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Energy Consumption Status and Energy Efficiency of Transportation Industry: The Case of China

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ABSTRACT

Transportation industry is an important pillar in China's economic development and one of the main industries that consumes fossil energy and emits pollution gases. Decreasing the pollutant emission during the energy consumption process by improving energy efficiency of the transportation industry can realize coordinated development of transportation industry and ecological environment. The existing literature regarding estimation of energy efficiency in the transportation industry was reviewed firstly. Then, energy consumption status of transportation industry in China was summarized. In addition, the data envelopment analysis (DEA) model was presented to estimate transportation energy efficiency. Results demonstrate that the transportation industry's energy consumption status can be manifested by sustainable rapid growth of total energy consumption, continuous high proportion of energy consumption of the transportation industry in total energy consumption, and year-by-year growth of energy utilization efficiency. The mean values of industrial energy overall technical efficiency, industrial energy pure technical efficiency and industrial energy scale efficiency are 0.994, 0.998, and 0.996. Moreover, the overall conditions of the energy input and output efficiency in the transportation efficiency are benign and stable. The conclusions in this study are important positive reference for adjusting energy consumption structure, realizing energy conservation and emission reduction objectives, and improving economic efficiency and technological progress in terms of energy utilization of the transportation industry.

INTRODUCTION

The transportation industry, a fundamental and service industry of the national socio-economic development, is an essential aspect to guarantee normal development of industries and agriculture. China's economy has entered a rapid growth period in recent years, accompanied by economic growth, accelerated urbanization progress, and continuous growth of turnovers of freight and passenger traffic, as shown in Fig. 1. The transportation industry is a key national terminal energy utilization industry. Transportation pollution has become the main air pollution source, and energy conservation in the transportation industry is an urgent requirement in relieving intense energy utilization and satisfying transportation demand. Expanding the transportation capability is the most direct measure of satisfying transportation demand. More transportation demands can be satisfied under consumption of equal amount of energy sources with the improving energy consumption efficiency. Therefore, it is of vital significance to get full understanding of the environmental pollution and energy consumption conditions caused by the transportation industry, estimate energy consumption efficiency, establish the key points of energy conservation in the transportation industry to pertinently determine its energy saving potential and propose energy conservation and emission reduction measures in the transportation industry are necessary.

EARLIER STUDIES

Under the energy crisis in the 1970s, governments of developed countries started concerning on energy efficiency, formulated and implemented energy efficiency standards, and forced and guided energy conservation from laws and regulations, which achieved remarkable results. Considerable domestic and foreign studies have been conducted for environmental pollution caused by the transportation industry and estimation of energy efficiency. In the aspect of environmental pollution caused by the transportation industry, Fu et al. (2000) conducted a simulation study of the dynamic relation between the transportation on one street in Beijing and air pollution. Komarov et al. (2006) proposed the paths used to improve transportation safety and decrease concentration of hazardous emissions in cities. Wen et al. (2017) established a system dynamics model to study the influence of different strategies on transportation energy consumption and carbon emission using Beijing as an example. Bayasgalan et al. (2017) analysed the environmental pollution status caused by road traffic in Ulaanbaatar City and estimated and predicted carbon emission in the transportation industry. Advenier et al. (2002) analysed the relation between energy efficiency in road traffic and CO_2 emission from the perspective of comparative analysis of technology and fuel. Sperling et al. (2009) estimated energy efficiency in American transportation industry and believed that deep-rooted expectations and habits of consumers resulted in the difficult utilization of new energy sources and low-carbon fuels. Romanos et al. (2010) used linear programming optimization technology to analyse an existing problem regarding allocation of urban new land utilization activities and improve energy utilization efficiency in the transportation industry. Liao et al. (2013) estimated the influences of energy consumption in Taiwan on wind energy efficiency and CO_2 emission. Cui et al. (2014) used a three-phase DEA model to estimate energy efficiency in the transportation industry and discovered that the transportation structure and management measures could exert important influences on transportation energy efficiency. Song et al. (2014) estimated energy efficiencies of the Shanghai transportation industry from 2000 to 2010 and proposed some suggestions for energy policies of the transportation industry. Phoualavanh et al. (2015) deemed that land transportation was the main mode of transportation in Laos and consumed 96% of the total energy sources utilized by the transportation department. Energy consumption and CO_2 emission could be decreased through fuel conversion, advanced technologies, and pattern conversion. Zhen et al. (2016) studied the energy performance of China's transportation efficiency, and results indicated that it presented an overall descending trend. Moreover, the main cause for degrading transportation energy efficiency was the decrease of technical performance. Meng et al. (2017) analysed the energy efficiency of the urban high-speed coaching traffic system and indicated that a bus rapid transit had better energy and environmental performance than normal bus traffic. Chen et al. (2018) estimated transportation energy efficiencies in 15 cities in the Yangtze River Delta during 2009-2013, and results showed that per capita gross domestic product and paving area in a city had negative influences on efficiency value. According to existing literature, the continuous growth of energy consumption in the transportation industry will unavoidably result in a series of environmental pollution. Developed countries have effectively decreased environmental pollution by improving its energy efficiency. Therefore, energy utilization efficiency of the transportation industry was estimated to promote transition of the transportation industry from low-efficiency extensive, and high-pollution mode into high-efficiency, intensive, and clean mode through pertinent measures on the basis of an analysis of causes for environmental pollution due to the transportation industry.

