

Transportation Energy Consumption and Energy Security in China

Sai-ni Yang, Dan Wu and Ming Wang

Abstract This chapter is aimed at analyzing the energy consumption of transportation industry in China and its relationship with national energy security from a macro and quantitative point of view. Based on analyses of historical transportation energy demand and relevant planning policies, regression models were established in order to estimate the demand and structure changes of transportation. Combined with the main factors affecting transportation energy consumption, an econometric model was established using the Partial Least Square Regression method to analysis and predict the transportation energy consumption scenarios as well as energy-saving rate in China in the middle and long-term. Study results confirm that China's transportation demand and its energy consumption will keep growing within a period of time, and transportation structure has changed a lot in the past two decades, with road and air transport currently the fastest developing transport modes. Future growth of transportation system's energy consumption, especially petroleum consumption will pose a serious threat to energy security in China. Technique substitution, especially in road transport mode may significantly mitigate the energy gap.

Keywords Transportation · Energy consumption · Prediction model · Energy-saving rate · China

Introduction

From the mid-1970s of the twentieth century, United State is the country with the largest oil-imports in the world. However, it is bypassed by China in December 2012. The net-oil-import reaches 6,120,000 barrels in December according to the

S. Yang (✉) · D. Wu · M. Wang
State Key Laboratory of Earth Surface Processes and Resource Ecology,
Beijing Normal University, Beijing 100875, China
e-mail: yangsaini@bnu.edu.cn

statistics of General Administration of Customs of China. Though someone argues that the data of December is heavily affected by annual taxation and data of a single month cannot represent the trend in long run, the high oil-imports make many people anxious about energy security in China.

With the development of economy and acceleration of urbanization process, energy consumption in China grows dramatically. Among all departments, transportation industry grows even faster than that of the whole society. As pointed by many researchers "...transportation industry is the major user of petroleum. Analysis of transportation energy consumption becomes a must in China..." [1]. Transportation energy consumption has put a serious threat to the country's energy security. Meanwhile, since transportation is a major user of carbon-based fuels, it is also increasingly being highlighted as the industry, which contributes least to CO₂ emission reduction targets [2].

As the main factor that hinders sustainable development, energy consumption in transportation system has aroused extensive attention of domestic and international scholars as well as government departments. Within domestic and international study on issues related to energy consumption in Chinese transportation system, energy consumption prediction is the basic part and occupies an important position. Traditionally, predictive models are usually built using historical data to analysis and predict transportation energy consumption levels in the future, which include energy efficiency, total energy consumption [3–6]. In addition, some work has also been undertaken to further explore issues like transportation structure optimization, planning and policy strategies and transportation sustainable development from the perspective of energy consumption. Shen [7] analyzed the sustainable transportation strategies against energy insufficiency and environmental needs; Tao and Xue [8] brought forward an analytical method of tax policy research on sustainable energy for transportation system in China; Creutzig and He [9] investigated the role of demand elasticity and demonstrated that joint demand and supply-side policies provide considerable synergies. However, these researches have been restricted to the lack of a complete and objective evaluation system to determine the impact factors of transportation energy consumption on energy security. Comparability of indicators and reliable data are also needed for further study.

In this study, an energy consumption prediction model is proposed to take comprehensive consideration of factors influencing energy consumption in China in middle and long-term. Further analysis and discussion are provided on intrinsic relationship and regularity between different transport modes' energy consumption proportions, the relevant influencing factors and national energy security. This study aims at not only helping obtaining better understand on current energy consumption situation of China's transportation system, but also providing a scientific reference for the development of China's middle and long-term sustainable transportation planning as well as national energy security.

