Analysis of Factors Affecting Transport Sector N_2O Emissions in China

W. Wang[1], R. Liu[1] and M. Zhang[2,*]

[1]School of Science, China University of Mining and Technology, Xuzhou, 221116, P.R.China
[2]School of Management, China University of Mining and Technology, Xuzhou, 221116, P.R.China
*Corresponding author: zhangmingdlut@163.com Tel./fax:+8651683883159

Abstract: This paper aims at investigating the potential factors influencing the change of transport sector N_2O emissions in China. First, the transport sector N_2O emissions over the period 1985-2009 are calculated based on the presented method. Then the presented LMDI (logarithmic mean Divisia index) method is used to find the nature of the factors that influence the changes in transport sector N_2O emissions. We find that: (1) Transport sector N_2O emission increased from 557.09 Tt (Thousand tonnes) in 1985 to 4860.77 Tt in 2009, at an annual growth rate of 9.44%. And highways transport was the biggest N_2O emitter both in 1985 and in 2009. (2) The economic activity effect and transportation modal shifting effect are found to be primarily responsible for driving transport sector N_2O emissions growth over the study period. (3) The transportation intensity effect and emission coefficient effect are found to be the main drivers of the reduction of N_2O emissions of transport sector in China.

Keywords: Transport sector; N_2O emissions; LMDI.

1. Introduction

The global warming has become a serious issue in the world since the late 1980s. The reduction of emitted greenhouse gases and atmospheric pollutants constitutes the foremost objective of contemporary energy and environmental policy. Among six kinds of GHG, the smallest contribution to the greenhouse effect is nitrous oxide (N_2O), and its share of greenhouse effect is merely about 6%, but its heat-absorbing capacity is as large as 270 times than that of carbon dioxide (CO_2) [1]. Energy consumption by transport sector is likely to grow up further with economic and population growth, rapid industrialization, urbanization and agricultural development increase freight and passenger transport, and higher real incomes stimulate leisure-related travel. However, the transport sector has also been identified as one of the major contributors to the depletion of fossil fuels, the degradation of the environment and the deterioration of human health, especially N_2O emissions. Thus it is very necessary for China's energy and environmental policymakers to investigate the driving forces governing energy-related N_2O emissions in transport sector.

In the literature, the Index Decomposition Analysis (IDA) has been used, sucessfully so far, to quantify the impact of different factors on the change of energy consumption and CO_2 emissions. There are a variety of different indexing methods that can be used in IDA [3]. Ang provided a useful summary of the various methods and their advantages and disadvantages and concluded that the LMDI method was the preferred method, due to its theoretical foundation, adaptability, ease of use and result interpretation, along with some other desirable properties in the context of decomposition analysis [4].

However, due to the logarithmic terms in the LMDI formulae, complications arise when the data set contains zero values. Ang and Choi showed that the zero values may be replaced by a small number δ and converging results were obtained when δ approaches zero [5]. Wood and Lenzen argued that the above strategy was not necessarily robust because it would produce significant errors if applied in the decomposition of a data set containing a large number of zeros and/or small values [6]. At last, Ang gave eight strategies to handle zero values in LMDI decomposition approach [7].

Nevertheless, a few studies have identified factors affecting energy consumption and CO_2 emissions in transport sector. Scholl et al. examined how changed in transport activity, modal structure, CO_2 intensity, energy intensity and fuel mix affect CO_2 emissions from passenger transport in nine OECD countries between 1973 and 1992 [8]. In 1997, Schipper et al. also investigated the relative contribution of activity, modal structure, and energy intensity to changes in energy use and CO_2 emissions from freight transport in ten industrialized countries from 1973 to 1992 [9]. Lakshmanan and Han attributed the change in transport sector CO_2 emissions in the US between 1970 and 1991 to growth in people's propensity to travel, population and GDP [10]. Transport sector CO_2 emission growth was attributed to transportation activity, modal structure, modal energy intensity and fuel mix by Schipper et al [11]. The Adaptive Weighted Divisia was applied to investigate factors affecting CO_2 emissions from the freight sector of 10 OECD countries for the period 1970-1993 [12]. Mazzarino applied a comparative static approach highlight the main factors determining the variation of carbon dioxide emissions over the period 1980-1995 in India [13]. Lu et al. attributed changes in CO_2 emissions from highway vehicles in Germany, Japan, South Korea and Taiwan during 1990-2002 to changes in emission coefficient, vehicle fuel intensity, vehicle ownership, population intensity and economic growth [14]. Timilsina and Shrestha utili zed LMDI method to identify factors affecting CO_2 emissions in 20 Latin American and Caribbean countries [15]. Similarly, Timilsina and Shrestha analyzed the potential factors influencing the growth of transport sector CO_2 emissions in selected Asian countries during the 1980-2005 periods by decomposing annual emissions growth into components representing changes in fuel mix, modal shift, per capita GDP and population, as well as changes in emission coefficients and transportation energy intensity [16]. The logarithmic mean Divisia index (LMDI) technique is used to find the nature of the factors those influence the changes in China transportation energy consumption [17].

