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Factor decomposition analysis and causal mechanism investigation on urban transport CO_2 emissions: Comparative study on Shanghai and Tokyo

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Abstract: Low-carbon urban development has been regarded as a promising pathway for mitigating climate change, and the transportation sector makes a key contribution to a significant proportion of all CO_2 emissions. Investigating the driving factors and analysing the causal mechanism on urban transport CO_2 emissions is critical for stakeholders and policy-makers to draft appropriate policies for low-carbon transport, and conducting a comparative study on developed and developing countries' experiences will provide beneficial insights from an evolving perspective. To date, many emerging case studies have analysed urban transport CO_2 emissions in China; however, they lack an in-depth decomposition and causal mechanism analyses as well as a comparative study. To fill this gap, this study aims to conduct a decomposition analysis and causal mechanism investigation study on the urban transport sector with comparative studies on two Asian mega cities, Tokyo and Shanghai. We illustrate the driving forces of the urban transport sector and the causal mechanism of each factor and provide critical policy insights through comparative studies. The outcomes of this study provide critical insights to recent practices in Shanghai as well as practical guidance to low-carbon urban planning in developing countries.

Keywords: Urban transport; Decomposition analysis; CO_2 emission; Causal mechanism; TOD; Mega cities

1. Introduction

City development has become the key driver to global GHG emissions increases; therefore, low-carbon urban development has become a point of focus to mitigate global climate change. It is reported that urban land use contributes to 80% of world CO_2 emissions while only occupying 2% of the earth's surface (Grimm et al., 2008; Wu, 2008). With economic growth and urbanization, the transport sector has become an important driving force for CO_2 emissions (Nakamura and Hayashi, 2013): the sector emits a significant proportion of total emissions, at 32.9% in United States, 17.7% in Japan, and 8.6% in China in 2012 (IEA, 2014).

Various low-carbon strategies and instruments are designed and implemented to mitigate urban transport CO_2 emissions (Feng et al., 2013; Hao et al., 2014, 2011; Hickman and Banister, 2007; Jie and van Zuylen, 2014; Lehmann, 2013). As a mixed-use urban design methodology, the Transit-oriented Development (TOD) strategy, which promotes sustainable urban transport by integrating transport infrastructures with surrounding land uses (Cervero, 1998; Curtis et al., 2009; Dittmar and Ohland, 2004; Loo et al., 2010; Sung and Oh, 2011) provides a novel methodology for low-carbon urban planning (Nakamura and Hayashi, 2013).

China, which has become the highest CO_2 emitter in the world, faces significant pressure regarding CO_2 mitigation. China is under pressure due to its responsibility for climate change and criticism from the international community; thus, China's administration had been planning various measures for the mitigation of CO_2 emissions. In 2009, the Chinese government declared that it would reduce its CO_2 emission intensity by 40–45% by 2020. It was reported (Fig. 1) that the transport sector's CO_2 emissions in China increased by 8.6% annually, reaching 630 million tons in 2008. Compared to sector energy consumption in 2000, transport-related energy consumption increased by 93.2% in 2008 (Chen and Yang; Hao et al., 2014). Especially in some mega cities of China, as economic growth and migration increases, the trend of motorization also increases quickly; as a result, transport sector-related emissions are still surging (Feng et al., 2013; Wang et al., 2012; Wei et al., 2013).