Analysis of Transportation Demand

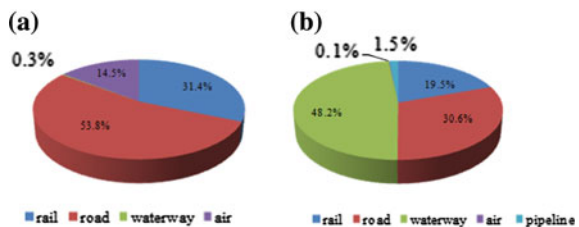
Changes of Transport Structure

To predict the future energy consumption of transportation industry, transportation demand is an important indicator to measure the development level of transportation industry. In recent years, with the economic development and technological progress, Chinese transportation industry continues expanding, and transportation demand is surging. From 1990 to 2010, total demands of passenger volume and freight volume have increased as much as 5 times and 5.4 times, and have reached 2,789,426 million passenger km and 14,183,742 million ton km in 2010 respectively. Average annual growth of passenger volume and freight volume are 7.9 and 8.4 % during the past 21 years, which provides a strong evidence for the fast development of transportation capacity.

The proportion change of passenger and freight volume by different transport modes varies and forms different transport structure. Since people pay more and more attention to convenience and comfort besides accessibility when selecting transport modes, road transport now has replaced rail transport and become the most important transport mode in terms of passenger volume, and air transport becomes the fastest growing one. Road passenger volume proportion in China grows from 46.6 % in 1990 to 54 % in 2010. Although replaced by road transport from the first place, rail transport is still very attractive to the passengers with the improvement of comfort and speed. Especially, railway is suitable for bulk cargo transport. Therefore, it will maintain its important position in integrated transportation system in the future. Waterway shares a small part of passenger transport, while it keeps a steady growth in freight transport as well as pipeline transport because of its low cost. Freight volume proportion of water transport is 44.2 % in 1990 and it grows up to 48.2 % in 2010.

Figures 1a and b illustrated the share of passenger volume and freight volume for major modes respectively. The current rank of main passenger-transport modes is road, rail, air, waterway, and the order of freight-transport modes is waterway, road, rail, pipeline and air. Air and road transport are now the top two modes with fastest growing speed of demand.

Fig. 1 a Passenger volume (left) and b freight volume (right) in year 2000 in China



Prediction of Passenger and Freight Volume

In recent two decades, integrated transportation capacity and transport volume constantly increased because of the rapid development of transportation industry. Generally speaking, transport volume is closely related to economic development. In order to predict passenger and freight volume in the future, regression equations between passenger (freight) volume and GDP are established using data from 1994 to 2010 (Eqs. (1), (2)). R^2 of the two equations are 0.9844 and 0.9966 respectively, which show that the regression equations established have a good quantitative reflection at the relationship between transport volume and national economy.

$$\text{Freight volume} = 1.0347GDP - 4558.5, \quad R^2 = 0.9844 \quad (1)$$

$$\text{Passenger volume} = 0.1812GDP + 2970.4, \quad R^2 = 0.9966 \quad (2)$$

*(Data resource: “China Statistical Yearbook”; price base year of GDP is 1990.)

According to the GDP growth prediction results provided by Chinese Academy of Social Sciences (CASS) and national development plan of the government, we make the following assumptions: by 2020, 2030 and 2050, GDP growth rate will be 7.7, 6 and 5 %, and the GDP value will be 29,292,310, 52,458,060, 139,106,800 million yuan. By Eqs. (1) and (2), predictive value of passenger and freight volume in 2020, 2030, 2050 will be obtained respectively (as shown in Table 1).

Energy Consumption Prediction of Transportation Industry in China

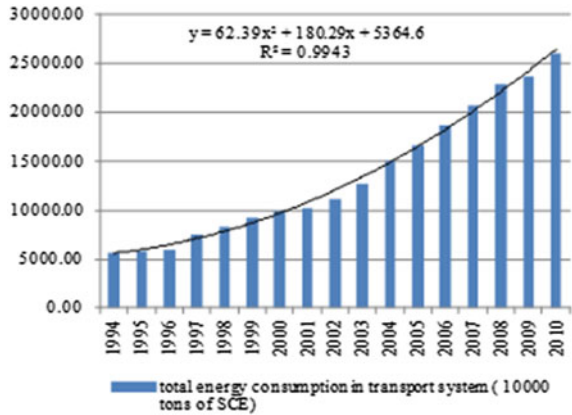
Current Statues of Energy Consumption of Transportation Industry

