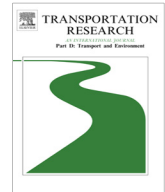




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## Decomposition analysis of energy-related carbon emissions from the transportation sector in Beijing



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### ABSTRACT

In the process of rapid development and urbanization in Beijing, identifying the potential factors of carbon emissions in the transportation sector is an important prerequisite to controlling carbon emissions. Based on the expanded Kaya identity, we built a multivariate generalized Fisher index (GFI) decomposition model to measure the influence of the energy structure, energy intensity, output value of per unit traffic turnover, transportation intensity, economic growth and population size on carbon emissions from 1995 to 2012 in the transportation sector of Beijing. Compared to most methods used in previous studies, the GFI model possesses the advantage of eliminating decomposition residuals, which enables it to display better decomposition characteristics (Ang et al., 2004). The results show: (i) The primary positive drivers of carbon emissions in the transportation sector include the economic growth, energy intensity and population size. The cumulative contribution of economic growth to transportation carbon emissions reaches 334.5%. (ii) The negative drivers are the transportation intensity and energy structure, while the transportation intensity is the main factor that restrains transportation carbon emissions. The energy structure displays a certain inhibition effect, but its inhibition is not obvious. (iii) The contribution rate of the output value of per unit traffic turnover on transportation carbon emissions appears as a flat "M". To suppress the growth of carbon emissions in transportation further, the government of Beijing should take the measures of promoting the development of new energy vehicles, limiting private vehicles' increase and promoting public transportation, evacuating non-core functions of Beijing and continually controlling population size.

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### Introduction

In the 21st century, global warming and the energy crisis pose a serious challenge to sustainable human development. Low carbon development has become the global consensus for growth. However, with the rapid development of the economy and society, cities have become a major source of carbon emissions, and urban transportation is an important contributor to urban carbon emissions. According to UN statistics, urban carbon emissions account for 75% of the total global carbon emissions, in which transportation accounting for 17.5% (Li and Liu, 2014). Our calculation reveals that the transportation

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carbon emissions of Beijing in 2012 accounted for approximately 22.28% of the total carbon emissions. In the worldwide, transportation has already become the second highest carbon dioxide (CO<sub>2</sub>) emission sector, trailing the electricity and heat generation (IEA, 2014).

Increased transportation carbon emissions have become an important factor restricting the sustainable development of the global economy. Low-carbon transportation and related issues have thus become a substantial topic in the community. Multiple studies have investigated the factors influencing carbon emissions in the transportation sector. Lakshmanan (1997) developed a decomposition scheme to identify the magnitude and the relative effects of the various factors in the U.S. transportation energy use and CO<sub>2</sub> emissions between 1970 and 1991. The results revealed that the growth in the propensity to travel, population, and gross domestic product (GDP) were the three most important factors driving U.S. transportation energy use and CO<sub>2</sub> emissions. Data covering 146 urbanized areas in the United States indicated that the population density, transit share, freeway lane miles per capita, private vehicle occupancy, and average travel time had a statistically significant explanatory effect on passenger travel-related CO<sub>2</sub> emissions (Mishalani et al., 2014). Lu et al. (2007) adopted the Divisia index approach to explore the effects of five factors on the total carbon dioxide emissions from highway vehicles in Germany, Japan, South Korea and Taiwan during 1990–2002. Their results suggested that the rapid growth in the economy and of vehicle ownership were the most important factors for the increased CO<sub>2</sub> emissions, whereas population intensity contributed significantly to decreasing the emissions. Timilsina and Shrestha (2009) analyzed the potential factors influencing the growth of transportation sector CO<sub>2</sub> emissions in selected Asian countries during 1980–2005 and identified changes in per capita GDP, population growth and transportation energy intensity as the main factors driving transportation sector CO<sub>2</sub> emission growth. Schipper et al. (1997) performed a decomposition analysis on the changes in freight energy use of 10 industrialized countries from 1973 to 1992 to identify the relative contribution of the activity, modal structure, and energy intensity to increases in the energy use observed in each country. The major findings were as follows: Domestic freight volumes increased with trucks carrying the majority of the increased freight. Freight energy use and the associated carbon emissions increased markedly and were rising when compared to the emissions associated with passenger travel. The energy used for freight will continue to increase unless substantial reductions occur in the energy intensities of truck freight. Andreoni and Galmarini (2012) also used a decomposition analysis to investigate the main factors influencing CO<sub>2</sub> emissions from the water and aviation transportation sectors in Europe during 2001–2008. The results indicated that economic growth was the main factor behind CO<sub>2</sub> emissions. Kwon (2005) investigated the key factors in the change in CO<sub>2</sub> emissions from car travel in Great Britain over the last 30 years using the IPAT identity. The results revealed that car driving distance per person was a dominant force for the growth of emissions. Technology factors, such as fuel efficiency and substitution of diesel fuel, partly cancelled out the growth effects, while the contribution of the other factors was relatively small. Mazzarino (2000) adopted a comparative static approach to analyze the main factors by determining the variation of transportation sector CO<sub>2</sub> emissions in Italy during 1980–1995. The results indicated that the main driving force in the variation of CO<sub>2</sub> emissions was the growth of the GDP. Timilsina and Shrestha (2009) determined the factors responsible for the growth of transportation sector CO<sub>2</sub> emissions in 20 Latin American and Caribbean (LAC) countries during 1980–2005 by decomposing the emission growth into components associated with changes in the fuel mix, modal shift, economic growth, emission coefficients and transportation energy intensity. The key finding was that economic growth and the changes in transportation energy intensity were the principal factors driving transportation sector CO<sub>2</sub> emissions growth in the countries considered.

