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Environmental Pollution and Energy Efficiency of Regional Transportation Industry: A Case Study of Jilin Province, China

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ABSTRACT

The transportation industry is the fundamental and strategic industry for social and economic development. However, this industry becomes a considerable barrier against green, sound, and sustainable economic and social development due to the rapid increase in energy consumption and greenhouse gas emission. Transportation industry becomes one of weakness of energy saving and emission reduction with its increasing energy consumption and carbon emission. Environmental pollution caused by the transportation industry can be relieved effectively by increasing energy efficiency. A case study based on Jilin Province, China is carried out. First, environmental pollution types caused by regional transportation industry are analysed. Second, energy efficiency of transportation industry in eight prefecture-level cities in Jilin Province from 2011 to 2017 is determined using the DEA-Malmquist index. Finally, measures to control environmental pollution caused by the transportation industry are proposed. Results show that in Jilin Province, environmental pollution caused by the transportation industry manifests through increasing energy consumption, pollution from car exhaust, and degree of traffic jams. In its eight prefecture-level cities, the average energy efficiency change index of transportation industry is 1.054, which is higher than 1. The means of technological efficiency and progress are 0.973 and 1.084, respectively. The mean pure technological efficiency of energy use slightly increases, while the mean scale efficiency decreases significantly. Results can provide beneficial references for full understanding on energy consumption and environmental emission of transportation industry in Jilin Province. This understanding can lead to the exploration of scientific and reasonable energy-saving and emission-reduction ways and countermeasures, aiming to offer decision-making references for energy saving and emission reduction of the transportation industry in Jilin Province.

INTRODUCTION

The transportation industry is the fundamental and strategic industry for social and economic development. However, this industry becomes a considerable barrier against green, sound, and sustainable economic and social development due to the rapid increase of energy consumption and greenhouse gas emission. Moreover, the transportation industry is typically characterized by high-energy consumption, which increases with continuous economic, social, and industrial developments and proposes a huge challenge to the whole society and energy-saving development of the industry. Nevertheless, industry energy consumption show significant regional differences in China. Lack of regional energy-saving goals and policy may cause mutual restraints between development and energy saving of regional transportation industries.

Jilin Province experiences continuous economic prosperity and accelerating urbanization. As such, pressure over resources and environment intensifies due to the rapid growth of urban population and dramatically expanding urban scale, accompanied with increasing prominent negative externality of economic agglomeration. “Urban diseases,” which are centred at atmospheric pollution and traffic jams, are becoming important factors that restrict the development of different cities in Jilin Province. In this province, the transportation industry is the pillar industry of national economic development, attracting wide attention and serving as a key industry with high-energy consumption and pollutant emission. Table 1 shows that this transportation industry accounts for high-energy consumption and causes heavy environmental pollution. As a response to economic development and rising population and number of vehicles in Jilin Province, transportation demands continuously increase. Moreover, problems such as traffic jams, transportation pollution, energy consumption, and public health become more prominent. Therefore, full understanding on energy consumption and pollutant emission of Jilin Province under various transportation policies is significant to the future sustainable development of the province. In addition, this understanding can provide decision-making references to

Table 1: Energy consumption of transportation industry in Jilin Province from 2010 to 2017.

Year	Raw coal (10,000 tons)	Gasoline (10,000 tons)	Coal oil (10,000 tons)	Diesel (10,000 tons)	Electricity (TWh)
2010	125.3	40.43	0.23	194.06	12.76
2011	116.97	40.27	0.23	213.42	13.94
2012	85.32	43.51	0.25	238.58	14.47
2013	76.89	37.85	0.25	256.74	17.43
2014	249.62	39.06	0.25	216.33	17.87
2015	312.73	37.58	0.26	198.68	19.22
2016	294.01	35.98	0.36	193.12	22.95
2017	214.04	45.88	5.2	213.91	24.63

realize the goal of energy saving and emission reduction and increase environmental performance of industries.