From 1994 to 2010, energy consumption of transportation industry and its proportion occupancy of the total social energy consumption show a significant upward trend (Fig. 2). In 1995, energy consumed by the transportation industry was only 4.47 % of whole society’s energy consumption. This number reached 7.05 % in 2005 and 8.02 % in 2010. Annual growth rate of energy consumption of

Table 1 Predict value of transport volume

	2020	2030	2050
Predict passenger volume (100 million passenger-km)	56,048.1	98,024.4	255,177
Predict freight volume (100 million ton-km)	298,529	538,225	1,435,608

Fig. 2 Energy consumption trend of transportation industry



the whole society was 6.3 % during 1994–2010, while the annual growth rate was 10.1 % for transportation industry in the same period of time.

Compared with the developed countries, energy consumption proportion of transportation industry in China is relatively low. In 2003, energy consumption proportion of transportation industry in America is 27.1 % and the proportion is 24.4 % in Japan in 2005 [10]. While the number is only 6.93 and 7.05 % in China in the same period. There are two main factors lead to this deference: first, statistic methods are different in various countries; second, the fast booming industry sector consumes more energy than transportation industry in emerging countries like China.

As to energy structure, among the various kinds of energy consumed by transportation industry, petroleum accounts for the largest proportion, which has a closely relationship with the fast development of road and air transportation (Fig. 3). From 1993 to 2010, petroleum consumption of transportation industry in China keeps fast growth, while the domestic production of petroleum is limited

Fig. 3 Energy consumption structure of transportation industry in 2010, China

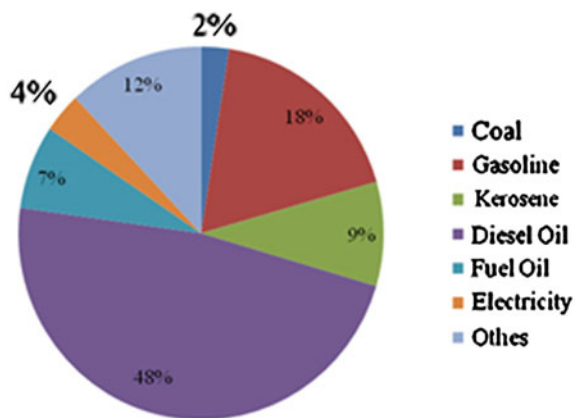
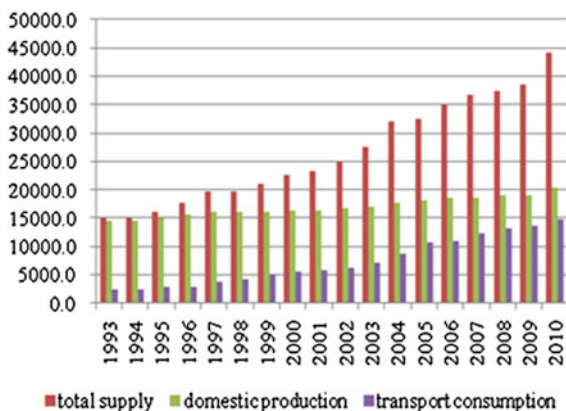


Fig. 4 Petroleum consumption (10,000 t)



since it is non-renewable energy. Large consumption of petroleum resource in transportation industry forces China's annual import volume of petroleum increase continuously (Fig. 4). In 1993, petroleum consumption of transportation industry is only 17.2 % of total domestic petroleum production. However, the proportion reached 73.2 % in 2010. Though the energy consumption proportion of transportation industry in China is much lower than that of most of the developed countries, transportation industry's heavy dependence on petroleum energy brings a great threat to China's energy security. In addition, petroleum is highlighted as the serious environment unfriendly energy since it will emit large number of green gas. The amount of petroleum energy use will directly influence the effectiveness of energy saving and emission reduction of the whole country. It is extremely important to minimize petroleum consumption proportion and adjust energy consumption structure of transportation industry in China in order to achieve sustainable development in the future.