ENERGY CONSUMPTION STATUS OF TRANSPORTATION INDUSTRY

Sustainable rapid growth of total energy consumption: Transportation is the foundation for survival and development of modern society, and normal operation of transportation and production of all kinds of social activities are inseparable from the support of energy. Reliance on and demand for energy sources of the transportation industry are presenting continuous growth in its prosperous development with economic development. The total energy consumption in China's transportation industry in 2015 was approximately 383.17 million tons of standard coal, which was nearly 2.4 times of that in 2000 with annual growth rate being 16% as shown in Fig. 2.

Continuous high proportion of energy consumption: As shown in Fig. 3, the growth rate of the total energy consumption in China continuously increases. Moreover, the proportion of the total energy consumption in the transportation industry in the total energy consumption in the entire China is always kept within 7%-9%. Simultaneously, as China's transportation industry uses petroleum as the main energy source, the proportion of the total petroleum consumption in the entire society is only second to the industry, and the growth rate is particularly high.

Year-by-year growth of energy utilization efficiency: Energy consumption intensity is a comprehensive evaluation index of energy conservation and emission reduction in the transportation industry, including energy consumption of unit gross domestic product and per unit turnover. As shown in Fig. 4, energy consumption intensity has decreased year by year since 2000, thereby indicating that the concept of energy conservation and emission reduction of the transportation industry has received substantial support as energy utilization efficiency improved year by year.

RESEARCH METHODOLOGIES

Model profile: The data envelopment analysis (DEA) method is a kind of non-parametric system used to evaluate production efficiency, where the "relative efficiency" concept can be used to evaluate the effectiveness of the bus route operation performance and resource utilization status. This model was used to analyse China's transportation energy efficiency from a macroscopic angle.

In the mode, n decision-making units exist. Each decision-making unit has m and s types of input and output variables, respectively, thereby expressing "consumed resource" and "working performance" of this unit. $x_{ij}(x_{ij} > 0, i = 1, 2, \cdots, m)$ is used to represent the numerical value given by the j[th] decision-making unit to the i[th] input variable; and $y_{rj}(y_{rj} > 0, r = 1, 2, \cdots, s)$ indicates the numerical value given by the j[th] decision-making unit to the r[th] input variable. After Archimedes infinitesimal ε , the input s^- and generated s^+ slack variables are introduced. Finally, the model is the expression form of Formula (1).

$$\begin{cases} \min\left[\theta - \varepsilon(\hat{e}^T s^- + e^T s^+)\right] \\ s.t. \sum_{j=1}^{n} X_j \lambda_j + s^- = \theta x_0 \\ \sum_{j=1}^{0} Y_j \lambda_j - s^+ = Y_0 \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda_j \geq 0, j = 1, 2, \cdots, n \\ s^- \geq 0, s^+ \geq 0 \end{cases} \quad ...(1)$$