Currently, research on the factors influencing transportation carbon emissions in China remains limited. Wang et al. (2011) applied the logarithmic mean Divisia index (LMDI) method to determine the factors that influence changes in transportation sector CO<sub>2</sub> emissions in China over the period 1985–2009. The results showed that highway transportation was the most substantial source of CO<sub>2</sub> emissions. The per capita economic activity effect and transportation modal shifting effect were primarily responsible for driving the growth in the transportation sector CO<sub>2</sub> emissions. The transportation intensity effect and transportation services share effect were the main drivers of the reduction of CO<sub>2</sub> emissions in China. However, the emission coefficient effect played a minor role over the study period. Through a daily activity survey conducted in Beijing from 2000 to 2011, Wang and Liu (2014) examined the effects of individual travel behavior on carbon emissions from urban transportation in Beijing. The results showed that the vehicle-use intensity, disposable income per capita and population size were the main drivers for the increase of household daily travel carbon emissions. Both the transportation intensity and emission coefficient had significant effects on the reduction of carbon emissions. However, the transportation mode share played a minor role. Based on data covering Beijing, Tianjin, Shanghai and Chongqing, Su et al. (2011) empirically analyzed the factors influencing urban transportation carbon emissions during 1995–2009. The results showed that the city population size and vehicle ownership had important effects on urban transportation carbon emissions by influencing passenger and freight turnover. Urban passenger and freight turnover had significant positive effects on urban transportation carbon emissions, whereas the proportion of buses had a significant negative effect. Yang et al. (2014) and Wu et al. (2012) applied the LMDI decomposition method to analyze transportation sector carbon emissions in Jiangsu and Shanghai, respectively, and yielded consistent conclusions: the positive driving factors were the economic output, population size and industrial structure, whereas the negative drivers were the transportation energy structure and energy intensity. Shen and Chi (2012) analyzed the driving factors of CO<sub>2</sub> emissions from transportation sector in China from 1991 to 2009. The results showed that the main positive drivers of CO<sub>2</sub> emissions from the transportation sector were the urbanization level, proportion of tertiary industries and total population, and that the main negative drivers were the traffic turnover per unit of GDP, energy consumption per unit of traffic turnover, secondary and tertiary industries value per unit of population, and the contribution of tertiary industry to GDP. Based on the STIRPAT model and the energy-related carbon emissions from

transportation in Jilin Province from 1999–2011, Gao et al. (2013) revealed that the population, per capita GDP, transportation, city investment rate, and number of private cars displayed positive driving effects on carbon emissions, and that energy consumption per GDP, in contrast, had an inhibitory effect on carbon emissions. The main influencing factors of the relevant literature are summarized in Table 1.

Increasing the energy-savings and emission-reductions in transportation has become an inevitable goal to relax the tension of energy supply, to ease the pressures on the environmental capacity and to build a low-carbon ecological city. Beijing is an international metropolis, and the transportation carbon emissions continue to grow along with the increasing expansion of urban space and increased car ownership. From 1995–2012, the average annual growth rate of transportation carbon emissions in Beijing reached 11.81% and is expected to grow continuously. It has become a primary issue to analyze the key factors affecting urban transportation carbon emissions and their influence degree in establishing low-carbon urban transportation policy and controlling urban transportation carbon emissions. Previous studies have adopted different countries or regions as research areas, analyzing the influencing factors of transportation carbon emissions. However, we only found Wang and Liu (2014) discussed the effects of individual behavior on carbon emissions from urban transportation in Beijing. A systematic analysis of the factors affecting transportation sector CO<sub>2</sub> emissions in Beijing has not been involved. Moreover, industrial characteristics in the factor decomposition analysis have not been included in most previous studies. This study aims to draw a comprehensive picture of the driving forces of the changing carbon emissions related to transportation sector in Beijing by building a multivariate generalized Fisher index (GFI) decomposition model based on the expanded Kaya identity using the data from 1995 to 2012 in Beijing. Policy suggestions will be proposed following the research results.

## Methodology and data

We use the expanded generalized Fisher index method to analyze different factors on transportation carbon emissions in Beijing based on the expanded Kaya identity. The main reason is that the most commonly used index decomposition methods of the Laspeyres and Divisia index methods cannot handle the residuals in the decomposition process and the explanation of all the changes in carbon emissions is inhibited. The generalized Fisher index has better decomposition characteristics than the Laspeyres and Divisia index methods. Ang et al. (2004) compared the generalized Fisher index method with five widely employed index decomposition methods on a basis of the factor-reversal, time-reversal, proportionality, aggregation, zero-value robust and negative-value robust tests (see Table 1 in Ang et al. (2004) for details). The generalized Fisher index passed all of the tests except the aggregate test, and achieved complete factor decomposition. This suggests the generalized Fisher index should be a better way to perform decomposition.

