Decomposition analysis of CO₂ emissions increase from the passenger transport sector in Shanghai, China

Yunjing Wang a, Yoshitsugu Hayashi a, Hirokazu Kato a & Chen Liu a

a Graduate School of Environmental Studies, Nagoya University, Japan

Available online: 31 Oct 2011

To cite this article: Yunjing Wang, Yoshitsugu Hayashi, Hirokazu Kato & Chen Liu (2011): Decomposition analysis of CO₂ emissions increase from the passenger transport sector in Shanghai, China, International Journal of Urban Sciences, 15:2, 121-136

To link to this article: http://dx.doi.org/10.1080/12265934.2011.615983

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Decomposition analysis of CO₂ emissions increase from the passenger transport sector in Shanghai, China

Yunjing Wang*, Yoshitsugu Hayashi, Hirokazu Kato and Chen Liu

Graduate School of Environmental Studies, Nagoya University, Japan

(Received 21 April 2011; revised version received 18 May 2011; final version accepted 11 July 2011)

This study identified the relationships between CO₂ emissions from passenger transport and its driving factors by taking Shanghai as an example. The Logarithmic Mean Divisia Index (LMDI) technique was used to disassemble the total passenger transport CO₂ growth into five driving factors: economic activity, population, modal share, passenger transport intensity and passenger transport CO₂ emission factor. The study found that: (1) in 2009, the passenger transport CO₂ emissions in Shanghai increased by 2.59 times against that of 2000; (2) the increased economic activity was the main factor driving passenger transport CO₂ emissions growth from 2000 to 2009 that accounted for 75% of the total passenger transport CO₂ emissions growth in Shanghai; (3) the effects of modal share change and population growth were relatively small but not trivial; and (4) The inhibitory effects of passenger transport CO₂ emissions growth were 90% from the improvement of passenger transport intensity, and 10% from the changes of passenger transport CO₂ emission factor. However, these effects were too small to offset the whole increase.

Keywords: decomposition analysis; passenger transport; CO₂ emissions; Shanghai

1. Introduction

Transport accounted for 23% of world energy related GHG emissions (International Energy Agency [IEA], 2006) and its share in the overall energy consumption is continuously growing, and this makes the transport sector one of the most important contributors to global CO₂ emissions (Papagiannaki and Diakoulaki, 2009). Rapid urbanization and economic growth in developing countries have resulted in substantial increases in urban transport services and associated energy demand, as rising incomes are associated with higher levels of car ownership and usage (Webster, Bly, Johnson, and Dasgupta, 1986), as well as greater trip rates and distances (Schäfer, 2000). As one of the most rapidly growing countries and the largest CO₂ emitter in the world (IEA, 2010), China is experiencing rapid and substantial growth in its economy and motorized mobility, and transport related energy consumption and pollution problems are poised to soar further, especially in metropolitan areas. Therefore, the identification of key factors driving transport CO₂ emissions growth is essential for the formulation of effective climate change mitigation policies and strategies.

*Corresponding author. Email: yunjingw@gmail.com
The main approaches to identifying the key driving factors are statistical methods such as regression analysis and decomposition method. The statistical method for identifying the key driving factors is to analyse the relationship of quantitative change between two or more independent variables and one dependent variable based on some equations and assumptions; while decomposition analysis is a descriptive method without involving any statistical estimation of relevant parameters. The latter’s advantage is that it gives a detailed and transparent assessment of the key drivers underlying past development and indicators based on easily verified identities and sparse assumptions. This brings another advantage of decomposition analysis, namely its low data requirement (Löfgren and Muller, 2010). Although inference is not available for future development in decomposition analysis compared to the statistical method, the decomposition method is popular in studies on national energy consumption and CO2 emissions areas, especially the manufacturing and power sectors (Timilsina and Shrestha, 2009).