Where, $X_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T$; $Y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T$; $\hat{e} = (1, 1, \cdots, 1)^T \in E^m$; $e = (1, 1, \cdots, 1)^T \in E^s$; $X_0 = X_{j0}$; $Y_0 = Y_{j0}$; $s^- = (s_1^-, s_2^-, \cdots, s_m^-)^T$; and $s^+ = (s_1^+, s_2^+, \cdots, s_m^+)^T$

Data processing: According to the total factor productivity theory, energy, capital, and labour force of the transportation industry are utilized as input factors of energy efficiency evaluation. Moreover, the economic output and environmental influence of the transportation industry are used as output indexes. The time-series data of China's transportation industry during 2007-2015 are investigated, and a concrete index selection is shown in Table 1.

As shown in Table 1, concrete values of the four indexes-energy consumption, fixed-asset investment, employment figure, and added value of the transportation industrycan be directly collected and organized from the database of National Bureau of Statistics of China (http://data.stats.gov.cn/). At present, China has no established statistical system regarding CO_2 emission yet with particularly few authoritative statistical data. In addition, acquiring data regarding CO_2 emission is difficult. Therefore, CO_2 emission in the transportation industry can be obtained only through indirect calculation of the carbon emission coefficients, as shown in Table 2.

RESULTS AND ANALYSIS

A computational analysis was conducted for the processed data under the output guide using software (DEAP 2.1) to evaluate whether the energy efficiency of China's transportation industry remained high during the nine years from 2007 to 2015. The CRSTE is technical or comprehensive efficiency; VRETS is pure technical efficiency; and SCALE is scale efficiency (drs is progress decrease of scale efficiency; and irs is progressive increase of scale efficiency), where $\text{CRSTE} = \text{VRSTE} \times \text{SCALE}$.

As shown in Table 3 (energy efficiency in China's transportation industry during 2007-2015), the mean values of the comprehensive, pure technical, and scale efficiencies reach 0.994, 0.998, and 0.996, respectively. Thus, within the nine years, the overall energy input and output efficiency of China's transportation industry is good and stable. During the nine years, the annual comprehensive efficiency "invalid" year accounts for 4/9, and the mean values of the comprehensive, pure technical, and scale efficiencies are 0.987, 0.996, and 0.991, respectively. The scale over pure technical efficiency is lower in the four years, and the main cause for zero comprehensive efficiency is scale efficiency, thereby indicating that the increment of the transportation energy input is smaller than the output increment. Specifically, a problem of insufficient input exists. Therefore, China's transportation industry should further increase the element input and improve its pure technical efficiency.

As shown in Table 4, the slack movement values of employment figure, added value, and CO_2 emission in the transportation industry are 268 ten thousand tons of standard coal, 65 million 760 thousand people, 3 billion 500 million yuan, and 790 thousand tons respectively in 2009, while scale efficiency presents progressive reduction of scale remuneration, mainly because energy consumption of China's transportation industry and fixed-asset investment were large in 2007. Consequently, effectively coordinating various production aspects of the transportation industry is diffi-

Table 1: Input-output index system.

Input-output factor	Index	Unit
Energy input	Energy consumption of the transportation industry	Ten thousand tons of standard coal
Capital input	Fixed-asset investment in the transportation industry	100 million yuan (RMB)
Labor force input	Employment figure in the transportation industry	Ten thousand people
Economic output	Added value in the transportation industry	100 million yuan (RMB)
Environmental output	CO_2 emission in the transportation industry	Ten thousand tons