### The expanded Kaya identity

The Kaya identity was proposed by Japanese scholar Yoichi Kaya (Kaya, 1990) for the first time at an IPCC workshop; it is a useful tool for analyzing the factors of carbon emissions (Albrecht et al., 2002). The expression is:

$$C = (C/E) (E/GDP) (GDP/P) P \quad (1)$$

The Kaya identity relates energy-related carbon emissions with energy ( $E$ ), economic growth level (GDP) and population ( $P$ ). Its structure is relatively simple and only explores the quantitative relationship among the carbon emissions, energy intensity, economic growth and population at a national level without considering the influence of structural factor. Therefore, we added the energy structure as a factor to the Kaya identity because of the available data, and we decomposed carbon emissions into energy structure, energy efficiency, economic growth and population. The expansion of the equation is as follows:

$$C = \sum_i C_i = \sum_i \frac{C_i}{E_i} \frac{E_i}{E} \frac{E}{GDP} \frac{GDP}{P} P \quad (2)$$

where  $C$  represents the carbon emissions;  $C_i$  is the carbon emissions of the  $i$ th fuel type;  $E_i$  and  $E$  represent the  $i$ th fuel consumption and the total primary energy consumption, respectively; GDP is the gross domestic product; and  $P$  is population.

As a type of induced demand of a national economy, energy-related carbon emissions in the transportation sector are influenced by regional economic development level, energy intensity of the sector and other factors. Therefore, Beijing's transportation carbon emissions are expanded as the following according to Eq. (2) and the characteristics of the transportation sector:

$$C = \sum_i C_i = \sum_i \frac{C_i}{E_i} \frac{E_i}{E} \frac{E}{GDP_{tr}} \frac{GDP_{tr}}{V} \frac{V}{GDP} \frac{GDP}{P} P \quad (3)$$

where  $GDP_{tr}$  is the GDP in the transportation sector;  $V$  represents the traffic turnover;  $C_i/E_i$  is the carbon emissions of the  $i$ th fuel type, namely, the carbon emission coefficient;  $E_i/E$  represents the total energy consumption share of the  $i$ th fuel type in the transportation sector, namely, the energy structure;  $E/GDP_{tr}$  is the energy consumption per unit of GDP in the transportation sector, namely the energy intensity;  $GDP_{tr}/V$  represents the value of the transportation GDP brings by per unit

**Table 1**  
Literature on the main factors influencing transportation carbon emissions.

Author	Region	Year	The main influencing factors									
			P	EO	EI	ES	MS	FM	TI	IS	CI	
Mishalani et al.	America	2014	✓									
Lu et al.	4 countries	2007	✓	✓								
Timilsina and Shrestha	Asian countries	2009	✓	✓	✓				✓			
Lakshmanan	America	1997	✓	✓				✓				
Schipper et al.	10 countries	1997			✓			✓	✓			✓
Andreoni and Galmarini	Europe	2012		✓	✓						✓	
Kwon	England	2005	✓									✓
Mazzarino	Italy	2000	✓	✓	✓			✓	✓	✓		
Timilsina and Shrestha	20 countries	2009		✓	✓				✓			
Wang et al.	China	2011	✓	✓				✓		✓		
Wang and Liu	Beijing	2014	✓					✓		✓		
Su et al.	4 provinces of China	2011	✓							✓		
Yang et al.	Jiangsu	2014	✓	✓	✓	✓					✓	
Wu et al.	Shanghai	2012	✓	✓	✓	✓						
Shen and Chi	China	2012	✓							✓	✓	
Gao et al.	Jilin	2013	✓	✓	✓							

Note: P, EO, EI, ES, MS, FM, TI, IS, CI respectively represent population, economic output, energy intensity, energy structure, modal structure, fuel mix, transportation intensity, industrial structure and carbon intensity.

transportation turnover;  $V/GDP$  represents the traffic turnover per unit of GDP, defined as the transportation intensity; and  $Y/P$  represents the per capita GDP, namely, the economic growth.  $P$  represents population size.

*Generalized Fisher index decomposition*

The Fisher index decomposition method was first proposed by Fisher in 1922. The model is expressed as follows:

$$V = \sum_i V_i = \sum_i X_{1i} X_{2i} \tag{4}$$

where  $V$  represents an aggregate indicator,  $i$  denotes the sub-category of the aggregate, and  $X_{1i}$  and  $X_{2i}$  indicate the decomposed variables. The effect associated with changes in  $X_1$  and  $X_2$  from year 0 to year  $T$  is given in Eq. (5):

$$D = \frac{V^T}{V^0} = \frac{\sum_i X_{1i}^T X_{2i}^T}{\sum_i X_{1i}^0 X_{2i}^0} = D_{X_1} \cdot D_{X_2} \tag{5}$$

According to the Fisher index formula, we have

$$D_{X_1} = \left[ \frac{\sum_i X_{1i}^T X_{2i}^0 \cdot \sum_i X_{1i}^0 X_{2i}^T}{\sum_i X_{1i}^0 X_{2i}^0 \cdot \sum_i X_{1i}^T X_{2i}^T} \right]^{1/2} \tag{6}$$

$$D_{X_2} = \left[ \frac{\sum_i X_{1i}^0 X_{2i}^T \cdot \sum_i X_{1i}^T X_{2i}^0}{\sum_i X_{1i}^0 X_{2i}^0 \cdot \sum_i X_{1i}^T X_{2i}^T} \right]^{1/2} \tag{7}$$