To our knowledge so far no study has used systematically the decomposition technique on the transport sector N_2O emissions in China. This paper serves as a preliminary attempt to apply LMDI method to analyze the China transport sector over the period 1985-2009, to cast light upon the contribution of the factors influencing energy-related N_2O emissions. Owing to N_2O data is not available, this paper first estimates N_2O emissions in transport sector depended on current transportation statistical data. Because the transportation sector is very complex in China, and the transportation energy statistical data is scarce, especially for urban transportation. So this paper only considers intercity transportation. The transportation system in China is regarded consisting of five essential modes, i.e., highways, railways, waterways, civil aviation and pipeline transportation. Among such modes, highways transportation only includes the vehicle possessed by the conveyance of enterprise, which is being engaged in the operation of freight/passenger transportation.

The remainder of this paper is organized as follows. In the next section, we present a method to calculate N_2O emissions in the transport sector, and then use the proposed LMDI approach to decompose the change of aggregate N_2O emissions in transport sector over time. Section 3 discusses the related data used in this paper. The main results are reported in Section 4. Finally, we conclude this study.

2. Experimental

The symbol definitions are as follows.

N^t N_2O emissions in year t;

i transportation mode;

j fuel type;

N_i^t N_2O emissions (in Thousand tonnes, Tt) of the i th transportation mode in year t;

N_{ij}^t N_2O emissions of the i th transportation mode based on fuel type j in year t;

V_{ij}^t transportation services of the i th transportation mode based on fuel type j in year t;

R_{ij}^t energy consumption per transportation services of the i th transportation mode based on fuel type j in year t;

F_j N_2O emission factor of the j th fuel (kgN_2O /TJ).

V_i^t transportation services of the i th transportation mode in year t;

V^t total transportation services in year t;

GDP^t economic output in year t;

the emission coefficient of the i th transportation mode in year t;

$TS_i^t = \frac{V_i^t}{V^t}$ the transportation modal share of the i th transportation mode;

$TI^t = \frac{V^t}{GDP^t}$ the transportation intensity in year t;

GDP^t economic activity in year t;

2.1 Estimation of N_2O emissions

Following the method given by the IPCC [1], transport sector N_2O emissions in year t is estimated based on transportation services, energy consumption per transportation services, N_2O emissions factors as follows.

$$N^t = \sum_i N_i^t = \sum_{i,j} N_{ij}^t = \sum_{i,j} V_{ij}^t \times R_{ij}^t \times F_j \tag{1}$$

The nitrous oxide emission factors (F) are given in Table 1. Because the 1985-2009 period analyzed in this paper is a relatively short term, we assume that the nitrous oxide emission factors of coal, gasoline, kerosene, diesel oil, fuel oil and natural gas are constant. In fact, these coefficients have changed over time because of a change in grade of fuels; these changes are so small that they are negligible when we analyze the macro changes in N_2O emissions. The nitrous oxide emissions factors of electricity, however, is changing because the fuel mix used in the generation of electricity is always changing, and technological improvements in generation are also always driving the decrease of coal consumption used in electricity generation. The nitrous oxide emission factor of electricity is calculated based on the use of individual fossil fuels used in power generation.