In the transport sector, a few studies regarding examining factors affecting emissions growth have been conducted over the past few decades. Generally, those studies can be classified into two categories. First, most researches are composed of international comparisons. For example, Scholl, Schipper and Kiang (1996) and Schipper, Scholl and Price (1997) compared the CO2 emissions growth from passenger transport and freight transport respectively in some OECD countries between 1973 and 1992 from transport activity, modal structure and energy-intensity perspectives; Lu, Lin, Sue and Lewis (2007) decomposed changes in highway vehicles’ CO2 emissions in Germany, Japan, South Korea and Taiwan between 1990 and 2002 into changes in emission coefficient, vehicle fuel intensity, vehicle ownership, population intensity and economic growth; Timilsina and Shrestha compared the growth of transport sector CO2 emissions and their underlying factors in Latin America and the Caribbean (2008) and Asian countries (2009) respectively. Second, the rest of the researches are on a national level covering one or more transport modes. Lakshmanan and Han (1997) disassembled the change in transport sector CO2 emissions in the US between 1970 and 1991, and found that the growths in people’s propensity to travel, population and gross domestic product (GDP) were the three most important driving factors; Kwon (2005) decomposed the factors determining the trend of CO2 emissions from car travel in Great Britain from 1970 to 2000; Sorrell, Lehtonena, Stapletona, Pujola and Championb (2009) estimated the relative contributions of 10 variables to the change in UK road freight energy use over the period between 1989 and 2004; Zhang, Zhou and Mu (2011) identified the relationships between transport sector energy consumption and the changes of transport mode, passenger-freight share, energy intensity and transport activity in China between 1980 and 2006. However, to the best knowledge of the authors, a survey of these literatures indicates the absence of city-scale transport sector decomposition analysis, especially for some rapid developing metropolitan areas, which is useful for improving urban transport planning and strategies to alleviate growing traffic congestion and environmental pollution.

Shanghai, one of the most dramatic urbanization metropolitan areas of China over the past 10 years, is experiencing rapid urban sprawl and motorization. This study takes the passenger transport of Shanghai as a case: the objective is to decompose the passenger transport CO2 emissions growth from 2000 to 2009, find the main driving factors, and then suggest some emissions mitigation policies and strategies. Section 2 starts with an introduction of the study area, data and
methodology; section 3 discusses the passenger transport CO₂ emissions growth and potential driving factors; the decomposition results analysis composes section 4; and finally, section 5 offers key conclusions.

2. Study area, data and methodology

2.1. Study area

Shanghai situates on the banks of the Yangtze River Delta in East China (Figure 1); it is the largest city in China and the eighth largest in the world. As a famous transportation hub, Shanghai has a sophisticated network with roads, railways, shipping lanes and an aviation system. Moreover, there is an extensive public transport system, largely based on public buses, taxis, ferries and a rapidly expanding metro system in Shanghai.

The Shanghai metro system is one of the fastest growing rapid transit systems in the world, serving the urban and suburban districts of the Shanghai municipality – the first line opened in 1995 and, since 2010, the Shanghai Metro has become the largest one in the world by length (420km) (Figure 1). Although the metro network delivers about 7.5 million rides on the largest passenger trip day, the existing network still cannot adequately meet the city’s mass transit needs and is undergoing rapid expansion. The entire network will reach 600km in operation by 2014. Shanghai also has the world’s most extensive public bus system, which is operated by numerous transportation companies. In 2010, there were 1129 public bus routes in Shanghai, including a 109km Exclusive Bus Lane, and the public bus network, with a length of 23,033km, delivered about 7.4 million rides per day. Taxis, another important means of urban public transport, attract more and more travellers because of their flexibility, convenience and security, especially at night when the public busses and metro are closed.

Figure 1. Location and transport network of Shanghai.
Besides the developed public transport, private cars and motorcycles are the main personal transport modes in Shanghai. This study investigated the CO$_2$ emissions in Shanghai from the five main passenger transport modes: metro, public busses, taxis, private cars and motorcycles. When considering the CO$_2$ emissions of each mode, however, other modes such as ferry and non-motorized transport were omitted because of their small share and limitations on existing data.

### 2.2. Data

The data used in this study come from the *Shanghai Statistical Yearbook* (2001–2010), *Shanghai Comprehensive Transportation Annual Report* (2010) and *Shanghai Statistical Yearbook on Industry, Energy and Transport* (2001–2010). The data include the annual population of private cars and motorcycles, operating vehicles, passengers and mileage travelled per year on public busses, taxis and metro, as well as economic data and population data from 2000 to 2009, and the conversion factor used is from the physical unit to coal equivalent in the *Chinese Energy Statistical Yearbook* (2010).