Some scholars have used the traditional Fisher model to study energy and relative gas emissions (Liu and Ang, 2003; Boyd and Roop, 2004), but in empirical studies, two factors are insufficient for meeting the needs of solving this problem. Ang et al. (2004) extended the two factors to multiple factors and proposed the generalized Fisher index. The specific steps are as follows:

$V$  is the total index is composed of  $n$  elements:

$$V = \sum_i X_1 X_2 \dots X_n \tag{8}$$

Define the set  $N = \{1, 2, \dots, n\}$  in which the cardinality of  $N$  is  $n$ .  $S$  is a subset of  $N$ , for which the cardinality is  $s'$ . Define a function  $V(S) = \sum (\prod_{l \in S} X_l^T \prod_{m \in N \setminus S} X_m^0)$  and  $V(\Phi) = \sum (\prod_{m \in N} X_m^0)$  where  $\Phi$  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  $X_j$  ( $j = 1, 2, \dots, n$ ) are given by the following:

$$D_{X_j} = \prod_{\substack{S \subset N \\ j \in S}} \left[ \frac{V(S)}{V(S \setminus \{j\})} \right]^{\frac{1}{n} \frac{1}{(s'-1)}} = \prod_{\substack{S \subset N \\ j \in S}} \left[ \frac{V(S)}{V(S \setminus \{j\})} \right]^{\frac{(s'-1)!(n-s')!}{n!}} \tag{9}$$

$D_{X_j}$  ( $j = 1, 2, \dots, n$ ) is the decomposition factor of the generalized Fisher index method.

According to the above method, formula (3) is defined for the energy-related carbon emission coefficient  $X_{1i} = C_i/E_i$ , energy structure  $X_{2i} = E_i/E$ , energy intensity  $X_{3i} = E_i/GDP_{tr}$ , output value of per unit traffic turnover  $X_{4i} = GDP_{tr}/V$ , transportation intensity  $X_5 = V/GDP$ , economic growth  $X_6 = GDP/P$ , and population size  $X_7 = P$ . Thus, the carbon emission formula can be written as follows:

$$C = \sum_i C_i = \sum_i \frac{C_i}{E_i} \frac{E}{E} \frac{E}{GDP_{tr}} \frac{GDP_{tr}}{V} \frac{V}{GDP} \frac{GDP}{P} P = \sum_i X_{1i} X_{2i} X_{3i} X_{4i} X_5 X_6 X_7 \tag{10}$$

Generally, the carbon emission coefficients of all types of fossil fuels  $X_{1i}$ , are fixed; therefore, the factors affecting transportation carbon emissions in Beijing are mainly the energy structure, energy intensity, output value of per unit traffic turnover, transportation intensity, economic growth and population size. The change in emissions can be decomposed into the following:

$$C^T/C^0 = D_{X_1} D_{X_2} D_{X_3} D_{X_4} D_{X_5} D_{X_6} \tag{11}$$

In Eq. (11),  $C^T$  is the carbon emissions in year  $T$ ;  $C^0$  is the carbon emissions in the base year;  $D_{X_1}$  is the energy structure effect where  $X_1$  is the product of the energy consumptions structure ( $E_i/E$ ) and corresponding carbon emission coefficients ( $C_i/E_i$ ),  $D_{X_2}$  is the energy intensity effect,  $D_{X_3}$  is the output value of per unit traffic turnover effect,  $D_{X_4}$  is the transportation intensity effect,  $D_{X_5}$  is the economic growth effect, and  $D_{X_6}$  is the population size effect. Among these values, the following can be written:

$$D_{X_1} = \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{6}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \cdot \left[ \frac{\sum_i X_{1i}^T X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_{1i}^0 X_{2i}^0 X_{3i}^0 X_{4i}^0 X_5^0 X_6^0} \right]^{\frac{1}{60}} \tag{12}$$

$D_{X_2}$ ,  $D_{X_3}$ ,  $D_{X_4}$ ,  $D_{X_5}$ , and  $D_{X_6}$  can be obtained by formula (9).

Data sources

Energy consumption data in the transportation sector are adopted from energy balance tables for Beijing in previous China Energy Statistical Yearbook. The fuel types include coal, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas, natural gas, heat and electricity. Consistent with most studies (Yang et al., 2014a; Shen and Chi, 2012), we assume that heat and electricity do not directly generate carbon emissions. To ensure comparability among the data, energy sources were converted into standard coal equivalent according to standard coal coefficients from appendix 4 of the 2013 China Energy Statistical Yearbook. Carbon emission coefficients upon the standard coal equivalent are referred to Zhao (2009).

In the China Energy Statistical Yearbooks, transportation, storage and postal services are identified as one single industry sector. The proportion of energy consumed by the storage and postal services is small (accounting for approximately 7.6% in 2007, according to the National Bureau (He, 2012)); therefore, the total energy consumed by this category is approximately the value consumed by transportation. Economic and traffic turnover data originate from past Beijing Statistical Yearbooks. The sample data spans the period from 1995 to 2012, and the statistical data are reported at current prices. To eliminate the effect of price fluctuations, GDP and  $GDP_{tr}$  have been converted into the 1995 value according to the corresponding value.