2.2 Decomposition of N_2O emissions

The transport sector N_2O emissions can be expressed as an extended Kaya identity, which is a useful tool to decompose N_2O emissions. It is shown as Eq. (2)

$$\begin{aligned} N^t &= \sum_i N_i^t = \sum_i \frac{N_i^t}{V_i^t} \times \frac{V_i^t}{V^t} \times \frac{V^t}{GDP^t} \times GDP^t \\ &= \sum_i NI_i^t \times TS_i^t \times TI_i^t \times GDP^t \end{aligned} \tag{2}$$

The change of N_2O emissions in transport sector between a base year 0 and a target year t, denoted by ΔN_{tot}, can be decomposed to four effects as follows: (i) the changes in the emission coefficient effect (denoted by ΔN_{ni}); (ii) the changes in the transportation modal shifting effect (denoted by ΔN_{ts}); (iii) the changes in the transportation intensity effect (denoted by ΔN_{ti}); and (iv) the changes in the economic activity effect (denoted by ΔN_{gdp}); in additive form, as shown in Eq. (3):

$$\Delta N_{tot} = \Delta N_{ni} + \Delta N_{ts} + \Delta N_{ti} + \Delta N_{gdp} \tag{3}$$

where superscripts 0 and t denote a base year and a target year, respectively. According to the LMDI method given by Ang [7], each effect in the right hand side of Eq. (3) can be computed as follows:

$$\Delta N_{ni} = \sum_i \Delta N_{ni,i} = \begin{cases} \Delta N_{ni,i} = 0, & \text{if } N_i^t \times N_i^0 = 0 \\ \Delta N_{ni,i} = \sum_i L(N_i^t, N_i^0)\ln(\frac{NI_i^t}{NI_i^0}), & \text{if } N_i^t \times N_i^0 \neq 0 \end{cases}$$

$$\Delta N_{ts} = \sum_i \Delta N_{ts,i} = \begin{cases} \Delta N_{ts,i} = 0, & \text{if } N_i^t \times N_i^0 = 0 \\ \Delta N_{ts,i} = \sum_i L(N_i^t, N_i^0)\ln(\frac{TS_i^t}{TS_i^0}), & \text{if } N_i^t \times N_i^0 \neq 0 \end{cases}$$

$$\Delta N_{ti} = \sum_i \Delta N_{ti,i} = \begin{cases} \Delta N_{ti,i} = 0, & \text{if } N_i^t \times N_i^0 = 0 \\ \Delta N_{ti,i} = \sum_i L(N_i^t, N_i^0)\ln(\frac{TI_i^t}{TI_i^0}), & \text{if } N_i^t \times N_i^0 \neq 0 \end{cases}$$

$$\Delta N_{gdp} = \sum_i \Delta N_{gdp,i} = \begin{cases} \Delta N_{gdp,i} = 0, & \text{if } N_i^t \times N_i^0 = 0 \\ \Delta N_{gdp,i} = \sum_i L(N_i^t, N_i^0)\ln(\frac{GDP_i^t}{GDP_i^0}), & \text{if } N_i^t \times N_i^0 \neq 0 \end{cases}$$

In the index number, we form

$$\frac{\Delta N_{ni}}{\Delta N_{tot}} \times 100\% + \frac{\Delta N_{ts}}{\Delta N_{tot}} \times 100\% + \frac{\Delta N_{ti}}{\Delta N_{tot}} \times 100\% + \frac{\Delta N_{gdp}}{\Delta N_{tot}} \times 100\% = 100\% \quad (4)$$

To carry out this analysis, it is necessary to take into account the different factors that cause the change in N_2O emissions in transport sector. The emission coefficient effect ($\Delta \boldsymbol{N}_{ni}$) is used to evaluate fuels quality and the installation of abatement technologies. The transportation modal shifting effect ($\Delta \boldsymbol{N}_{ts}$) measures the relative share of a mode in the transport sector. The transportation intensity effect ($\Delta \boldsymbol{N}_{ti}$) is used to evaluate the efficiency of transport sector. The economic activity effect ($\Delta \boldsymbol{N}_{gdp}$) is measured by GDP, which is regarded as the theoretical N_2O emissions.