### 2.3. Methodology

#### 2.3.1. Passenger transport CO$_2$ emissions estimation

Equation (1) is used for estimating CO$_2$ emissions based on the guidelines for national GHG inventories provided by the International Panel on Climate Change (IPCC, 2006) and City’s Greenhouse Gas (GHG) Emission Inventory Research (Cai, 2009) in China.

$$CO_2t = \sum_{ij} CO_2_{ijt} = \sum_{ij} (EC_{ijt} \times \mu_i \times \sigma \times \theta \times \varphi)$$

Subscripts $i$, $j$ and $t$ refer to energy types (e.g. gasoline, diesel, electricity, Liquids Natural Gas (LNG) and Liquids Petrol Gas (LPG)), transport mode (e.g. metro, public busses, taxis, private cars and motorcycles) and year respectively. $EC$ is energy consumption (based on the annual mileage data and average energy consumption standard of each mode, this study estimated the energy consumption of each mode); $\mu_i$ is the conversion factor between energy type $i$ and coal equivalent. Although Equation (1) allows consideration of different types of energy used by each mode, here, to simplify calculation, energy consumptions of each mode are all converted to the same type of coal equivalent according to the conversion factor from different energy types to coal equivalent in the *Chinese Energy Statistical Yearbook*. $\sigma$ is the net calorific value of coal equivalent taking value for $25.9 \times 10^{-6}$ TJ/kg; $\theta$ is the effective CO$_2$ emission factor of coal equivalent which is 94,600kg/TJ when the default carbon oxidation factor $\varphi$ is estimated at the default value 100%.

#### 2.3.2. Decomposition methodology

Ehrlich and Holdren (Kwon, 2005) suggested a simple identity equation referred to as the IPAT identity (Equation (2)), which summarizes a general relationship between human behaviour and its environmental consequence.

$$Impact = Population \times Affluence \times Technology$$

(2)
The Kaya identity suggested by the Intergovernmental Panel on Climate Change is a specific application of the IPAT identity. It multiplies population growth, per capita economic growth, energy consumption per economic growth and emissions per unit of energy on one side of the identity to produce total CO₂ emissions on the other side. The Kaya identity provides this study with a primary accounting framework to investigate potential factors affecting the trend of passenger transport CO₂ emissions. The transport sector is comprised of a diverse set of activities, connected by their common purpose of moving people and goods. Broadly speaking, emissions in the passenger transport sector are dependent on the level of passenger transport activity in passenger kilometres (PKM) across all modes, which directly relates to people’s travel demand and economic development, the modal structure used, the passenger transport energy consumption and emissions characteristic of each mode (Schipper, Fabian, & Leather, 2009). Equation (1) can also be expressed as:

\[
\text{CO}_2^t = \sum_j \left( \frac{POP_t \times GDP_t \times PKM_{jt} \times CO_2_{jt}}{POP_t \times GDP_t \times PKM_{jt} \times PKM_t} \right)
\]

Equation (3) can be shortened to:

\[
\text{CO}_2^t = \sum_j (POP_t \times EA_t \times EI_t \times EF_{jt} \times MS_{jt}).
\]

Where \(POP\) is population, \(EA\) is economic activity as captured by GDP per capita, \(EI\) is the passenger transport intensity defined by the ratio of total passenger kilometres for all passenger transport modes in an economy to its GDP (i.e. PKM/GDP), which varies significantly across regions and over time; \(EF\) is the passenger transport CO₂ emission factor which represents the relationship between the amount of CO₂ produced and the amount of passenger kilometres travelled for each mode (i.e. CO₂/PKM); and \(MS\) refers to the share of travel in each mode in terms of passenger kilometres.

In decomposition analysis, index decomposition methods have been widely used in literature to break down an aggregate indicator and quantitatively measure the relative contributions of a set of predefined factors leading to the change in the aggregate indicator. According to Ang and Zhang (2000), the most widely applied index decomposition methodologies in recent decades are based on the Laspeyres and the Divisia indexes. The same problem encountered with conventional Laspeyres and Divisia indexes methods was the large residual term found in most applications, leaving a significant part of the examined changes unexplained. Fortunately, a refined Divisia index method, the Logarithmic Mean Divisia Index (LMDI) approach, which had the desirable characteristics of perfect decomposition and consistency in aggregation, was introduced by Ang and Liu in 2001. The LMDI method makes use of the logarithmic mean of two end-point values as a weight function and leaves no residual term after the decomposition.