**Results**

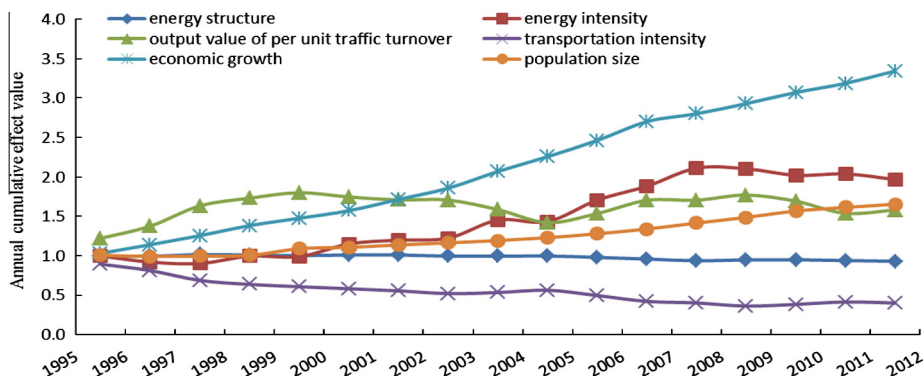
The decomposition results for the factors influencing transportation carbon emissions in the above formulas are shown in Table 2 and in Fig. 1.

- (i) Economic growth, energy intensity, population size and output value of per unit traffic turnover play positive roles in increasing transportation carbon emissions, with cumulative contributions of 334.5%, 196.7%, 165.4% and 158.2%, respectively. Among them, economic growth contributes the most in increasing transportation carbon emissions, Energy intensity, population size and output value of per unit traffic turnover generally display positive effects on transportation carbon emissions, but the effects are weaker than that of economic growth.
- (ii) The effect of energy intensity on transportation carbon emissions shows a fluctuating trend over time, alternating performance of inhibition and promotion. During 1998–1999, 2000–2004, 2005–2008, and 2010–2011, energy intensity displays a promotion role, while an inhibition role in the other years. The annual cumulative effect of output value of per unit traffic turnover on transportation carbon emissions appears as a flat “M”, where the effect on transportation carbon emissions is negative in 2000–2005 and 2009–2011 but positive in the other years.

**Table 2**  
Decomposition effect of carbon emissions from the transportation sector in Beijing.

Year	$D_{X_1}$	$D_{X_2}$	$D_{X_3}$	$D_{X_4}$	$D_{X_5}$	$D_{X_6}$
1995–1996	0.995	0.998	1.220	0.894	1.031	1.007
1996–1997	1.000	0.922	1.128	0.908	1.106	0.985
1997–1998	1.021	0.981	1.187	0.847	1.101	1.005
1998–1999	0.994	1.104	1.060	0.927	1.101	1.009
1999–2000	0.993	0.993	1.040	0.954	1.068	1.084
2000–2001	1.007	1.163	0.970	0.958	1.065	1.016
2001–2002	1.001	1.042	0.979	0.954	1.091	1.028
2002–2003	0.985	1.021	0.999	0.937	1.083	1.023
2003–2004	1.000	1.187	0.929	1.026	1.114	1.025
2004–2005	1.002	0.987	0.896	1.054	1.091	1.030
2005–2006	0.982	1.190	1.081	0.881	1.091	1.041
2006–2007	0.979	1.103	1.109	0.851	1.097	1.047
2007–2008	0.977	1.122	1.001	0.953	1.037	1.057
2008–2009	1.012	0.996	1.038	0.900	1.046	1.050
2009–2010	1.001	0.961	0.956	1.060	1.048	1.055
2010–2011	0.990	1.008	0.909	1.080	1.038	1.029
2011–2012	0.990	0.965	1.028	0.966	1.049	1.025
1995–2012	0.930	1.967	1.582	0.400	3.345	1.654

Note:  $D_{X_1}$ ,  $D_{X_2}$ ,  $D_{X_3}$ ,  $D_{X_4}$ ,  $D_{X_5}$ ,  $D_{X_6}$  and  $V$  represent energy structure effect, energy intensity effect, output value of per unit traffic turnover effect, transportation intensity effect, economic growth effect, population size effect.



**Fig. 1.** Influencing factors of transportation carbon emissions in Beijing from 1995 to 2012.



- (iii) Transportation intensity and energy structure inhibit transportation carbon emissions. The decrease in transportation intensity has a great contribution to the reduction of transportation carbon emissions. The cumulative effect value decreased from 0.894 in 1995 to 0.400 in 2012, which indicates a strengthening trend of inhibition.
- (iv) The annual effect of transportation intensity on transportation carbon emissions fluctuates in different periods. A promoting effect appears in 2003–2005 and 2009–2011 but an inhibitory effect emerges in 1995–2003, 2005–2009, and 2011–2012. The effect of energy structure on transportation carbon emissions is similar to energy intensity with inhibition and promotion effects appearing alternatively. Although its contribution is small, energy structure cumulatively plays an inhibiting role in transportation carbon emissions.

## Discussion

The above results indicate that the contribution of each factor to the changes of transportation carbon emissions in Beijing is different. The economic growth, energy intensity, population size and output value of per unit traffic turnover play promotion roles in increasing transportation carbon emissions, while the transportation intensity and energy structure generally inhibit the emissions. The effects of energy intensity, output value of per unit traffic turnover, transportation intensity and energy structure fluctuate in some way at different stages. Effects of these six decomposition factors are discussed one by one in the following sections.

