

Decomposition analysis of transportation energy consumption in China's three major regions

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Abstract. The purpose of this paper is to determine the relationship between regional transportation energy consumption and its influencing factors. We first determine the three research sections in the eastern, central and western regions. Then, the log-average Divisia index (LMDI) technique was used to identify the nature of the factors affecting changes in transportation energy consumption. We find that: (1) The GDP effect and the transport structure effect will promote the increase of energy consumption in different regions. (2) The energy intensity effect exerts an inhibitory effect in the central and eastern regions, while promoting the increase of energy consumption in the western region. (3) The effect of share of passenger and cargo transport on energy consumption is not significant. (4) The increase in energy consumption due to economic development and transport structure effects will continue for some time.

1. Introduction

As an industry with a wide range of social foundations and social services, the energy consumption of the transportation industry is mainly affected by the development of the social economy and the development of the transportation industry. On the one hand, the national economic construction and the improvement of people's living standards require that the capabilities and quality of China's transportation industry be further improved; On the other hand, the development of the transportation industry has brought a lot of energy consumption, especially petroleum products. As early as 2003, China became the world's second-largest oil consumer. This would pose great challenges and threats to the country's energy security and energy resources reserves. This requires that it is very necessary for China to investigate clearly the driving forces of the energy consumption of the transportation industry to solve the thorny problem of high traffic energy consumption. As shown in Figure 1, in recent years, the consumption of gasoline, diesel and kerosene respectively accounted for 50%, 60% and 90% of the national total.

In China, due to the different levels of reform and opening up in the region, the large differences in regional economic development have resulted in different demand for transportation, which has led to different levels of energy consumption in transportation. The energy consumption of transportation in coastal areas is significantly higher than that in inland areas. According to the national natural conditions, economic basis, development level, and degree of opening to the outside world, the China Statistical Yearbook divides the country into three economic zones: the eastern, central, and western regions. This article will use this as a basis to decompose the energy consumption of the three major economic zones.

Decomposition analysis method is a kind of analysis method that studies the influence of the analysis object on the quantity change of each influencing factor. At present, there are many



decomposition methods used to analyze energy consumption and carbon dioxide emissions influencing factors such as econometric regression, structural decomposition analysis (SDA) and index decomposition analysis (IDA). Among them, the two methods of SDA and IDA are the most widely used in the analysis of driving forces. SDA needs the input-output table data as a support. It can use a series of technical effects and final demand influences to distinguish the factors affecting the size, but also analyze the effect of indirect factors, but the large amount of data needed, the model is more complex; IDA It is more widely used in environmental economic research because it is suitable for disaggregating time series data and containing fewer factor models. IDA has more than 10 calculation methods. The most commonly used are Laspeyres and Divisia. Divisia is commonly used as the Arithmetic Mean Divisia Index. Method, AMDI) and Logarithmic Mean Divisio Index Method (LMDI) [1].

In the related research of energy consumption decomposition, the IDA is the current mainstream method. The Laspeyreshe and Divisia decomposition methods are the most commonly used methods. Ang and Zhang and Sun presented the detailed decomposition process of two IDA methods [2]. However, the two methods involve the decomposition of a residual component, and Divisia decomposition analysis encounters the zero-value problem. Ang compared various index decomposition analysis methods. He reported that the LMDI method can be completely decomposed without containing an unexplained residual component [3]. He proposed the use of a very small positive number instead of a zero value in logarithmic operations [4]. Therefore, the LMDI method is the preferred method for energy consumption decomposition. Achour decomposed the influencing factors of energy consumption in the Tunisian transportation sector by using the LMDI method. The study considered GDP and population size indicators in model construction and identified a high degree of association between the transportation industry and socio-economic development [5]. Meanwhile, Zhang used the LMDI method to analyze the influencing factors of carbon dioxide emission intensity in China and discovered that energy intensity plays a leading role; however, the study only considered intercity traffic, and the results are not suitable for energy consumption analysis under the concept of large transportation. [6]. Wang used the LMDI method and found that China's carbon dioxide emissions decreased sharply from 1957 to 2000 mainly due to the increase in energy intensity. However, the interval-based decomposition in this study does not provide the annual change mechanism of energy consumption [7]. Ebrahim et al. introduced LMDI decomposition technology for the analysis of energy use in Iran. The data span was from 2001 to 2006. The results obtained show that the energy consumption changes are determined by the level of traffic activity. The most important decisive factors are the transport structure and energy intensity [8].