3. Data management

In China, the data, spanning from 1985 to 2009 used in this study, have been collected from various issues of the China Statistical Yearbook and Yearbook of China Transportation & Communications [18-19].The GDP data is in in 10^9 yuan in constant 1978 price. Because of the scarcity of urban transportation statistical data in China, this paper only considers intercity transportation. The intercity transport sector in China is regarded consisting of five essential modes, i.e., highways, railways, waterways, civil aviation and pipeline transportation. The highways transport mode considers two fuel types: gasoline and diesel oil. There are three fuel types for railways transport, i.e. coal, diesel oil and electricity. Diesel fuel is used for waterways. Kerosene is only consumed by civil aviation mode. And pipeline transportation consumes two kind of fuel: fuel oil and natural gas.

The transportation services are measured by tonne-km in this paper. For passenger-trips, person-km must be converted to tonne-km. The total transportation services of passenger and freight traffic is equal to the transportation services of passenger traffic divided by a conversion coefficient, plus that of freight traffic. The conversion coefficient is determined through experience in comparing revenues and expenditures per person-kilometer (moving one person one kilometer) with those of moving one tonne of goods one kilometer. The coefficient, measured by one person per tonne, means that transporting one tonne of goods one kilometer is equivalent to transporting one passenger one kilometer. The conversion coefficient is available from TSNET [20].

4 Results and discussion

4.1 Analysis of N_2O emissions

The time variation of transport sector N_2O emissions in China for the period from 1985 to 2009 is shown in Fig. 1. The total N_2O emissions in 2009 was 4860.77 Tt whereas in 1985 was 557.09 Tt, following an annual growth rate of 9.44%. However, N_2O emissions increased about 215.4% from the year 2003 to 2009. This may be attributed to the fast increases of the number of vehicles using highway, possession of civil vehicles has increased from 321.12 ten thousand in 1985 to 6280.61 ten thousand in 2009, representing an overall annual growth of 13.18%. The ascending trends of the N_2O emissions in Fig. 1 illuminate the increasing demand for mobility in China over the past two decades, which also shows that the transport sector not only plays a crucial role to socio-economic development but also is influenced both directly and indirectly by other socioeconomic factors such as fiscal policy, industry structure, etc., especially for GDP. During the past decades between 1985 and 2009, China’s economy grew with an average annual GDP growth rate of 9.91%. In accordance with this, the average annual growth rate of passenger–km was 7.4%, and that of freight transport was 6.0%. It is obvious that as transport grows, it emits more GHG. Therefore transport demand and energy use are closely linked

The N_2O emissions of each transport mode for the period from 1985 to 2009 are presented in Fig. 2. In 1985, highways transport was the biggest N_2O emitter with a share of 71.2%, waterways, railways, civil aviation and pipeline, ranked second, third, fourth and fifth making up 20.4%, 7.9%, 0.25% and 0.1%, respectively. The share of railways N_2O emissions decreased from 7.9% in 1985 to 1.8% in 2009. The reduction of N_2O emissions by railways is mainly attributed to the phase-out of the steam locomotives. The share of N_2O emissions from waterway remained about 20% during the period 1985-2007, and that quickly decreased to 10.9% in 2008, which may be explained by the financial crisis. The share of civil aviation N_2O emissions increased from 0.2% in 1985 to 0.6% in 2009. The N_2O emissions trends are noticed in 2009, where highways transport was the biggest N_2O emissions emitter with a share of 86.5%, and waterways, railways, civil aviation and pipeline also ranked second, third, fourth and fifth making up 10.9%, 1.8%, 0.6% and 0.03%, respectively. The mainly reason is the modal shifting, from less energy consumption mode (in terms of energy consumption per passenger/freight kilometer), such as railway, to more energy consumption intensive modes, such as highways and civil aviation. It is obvious that highways transport is the dominant factor regarding transport N_2O emissions in China. The N_2O emissions by highways increased rapidly with the expanding demand for flexibility and convenience, closely related to the transition of the industry structure and the residents' living standards. The fuel used in highway is presented in Fig. 3, which shows that combustion engines of vehicle using highway is the main source of N_2O emission.

4.2 Decomposition of N_2O emissions

The results of the decomposition for transport sector N_2O emissions in China from 1985-2009 are listed in Tables 2 and 3.