### Energy structure

Energy structure shows an inhibitory effect on transportation carbon emissions in Beijing, which is consistent with a general theoretical expectation. However, a significant inhibitory effect has not been observed in this study. The result here is consistent with the previous observations on Jiangsu and Shanghai in China (Yang et al., 2014a; Wu et al., 2012). In fact, the energy structure adjustment has an indispensable role in controlling transportation carbon emissions resulting from energy consumption. Since 2004, Beijing has adopted a series of measures, such as substituting coal with oil and gas, to optimize the energy structure and promote natural gas, heat, electricity and other clean energy sources, making natural gas, heat and electricity accounted for 14.6% of energy consumption in 2012 against 9.1% in 2004, thereby slowing down the increase of transportation carbon emissions in Beijing. However, the situation is difficult to change in the short term that the energy consumption in the transportation sector is dominated by oil. Therefore, the demand for fossil fuels such as oil and other fossil fuels makes the inhibition of carbon emissions from energy consumption inapparent.

As shown in Table 2, the annual effect of energy structure on the growth of transportation carbon emissions in Beijing shows some volatility. This is mainly due to a lack of substantial technology revolution in transportation during the studied period, The inhibitory effect by advancing in energy structure thus is not strong enough to overcome the promotion effects brought by other factors, e.g., economic growth, energy intensity, etc.

### Energy intensity

Energy intensity is calculated by the energy consumed per unit of transportation sector GDP, and thus reflects the overall energy efficiency of the transportation sector. Concerning the effect of energy intensity on transportation carbon emissions, previous studies have not achieved consistent results yet because different regions are chosen in different studies. Lakshmanan (1997) analyzed the factors influencing transportation carbon emissions in the United States and pointed out that, the decreased energy intensity in passenger vehicles and light trucks is the main factor to reduce transportation carbon emissions. Timilsina and Shrestha (2009) analyzed the potential factors influencing the transportation sector CO<sub>2</sub> emissions in selected Asian countries during 1980–2005 and found that the decline in energy intensity corresponds to the decreasing CO<sub>2</sub> emissions in Mongolia, but the increasing emissions in Bangladesh, the Philippines and Vietnam. Timilsina and Shrestha (2009) determined the factors responsible for the growth in transportation sector CO<sub>2</sub> emissions in 20 Latin American and Caribbean countries during 1980–2005. Energy intensity is the main driving force in Bolivia, Caribbean, Cuba, Ecuador, Guatemala, Honduras, Panama, Paraguay, and the other Latin America in increasing transportation carbon emissions except in Cuba due to energy shortages during 1989–1994.

The results of this study show that energy intensity is an important factor causing the increase of transportation-related carbon emissions in Beijing. During 1995–2012, energy intensity in the transportation sector of Beijing increased from 1.982 standard coal equivalent per 10<sup>4</sup> yuan to 3.469 standard coal equivalent per 10<sup>4</sup> yuan (in 1995 prices), and the development over time is shown in Fig. 2. This observation may be due to the fast growing of private cars and a large number of state-owned vehicles.<sup>1</sup> For these parts of vehicles, energy consumption has been included while GDP cannot be calculated. As counted, the private cars grew from 494,143 in 2000 to 2,483,494 in 2008, which caused rapid growth of gasoline, kerosene, diesel oil consumption. Thus, the contribution of energy intensity to transportation sector carbon emissions in Beijing reflects the growth of private cars on transportation carbon emissions in some way. Inhibition role of energy intensity appears mainly

<sup>1</sup> State-owned cars refers to the official vehicles purchased by public funds from all levels of the administrative organs, social groups, institutions, state-owned enterprises and other units.

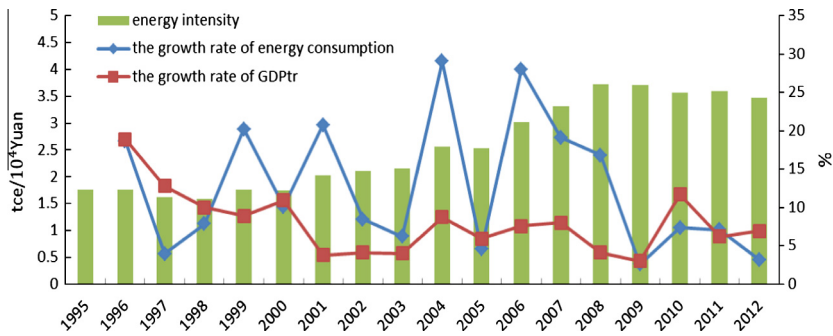


Fig. 2. The development over time of transportation energy intensity in Beijing.

post 2008 after the introduction of the fourth phase of national emission standards for motor vehicles in Beijing and usage limitation rule for motor vehicles based on license numbers.

