Decomposition analysis: Carbon emissions in China’s transportation sector

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Abstract. In order to deal with global warming and control carbon emissions, it is of great importance to identify the factors and their impact on the growth of carbon emission in the transportation sector. In this paper, the situation of carbon emissions in China’s transportation sector during 1996-2013 has been discussed and the decomposition analysis has been carried out by using the generalized Fisher index (GFI) method. It is found that: (i) Economic growth, energy intensity, population size and transportation intensity have positive effect on the growth of carbon emissions. (ii) Output value of per unit traffic turnover and energy structure have negative effects, among them, the former is the primary factor and the latter has an unobvious inhibition effect. We put forward suggestions to develop low-carbon transportation in China including to encourage people to adopt new energy vehicles in the passenger transport area, to utilize new energy vehicles in road freight and new energy ships in water freight, to encourage public and shared transportation, and promote the infrastructure construction of national multimodal transport.

1. Introduction

The main reason for the climate change is the cumulative emissions of CO₂ [1]. Low carbon development has become a consistent countermeasure for countries worldwide to address global warming. However, as the second largest carbon emissions industry, transportation sector accounts for 23% of global CO₂ emissions from fuel combustion in 2014 [2]. Researchers have shown increased interest in low-carbon transportation and have studied the carbon emissions of many regions including America [3-4], Europe [5-6], Latin America [7], and Asia [8]. Studies on China’s energy-related carbon emissions in transportation sector focus on cities and provinces such as Shanghai [9], Beijing [10], Jilin [11] and Jiangsu [12], but few studies discussed the issue from the nation-wide perspective [13-17]. Models and decomposition analysis method include nonparametric additive regression model [16], panel data model [17], the stochastic impacts by regression on population, affluence and technology (STIRPAT) model [11,15], the log mean divisia index (LMDI) method [7,9,12,13] and the generalized Fisher index (GFI) method [10]. The previous studies have made great achievements. However, thorough decomposition analysis on the influencing factors of energy-related transportation carbon emissions in China from a national perspective is yet absent. Therefore, we intend to use
historic data during 1996-2013 to analyze the situation of carbon emissions in China’s transportation sector and to make further analysis on related factors’ effect by GFI method. Suggestions will be proposed based on our study results.

2. Methodology and data

The results of the comparative study among various index decomposition methods that done by Ang et al. make GFI method a better choice due to its excellent performance [18]. After considering the advantages of GFI method and the availability of data, GFI method was chosen.

2.1. The expanded Kaya identity

Kaya identity is a widely used tool to analyze carbon emissions’ influencing factors which was first used by Yoichi Kaya at an Intergovernmental Panel on Climate Change (IPCC) workshop [19-20] with its expression as shown in Eq. (1).

\[ C = \frac{C}{E} \times \frac{E}{GDP} \times \frac{GDP}{P} \times P \] (1)

The identity can be modified into an expanded one by considering influencing factors particular in the transportation sector in Eq. (2). The factors and their representations in the above equation are given in Table 1.

\[ C = \sum \frac{C_i}{E_i} \times \frac{E_i}{GDP_i} \times \frac{GDP_i}{V_i} \times \frac{V_i}{GDP_i} \times \frac{GDP_i}{P} \times P \] (2)

| Factor | Representation |
|--------|----------------|
| C | Carbon emissions |
| \( C_i \) | The carbon emissions of the \( i \)th fuel type |
| E | The total primary energy consumption |
| \( E_i \) | The \( i \)th fuel consumption |
| GDP\(_{tr} \) | The GDP in the transportation sector |
| V | The traffic turnover |
| GDP | The gross domestic product |
| P | Population |
| \( C_i/E_i \) | The carbon emission coefficient |
| \( E_i/E \) | The energy structure |
| \( E/GDP_{tr} \) | The energy intensity |
| \( GDP_{tr}/V \) | The transportation GDP per unit transportation turnover |
| \( V/GDP \) | The transportation intensity |
| \( GDP/P \) | The economic growth |

2.2. GFI decomposition method

GFI method, first raised in 1922, is a better decomposition method among others for it can effectively deal with the decomposition process and explain the residuals in carbon emission changes.