Based on the detailed explanation and practical guide of the LMDI method (Ang, 2005), this study decomposed the total change \(D_{tot}\) of CO₂ emissions from year \(t\) to year 0 by multiplicative decomposition:

\[
D_{tot} = \frac{CO_2^t}{CO_2^0} = D_{POP} \times D_{EA} \times D_{EI} \times D_{EF} \times D_{MS}
\]
The factors on the right-hand side of Equation (5) are Equations (6) to (10) respectively:

\[
D_{\text{POP}} = \exp \left[ \sum_j \frac{(C_{2j} - C_{20})}{(C_{2t} - C_{20})} \frac{(\ln C_{2j} - \ln C_{20})}{(\ln C_{2t} - \ln C_{20})} \ln \frac{\text{POP}_t}{\text{POP}_0} \right] \tag{6}
\]

\[
D_{\text{EA}} = \exp \left[ \sum_j \frac{(C_{2j} - C_{20})}{(C_{2t} - C_{20})} \frac{(\ln C_{2j} - \ln C_{20})}{(\ln C_{2t} - \ln C_{20})} \ln \frac{E_{A_t}}{E_{A_0}} \right] \tag{7}
\]

\[
D_{\text{EI}} = \exp \left[ \sum_j \frac{(C_{2j} - C_{20})}{(C_{2t} - C_{20})} \frac{(\ln C_{2j} - \ln C_{20})}{(\ln C_{2t} - \ln C_{20})} \ln \frac{E_{I_t}}{E_{I_0}} \right] \tag{8}
\]

\[
D_{\text{EF}} = \exp \left[ \sum_j \frac{(C_{2j} - C_{20})}{(C_{2t} - C_{20})} \frac{(\ln C_{2j} - \ln C_{20})}{(\ln C_{2t} - \ln C_{20})} \ln \frac{E_{F_t}}{E_{F_0}} \right] \tag{9}
\]

\[
D_{\text{MS}} = \exp \left[ \sum_j \frac{(C_{2j} - C_{20})}{(C_{2t} - C_{20})} \frac{(\ln C_{2j} - \ln C_{20})}{(\ln C_{2t} - \ln C_{20})} \ln \frac{M_{S_t}}{M_{S_0}} \right] \tag{10}
\]

3. Passenger transport CO2 emissions and potential driving factors

3.1. Passenger transport CO2 emissions

Figure 2 presents the trends of passenger transport CO2 emissions in Shanghai. Aggregate passenger transport CO2 emissions more than doubled from 3.13 million tons in 2000 to 8.12 million tons in 2009, with a robust average annual growth rate of 11%. Within each mode, although the CO2 emissions absolutely increased from all modes, the share of each mode was largely different. For personal transport modes, CO2 emissions from private cars increased more than 20 times, and its share reached
44% in 2009 from 5% in 2000. At the same time, CO\(_2\) emissions from motorcycles increased more than two times, while its share first increased and then decreased back to the level of 2000 (14%). As for the public transport modes, the share of taxis decreased to 26% in 2009, while it was the largest emitter and accounted for 49% in 2000; Similarly, the share of public busses also declined to 16% in 2009 from 31% in 2000, although the amount of CO\(_2\) emissions from public busses remained more or less stable in this period; The metro, as the lowest passenger transport CO\(_2\) emissions mode, had a share that was still relatively low (1%), although the emissions increased more than eight times with the network expansion and the increasing number of passengers carried per year.

### 3.2. Potential driving factors

#### 3.2.1. Passenger transport activity increasing

The relationships between transport activity, economic growth and population growth have been presented in several studies (Scholl et al., 1996; Stead, 2001). Figure 3 shows the evolution of the total daily trips and the population growth in Shanghai examined from 2000 to 2009. It can be seen that total daily trips closely followed the population growth, except that there was a significant decline in passenger traffic in 2003 because of the impact of SARS. Moreover, growth in the economy, improvements in technology and infrastructure, and increasing time available for leisure trips have allowed people to travel more frequently and further. The average travel distance in Shanghai increased from 4.5km in 2000 to 8.1km in 2009. At the same time, daily trips per person increased by 26% during this period and reached 2.4 trips per person in 2009. The increasing of the average travel distance and daily trips per person promoted further motorization.