This paper attempts to use the LMDI method to analyze the driving forces of energy consumption in the eastern, central and western regions of China during the period of 2005-2015. Since the statistical data on China's transportation energy consumption is not detailed and lacks data on pipeline transportation in many provinces, this paper only considers the energy consumption of operational tools in the four transportation modes of highways, railways, waterways (inland waterways and coastal transportation) and civil aviation. At the same time, due to the lack of data in Hong Kong, Macao, and Taiwan, this article only considers data samples from 31 provinces in China.

2. Methods

2.1. Data sources

The raw data includes the gross domestic product of each region, the passenger and freight turnover of the four modes of transport, and the transportation energy intensity of different operating tools. The statistical units for passenger traffic volume are converted to ton-kilometers according to the conversion factor for passengers and freight (1 for railways, coastal and inland rivers, 0.1 for highways and 0.073 for aviation) as defined by the Chinese statistical system; The unit of GDP is ten thousand yuan. The data of these two indicators are obtained from the National Bureau of Statistics and the "China Transportation Yearbook". The railway transportation is mainly based on electric locomotives

and diesel locomotives. The transportation energy intensity is based on the power consumption and diesel consumption per kiloton. The road transport is mainly based on diesel vehicles and gasoline vehicles. The transportation energy intensity is recorded according to the consumption of diesel and gasoline per kiloton, respectively. The statistics of water transport and civil aviation are based on diesel and aviation kerosene respectively. According to the energy conversion factor, the relevant unit of energy intensity is unified as tons of standard coal/kiloton-kilometer. The relevant data comes from the local statistics bureau and the “China Energy Statistical Yearbook”; the unit of transport intensity is thousand tons km/ten thousand.

2.2. Energy Consumption Decomposition Model Based on the LMDI Method

In this work, we establish an LMDI decomposition model to analyze quantitatively the influence of transportation energy intensity, transportation structure, transportation intensity, and economic development level by using the additive decomposition mode. The basic model of energy consumption in the transportation sector is constructed as follows:

$$E^t = \sum_i E_i^t = \sum_i \sum_j E_{ij}^t = \sum_i \sum_j \frac{E_{ij}^t}{V_{ij}^t} \times \frac{V_{ij}^t}{V_i^t} \times \frac{V_i^t}{V^t} \times \frac{V^t}{G^t} \times G^t \quad (1)$$

where i represents the four transportation modes, j represents the type of transportation, including passenger and freight transport, E^t is the total energy consumption in year t , E_{ij}^t is the energy consumption of the j type of i transportation mode in year t , V_{ij}^t is the converted turnover of the j type of i transportation mode in year t , V_i^t is the converted turnover of the i transportation mode in year t , V^t is the total converted turnover in year t , and G^t is the regional GDP in year t .

From Equation (1), the five influencing factors can be defined as follows:

$$E^t = \sum_i \sum_j I_{ij}^t T_{ij}^t S_i^t R^t G^t \quad (2)$$

where I_{ij}^t is the energy consumption intensity of the j th type of i mode in year t , T_{ij}^t is the share of the j th type of i mode to the i th mode in year t , S_i^t is the share of the i th transportation mode in year t , and R^t is the transportation intensity in year t .

According to the additive decomposition of the LMDI method, we have

$$\Delta E = E^t - E^0 = \Delta E_I + \Delta E_T + \Delta E_S + \Delta E_R + \Delta E_G \quad (3)$$

Each effect on the right-hand side of Equations (3) can be computed as follows:

$$\Delta E_I = \sum_i \sum_j \frac{E_{ij}^t - E_{ij}^0}{\ln E_{ij}^t - \ln E_{ij}^0} \ln \frac{I_{ij}^t}{I_{ij}^0} \quad (4)$$

$$\Delta E_T = \sum_i \sum_j \frac{E_{ij}^t - E_{ij}^0}{\ln E_{ij}^t - \ln E_{ij}^0} \ln \frac{T_{ij}^t}{T_{ij}^0} \quad (5)$$

$$\Delta E_S = \sum_i \sum_j \frac{E_{ij}^t - E_{ij}^0}{\ln E_{ij}^t - \ln E_{ij}^0} \ln \frac{S_i^t}{S_i^0} \quad (6)$$

$$\Delta E_R = \sum_i \sum_j \frac{E_{ij}^t - E_{ij}^0}{\ln E_{ij}^t - \ln E_{ij}^0} \ln \frac{R^t}{R^0} \quad (7)$$

$$\Delta E_G = \sum_i \sum_j \frac{E_{ij}^t - E_{ij}^0}{\ln E_{ij}^t - \ln E_{ij}^0} \ln \frac{G^t}{G^0} \quad (8)$$