EARLIER STUDIES

Environmental pollution from and energy efficiency of the transportation industry are key concerns of the academic circle. Recently, the energy efficiency of the transportation industry has been widely discussed, but environmental constraints and the unexpected output from energy input are mostly ignored. Given that carbon emission is a by-product of transportation, studies on energy efficiency of highway traffic should consider the negative effects of and consider CO_2 emission as an unexpected output. These studies aim to accurately evaluate energy efficiency of the transportation industry under environmental constraints. With respect to environmental pollution caused by the transportation industry, Bose (1998) mainly estimated the traffic demands of residents in Delhi, Calcutta, Bombay, and Bangalore in India from 1990 to 2011. SO_2 and NOx emissions caused by the transportation industry were believed to be the main causes of environmental pollution. Poon et al. (2006) simulated influences of energy, transportation, and trade activities on local air pollutant emission (e.g., SO_2 and smoke particles) based on the environmental Kuznets model. Carbon black particle pollution in China caused by the transportation industry is more severe than SO_2 pollution. Atabani et al. (2011) pointed out that the transportation industry is the second highest in energy consumption, next to the industrial sectors. Energy consumption of the transportation industry accounts for 30% of global transmission energy. Highway traffic leads in oil consumption, accounting for 81% of total energy transportation demands. The transportation industry causes significant environmental pollution. Peng et al. (2015) believed that the increasing urban passenger transportation, as a result of the rapid growth of vehicle quantity in China, causes energy consumption, greenhouse gas emission, and atmospheric pollutants (NOx, CO, HC, and PM). In addition, the most effective regulation of vehicle quantity could reduce energy consumption, CO_2, and atmospheric pollutant emissions to the maximum extent. Bansal (2018) believed that in developing countries, such as India, urbanization hinders sustainable growth of rapid mechanization and transportation infrastructures, and emissions from highway transportation are partial causes of ozone consumption, acid deposition, and other climatic changes. With respect to energy efficiency, Wang et al. (2012) believed that transportation industry accounted for approximately 8% of total energy consumption in China. The direct rebound effect of urban passenger transportation is also investigated and validated empirically. Using the double logarithmic regression equation and error correction model, Wang et al. (2014) measured the long- and short-term direct rebound effects through panel data of 31 provinces in China from 1999 to 2011. A partial rebound effect is observed in highway freight transportation in China, and the increasing energy efficiency independently is not very satisfying. Liu et al. (2016) measured energy environmental efficiency of highway and railway departments in 30 Chinese provinces by combining non-radial data envelopment analysis (DEA) model and window analysis. The findings show U-shaped and inverted U-shaped curves of the relations between energy environmental efficiency and income level of highway and railway departments. Wu et al. (2016) measured energy and environmental performances of China's transportation system using DEA. Empirical findings demonstrate relatively low energy efficiency of transportation system in most provinces and effective control measures are proposed. Song et al. (2016) calculated environmental efficiency of highway transportation system in different regions in China. The environmental efficiency of China's highway transportation system is found generally unsatisfying, accompanied with considerable regional differences, excessive energy consumption, and motor vehicle pollution in most regions. Liu et al. (2018) studied interprovincial energy efficiency of the transportation industry in China and relevant influencing factors, finding evident gradient distribution of energy efficiency. The highest energy efficiency among the transportation industries are found in provinces in East China, followed by those in central and West China. This interprovincial difference in energy efficiency is gradually narrowing. Liu et al. (2019) evaluated energy and environmental efficiencies of the highway transportation industry in China. Empirical proof shows that diffusion and use of optical production technology in the highway transportation industry in Western and Central China is superior to technological innovation progress. Omrani et al. (2019) evaluated energy efficiency of transportation departments in 20 Iran provinces by combining DEA and cooperative game method. Compared with large economic provinces, several small economic provinces show better energy efficiency in their transportation industry. Extant studies show that the transportation industry cause heavy environmental pollution during its development, but such pollution can be relieved effectively through technological progress and improvements in energy efficiency. Increasing energy utilization of the transportation industry is the most important way to solve the contradiction between its rapid development and the goals of energy saving and emission reduction. Therefore, scientific evaluation of energy efficiency of the transportation industry in prefecture cities of Jilin Province (China), exploring key factors to improve energy efficiency, and proposing specific suggestions present important practical significance to green sound development of the transportation industry.