Energy Assumption Model for Transportation Industry

Energy consumption of transportation industry is affected by various factors. The following factors are generally considered in estimation: GDP, fuel prices, population, urbanization rate, passenger (freight) volume, per capita disposable income of urban households, etc. [11]. In this study four main factors: GDP, passenger volume, urbanization rate and freight volume are selected to establish a model by PLSR method to predict energy consumption of transportation industry. 17 years' (1994–2010) national annual statistical data is used in modelling. Variables x_1 , x_2 , x_3 , x_4 and y represent GDP, passenger volume, freight volume, urbanization rate and energy consumption respectively.

As shown in Table 2, correlation matrix shows a strong correlation exists between each selected variable.

Table 2 Correlation matrix

Variables	X_1	X_2	X_3	X_4	y
X_1	1.000	0.997	0.987	0.966	0.997
X_2	0.997	1.000	0.987	0.966	0.996
X_3	0.987	0.987	1.000	0.924	0.987
X_4	0.966	0.966	0.924	1.000	0.968
y	0.997	0.996	0.987	0.968	1.000

We use data from 1994 to 2009 to establish the prediction model by PLSR method, and data in 2010 to validate this model. With software SXLATAT, we get the regression Eq. (3), and R^2 is 0.996.

$$y = -7198.524 + 0.055x_1 + 0.305x_2 + 0.055x_3 + 224.4x_4 \tag{3}$$

Table 3 shows that the model prediction results and actual energy consumption values of transportation system in China from 1994 to 2009, which are quite similar. The maximum relative error is 7.6 %, the average relative error is 3.05 %, and the relative error in the test year 2010 is 4.66 %. The study results indicate that the prediction model established by the PLSR method is applicable to predict the transportation energy consumption if without structural change.

Table 3 Prediction results of PLSR model for transportation industry

Year	Actual energy consumption value (10,000 tons of SCE)	Calculate results of PLSR model (10,000 tons of SCE)	Relative error (%)
1994	5,625.58	5,298.1865	-5.82
1995	5,862.90	5,857.5001	-0.09
1996	5,994.45	6,449.8131	7.60
1997	7,543.10	7,327.1145	-2.86
1998	8,245.02	7,982.5477	-3.18
1999	9,242.62	8,821.7007	-4.55
2000	9,916.12	9,858.4443	-0.58
2001	10,257.08	10,869.096	5.97
2002	11,086.49	11,920.339	7.52
2003	12,740.10	12,647.83	-0.72
2004	15,104.00	14,903.872	-1.32
2005	16,629.00	16,573.04	-0.34
2006	18,582.72	18,431.389	-0.81
2007	20,643.37	20,901.074	1.25
2008	22,917.25	22,668.849	-1.08
2009	23,691.84	24,691.845	4.22

Prediction of Energy Consumption of Transportation Industry in Mid-Long Term

To estimate the energy consumption of transportation industry in mil-long term, urbanization rate in the future needs to be first determined. According to the forecast of CASS and the World Bank, urbanization rate of China will be 57.67 % in 2020 and 67.81 % in 2030. While 68 % may be the top of the next 20 years, after 2050 the urbanization rate will remain at that level in a long time. By bringing the above predictive value of GDP, passenger volume and freight volume into the PLSR model, prediction results of energy consumption of transportation industry in 2020, 2030 and 2050 are obtained, as shown in Table 4.

The petroleum consumption in whole society and transportation industry is illustrated as in Fig. 4. The petroleum consumption of transportation industry is nearly the total domestic production in 2010. If we further look at the consumption and market share of major energy resources in transportation industry (Figs. 5 and 6), oil is the dominant energy resource, while the consumption and market share of coal are both declining. In the past 15 years, there is no significant market share increment of electricity but the total consumption has a similar trend as that of petroleum.