Define \( V \) as the total index which is composed of \( n \) elements:

\[ V = \sum X_1 X_2 \cdots X_n \] (3)

Define the set \( N = \{1, 2, \cdots, n\} \) in which the cardinality of \( N \) is \( n \). \( S \) is a subset of \( N \), for which the cardinality is \( s' \). Define a function \( V(S) = \sum (\prod_{i \in S} X_i^T \prod_{m \in N \setminus S} X_m^0) \) and \( V(\emptyset) = \sum (\prod_{m \in N} X_m^0) \) where \( \emptyset \) is a null set and the superscripts denote the current year \( T \) and the base year 0. According to the ‘‘geometric average” principle, \( V^T/V^0 \) is divided into \( n \) parts, and the decomposition results of factor \( X_j = (j = 1, 2, \cdots, n) \) are as shown in Eq. (4):

\[ D_{X_j} = \prod_{j \in S} \left[ \frac{V(S)}{V(S \setminus j)} \right]^{\frac{1}{n-1}} = \prod_{j \in S} \left[ \frac{V(S)}{V(S \setminus j)} \right]^{\frac{(s'-1)(n-s)}{n!}} \] (4)
\( D_{X_j} (j = 1, 2, \cdots, n) \) represents each decomposition factor. We define carbon emission coefficient \( X_{1t} \), energy structure \( X_{2t} \), energy intensity \( X_3 \), output value of per unit traffic turnover \( X_4 \), transportation intensity \( X_5 \), economic growth \( X_6 \), and population \( X_7 \) and rewrite Eq. (2) into Eq. (5):

\[
C = \sum_{t} E_t \times \frac{E}{GDP} \times \frac{GDP}{V} \times \frac{V}{GDP} \times P = \sum_{t} X_{1t} X_{2t} X_3 X_4 X_5 X_6 X_7
\]

(5)

\( X_{1t} \) are generally consistent. Thus, the change in carbon emissions can be expressed by the rest six decomposition factors as shown in Eq. (6).

\[
\frac{c^T}{c^0} = D_{X_1} D_{X_2} D_{X_3} D_{X_4} D_{X_5} D_{X_6}
\]

(6)

Where, \( c^T \) and \( c^0 \) represents the carbon emissions in year T and in the base year, respectively. \( D_{X_1} \) to \( D_{X_6} \) represents the energy structure effect, the energy intensity effect, the output value of per unit traffic turnover effect, the transportation intensity effect, the economic growth effect and the population size effect respectively.

2.3. Data sources

All the data used in the calculation are from China Statistical Yearbook (1997-2014) and China Energy Statistics Yearbook (1999 and 2014). The fuel types include raw coal, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas, natural gas, heat and electricity. Among these fuel types, heat and electricity are assumed to generate no carbon emissions in order to be consistent with most studies [9-17]. The standard coal coefficients of each fuel type come from appendix 4 of China Energy Statistical Yearbook (2014). In order to eliminate the impact of price volatility, the annual GDP of 1997-2013 and the absolute value of \( GDP_{1996} \) are converted into actual GDP and \( GDP_{1996} \) value based on 1996. According to China's conversion factor for passenger and freight turnover, the passenger and freight turnover are unified, and then added to get the total traffic turnover. The conversion factors of passenger and freight in railway, road, water, and air transport are 1:1, 10:1, 2:1, and 13.7:1 respectively [21].

3. Results

The amount of total carbon emissions and the carbon emissions of each fuel type in China's transportation sector during 1996-2013 are shown in Figure 1. The carbon emissions increased from 31,419,000 tons in 1996 to 174,359,800 tons in 2013. The carbon emissions increase 25.28% annually. In 2013, 54.04% of the total carbon emissions in China's transportation sector came from diesel, 20.48% from gasoline, 9.64% from kerosene, 7.21% from fuel oil, 6.01% from natural gas, and the remaining 2.63% from raw coal, coke and crude oil. Therefore, the main reason for the energy-related carbon emissions in China's transportation sector is the consumption of large amounts of diesel and gasoline.

As can be seen from the decomposition results in China during 1996-2013 (shown in Table 2 and Figure 2), economic growth, energy intensity, population size and transportation intensity show cumulative contributions of 424.59%, 169.84%, 111.18% and 100.49%, respectively, which means these four factors have positive effect on increasing carbon emissions in the transportation sector. And, it is obvious to notice that economic growth contributes the most.

Economic growth and population size have continuously promoted the growth of carbon emissions. Energy intensity played a promoting role except during 1999-2001. Transportation intensity effect showed fluctuations during 1996-2013 and its effect values are close to 1, indicating that the transportation intensity has no significant effect. The cumulative effect value of transportation intensity during 1996-2013 is 1.0049. Therefore, transportation intensity has a weak promotion effect.

Energy structure and output value of per unit traffic turnover have inhibited carbon emissions in China’s transportation sector. The energy structure effect showed fluctuating changes that it played a promoting role in 1996-1999, 2004-2005, and 2011-2012, while played an inhibiting role in the rest years. Energy structure has a weak inhibition effect with its cumulative effect value of 0.9541. Output value of per unit traffic turnover also showed fluctuating changes that it played a promoting role in
1997-1998, 1999-2002, 2004-2006, 2007-2008, and 2012-2013, while, played an inhibiting role in the rest years. Output value of per unit traffic turnover shows strong inhibition effect with its cumulative effect value of 0.6421.