TRAFFIC POLLUTION STATUS OF JILIN PROVINCE

Continuous Increase of Energy Consumption by the Transportation Industry

The automobile industry of Jilin Province is flourishing. The quantity of cars in cities is quickly increasing in recent years. Fig.1 shows that the quantity of cars for highway transportation in Jilin Province increased from 179,700 in 2006 to 351,900 in 2018. This sharp increase causes energy consumption and tail gas pollution that are difficult to avoid. The transportation industry is a major energy consumer, and the proportion of its energy consumption to total social energy consumption increases continuously.

Continuous Intensification of Tail Gas Pollution of Cars

Most cities in Jilin Province have developed highway transportations and various types of motor vehicles, resulting in highly excessive tail gas emission compared with standard figures. Dust particle density is relatively high and urban air pollution is observed. Fig. 2 shows the external diseconomies brought by rapid development of the transportation industry and inappropriate transportation development in Jilin Province. PM2.5 emission is rapidly intensifying. Vehicle emission has become a primary pollution source such as CO and hydrocarbon. Tail gas emission from cars is extremely high in most cities of Jilin Province. In addition, externality of air pollution caused by the increased tail gas emission of vehicles cannot be ignored, thus resulting in chronic intoxication of the central nervous system and functions of the human body, manifested by headaches and crossing eyes.

Gradual Intensification of Traffic Jams

With the increasing traffic demands of residents in Jilin Province, road traffic changes from smooth to disordered, and commuting takes longer to reach destinations. When traffic demands further increase and exceed the ultimate traffic efficiency in places with minimum traffic capacity, the road traffic state changes accordingly. Traffic jams not only cause invalid waiting and wasted times, but also decreases efficiency of the transportation system and causes traffic accidents.

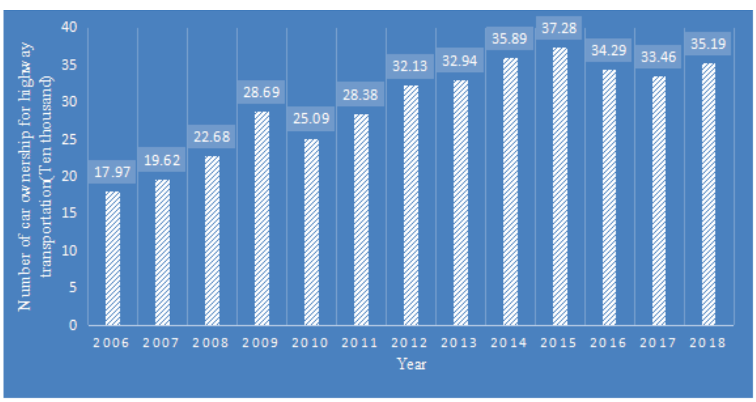

Fig.1: Number of car ownership for highway transportation in Jilin Province in 2006-2018.
(Data source: Jilin Statistical Yearbook)

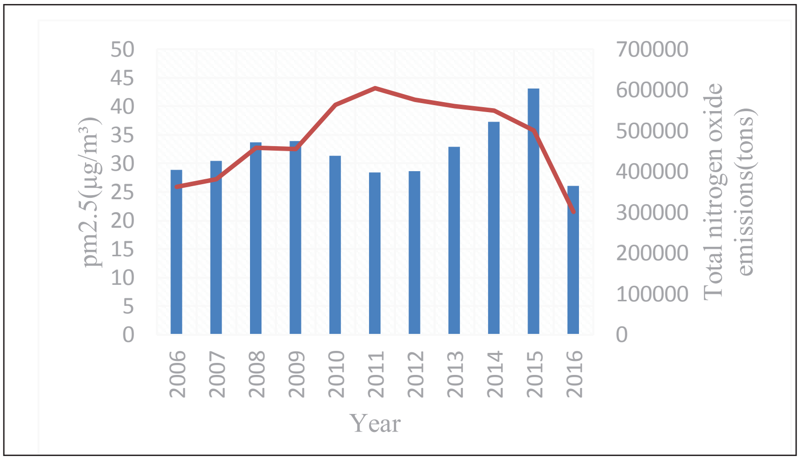

Fig. 2: PM2.5 and total Nitrogen oxide emissions in Jilin Province in 2006-2016.
(Data source: Jilin Statistical Yearbook)

More importantly, traffic jams cause negative external cost. Fuel utilization decreases whereas energy consumption and pollutant emissions increase, because pollutant emissions from incomplete combustion during traffic jams are far higher than pollutant emissions during normal driving.