The annual petroleum production is about 3,820 million tons globally and about 200 million tons domestically in 2010 [12]. Based on these estimated energy consumptions, if the energy consumption structure maintains the same as that in 2010, the annual consumption of petroleum by transportation industry in China will reach 659 million ton in 2020, 1,173 million ton in 2030 and 3,050 million ton in 2050. That is, the oil dependency will soar to 456 million tons by 2020,

Table 4 Prediction results of transportation energy consumption in the future

	2020	2030	2050
Predict energy consumption (10,000 tons of SCE)	115,987.37	206,419.94	536,957.34

Fig. 5 Consumption of three major energy transportation industry

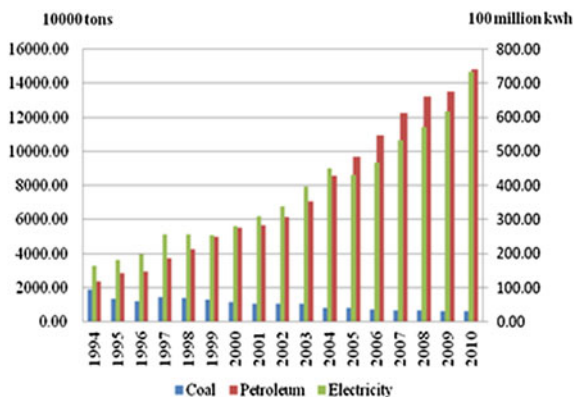
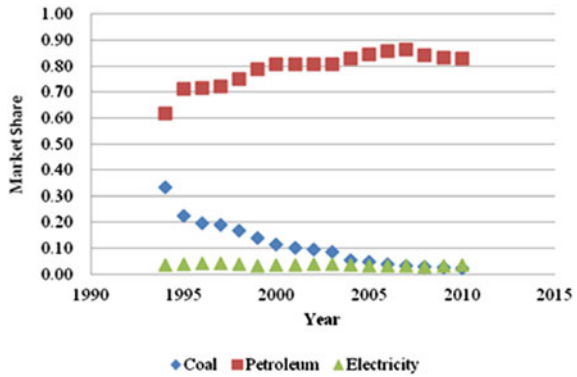


Fig. 6 Market share of three major energy resources in transportation industry



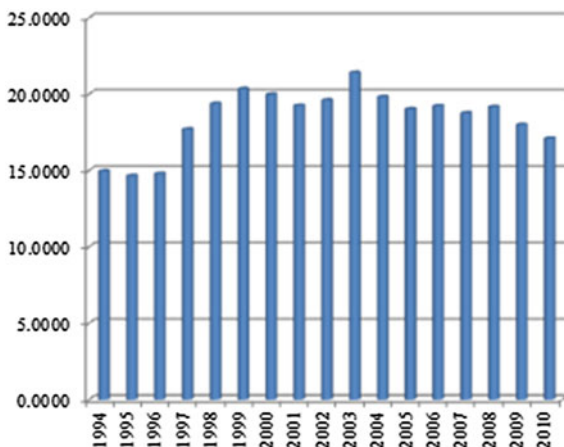
970 million tons by 2030, and about 2,850 million tons by 2050, if there no significant change in domestic oil-production. 2,850 million tons is more than 70 % of the current global annual production. It is impossible to satisfy such a huge demand of the transportation industry in one country. The current development path is unsustainable in the energy perspective. What can we do to achieve energy security?

Analysis of the Energy-Saving Potential of Transportation System

Integrated Energy Intensity Analysis

Energy intensity is one of the main factors that affect transportation energy consumption, and it can be represented by energy use per passenger km or ton km [13]. Although the transport volume proportion of high energy consumptive transport modes, such as road and air, keeps growing, integrated energy intensity of transportation industry in China has shown a fluctuated downward trend since 2003 (Fig. 7). This is because of the efficiency improvement of fuel utilization due to science and technology development. Figure 8 shows the change of energy intensity of each transport mode in recent 15 years. We found that the energy intensity of each transportation mode in a logarithmic scale shows a clear descending linear trend except road transport. As a result of the elimination of a large number of steam locomotive and increment in the proportion of diesel locomotive and electronic locomotives, energy intensity of rail transport dropped significantly. However, with the elimination of steam locomotive completes, trains speed up, and equipments become more comfortable, it may be rather difficult to further reduce energy intensity of rail transport in the future. Both water and air transports show a clear downward trend in energy intensity, due to new design,