As shown in Table 2, economic activity (i.e., GDP growth) and transportation modal shifting are the critical factors in the growth of transportation sector N_2O emissions in China. The economic activity effect ($\boldsymbol{N}_{gdp}$) make the continual increase of N_2O emissions over the period 1985-2009. The accumulated (period-wise) effect is an increase of 3292.8Tt, which accounts for 76.5% of the total change ($\boldsymbol{N}_{tot}$) in absolute value. Transport demand is closely linked to economic growth. GDP increased from 703.1 billion yuan in 1985 to 6789.2 billion yuan in 2009 in 1978 prices, representing an overall annual growth of 9.9%. Currently, China is still at an early stage of motorization and urbanization. As the economic level is enhanced, people with a high living standard should pursue high life quality highly reliant on the convenient transportation, and the modern logistic system featuring significantly in the growing economic system requires efficient transportation system, which deduce to the demand of the passenger and freight transport. Another important factors leading to the rapid growth of transportation is the development of tourism, which is highly reliant on transportation. According to the available data, the passenger traffic by highways and railways during the Spring Festival took 10.8% and that during the two long vacations remarking the Labor Day and National Day took 18.8% of the total passenger traffic in 2002.

Our results show that the transportation modal shifting effect (N_{ts}) increased N_2O emissions in most years except 1989-1991, 1994-1995, 1998-2001 and 2002-2005. The accumulated (period-wise) effect is a decrease of 2243.6 Tt, which accounts for 52.1% of the total N_2O emissions (N_{tot}) in absolute value. This may be attributed to the modal shifting, from less energy consumption modes, such as railway, to more energy consumption intensive modes, such as highways and civil aviation. The ratio of railways to total transportation services decreased from 49.7% in 1985 to 24.9% in 2009. And the share of civil aviation energy consumption increased from 0.05% in 1985 to 0.27% in 2009. It should be noted that highways has been the dominant transportation mode, which accounted for about 29.9% of total turnover in 2009. Due to the transportation services from international waterways is considered in the modal data for China, the share the waterways steady increased from 36.7% in 1985 to 43.2% in 2009.

As shown in tables 2 and 3, the emission coefficient effect (N_{ni}) is the dominant factor that decreasing N_2O emissions over the period 1985-2009. The accumulated (period-wise) effect is a decrease of 866.6Tt, which accounts for 13.3% of the total N_2O emissions change (N_{tot}) in absolute value. The impact of emission coefficients is related to the phase-out of the steam locomotives. Another reason may be attributed to fuel

Table 2. Complete decomposition of transport sector N_2O emissions change (1985-2009).

	N_{ni}	N_{ts}	N_{ti}	N_{gdp}	N_{tot}
1985-1986	-9.2	10.8	3.3	49.5	54.5
1986-1987	-11	52.3	-7.8	72.6	105.9
1987-1988	-33.4	58	-21.6	81.1	84.2
1988-1989	-13.2	0.2	12.3	32.6	31.9
1989-1990	8.6	-4.1	-26.5	31.6	9.6
1990-1991	-37.5	-17.1	-17.2	74.1	2.4
1991-1992	-4.8	25.2	-72.4	116.8	64.8
1992-1993	-9.9	26.9	-74.8	123.2	65.4
1993-1994	-44.1	20.5	-40.4	123.5	59.6
1994-1995	-47.4	-2.8	-38.3	108.4	19.8
1995-1996	6.7	41.3	-89.1	103.6	62.5
1996-1997	-20.3	13.2	-43	101.6	51.6
1997-1998	75.7	42.6	-93.6	92.5	117.2
1998-1999	16	-15.9	-11.3	97.6	86.4
1999-2000	-66.5	-14.5	10.2	112.8	42
2000-2001	52.8	-29.7	-11.9	117.9	129.1
2001-2002	-136.2	13.7	-42	132.8	-31.7
2002-2003	-28.6	-19.5	-68.9	145.9	28.9
2003-2004	-63.2	-134.5	244.4	157.5	204.2
2004-2005	-63.7	-37	53.8	194.8	147.9
2005-2006	-70	14.8	-34.9	234.5	144.5
2006-2007	-13.7	37.8	-9.5	289.6	304.3
2007-2008	-272.8	2051.5	-28.4	295.4	2045.7
2008-2009	-80.6	109.9	40.8	402.9	473.1
1985-2009	-866.6	2243.6	-366.8	3292.8	4303.8

a) Data Source: CSY; CTCY; authors' calculation; Unit: Tt; b) Negative values indicate decreasing energy consumption.

Table 3. Complete decomposition of transport sector N_2O emissions change in percentage (1985-2009).