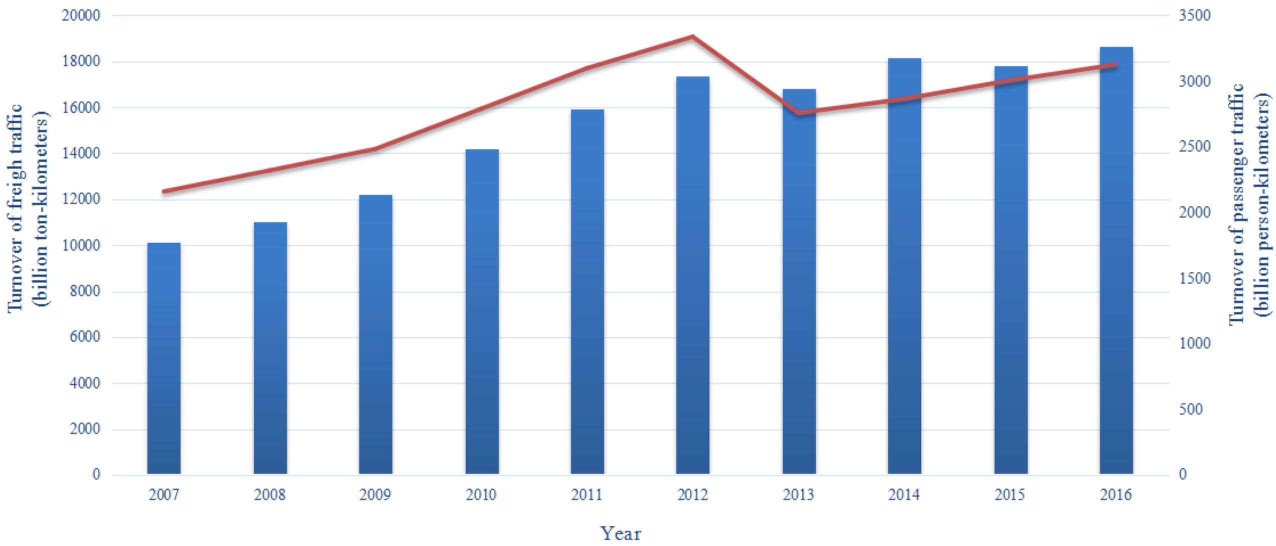

Fig. 1: Turnovers of freight and passenger traffic during 2007-2016.
(Data source: China Statistical Yearbook (2008-2017))

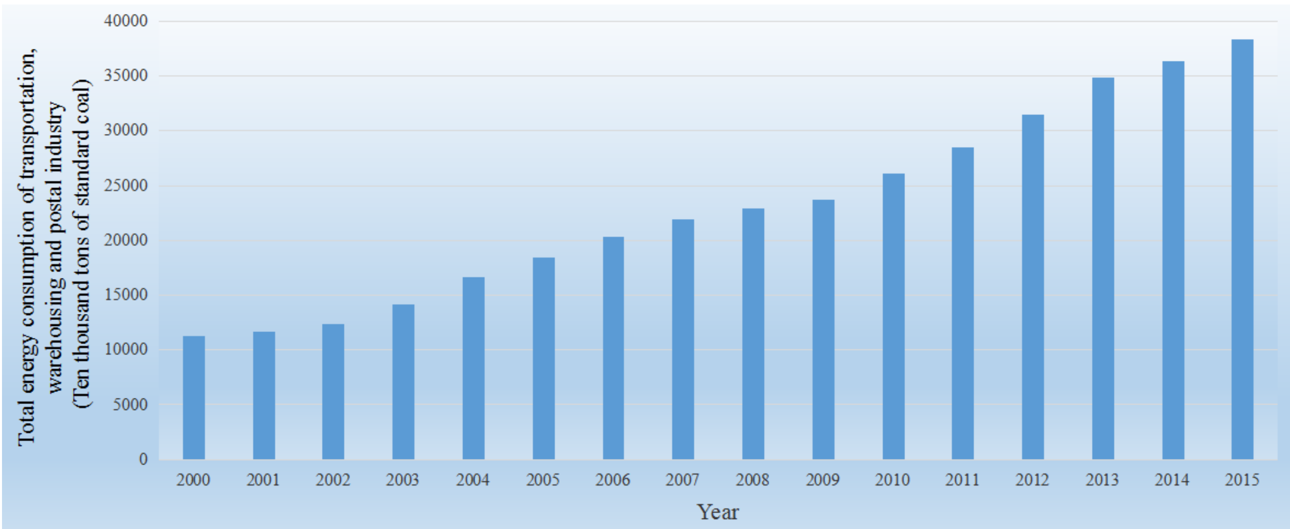

Fig. 2: Total energy consumption of the transportation industry.
(Data source: China Statistical Yearbook (2001–2016))