Fig. 7 Integrated energy intensity (tce/million-t-km)



new technology and operations optimization. As to pipeline transport, its energy intensity is greater than that of the waterways and railways in recent years, and the main influencing factors are the long update cycle of equipments and unsaturation of transport volume. However, toad transport, as the mode that contributes most to energy consumption in transportation industry, its energy intensity keeps growing [11]. These send an important message that the energy technique innovation of road transport is the key to energy security of China.

Prediction of Energy-Saving Rate in Transportation Industry

Transportation energy-saving rate is an important indicator to reflect transportation development level and energy saving effect, which refer to the ratio of energy saving in a specific period and the energy consumption in the base period. It can be expressed by Eqs. (4) and (5) [14].

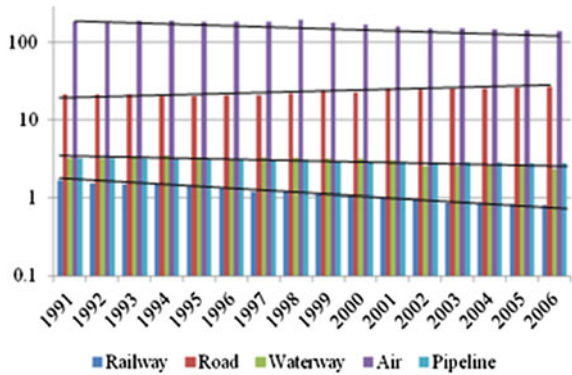
$$E = \alpha \cdot Q \quad (4)$$

$$\varepsilon_t = (E_0 - E_t)/E_0 \cdot 100 \% \quad (5)$$

where, E is the energy consumption amount; α : energy intensity; Q is the transportation volume; ε_t is energy-saving rate in predicted year; E_t is the energy consumption in predicted year and E_0 is the energy consumption in the base year.

With the calculated transport volumes of various transport modes in the forecast years and based on the assumption that transportation structure in the predicted year is the same as that in 2010, transport volume in each mode is converted to standard transport volume using the following conversion factors: rail transportation is 1:1, road is 10:1, waterway is 2:1 and air is 13.7:1. Thus, combined with the prediction results of passenger and freight volume in 2020, 2030 and 2050 in

Fig. 8 Energy intensity of each transport mode in a logarithmic scale (PJ/100 million ton)



section [Prediction of Passenger and Freight Volume](#), we can get the converted volume for different transport modes (Table 5). According to the “Middle and long-term Railway Network Plan” of the National Development and Reform Commission and the “Highway and Waterway Mid-long-term Energy Conservation Plan” of Transport Management Department of China, as well as reference of related research [15], reduction of integrated unit energy consumption of various transport modes 2020, 2030 and 2050 are determined as follows with 2005 as the base year (Table 6). If these goals are achievable, by solving Eqs. (4) and (5), energy-saving rates of 2020, 2030 and 2050 can be obtained respectively.

Table 7 shows that energy saving rate of five major transport modes in China in the future. Among these transport modes, energy-saving rates of road, pipeline and air will be the top three. Rapid growth of energy consumption of road transportation is mainly enhanced by the increment of traffic volume and energy intensity. Energy consumption of air transportation will keep growing though its energy intensity declines with the updates of machine and ascension of occupancy rate, mainly due to the rapid increase in transport volume attracted by its fast, comfortable and efficient features. Energy consumption of pipeline also shows an

Table 5 Total transport volume after conversion (100 million ton-km)

	Rail	Road	Waterway	Air	Pipeline
2020	75,789.24	94,341.54	144,064.80	968.91	4,624.49
2030	135,691.67	169,927.64	259,735.49	1,714.89	8,337.60
2050	359,956.71	452,909.78	692,787.80	4,507.71	22,238.90

Table 6 Proposed reduction of unit energy consumption for various transport modes [15]