	N_{ni}	N_{ts}	N_{ti}	N_{gdp}	N_{tot}
1985-1986	-16.9	19.9	6.1	90.9	100
1986-1987	-10.6	49.4	-7.3	68.6	100
1987-1988	-39.6	68.9	-25.6	96.3	100
1988-1989	-41.2	0.5	38.6	102.1	100
1989-1990	89.3	-42.3	-276.1	329.1	100
1990-1991	-1562.3	-712	-714.8	3089.1	100
1991-1992	-7.4	38.9	-111.7	180.3	100
1992-1993	-15.2	41.2	-114.4	188.4	100
1993-1994	-74	34.5	-67.7	207.2	100
1994-1995	-239.3	-14.3	-193	546.5	100
1995-1996	10.7	66.1	-142.4	165.6	100
1996-1997	-39.2	25.7	-83.3	196.9	100
1997-1998	64.6	36.3	-79.8	78.9	100
1998-1999	18.5	-18.4	-13.1	113	100
1999-2000	-158.4	-34.4	24.2	268.7	100
2000-2001	40.9	-23	-9.2	91.3	100
2001-2002	429.5	-43.2	132.4	-418.7	100
2002-2003	-98.7	-67.3	-238.2	504.1	100
2003-2004	-30.9	-65.9	119.7	77.1	100
2004-2005	-43.1	-25	36.4	131.7	100
2005-2006	-48.4	10.3	-24.1	162.3	100
2006-2007	-4.5	12.4	-3.1	95.2	100
2007-2008	-13.3	100.3	-1.4	14.4	100
2008-2009	-17	23.2	8.6	85.2	100
1985-2009	-20.1	52.1	-8.5	76.5	100

a) Data Source: CSY; CTSY; authors' calculation; b) Negative numbers represent that the associated effect is in the opposite direction of the total intensity change.

substitution mostly occurred between diesel and gasoline, and their N_2O emission factors are significantly different.

Our results also show that the transportation intensity effect (N_{ti}) plays role in decreasing transport sector N_2O emissions. The accumulated (period-wise) effect is a decrease of 366.8Tt, which accounts for 8.5% of the total N_2O emissions change (N_{tot}) in absolute value. The changes of transportation intensity for the period from 1985 to 2009 is presented in Fig. 4, illustrating a general decrease in transport intensity (measured a transportation services-GDP ratio). This may be attribute to our country take effective measures and policies, such as improving fuel quality, promoting new technology, improving traffic equipment, promoting alternative fuels etc. In China, there have been several contradictions between energy supply and demand, and energy price, that is to say energy prices have not fully reflected environmental externalities, scarcity of energy sources, and imbalances in domestic demand and supply. Since the reform and opening-up, China's energy prices have risen significantly, but they are once again lower than international ones. Thus, energy prices have little impact to the change of transportation intensity.

5 Conclusions

Nowadays, transport sector has also been identified as one of the major contributors to the depletion of fossil fuels, the degradation of the environment and the deterioration of human health, especially N_2O emissions. This paper first utilizes current transportation statistical data to calculate the transport sector N_2O emissions from 1985 to 2009. Then the presented LMDI method is used to find the nature of the factors that influence the changes in transport sector N_2O emissions. To identify the driving factors, the N_2O emission growth is decomposed into four factors: emission coefficient effect, transportation modal shifting effect, transportation intensity effect and economic activity effect. The main conclusions drawn from the present study may be summarized as follows:

(1) Transport sector N_2O emission has increased from 557.09 Tt in 1985 to 4860.77 Tt in 2009, following an annual growth rate of 9.44%. Both in 1985 and in 2009, highways transport was the biggest N_2O emitter, waterways, civil aviation, railways and pipeline, ranked second, third, fourth and fifth, respectively.

(2) The economic activity effect and transportation modal shifting effect are found to be primarily responsible for driving transport sector N_2O emissions growth over the study period.

(3) The transportation intensity effect and emission coefficient effect are found to be the main drivers of the reduction of N_2O emissions in China.

Based on above research results, the following strategies should be undertaken to reduce transport sector N_2O emissions:

(1) Fiscal instruments, such as subsidies for public transportation, clean fuels and clean vehicles, would be helpful in reducing emission coefficient and modal shifting activities.