cult, thereby resulting in the reduction of production efficiency and affecting effective operation of the production. The Chinese Government has enlarged structural adjustment of the transportation industry since 2010, and energy efficiency has been effectively improved.

MEASURES OF IMPROVING ENERGY EFFICIENCY OF TRANSPORTATION INDUSTRY

Reasonable adjustment of the industrial structure: Adjustment and optimization on traffic governance for the industrial structure is important to inhibit blind growth trend of the heavy industry, and firmly eliminate backward productivity, energetically develop service and high and new technology industries, gradually lower the proportion of the secondary industry and increase that of the tertiary industry, and reduce energy consumption brought by excessive transportation. Perfecting the comprehensive transportation system and optimizing the transportation structure can effectively improve energy utilization efficiency of the transportation system, thereby attaining the goal of system

Table 2: CO_2 emission interchange coefficients.

Energy type	Carbon emission interchange coefficients
Coal	20,189 tons/ten thousand tons
Coking coal	30,193 tons/ten thousand tons
Crude oil	30,102 tons/ten thousand tons
Gasoline	30,700 tons/ten thousand tons
Kerosene	31,478 tons/ten thousand tons
Diesel	31,849 tons/ten thousand tons
Fuel oil	31,256 tons/ten thousand tons
Natural gas	29,831 tons/ten thousand tons
Electricity	105,230 tons/Gw/h

(Data source: National Guidelines for Greenhouse Gases formulated by the Intergovernmental Panel on Climate Change in 2006)

Table 3: Calculation results of energy efficiency in China's transportation industry during 2007–2015.

Year	CRSTE	VRSTE	SCALE	Returns to scale
2007	1	1	1	-
2008	1	1	1	-
2009	0.983	0.984	0.999	drs
2010	0.989	1	0.989	irs
2011	1	1	1	-
2012	0.987	1	0.987	drs
2013	0.987	1	0.987	drs
2014	1	1	1	-
2015	1	1	1	-
Mean	0.994	0.998	0.996	-

energy conservation. The government should adjust the passenger transportation structure and develop high-speed railway and rail rapid transit, adjust freight transportation structure, and take full advantages of railway and waterway transportation. In addition, the government should adjust the urban traffic structure and unswervingly conduct the development concept of the public transport priority.

Strengthen energy conservation management of the transportation industry: Defining the principal positions and supervision and management functions of competent authorities regarding law enforcement in energy conservation will be conducted step by step, which will facilitate transportation department to strengthen intervention force in transportation energy conservation by energy-saving planning. The transportation department should formulate the corresponding special energy conservation plans and incorporate them into the development plan of various transportation sectors to guide the transportation industry to step on the scientific development road. Administrative policies and regulations and standard systems supporting Energy Conservation Law of the People's Republic of China should be established and perfected. Moreover, no loopholes should exist in the aspect of transportation energy conservation. The coordination and cooperation between different transportation management departments with regard to energy-saving policies and management should be strengthened to realize energy management and utilization with accordance with the law.

Promote technological progress of the transportation industry: The reform of the current traffic management system, the establishment of a unified comprehensive transport management agency, and the classification of five transport modes into the an unified government department will avail establishment of an energy-saving comprehensive transport system. More new type of rail vehicles, automobiles, boats, and air-crafts should be selected to remove old transportation tools featuring high energy consumption. Fuel economy should be improved, and energy consumption of existing transportation tools should be diminished. A fuel economy standard system of motor vehicles, including all of the main vehicle models, should be established at an accelerated speed. The management of transportation organizations should be improved, and the establishment of an intelligent transportation system should be accelerated to elevate transportation efficiency.