	Rail (%)	Road (%)	Waterway (%)	Air (%)	Pipeline (%)
2020	20	15	20	20	15
2030	30	35	30	30	20
2050	35	45	40	40	25

Table 7 Predicted of energy-saving rates in the future

	2020	2030	2050
Rail	-1.26	-2.55	-7.73
Road	-7.33	-10.48	-24.89
Waterway	-1.32	-2.66	-7.36
Air	-2.40	-4.26	-10.85
Pipeline	-2.61	-5.13	-14.33

Negative value indicates the growth of energy consumption

obvious upward trend because its construction speed in recent years continues to accelerate and its transportation capacity keeps expanding. As traditional transport modes, rail and waterway transportation have a relatively slow growth rate of energy consumption because of two main reasons. On one hand, there is less margin in demand for these two modes; on the other hand, energy intensity has decreased due to operation optimization and technology improvement. Take the energy assumption in 2020 for example, road transportation's energy intensity reduced more by 1 % will contribute 1.3 % to its energy consumption reduction, but 1 % more reduction of energy intensity will contribute 1.8 % to energy consumption reduction for air transportation. Again, all these depend on the fulfilment of the targeted unit energy consumption reduction.

Under target energy saving scenario, the future energy consumption in 2020, 2030 and 2050 are computed as in Table 8, with the assumption that the transportation structure maintains the same as in 2010. Compared with the prediction results in section [Prediction of Energy Consumption of Transportation Industry in Mid-long Term](#), the total energy consumption reduced 20.4, 36.5 and 44.5 % respectively. Correspondingly, the petroleum consumption in 2020, 2030 and 2050 will be 524, 744 and 1,692 million tons respectively. These amounts are still too much given the petroleum current production level. The proposed reduction of unit energy consumption alone cannot solve the national energy security issue. Significant changes have to be made in energy structure and transportation structure to ensure sustainable development.

Table 8 Predicted energy consumption for transport modes and transportation industry (10,000 tons of SCE)

Year	2020	2030	2050
Rail	5,371.94	8,415.60	20,729.90
Road	72,286.88	99,566.90	224,549.44
Waterway	9,692.68	15,290.63	34,958.07
Air	4,346.55	6,729.85	15,161.36
Pipe	598.90	1,016.25	2,541.24
Total energy consumption in transportation industry	92,296.95	131,019.23	297,940.03

Conclusions

Through data analyses and established prediction models, we get the following implications: With the strong confidence in economic develop in China; transport volume in China will maintain a rapid growth in the future. Passenger volume will reaches 25,517,700 million passenger km and freight volume will reaches 143,560,800 million ton km in 2050, which indicate energy consumption of transportation industry has become a serious threat to China's energy security, especially to petroleum security.

Petroleum energy consumption by transportation industry shared only 12 % of total domestic petroleum production in 1990, while the proportion reached 73.2 % in 2010. If the current consumption structure is not changed, the petroleum consumption in 2050 will reach 3,050 million tons, and this amount is about 1,500 % of the current domestic petroleum production and about 75 % of the global petroleum production. Adjustment of energy consumption structure and reduce the integrated energy intensity in transportation industry become the key to ensure energy security and sustainable development in China and in the world.

Transportation structure has changed significantly in the past decades since modern transportation pays more attention to transportation efficiency, comfort and convenience. In terms of passenger transportation volume, both road and air transport have significantly improved due to their speed and convenience. Road transport has replaced rail and becomes the major transport mode. Waterway and railway are still dominant in terms of freight transport. Road, pipeline and air become the top three transport modes with the fastest energy consumption growing speed. By 2020 their predict energy consumption values will be 8.3, 3.6, 3.4 times higher than that in 2005 respectively due to their high-energy intensity. This will exaggerate the total energy consumption in transportation industry. Therefore, the adaptation of technologies, such as new energy resource, electric cars and operation optimization may have a significant impact on petroleum consumption and energy security in the middle and long-term, and the adjustment of transport pattern with scientific guidance is the backbone of energy saving in transportation industry.

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