(2) Regulatory instruments, such as vehicle efficiency standards, vehicle-occupancy standards, congestion charges, investments in road maintenance and congestion reduction, would also be required to reduce transportation energy consumption and thereby reduce transport sector N_2O emissions.

Acknowledgments

The authors gratefully acknowledge the financial support from the Fundamental Research Funds for the Central Universities (JGJ101484), the Doctoral Fund of Ministry of Education of China (20100095120013), the Social Science Foundation Fund of Ministry of Education of China (10YJC790381), the China Postdoctoral Science Foundation (2011M500964), the Jiangsu Postdoctoral Sustentation Fund (1002074C) and the Talents Fund of China University of Mining and Technology.

References

[1] IPCC, *Greenhouse gas inventory: IPCC Guidelines for National Greenhouse Gas Inventories* (1995) United Kingdom Meteorological Office, Bracknell, England.

[2] Chang CC, A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China, *Applied Energy* 87 (2010) 3533-3537.

[3] Ma C, Stern DI, China’s changing energy intensity trend: a decomposition analysis, *Energy Economics* 30 (2008) 1037-1053.

[4] Ang BW, Decomposition analysis for policymaking in energy: which is the preferred method?, *Energy Policy* 32 (2004) 1131-1139.

[5] Ang BW, Choi KH, Decomposition of aggregate energy and gas emissions intensities for industry: a Refined Divisia Index Method, *The Energy Journal* 18 (1997) 59-73.

[6] Wood R, Lenzen M, Zero-value problems of the logarithmic mean divisia index decomposition method, *Energy Policy* 34 (2006) 1326-1331.

[7] Ang BW, Liu N, Handling zero values in the logarithmic mean Divisia index decomposition approach, *Energy Policy* 35 (2007) 238-246.

[8] Scholl L, Schipper L, Kiang N, CO_2 emissions from passenger transport: a comparison of international trends from 1973 to 1992, *Energy Policy* 24/1 (1996) 17-30.

[9] Schipper L, Scholl L, Price L, Energy use and carbon from freight in ten industrialized countries: an analysis of trends from 1973-1992, *Transportation Research-Part D: Transport and Environment* 2/1 (1997) 57-76.

[10] Lakshmanan T, Han X, Factors underlying transportation CO_2 emissions in the USA: a decomposition analysis, *Transportation Research Part D* 2/1 (1997)1-15.

[11] Schipper L, Marie-Lilliu C, Gorham R, *Flexing the Link Between Transport Greenhouse Gas Emissions: A Path for the World Bank* (2000) International Energy Agency, Paris.

[12] Greening LA, Ting M, Davis WB, Decomposition of aggregate carbon intensity for freight: trends from 10 OECD countries for the period 1971-1993, *Energy Economics* 21 (1999) 331-361.

[13] Mazzarino M, The economics of the greenhouse effect: evaluating the climate change impact due to the transport sector in Italy, *Energy Policy* 28 (2000) 957-966.

[14] Lu IJ, Lin SJ, Lewis C, Decomposition and decoupling effects of carbon dioxide emission from highway transportation in Taiwan, Germany, Japan and South Korea, *Energy Policy* 35/6 (2007) 3226-3235.

[15] Timilsina GR, Shrestha A, Factors affecting transport sector CO_2 emissions growth in Latin American and Caribbean countries: an LMDI decomposition analysis, *International Journal of Energy Research* 33 (2009) 396-414.

[16] Timilsina GR, Shrestha A. Transportsector CO_2 emissions growth in Asia: Underlying factors and policy options, *Energy Policy* 37 (2009) 4523-4539.

[17] Zhang M, Li HN, Zhou M, Mu HL, Decomposition analysis of energy consumption in Chinese transportation sector, *Applied Energy* 88 (2011) 2279-2285.

[18] CSY, *China Statistical Yearbook* (1986-2010) China Statistical Publishing House, Beijing.

[19] CTCY, *Yearbook of China Transportation and Communications* (1986-2010) China Transportation and Communications Yearbook Publishing House, Beijing;.

[20] TSNET, *Tianjin Statistics Net* (2004) Bureau of Statistics of Tianjin, at http://www.stats-tj.gov.cn/tjzs/tjzs44.htm.