Establish an incentive mechanism for transportation energy-saving technologies: Establishing and perfecting an economic leverage-centered incentive and constraint mechanism are important methods of realizing transportation energy conservation. The incentive mechanism for R&D, industrialization, and marketization of advanced transportation energy-saving and management technologies should be established. The R&D, industrialization, and marketization of transportation energy-saving and management technologies should be encouraged through various measures, such as direct governmental input, fiscal subsidies, load with discounted interests, tax preference, and rewards. Vehicle tax and fee system reform should be accelerated to inhibit particularly rapid growth momentum of demand for fuel oil and promote production and sale of small-emission vehicle models with favourable fuel economy. The vehicle tax and fee system reform mainly includes levying fuel oil tax, perfecting differential tax rates for vehicle purchase taxes, and establishing the motor vehicle efficiency labelling system.

Strengthen energy-saving capacity construction of the transportation industry: A perfect energy-saving organization and technical support team adapting to market requirements should be established and perfected within the transportation industry and their functions with regard to energy-saving technology certification and transfer, technical service, monitoring, and training of professional energy-saving talents should be intensified. The government

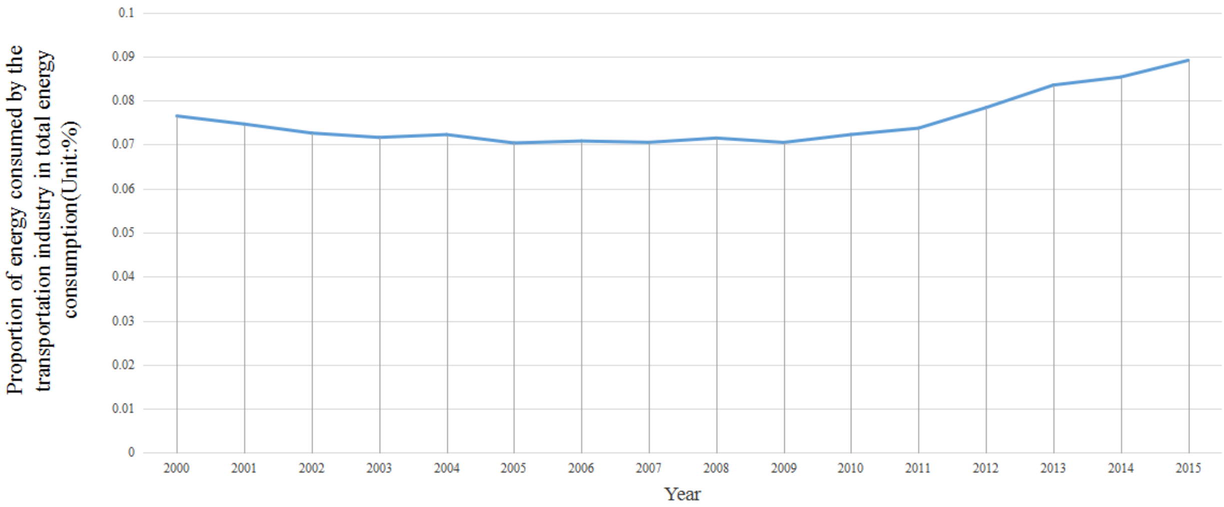

Fig. 3: Proportion of total energy consumption in the transportation industry in total energy consumption. (Data source: China Statistical Yearbook (2001-2016)).