Brief Introduction to The Model and Data Specification

Introduction to the model: Following Färe et al. (1992), the DEA-Malmquist Index, which is under variable returns to scale, oriented to output, and uses t and t+1 as technical references, is defined in formula (1):

$$M_{t,t+1} = \frac{D_{t+1}^{v}(x_{t+1},y_{t+1})}{D_{t}^{v}(x_t,y_t)} \times \left[\frac{D_{t}^{v}(x_t,y_t)}{D_{t}^{c}(x_t,y_t)} \div \frac{D_{t+1}^{v}(x_{t+1},y_{t+1})}{D_{t+1}^{c}(x_{t+1},y_{t+1})}\right] \times \left[\frac{D_{t}^{c}(x_t,y_t)}{D_{t+1}^{c}(x_t,y_t)} \times \frac{D_{t}^{c}(x_{t+1},y_{t+1})}{D_{t+1}^{c}(x_{t+1},y_{t+1})}\right]^{\frac{1}{2}} \quad \ldots(1)$$

Where $D^{c}(x,y)$ is the distance function under constant returns to scale and $D^{v}(x,y)$ is the distance function under variable returns to scale. $\frac{D_{t+1}^{v}(x_{t+1},y_{t+1})}{D_{t}^{v}(x_t,y_t)}$ is the change of pure technological efficiency (PTEC), $\frac{D_{t}^{v}(x_t,y_t)}{D_{t}^{c}(x_t,y_t)} \div \frac{D_{t+1}^{v}(x_{t+1},y_{t+1})}{D_{t+1}^{c}(x_{t+1},y_{t+1})}$ is the change of scale efficiency (SE), $\left[\frac{D_{t}^{c}(x_t,y_t)}{D_{t+1}^{c}(x_t,y_t)} \times \frac{D_{t}^{c}(x_{t+1},y_{t+1})}{D_{t+1}^{c}(x_{t+1},y_{t+1})}\right]^{\frac{1}{2}}$ and is technological progress (TC). In other words, the product of the previous two terms is the change of technological efficiency (EC). When $M_{t,t+1}$ >1, total factor productivity (TFP) progresses. When $M_{t,t+1}$ < 1, TFP regresses. When $M_{t,t+1}$ =1, TFP is constant. In the panel data analysis of the transportation industry in Jilin Province, TFP decomposes into the product of TC and EC. EC is further decomposed into the product of PTEC and SE. On this basis, the influence of PTEC and SE on technological efficiency can be determined. Contributions of pure technological inefficiency and scale inefficiency to influences of PTEC and SE, respectively, can be recognized separately as long as nontechnological efficiency is discovered in efficiency estimation of the transportation industry. On the basis of these results, policy suggestions are proposed. Specific meanings of different indexes are introduced as follows: Malmquist Index refers to the change process of TFP. The change index of EC is to measure whether production meets the optimal resource allocation. The change index of TC reflects changes of production technologies. The change index of PTEC is part of production technological inefficiency caused by pure technological inefficiency. The change index of SE is to judge whether the decision-making units are in the optimal production scale.

Data specification: Input indexes include capital, labour, and energy input. Capital input refers to fixed-asset investments (10,000 Yuan) to transportation industry in different cities of Jilin Province. Labour input refers to the number of employees in the transportation industry at year-end (10,000 persons). Energy input refers to energy consumption of the transportation industry (10,000 tons of standard coal). Energy resources consumed by transportation industry, such as coal, oils, natural gas, heating power, and electricity, are all transformed to standard coal. Output indexes include turnover volume of passenger traffic and of freight transport. The former is mainly expressed by annual passenger person-kilometres (10,000 persons km) and the latter is mainly expressed by freight turnover (10,000 tons km) in each city. This study uses panel data of eight prefecture cities of Jilin Province from 2011 to 2017. Data of various input and output indexes are all collected from Statistics Yearbook of Jilin Province.