**Figure 1.** The carbon emissions in China’s transportation sector during 1997-2013.

**Figure 2.** Influencing factors of carbon emissions in China’s transportation sector during 1997-2013.

| Year     | $D_{X_1}$ | $D_{X_2}$ | $D_{X_3}$ | $D_{X_4}$ | $D_{X_5}$ | $D_{X_6}$ |
|----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1996-1997| 1.0011    | 1.1955    | 0.6865    | 1.0151    | 1.0819    | 1.0101    |
| 1997-1998| 1.0009    | 1.0340    | 1.0361    | 0.9978    | 1.0685    | 1.0092    |
| 1998-1999| 1.0005    | 1.0344    | 0.8870    | 1.0076    | 1.0675    | 1.0082    |
| 1999-2000| 0.9928    | 0.9435    | 1.0770    | 0.9987    | 1.0760    | 1.0076    |
| 2000-2001| 0.9946    | 0.9545    | 1.0405    | 0.9974    | 1.0755    | 1.0070    |
| 2001-2002| 0.9977    | 1.0060    | 1.0142    | 0.9982    | 1.0839    | 1.0065    |
| 2002-2003| 0.9953    | 1.1081    | 0.9321    | 1.0002    | 1.0937    | 1.0060    |
| 2003-2004| 0.9936    | 1.0560    | 0.9484    | 1.0039    | 1.0944    | 1.0059    |
| 2004-2005| 1.0039    | 1.0084    | 1.0535    | 0.9969    | 1.1066    | 1.0059    |
| 2005-2006| 0.9991    | 1.0080    | 1.0019    | 0.9991    | 1.1208    | 1.0053    |
| 2006-2007| 0.9996    | 1.0125    | 0.9969    | 0.9983    | 1.1358    | 1.0052    |
| 2007-2008| 0.9910    | 1.0582    | 1.0628    | 0.9952    | 1.0908    | 1.0051    |
| 2008-2009| 0.9967    | 1.0420    | 0.9415    | 0.9983    | 1.0868    | 1.0049    |
| 2009-2010| 0.9951    | 1.0324    | 0.9742    | 0.9997    | 1.0992    | 1.0048    |
| 2010-2011| 0.9950    | 1.0071    | 1.0078    | 0.9993    | 1.0878    | 1.0048    |
| 2011-2012| 1.0001    | 1.0562    | 0.9793    | 0.9994    | 1.0712    | 1.0050    |
| 2012-2013| 0.9962    | 1.0056    | 1.0008    | 0.9994    | 1.0714    | 1.0049    |
| 1996-2013| 0.9541    | 1.6984    | 0.6421    | 1.0049    | 4.2459    | 1.1118    |

4. Discussion

We further analyze the promotion and inhibition effect of the six factors one by one based on the results.

4.1. Energy structure

The general theory expects that energy structure will inhibit the growth of carbon emissions in China’s transportation sector. However, in this paper, energy structure calculated has no significant inhibition
effect, which is consistent with the results of previous studies on Beijing, Shanghai and Jiangsu provinces in China [9-10,12]. Actually, energy structure adjustment is helpful for controlling energy-related transportation carbon emissions. However, in the short term, it is difficult to change the dominant position of diesel, gasoline and other oils as fuel in China’s transportation sector. Therefore, the demand for petroleum makes energy structure’s inhibition effect unobvious. The main reason for energy structure’s promoting effect on the growth of carbon emissions in certain periods during 1996-2013 is that China’s transportation sector lacked significant technological innovations which made energy structure’s inhibition effect could not withstand other factors’ (such as economic growth and energy intensity) promoting effect.

4.2. Energy intensity
There is no consistent conclusion of energy intensity’s effect because of various regions chosen in different studies [3,7-8,10]. In this paper, the results show that energy intensity has strong promoting effect. The transportation energy intensity in China has increased from 1.4361 tons of standard coal per 10,000 yuan in 1996 to 2.4390 tons of standard coal per 10,000 yuan in 2013 (GDP is calculated based on 1996) according to the calculation results. It can be seen that except for 2001 and 2005-2007, the growth rate of transportation energy consumption in other years is higher than the growth rate of transportation GDP. The reason for this phenomenon may be the rapidly increasing number of private cars and state-owned vehicles during the study period only generated energy consumption but have not created GDP. The number of private car ownership in China has increased from 2,896,700 in 1996 to 10,501,800 in 2013. In 2013, the number of state-owned vehicles in China reached 4 million, which result in a large amount of consumption of diesel, gasoline and kerosene.

4.3. Output value of per unit traffic turnover
Only few studies have explored output value of per unit traffic turnover’s effect on carbon emissions in transportation sector, such as its influence on the increase of transportation GDP [22] and its promoting effect on the growth of carbon emissions [10]. This index reflects the level of transportation efficiency. The more efficient the transportation is, the lower its value shows. As shown in Figure 3, its value during 1996-2013 generally shows a downward trend with two fluctuations during 1996-2005. It is indicated that the transportation efficiency has been improved during the period 1996-2013.