The transportation energy intensity effect (ΔE_I) is used to assess the energy use efficiency in the transportation process. The passenger–freight share effect (ΔE_T) reflects the effect of the ration of passenger–trips to freight-transportation. The transportation structure effect (ΔE_S) reflects the relative share of the transportation service of a mode in the total transportation service. The transportation intensity effect (ΔE_R) is used to measure the impact of economic development patterns on transportation. The GDP effect (ΔE_G) represents the level of regional economic development [9].

3. Decomposition results and discussion

There are two decomposition methods for the exponential decomposition method: time series decomposition and interval decomposition. The interval decomposition method ignores the changes in the middle years, but it is easy to observe the results of cumulative changes over many years; while the time series decomposition can show the annual energy consumption changes and the contribution of various factors, and can better study the driving force change mechanism. Therefore, this paper adopts a time series decomposition method to decompose the energy consumption of transportation in China's eastern, central and western regions.

The decomposition results of transport energy consumption in eastern China from 2005 to 2015 are shown in Table 1. During the study period, the energy consumption of transportation in the eastern region was increasing. Among them, the transportation structure effect (ΔE_S) and GDP effect (ΔE_G) are two important factors for the growth of energy consumption. From 2005 to 2015, they increased 23.11 million tons and 96.28 million tons of standard coal, respectively. The good regional economy results in a strong transportation demand. With the development of the economy, passenger transportation requires a more comfortable mode, and goods transportation presents a higher quality requirement [10]. The passenger-cargo share effect (ΔE_T) has little impact on changes in energy consumption, and the energy intensity effect (ΔE_I) and transport intensity effect (ΔE_R) have suppressed energy consumption growth by 23.11 million tons and 96.28 million tons of standard coal in 2005-2015, respectively. It may be attributed to the upgrading of industrial structure in the eastern region, and the economy's dependence on transportation is reduced. Due to the well-developed economy, new technologies for carrying energy-saving tools are applied well, and the energy intensity of vehicles is low.

Table 1. Complete decomposition of transportation energy consumption change in the eastern region

Year	ΔE_I	ΔE_T	ΔE_S	ΔE_R	ΔE_G	ΔE
2005—2006	-178.25	2.98	-21.24	-166.90	622.75	256.36
2006—2007	-108.46	6.42	119.42	-168.20	782.88	625.66
2007—2008	-120.92	12.28	1282.79	541.70	949.28	2665.12
2008—2009	-133.16	11.47	448.89	-222.49	685.60	778.85
2009—2010	-127.84	13.69	-31.61	-83.05	1474.64	1232.16
2010—2011	-46.68	4.93	54.54	-331.66	1597.72	1273.93
2011—2012	-728.94	8.77	296.32	-284.84	958.67	241.21
2012—2013	236.71	3.12	192.74	-1205.44	1029.61	253.73

2013—2014	-337.62	4.92	-338.34	374.31	840.69	539.06
2014—2015	-333.66	7.18	308.12	-774.62	687.09	-113.11
2005—2015	-1878.81	75.76	2311.62	-2321.20	9628.93	7752.97

Table 2. Complete decomposition of transportation energy consumption change in the central region

Year	ΔE_I	ΔE_T	ΔE_S	ΔE_R	ΔE_G	ΔE
2005—2006	-54.02	-4.38	56.79	-166.81	263.25	99.22
2006—2007	-21.41	-6.71	73.66	-182.17	373.23	243.31
2007—2008	-35.70	18.91	2025.06	1161.82	671.10	3841.18
2008—2009	-81.03	10.72	325.75	-227.07	576.02	593.67
2009—2010	-93.06	15.50	189.44	-379.93	1379.10	1095.56
2010—2011	39.13	3.91	253.30	-469.28	1607.69	1430.84
2011—2012	-662.69	0.26	513.36	-20.80	1001.86	831.74
2012—2013	390.80	7.51	-977.55	-533.64	884.49	-235.98
2013—2014	-371.55	12.48	300.73	-157.48	741.73	513.43
2014—2015	-159.06	2.20	-258.96	-1426.86	471.15	-1373.74
2005—2015	-1048.60	60.40	2501.56	-2402.20	7969.62	7039.22