Besides the average travel distance and daily trips per person, economic development has also historically been strongly associated with an increase in the demand for motorized vehicles and particularly in the number of road vehicles, and this relationship is also evident in the developing economies today. Figure 4 shows the annual GDP per capita and vehicle increasing trends in the last decade in Shanghai. From 2000 to 2009, the GDP per capita increased from 30 thousand to 79 thousand Yuan ($3914). Accordingly, as the largest share of private vehicles, motorcycles were a little less than doubled from 503 thousand to 943 thousand during the first three years, and the growth became steady at an average annual rate.

![Figure 3. Trends of total daily trips and population growth in Shanghai.](image-url)
of 3% since 2004 because motorcycles were forbidden from driving in more and more areas and road sections. The second share was private cars, which increased from 74 thousand in 2000 to 846 thousand in 2009. Compared to the rapid increase of private vehicles, the number of public transport modes kept at a stable level during this decade.

3.2.2. Overall level of modal structure shifting towards private cars

Modal structure represents the share of travel in each mode in terms of passenger kilometres in this study. One potential factor driving transport sector CO$_2$ emissions growth could be modal shifting, from less emissions-intensive modes, such as public busses and metro, to more emissions-intensive modes, such as private cars and motorcycles. Figure 5 illustrates the evolution of modal structure for passenger transport activity in Shanghai in terms of passenger kilometres. It is clearly shown that between 2000 and 2009 public busses always represented the largest share.

![Figure 4. Trends in vehicles and economic growth in Shanghai](image1)

![Figure 5. Modal mix for passenger transport in Shanghai.](image2)
However, it is also shown that there was a significant shift away from public busses, whose share declined to 32% in 2009 from 65% in 2000, towards private cars. The number of private cars increased more than 10 times over this decade and largely contributed to the modal share shifting to private cars. This share increased to 27% in 2009 from 3% in 2000. Moreover, the share of the metro increased to 17% in 2009 from 5% in 2000. While the share of motorcycles was more or less stable and the share of taxis declined slightly.

3.2.3. Improving of energy consuming and emission factor

The changing of energy consumption and emission factor characteristic of each transport mode is another reason that explains the changes of transport sector CO₂ emissions. The changes of the passenger transport sector energy consumption and emission factor are mainly due to the improvement of passenger transport intensity and passenger transport emission factor. As the economy grew and technology improved, telecommuting was growing in the information age in Shanghai. At the same time, the Shanghai government instigated a series of energy conservation policies in the transport sector, all of which promoted the improvement of energy consumption and emission factor. For example, in 1998 Shanghai issued ‘A Plan to Promoting Liquefied Natural Gas (LNG) Vehicle Development’ to request that all new registered taxis installed gas equipment that promoted the energy conversion to LNG from gasoline. In 2003, the Shanghai government implemented a more stringent emissions standard for newly purchased cars and began to restrict high-polluting vehicles entering the inner loop since 2005. Since 2004, a new scrap management on motorcycles was implemented to promote the unqualified emissions of motorcycles to be scrapped in advance, and motorcycles were forbidden from driving in more and more areas and road sections in Shanghai. Gasoline, diesel, electricity, LNG and LPG were the main energy types in Shanghai’s passenger transport sector, while converting to clean energy such as electricity, LNG and LPG in Shanghai had contributed to the energy efficiency improvement and passenger transport CO₂ mitigation.

The passenger transport intensity (EI) aggregates the trends for each transport mode of the whole sector into a single indicator, which is a measure of the total passenger transport performance of a nation’s economy directly related to economic growth and the travel demands of the people. Figure 6 shows steadily improved passenger transport intensity over the study period in Shanghai because of economic efficiency, technology improvement and energy conservation policies, except that in 2002 and 2003 the passenger transport intensity was a little upward. Actually, from 2001 to 2003, private cars and motorcycles had the fastest increase during the last decade. Private cars increased 71% and 54%, and motorcycles increased 19% and 35% in these two years, respectively. In terms of passenger kilometres, this caused a modal shifting to private cars and motorcycles of 10% away from public busses, with taxis and the metro stable. Since 2004, the whole level of passenger transport intensity in Shanghai improved because of stricter restriction policies on motorcycles, as well as the slow down of the increasing rate of private cars because of more and more expensive license plate fees in the license plate auction.