#### Output value of per unit traffic turnover

The effect of output value of per unit traffic turnover on transportation carbon emissions was not discussed in previous studies. Only Liu (2013) discussed the effect of output value of per unit traffic turnover on the transportation added value. The index used here is inverse to traffic turnover per unit transportation output value,  $V/GDP_{tr}$ , and could reflect the level of transportation efficiency to a certain extent. For example, a bus is more efficient than a car and its output value of per unit traffic turnover  $GDP_{tr}/V$  is lower. The output value of per unit traffic turnover on transportation carbon emissions appears as a flat “M” for Beijing. Total freight turnover displayed a negative trend against the cumulative effect of output value of per unit traffic turnover, while  $GDP_{tr}$  of Beijing keep steadily growing during the studied period (Figs. 1 and 3). Therefore, the fluctuation of  $GDP_{tr}/V$  in Beijing corresponds to the change of total freight turnover over time. Total freight turnover reflects the change of the economic cycle. From 2000 to 2005, Chinese accession to the World Trade Organization (WTO) increased the demand for cargo transportation. After 2006, due to the subprime mortgage crisis in the United States, logistics and freight transportation sector of Beijing, which plays an important role in international (and internal) production and trade, was depressed to a certain degree. After 2009, attributing to economic recovery of Beijing that promoted the rapid development of business and expanded the scale of commercial circulation, total freight traffic turnover has also increased.

#### Transportation intensity

The transportation intensity effect is a decisive factor contributing to the reduction of transportation carbon emissions, with a cumulative effect of 0.400. This is closely related to the change of transportation intensity. From 1995–2012, the transportation turnover per  $10^4$  Yuan GDP in Beijing declined by 60.02% (in 1995 prices). As shown in Fig. 4, transportation intensity declining owes to industrial adjustment policy in Beijing, which restricts high energy consumption, high pollution and high emission industries and encourages the development of high value-added high-technical industries. This is consistent with the analysis of the influencing factors of transportation sector  $CO_2$  emissions in China by Wang et al. (2011). Results of this study further shows that transportation intensity inhibited transportation carbon emissions except 2003–2005, 2009–2011. In 2003, the growth rate of passenger turnover in Beijing fell slightly because of Severe Acute Respiratory Syndrome (SARS). After the SARS crisis, passenger turnover rebound rapidly, and the growth rate increased significantly. In 2006,

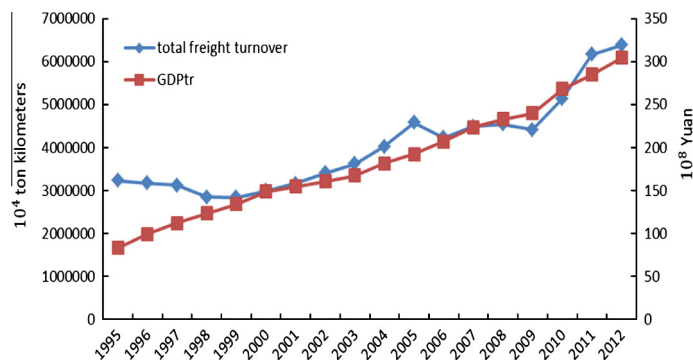


Fig. 3. Evolution of total freight turnover.



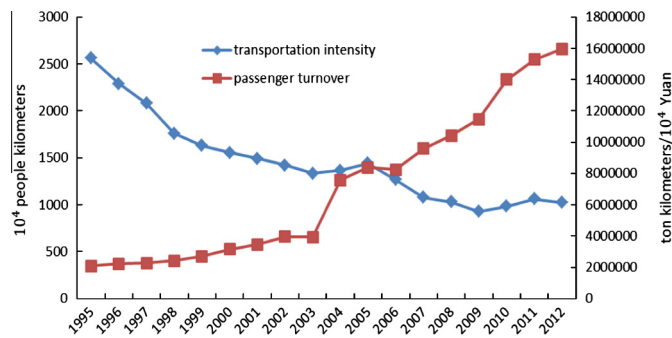


Fig. 4. Evolution of transportation intensity in Beijing.

Beijing implemented credit card system, part of the passenger turnover may not be calculated, resulting in the decreased passenger turnover in 2006. After 2009, when the US subprime mortgage crisis undermined and the economy of Beijing was recovered, traffic turnover grew rapidly. Therefore, during 2003–2005 and 2009–2011, the growth rate of traffic turnover exceeded that of GDP, and transportation intensity promote the transportation carbon emissions in Beijing. Accumulatively, the transportation intensity plays the main inhibition role on transportation carbon emissions in Beijing.

#### Economic growth

Expanding the scale of economic output is the decisive factor in the increasing transportation carbon emissions in Beijing. This is confirmed in most studies (Lu et al., 2007; Andreoni and Galmarini, 2012; Mazzarino, 2000). Our calculation shows that the per capita GDP rose from 12,690 yuan in 1995 to 42,443 yuan in 2012, equivalent to an increase of 234% (in 1995 prices). The corresponding transportation carbon emissions increased from 811,000 tons to 5,405,000 tons, yielding an increase of 566%. The increased living standards of residents have increased both tourism and the demand for private cars. The rapid development of the economic system establishes a new challenge to efficient logistics, and thus leads to substantially increasing of the energy consumption for transportation carbon emissions. Lin and Jiang (2009) noted that the process of urbanization and industrialization will basically end in 2020. Thus, we infer that Beijing's economy is not slowing down until 2020. The rigid expansion of energy consumption and high dependence on fossil energy will lead to successive growth in transportation carbon emissions. It is expected that economic growth will still be the main driving force of transportation carbon emissions in the next long period.