The decomposition results of transportation energy consumption in central China from 2005 to 2015 are shown in Table 2. It can be seen that the central region still has an increase in energy consumption led by the economic effect, with a total increase of 79.69 million tons of standard coal. Followed by the transport structure effect, the cumulative effect reached 25.01 million tons of standard coal. This is attributed to the rapid growth of the secondary industry in the central region in the past decade and the rapid growth of the economy. At the same time, the demand for a large number of cargo transportation has caused the proportion of road transport to remain at about 50% since 2008, which has led to a significant increase in the transport structure effect. The transportation intensity has obvious energy-saving effect, reaching 24.02 million tons. The energy-saving effect of energy intensity is not as good as that of the eastern region.

Table 3. Complete decomposition of transportation energy consumption change in the western region

Year	ΔE_I	ΔE_T	ΔE_S	ΔE_R	ΔE_G	ΔE
2005—2006	-128.61	0.13	13.62	-120.36	304.56	69.22
2006—2007	19.37	-0.41	1.13	-147.88	390.47	263.09
2007—2008	-126.06	9.62	811.36	463.86	590.35	1744.18
2008—2009	83.89	7.41	69.04	-120.92	416.72	448.73
2009—2010	-285.39	6.21	24.93	-291.95	870.77	318.37
2010—2011	11.26	4.41	189.16	-352.98	1051.60	899.15
2011—2012	-211.96	2.39	291.79	-158.99	746.04	666.90
2012—2013	450.27	4.20	-174.61	-1048.34	662.29	-110.44
2013—2014	519.33	2.57	296.04	-136.55	515.67	155.83
2014—2015	265.2	3.18	264.04	-492.76	300.24	-62.94
2005—2015	596.64	39.71	1786.51	-2406.87	5848.73	5829.72

The decomposition results of energy consumption in western China from 2005 to 2015 are shown in Table 3. The total energy consumption in the western region is significantly lower than that in the eastern and central regions. The effects of GDP and transport structure are still the main factors that increase energy consumption. Transport intensity became the only factor that inhibited the increase of energy consumption, reducing energy consumption by 24.06 million tons of standard coal. From the table, it can be found that the implementation of energy in the western region is less efficient, resulting in energy intensity effects in the transport process did not play a role in inhibiting energy consumption.

This situation is quite different from other regions, so the transportation energy intensity in the western region still has great potential for energy conservation. Passenger and cargo share effects have no significant effect on energy consumption.

4. Conclusion

After adopting the LMDI method in transport energy consumption factor analysis, the following results are obtained. (1) GDP is the first factor that promotes the increase in transport energy consumption, and the second factor is the transportation structure. (2) Transportation intensity is a factor that inhibits the increase in transportation energy consumption. (3) The impact of transportation energy intensity on transportation energy consumption varies from region to region.

Economic growth leads to an inevitable increase in transportation energy consumption, and this effect is expected to continue for a long time. The great economic development drives people's living standards. Passengers' travel volume and the amount of goods sent will inevitably increase, and they will tend to choose more comfortable and convenient travel modes and convenient and rapid modes of transport of goods, such as air and road transport. In the future, the trend will continue. Economic development must result in the transformation of the transportation structure, and the government should implement a policy of encouraging low energy consumption and pay attention to the reasonable development of the high-energy-consumption mode. Thus, the investment structure of traffic construction should be optimized, the development of railway, waterway, and public transport should be given more support through policies, and the link among the infrastructure of various transport modes should be strengthened. Reducing the intensity of transportation energy consumption is always the energy-saving direction and has already been emphasized and solved. Each region should popularize energy-saving technologies to improve the efficiency of energy utilization. Fossil fuel remains the most important fuel used in road, railway, waterway, and airway transportation. Thus, future comprehensive sustainable transport policies should focus not only on fossil fuel alternatives, such as using clean fuel and utilization of vehicles using clean fuel, but also on improving engine fuel efficiency and speed limit adjustment.

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