervise traffic pollution behaviors, and attention shall be given to public reporting and relevant rewarding systems.

CONCLUSIONS

The transportation industry is a typical high-energy-consumption industry. The energy consumption by the transportation industry in China has been increasing with social economic and industrial development, which causes a considerable challenge to energy saving in the entire society and industry. In this work, a case study of Jiangxi Province is conducted. A random STIRPAT is constructed, and the influencing factors of transportation-induced carbon emission in Jiangxi Province during 2007-2017 are analyzed through PLS regression. The results demonstrate that transportation-induced carbon emission is positively related to GDP per capita, population size, RPK, RFTK, and the number of car ownership, but negatively related to traffic energy intensity. With the increase in energy price, transportation-induced carbon emission can be inhibited significantly. Energy-saving and emission reduction in the transportation industry can be realized by strengthening the formulation of tax policy for traffic pollution, accelerating the development of low-energy-consumption transportation modes, improving technological innovation of the transportation industry, and increasing public consciousness in transportation-related environmental protection. Thus, the province should conduct further studies on the systematic influencing factors of transportation-induced energy consumption, transportation-induced energy consumption in different economic development regions, and influencing mechanisms on transportation energy consumption, as well as different transportation modes in influencing factors of energy consumption.

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