#### Population size

As for the effect of population size on transportation carbon emissions, Timilsina and Shrestha (2009), Lakshmanan (1997), and Wang and Liu (2014) noted that population size is an important factor promoting the growth of transportation carbon emissions based on their studies of different countries and regions. Our research found that the population size is a factor that increased carbon emissions, with a cumulative effect of 165.4%. Wang et al. (2011) noted that, assuming an increase of one permanent population, day trips in Beijing will increase 2.64 person-times. Li (2010) suggested that the number of cars will plus one every 2.5 people move to Beijing. With Beijing's continuing urbanization in recent years, the registered permanent population reached 21.14 million in 2013, resulting in a substantial pressure on urban transportation and promoting the increase of transportation carbon emissions.

## Conclusions and suggestions

### Conclusions

Based on the data for energy consumption and economic growth in the transportation sector in Beijing from 1995 to 2012, we established a transportation carbon emissions decomposition model of energy-related carbon emissions with the expanded Kaya identity and generalized Fisher index method. The effects have been measured of the energy structure, energy intensity, output value of per unit traffic turnover, transportation intensity, economic growth and population size on transportation carbon emissions from energy consumption in Beijing. The following conclusions can be drawn:

- (i) The energy intensity, output value of per unit traffic turnover, economic growth and population size display positive effects on transportation carbon emissions in Beijing, with cumulative contributions of 334.5%, 196.7%, 165.4% and 158.2%, respectively. The successive growth of economic output is the dominant factor of transportation carbon emissions in Beijing. The energy intensity, population size and output value of per unit traffic turnover generally display weaker effects than economic growth.

- (ii) The energy structure and transportation intensity have inhibitory effects on the transportation carbon emissions in Beijing. The transportation intensity is the main contributor to the decline in transportation carbon emissions. The inhibitory effect of the energy structure is weaker than that for the transportation intensity. The inhibition of both combined is limited and cannot overcome the increased effect of carbon emissions caused by other factors such as population size and economic growth.

### *Suggestions*

According to the above conclusions and considering the actual demand of transportation in Beijing, we suggest the following major measures to save energy and reduce carbon emissions.

- (i) Promote the development of new energy vehicles. The study shows that improvements in the energy structure inhibit transportation carbon emissions because of “low carbon” fuel adjustment. In order to improve the energy consumption structure of cars, Beijing may further promote new energy vehicles, e.g. electric ones. Taking into account of the problems that new energy vehicles face such as high acquisition and use costs, immature technology level, insufficient charging stations and other issues, recommendations are raised as follows: Power recharging stations of new energy automobiles should be greatly expanded both in station number and in location number. Further, a comprehensive taxation, finance, government procurement and other supporting policies may be put into action to encourage the vehicle companies to develop relevant key technology, thus to reduce the purchase and use costs of new energy vehicles and increase actual utilization rate of new energy vehicles.
- (ii) Limit private vehicles' increase and implement the reform of state-owned cars to promote public transportation. The results show that the energy consumption by rapid increase in private vehicles and a large number of state-owned vehicles cannot be compensated by the reduction of energy intensity based on technological progress, thus becoming important driving factors in the growth of transportation carbon emissions. The driving restriction policy and vehicle license allocation using a lottery did not reduce fuel consumption as much as expected (Wang et al., 2014; Yang et al., 2014b). Beijing has a large number of state-owned cars. Measures as the current state-owned cars reform, including auctioning state-owned cars, setting limits for the state-owned cars will not only help alleviate the urban traffic burden and improve public transport efficiency but will also save energy and reduce emissions. As for private cars, in addition to the existing policies, we may learn more experience from developed countries to further increase the cost of private cars by collecting fees for car purchase, license fees, gasoline taxes and other expenses in order to control their use. To encourage public transportation, the government needs to build a better public transportation system, such as increasing supplies according to the flow of people and develop rapid transit lines (Zhuo, 2015), as well as trying to provide multi-level public transport services in the form of customized buses. Meanwhile, the travel costs from public transportation should be further reduced.
- (iii) Evacuate non-core functions of Beijing and adjust industrial structure. The results show that economic growth plays a significant role in promoting transportation carbon emissions and optimization of industrial structure is conducive to the reduction of transportation intensity in Beijing. Reductions in transportation carbon emissions may be realized by evacuating non-core functions from Beijing to achieve a better industrial structure as well as to keep a suitable speed of development of GDP. As the capital of the country, Beijing may retain the core functions of the national political, cultural, international exchange, science and technology innovation center and eliminate high pollution and high energy-consuming industries such as iron and steel, nonferrous metals, building materials, chemical, textile, machinery, printing, and papermaking. As these industries have higher requirements for the convenient and efficient regional transportation system and contribute a lot to carbon emissions from transportation.
- (iv) Continuingly control the population size and improve population quality. Urban economic growth results in a larger urban population which is an important source of increasing transportation carbon emissions of the city. By considering energy conservation and emission reduction, we fully support the coordinating development strategy among Beijing, Tianjin and Hebei. Projects, money may be transferred to Tianjin City and Hebei Province to promote the flow and evacuation of the population. Anyway, population control policy has to be kept to avoid excessive population growth by increasing the standard of migrants entering the city and continuing to optimize the structure and quality of the population as the core of population development.

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