Freight and passenger turnover in China during 1996-2013 are shown in Figure 4. Freight turnover contributed more to the total traffic turnover. The proportion of freight turnover increased from 90% in 1996 to 93% in 2013. As for the composition of freight turnover in China, water freight turnover takes up the largest proportion (47% in 2013), followed by road freight turnover (33% in 2013). As for the composition of passenger turnover in China, road passenger turnover accounts for the largest proportion (40.8% in 2013), followed by railway passenger turnover (38.4% in 2013). As the main contributor to traffic turnover, freight transportation needs to be improved, especially in water freight and road freight. Meanwhile, the efficiency of road and railway passenger transportation needs to be improved as well.

4.4. Transportation intensity
Fan & Lei noted that transportation intensity is a decisive factor [10]. Transportation intensity in China during 1996-2013 fluctuated with fluctuations range of around 5% and showed no obvious upward and downward trend. Transportation intensity effect fluctuated accordingly with fluctuations range of only 1% and also showed unobvious trend. The results show that transportation intensity effect has no obvious inhibition or promotion effect.

4.5. Economic growth
Previous studies found that economic growth plays the crucial role in the growth of transportation carbon emissions [5-6]. According to the historic data, the per capita GDP in China experienced an increase of 325% from 1996 to 2013, while, carbon emissions in China’s transportation sector
increased from 31.42 million tons to 174.36 million tons correspondingly, yielding an increase of 455%. The rapid economic growth increases demand for travels which further leads to more transportation carbon emissions. The cumulative effect of economic growth in our study is 424.59%. It is expected that economic growth will still be the main influencing factor of transportation carbon emissions in the future.

4.6. Population size

It is confirmed that population size is a significant factor in increasing carbon emissions in transportation sector of various regions [3,7]. The cumulative effect of the population size is 111.18%. As the population increases, the number of travels increase, which in turn leads to growth of transportation carbon emissions. However, compared with economic growth effect and energy intensity effect, population size effect is weaker.

5. Conclusions and suggestions

5.1. Conclusions

The cumulative contributions of economic growth effect, energy intensity effect, population size effect and transportation intensity effect are 424.59%, 169.84%, 111.18% and 100.49% respectively which indicates these four factors have positive effect on the growth of transportation carbon emissions. Economic growth the most decisive and influential factor of transportation carbon emissions in China. Energy intensity, population size and transportation intensity generally have fewer positive effects than economic growth. Output value of per unit traffic turnover and energy structure have inhibition effect, among them, the former is the primary factor and the latter has unobvious inhibition effect. The combined inhibition effect of these two factors is overwhelmed by the integral promotion effect.

5.2. Suggestions

Encourage people to adopt new energy vehicles in passenger transport area. To replace the traditional cars with new energy vehicles helps improve energy structure in transportation sector. However, the price and charging problem are the major obstacles of promoting new energy vehicles. As for the price, manufacturing enterprises of new energy vehicles should not only do market research to understand the potential consumers of new energy vehicles but also improve manufacturing technology to reduce cost. As for the charging problem, the charging facility in residential areas, office buildings, shopping malls, highways and other regions should be provided and the availability information of charging facility should be offered in time.

Promote new energy vehicles in road freight and new energy ships in water freight. Since freight turnover takes up the most proportion of the total traffic turnover, it is suggested for the government and enterprises to develop awareness to reduce energy consumption and improving energy structure in
freight area, which is often neglected. New energy vehicles and new energy ships in freight should be
designed and developed according to the actual freight need. Financial and tax benefit need to be
offered to encourage enterprises to adopt green vehicles and ships. Besides, charging infrastructure
should be established accordingly.

Encourage public and shared transportation. The government may carry out buying, driving and
parking restriction policies to inhibit the growth of private vehicles. Public vehicles such as buses,
subways and light rails are encouraged to improve the efficiency of road transportation in passenger
transportation. The adoption of new energy buses can both improve energy structure and output value
of per unit traffic turnover. Actions such as the government procurement of new energy buses will
help the adoption of new energy buses. In addition, relying on the internet, big data and advanced
calculation methods, car-sharing, internet taxis and commercial vehicles service available from
various mobile apps are also efficient ways to practice low-carbon transportation.

Promote the infrastructure construction of national multimodal transport. Multimodal transport is
recognized as an efficient, safe, low-cost, low-carbon-emission modern transportation method in the
international logistics industry. We should coordinate various transport modes, take advantage of the
overall efficiency of integrated transportation and build a large transportation system with multimodal
transport around railway hubs and ports.

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