RESULT ANALYSIS

Energy efficiency of the transportation industry in different prefecture cities of Jilin Province was decomposed dynamically using the Malmquist Index by estimating the comprehensive efficiency of energy utilization. Regional differences and their causes were analysed. Annual variations of TFP of the transportation industry in Jilin Province from 2011 to 2017 were estimated using the DEAP2.1-XP software package from the perspective of output. Table 2 lists the results.

Table 2 shows that in eight cities of Jilin Province, the mean energy efficiency change index of transportation industry was 1.054 from 2011 to 2017, which was higher than 1. Energy utilization of transportation industry in Jilin Province increased to a certain extent during the study period. In view of the decomposition results, the mean EC and TC are 0.973 and 1.084, respectively. This finding reflects that energy utilization of the transportation industry increased by 0.54%, including 0.84% attributed to TC and 0.27% attributed to EC. Specifically, EC hindered the improvement of energy utilization. The mean PTEC of energy utilization increased slightly whereas the mean SE decreased significantly, indicating that EC reduction was mainly attributed to SE reduction. EC and SE were relatively low and could potentially increase. EC reached 1.015, and could further increase. The energy utilization of the transportation industry in Jilin Province was generally low due to low SE. EC and SE of the transportation industry in Jilin Province from 2011 to 2017 generally decreased, but PTEC was relatively stable. This finding possibly occurred because of the increased efforts in external industrial structural transfer and transportation enterprises made fundamental investments in response to the government's call of "industrial transfer". Enterprises were in the investment period and were exploring new technologies. Meanwhile, production scale was not controlled at a reasonable level. Enterprises were adapting to new policies. After 2012, Jilin Province increased investment to traffic infrastructure, released various successive policies, and encouraged investments of abundant capital and labour forces into the "Harbin-Changsha Urban Agglomeration" and "Changsha-Jilin-Tumen Development and Opening Up Pilot Region". These programs promoted the overall technological innovation transportation industry in Jilin Province, and comprise one possible cause why the EC of the transportation industry in Jilin Province was retained over 0.9 before 2012. However, SE was not as high as PTEC, because huge capital investment was mainly applied to technological innovation and expansion in the enterprise scale. Instead, enterprise problems of production efficiency were ignored, thus resulting in high PTEC and low SE.

POLICY SUGGESTIONS

Improve the Transportation Structure and Accelerate Development Transportation Mode with Low Energy Consumption

Jilin Province can accelerate energy-saving comprehensive transportation system, develop relative advantages of different transportation modes by planning the transportation system, and promote reasonable equilibrium development of different transportation modes by closely combining natural geological environment and economic development status. These improvements likewise increase the connection and informatization level of infrastructures of the comprehensive transportation system, realize fast transit of passenger and freight, and improve quality and efficiency of transportation services. Jilin Province can increase investment and support for railway, shipment, and pipeline transportation, increase proportion of transportation modes with low

Table 2: Variations of energy production efficiency indexes of the transportation industry of Jilin Province.

Year	EC	TC	PTEC	SE	TFP
2011-2012	0.755	1.021	1.087	0.695	0.771
2012-2013	0.832	0.976	1.002	0.830	0.812
2013-2014	0.925	1.286	0.982	0.942	1.190
2014-2015	0.987	1.042	0.998	0.989	1.028
2015-2016	1.123	1.153	1.008	1.114	1.295
2016-2017	1.214	1.025	1.012	1.200	1.244
Mean	0.973	1.084	1.015	0.958	1.054

single consumption, and guide transfer of bulk cargo to energy-saving environment-friendly transportation mode. Railway transportation in the market can be increased, and attention is necessary to improve service quality of railway passenger transportation. The speed and comfort advantages of railway, in relation to highway, can be improved through the development of high-speed rails. Considerable efforts can be made to develop urban public transport and railway system to increase public commuting rates.