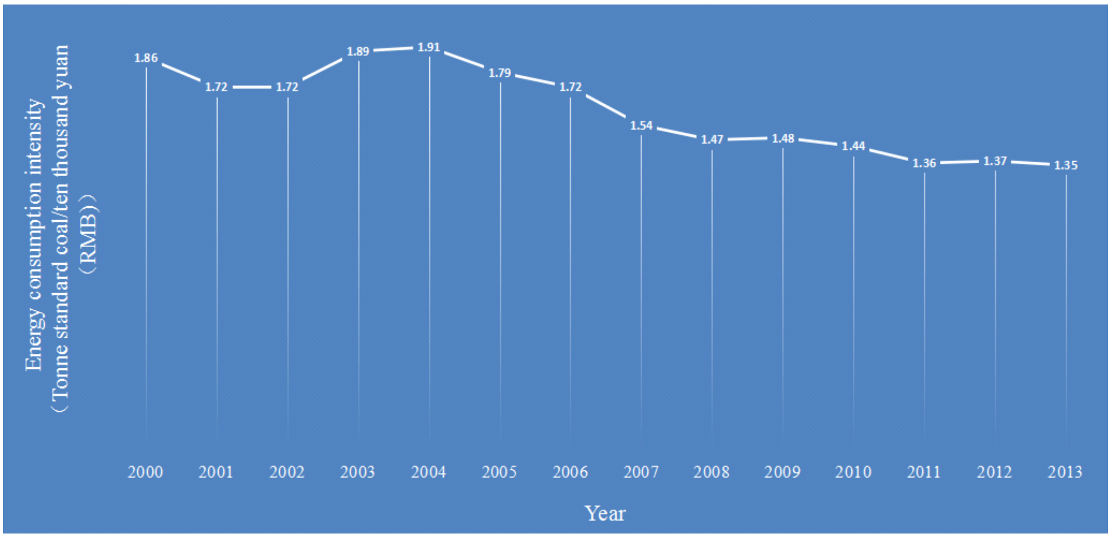

Fig. 4: Energy consumption intensity of China's transportation industry. (data source: *China Statistical Yearbook* (2001-2014))

should encourage and support the establishment of energy-saving social service agencies and conduct corresponding activities. In addition, the government should enlarge supporting force for scientific research institutions and enterprise energy-saving organizations and give full play to positive effects of these institutions with regard to energy technological research and development, popularization and application, and energy-saving information and technology transfer. Moreover, regular transportation energy-saving propaganda and educational training activities should be conducted in the entire society. Finally, the necessary subsidies should be provided to continuously improve transportation energy-saving awareness and ability of the entire society.

CONCLUSIONS

The total energy consumption of China's transportation industry is continuously increasing at a particularly high speed, and the environmental pollution problems due to enormous energy consumption are highly conspicuous. Transforming energy consumption structure and improving energy efficiency can effectively promote efficiency of the transportation industry and relieve environmental pollution caused by the transportation industry. The energy consumption status of the transportation industry was first summarized to obtain full understanding of environmental pollution caused by energy consumption of China's trans-

Table 4: Input-output projection analysis results of China's transportation industry (2009).

Year/value	Original value	Radial movement	Slack movement	Projected value
Energy consumption of the transportation industry	16522	268	0	16790
Fixed-asset investment of the transportation industry	0	0	0	0
Employment figure of the transportation industry	23271	0	-6575	16696
Added value of the transportation industry	24460	0	-35	24425
CO_2 emission of the transportation industry	2104	0	-79	2026

portation industry, and the data envelopment analysis (DEA) model was used to estimate transportation energy efficiency. The study findings show that the energy consumption status of the transportation industry can be manifested by sustainable rapid growth of the total energy consumption, continuous high proportion of energy consumption of the transportation industry in the total energy consumption, and year-by-year growth of energy utilization. The mean values of the comprehensive energy, pure technical, and scale efficiency reach 0.994, 0.998, and 0.996, thereby indicating that the overall conditions of energy input and output efficiency in the transportation efficiency are benign and stable. Energy efficiency of the transportation industry can be improved by adjusting the industrial structure, strengthening energy-saving management, reforming the current energy management system, establishing a transportation energy-saving technology incentive mechanism, and reinforcing energy-saving capacity construction within the transportation industry. A further study should be conducted on the determination of transportation energy consumption factors, estimation of transportation energy efficiency in different provinces, internal and external influential factors and action mechanism of transportation energy efficiency, and optimization of energy usage amount in the transportation industry.

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