Passenger transport CO₂ emission factor (EF) in this research refers to the relationship between the amount of CO₂ produced and the amount of passenger kilometres travelled. Figure 7 clearly shows that CO₂ emissions per passenger
kilometres from metro and public busses were the lowest, while CO₂ emissions per passenger kilometres from taxis and private cars were the highest. From 2000 to 2009, the CO₂ emissions per passenger kilometres from all modes kept stable except for taxis. The emission factor for taxis decreased to 0.30 in 2009 from 0.35kg CO₂ per passenger kilometres in 2000 because of the improvement of the kilometres’ utilization rate and the introduction of clean energy – LNG in taxis.

4. Decomposition results

Figure 8 illustrates the results of the multiplicative decomposition of the total passenger transport CO₂ emissions for the period from 2000 to 2009. The larger value of \( D \) shows the larger contributions of the factor. It is estimated that the growth of economic activity was the most important driving factor to the increasing of the passenger transport sector CO₂ emissions between 2000 and 2009, which accounted for 75% of the total passenger transport CO₂ emissions increase in
Shanghai. The effects of modal shift and population growth were found to be small but not trivial, as they contributed to 14% and 11% of the total Shanghai passenger transport CO₂ increase respectively. While the passenger transport intensity and emission factor had managed to partly cancel out the increasing effects, the inhibitory effects of CO₂ emissions growth were mainly from the improvement of passenger transport intensity, which accounted for 90% of the decreasing effects, and the rest of the 10% was from the change of the passenger transport CO₂ emission factor. However, these effects were too small to offset the whole increase of effects. From 2000 to 2009, the total CO₂ emissions from the passenger transport sector in Shanghai increased 4.99 million tons.

The using of chaining decomposition makes it possible to track the contribution of each driving factor over time. Figure 9 illustrates the estimated contributions of factors relevant to economic activity, population, modal share, passenger transport intensity and passenger transport CO₂ emission factor to the change in passenger transport CO₂ emissions in Shanghai based on 2000. It is notable that the contributions of these variables have not followed a smooth trend except in the cases of economic activity and population.

Economic activity and population were positive driving factors for passenger transport CO₂ increase during the entire period of the study. Considering the relationship between GDP per capita and passenger transport CO₂ emissions in Shanghai, the average increasing rate of passenger transport CO₂ emissions (11.2%) was a little lower than the average growth (11.4%) of economic activity. According to the OECD report (2002), the term ‘decoupling’ means breaking the connection between environmental pressure and economic performance. In other words, the decoupling indicator explores the relative growth rate of various environmental factors and the economic driving force over a given period. The decoupling factor of
CO₂ emissions in Shanghai passenger transport is shown in Figure 10, where the decoupling factor varied between -0.08 and 0.04 from 2000 to 2009. For the period from 2002 to 2005, the value of the decoupling index was negative, which occurred when the growth rate of CO₂ emissions was higher than the increase of economic benefit (GDP per capita). Thus, the index showed a relatively close coupling effect from 2002 to 2005. After 2005, the linkage effect of environmental pressure of passenger transport CO₂ and GDP per capita in Shanghai exhibited relative decoupling, although the decoupling effect was not obvious.

Figure 9. Time-series multiplicative decomposition of passenger transport CO₂ emissions in Shanghai.

Figure 10. Decoupling factor of passenger transport CO₂ emissions in Shanghai. Note: Decoupling factor = 1 - \frac{(EP/DF)_{endOfPeroid}}{(EP/DF)_{startOfPeroid}}, where EP = environmental pressure and DF = driving force (OECD, 2002).
As for the effect of modal share (Figure 11), the main contributor to the growth was the modal shift in terms of passenger kilometres to private cars which contributed to 99% of the modal share effect. The effects from metro and motorcycles were small. While the decreasing of the share of public busses and taxis reduced 1.6 million tons of emissions from 2000 to 2009, which accounted for 52% and 48% respectively. From 2000 to 2002, the CO$_2$ emissions effect of modal share was negative because the increasing effect of private cars was less than the effect of modal shift from public transport. But, since 2003, the effect of private cars became larger and larger, and was one of the main driving forces of passenger transport CO$_2$ emissions growth.