Reduce Energy Consumption Intensity and Increase Energy Utilization of The Transportation Industry

Jilin Province can formulate more energy-saving policies to decrease energy intensity. With the improvement of transport tools and development of clean energies, the existing transportation industry still has high energy-saving potential. For highway transportation, old vehicles with high-energy consumption can be eliminated. Instead, highway transportation vehicles can be developed in larger sizes and fuelled by diesel. Moreover, Jilin Province can promote the development of new energy automobiles, improve quick charge technology of electric cars and cruising ability of batteries, increase subsidies for electric cars, and strengthen competitive advantages of new energy cars in relation to traditional vehicles. For railway transportation, Jilin Province can promote the application of electric locomotives, gradually decrease proportion of diesel locomotives, and decrease dependence on petroleum products. In addition, the province can update old ships to larger sizes and professional makes, increase proportions of ships using clear energy dynamics, decrease energy-saving construction of civil air transportation system, choose the latest energy-saving transportation vehicles, and improve organization and management technologies of civil transportation.

Strengthen Energy Saving and Emission Reduction of the Transportation Industry, and Develop Public Transport System

Jilin Province can pay much attention to energy saving and emission reduction of land transportation, such as by implementing policies of public transport priority, perfecting relevant infrastructure equipment, and decreasing energy wastes while assuring and increasing transportation capacity. In addition, Jilin Province can increase proportion of clean energy in land transportation and shipment. Pilot projects and construction of relevant infrastructures from aspects which are easy to be regulated, including public bus, taxi, and water bus, can also be implemented. Good commuting conditions can be achieved to encourage citizens to choose biking and walking and advocate slow commuting. Moreover, these conditions enrich transportation mode, optimize transportation layout, combine land transportation and shipment organically, and take advantage of both transportation modes.

Pay Attention to the Development of Energy-Saving Technologies and Increase Technological Input

As a significantly effective transition direction, energy-saving technological development for the transportation industry can effectively save energies and decrease emissions in a relatively short period, which is a strong stimulus of the market and consumers. TC not only increases traditional energy efficiency, but also accelerates transition of other transportation modes such as electrification. Attention and investment to energy-saving technologies can be increased appropriately, while diversified parties, including scientific research units and enterprises, can be encouraged to participate in R&D. As such, potentials of technological energy saving from aspects of light weight, small size, and low-resistance electronic control, car network and intelligent driving, and applications of new materials, biofuel, and liquid hydrogen can be explored. Such enhancements can quickly and effectively accomplish energy transition of the transportation industry. With respect to transportation energy technologies, Jilin Province can respond to national policies to develop energy-saving technologies and assure marketing of energy-saving vehicles. For energy structure in the transportation industry, energy updating of urban transportation requires completion as soon as possible through economic means from private sectors and relevant enterprises, mandatory requirements on public sectors, and increased promotion of new clean energy vehicles.

CONCLUSIONS

Influences of the transportation industry on environmental pollution in urban areas of a certain region are increasing gradually. Energy consumption and atmospheric pollution are intensifying gradually. The transportation industry has rapidly become the highest contributor to energy consumption in the region. Accordingly, CO_2 emission from the transportation industry is increasing gradually. Hence, its energy transition development is urgently necessary. Development modes in foreign countries prove that the main direction to realize such energy transition in urban transportation is through increased energy efficiency of the industry by adjusting energy structure and developing energy-saving technologies. In this study, a case study is carried out on Jilin Province, China. Types of environmental pollutions caused by the regional transportation industry are analysed. Additionally, energy efficiency of the transportation industry in eight prefecture cities of Jilin Province from 2011 to 2017 is estimated using DEA-Malmquist. The results demonstrate that in Jilin

Province, continuously increasing energy consumption of the transportation industry, tail gas pollution of vehicles, and degree of traffic jams are the main types of environmental pollutions caused by the transportation industry. In the eight prefecture cities of Jilin Province, the mean energy efficiency change index of the transportation industry is 1.054, indicating the improvement of energy efficiency. The mean EC and TC are 0.973 and 1.084, respectively. The mean PTEC slightly increases whereas the mean SE significantly decreases. Further exploration is suggested for the factor decomposition of energy consumption of the transportation industry, interaction mechanism among different influencing factors of energy efficiency, systematic dynamic simulation between transportation industry and ecological environment, practicability of transportation energy policies in different regions, and effects of environmental and economic policies on transportation-induced environmental pollution control in cities with different development degrees.

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