As the main driving force to the decreasing effects of passenger transport CO$_2$ emissions, steadily improved passenger transport intensity showed a positive contribution to the decreasing effect of passenger transport CO$_2$ emissions in Shanghai since 2004, because of improved economic efficiency where there was more
economic activity produced per unit of transport movement. Another negative factor to the growth of passenger transport CO\(_2\) emissions is the passenger transport emission factor. Figure 12 clearly shows the passenger transport emission factor effect of each mode. The improvement of passenger transport emission factor of taxis was the most important driving force to the passenger transport emission factor effect. The overall inhibitory effect of the passenger transport emission factor of public busses was positive, where from 2002 to 2006 the inhibitory effect of the passenger transport emission factor of public busses was positive, while since 2007 the inhibitory effect changed to be negative. The passenger transport emission factor change of metro, private cars and motorcycles played a very minor role in decreasing the passenger transport CO\(_2\) emissions in Shanghai from 2000 to 2009.

5. Conclusion

From 2000 to 2009, the passenger transport CO\(_2\) emissions in Shanghai increased from 3.13 million tons to 8.12 million tons, with a robust average annual growth rate of 11%. Decomposition analysis found that the increase of economic activity, especially the rapid increase of private cars, was the main factor driving passenger transport CO\(_2\) emissions growth, which accounted for 78% of the total CO\(_2\) emissions growth; The effect of population growth was small but not trivial; Modal shifting to personal transport modes also contributed a lot to the passenger transport CO\(_2\) emissions growth in Shanghai. While the passenger transport intensity and emission factor have managed to partly cancel out the increased effect, where the inhibitory effect of passenger transport CO\(_2\) emissions growth was 90% from the improvement of passenger transport intensity, and 10% from the changes of passenger transport CO\(_2\) emission factor. However, these effects were too small to offset the whole increasing effects.

As one of the metropolitan areas in a developing country, Shanghai cannot afford to sacrifice economic growth to achieve the emissions reduction. Therefore, achieving economic development without a proportional increase in passenger transport emissions, in other words, decoupling passenger transport emissions from economic development, is purported to be one of the most important ways to deliver true long-term sustainability. Considering the most important dependent factors of passenger transport emissions, the level of passenger transport activity, modal structure and passenger transport energy consumption and emissions characteristic – AVOID, SHIFT and IMPROVE – are set as three steps to mitigate CO\(_2\) emissions in the passenger transport sector and decouple passenger transport emissions from economic development: (1) AVOID trips or travel demand, (2) SHIFT the modes from high carbon-intensive modes to low carbon-intensive ones which in most cases will be either non-motorized or public transport, and (3) IMPROVE existing forms of motorized transport through technological improvements and policies.

AVOID: In the last few decades, not only average travel distance and daily trips per person, but also total daily trips substantially increased in Shanghai. Moreover, the rapid increase of private vehicles promoted motorized mobility. Improving accessibility through better integration of land use and transport planning such as Transit Oriented Development and Bicycle Oriented Development, developing teleshopping and teleworking can reduce the amount of travel. In addition, as the largest vehicle share in Shanghai, motorcycles should be more stringently controlled by policies on buying and using. Other smart measures such as car sharing and high-occupancy vehicle lanes can encourage avoiding excessive use of private cars.
SHIFT: Although the Shanghai government has optimized the public bus lines many times, enlarged the service scope, and constructed more and more Exclusive Bus Lanes, its share in terms of passenger kilometres declined by 33% from 2000 to 2009. Fortunately, the share of metro increased 12% with the expansion of the Shanghai metro system. Overall, the modal shift from public transport to private cars was one of the most important contributors to the passenger transport CO₂ emissions increase in Shanghai. On one hand, increasing the attraction of public transport can prevent modal shifting away from public transport by using some smart measures such as price privilege and transfer convenience facilities. On the other hand, some regulations on private vehicles such as Controlled Parking Zones and road pricing (including urban congestion charging; motorway pricing) can encourage modal shifting from private vehicles to public transport.

IMPROVE: The improvement of economic efficiency and the introduction of clean energy in taxis contributed to most of the mitigation of passenger transport CO₂ emissions in Shanghai. Some smart measures such as fuel switching grants, subsidies for clean energy vehicles, technological developments (e.g. hydrogen fuel cells) and eco-driving will further promote the reduction target of CO₂ during rapid economic growth. AVOID, SHIFT and IMPROVE are all important strategies for mitigating emissions and decoupling passenger transport emissions from economic growth. Therefore, we do need to parallel promote the instruments for AVOID, SHIFT and IMPROVE to mitigate passenger transport CO₂ emissions.

Acknowledgement
This work was supported partly by the Nagoya University Global COE (Center of Excellence) Program “From Earth System Science to Basic and Clinical Environmental Studies” (GCOE-BCES) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

References