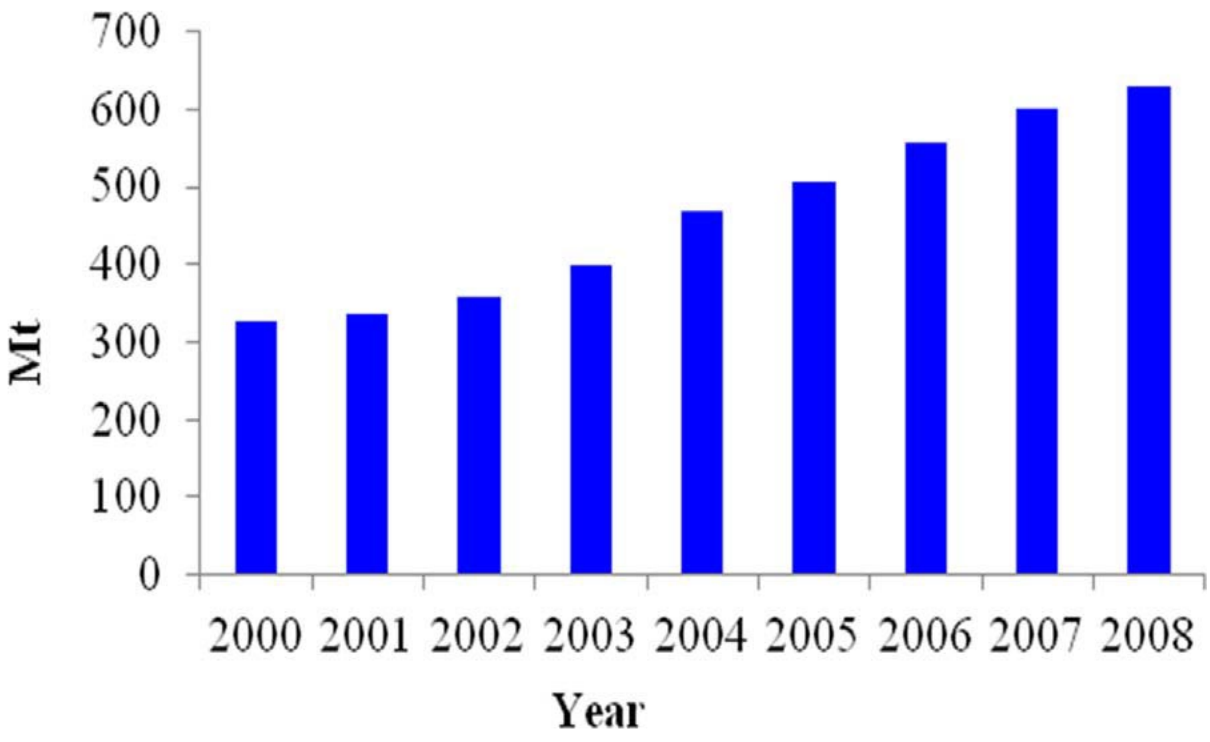

Figure 1: China transport sector CO2 emissions.

Source: Annual review of low-carbon development in China.

Many developing cities in China promote urbanization, and they face a conflict of increasing travel demand and limited transport supply as well as corresponding problems, e.g., traffic congestion, increasing traffic-related injuries and increasing transport-related air pollution, such as PM2.5, and significant transport energy consumption. The experiences of other cities can offer valuable lessons to cities in developing countries (Mittal et al., 2016a, 2016b). For instance, the experience of Tokyo, Japan is critical for some mega cities in China to learn about low-carbon urban development. From this perspective, it is beneficial to learn and analyse the lessons and experiences (both positive and negative) of developed cities to help developing cities achieve major advances with early and proper policy making. Given such circumstances, identifying the key factors affecting urban transport emissions (D'Agosto et al., 2013; Hickman et al., 2011; Liu et al., 2013; Makido et al., 2012; Ribeiro and Balassiano, 1997) and investigating the causal mechanisms in cities in both developing and developed countries is necessary to promote a sustainable and lowcarbon urban transport system for a TOD strategy (Dou et al., 2016; Mitric, 2013; Nicolas and David, 2009).

To date, there have been emerging studies on urban transport CO2 emissions, both domestically (Feng et al., 2013; Jie and van Zuylen, 2014; Wang et al., 2012; Wei et al., 2013) and internationally (Hickman et al., 2011; Hickman and Banister, 2007; Makido et al., 2012; Pérez et al., 2009; Ribeiro and Balassiano, 1997). As a powerful tool to trace the driving forces of emissions (Jiang et al., 2015; Wu and Xu, 2014; Zucaro et al., 2014), an increasing number of decomposition analysis methods have been applied in the transport sector (Wu and Xu, 2014). However, to our best knowledge, research on the combination of decomposition analysis and the urban transport sector has not yet been carried out. In addition, research on the follow-up causality mechanism investigation has not yet been done. A number of studies have focused on enumerating these features and making a full causality map for the driving forces of the urban transport CO2 emissions in developing cities.

This paper aims to fill this gap with a decomposition analysis and causal mechanism investigation study on the urban transport sector with comparative studies on a developed city — Tokyo — and one developing city in China. We aim to not only illustrate the driving forces of the urban transport sector and the causal mechanism of each factor but also provide critical policy insights from an evolving perspective through the comparative studies. Our results will be critical to finding the causality of urban transport CO2 emissions and the interfactor mechanisms in Asian cities and supporting the design of a policy framework to achieve urban transport CO2 mitigation targets towards a TOD strategy.

The rest of this paper is organized as follows. After this introduction, Section 2 presents details on the methodology; Section 3 introduces the case city and its urban transport development; Section 4 presents and discusses the analytical results; and finally, Section 5 presents the conclusions and addresses the policy implications.

2. Methodology

2.1 Causal mechanism investigation

In this research, all transport activities are considered an integrated system, shown as Fig. 2. The transport activities can be divided into 3 parts: (1) Trip generation, which is affected by the urban area, the concentration of urban activity and trip rate. The related policy, AVOID, includes TOD development, job-housing imbalance, control of sprawl, teleworking, etc. (2) Mode shift, which is affected by car ownership and access to public transport and roads. The related policy is SHIFT, which includes an improvement of bus/rail systems, encouraging the use of bicycles, Intelligent Transport System (ITS), parking regulations, and an integrated transport system. (3) Improvement of fuel efficiency, which is affected by the average engine technology level of car fleets, car occupancy rates, etc. The related policy, IMPROVE, includes encouraging the use of e-cars and renewable energy, the regulation of emissions standards, the introduction of fuel taxes, and subsidies for LEVs. Due to this mechanism, it is possible to analyse the causal mechanism of urban transport emissions.

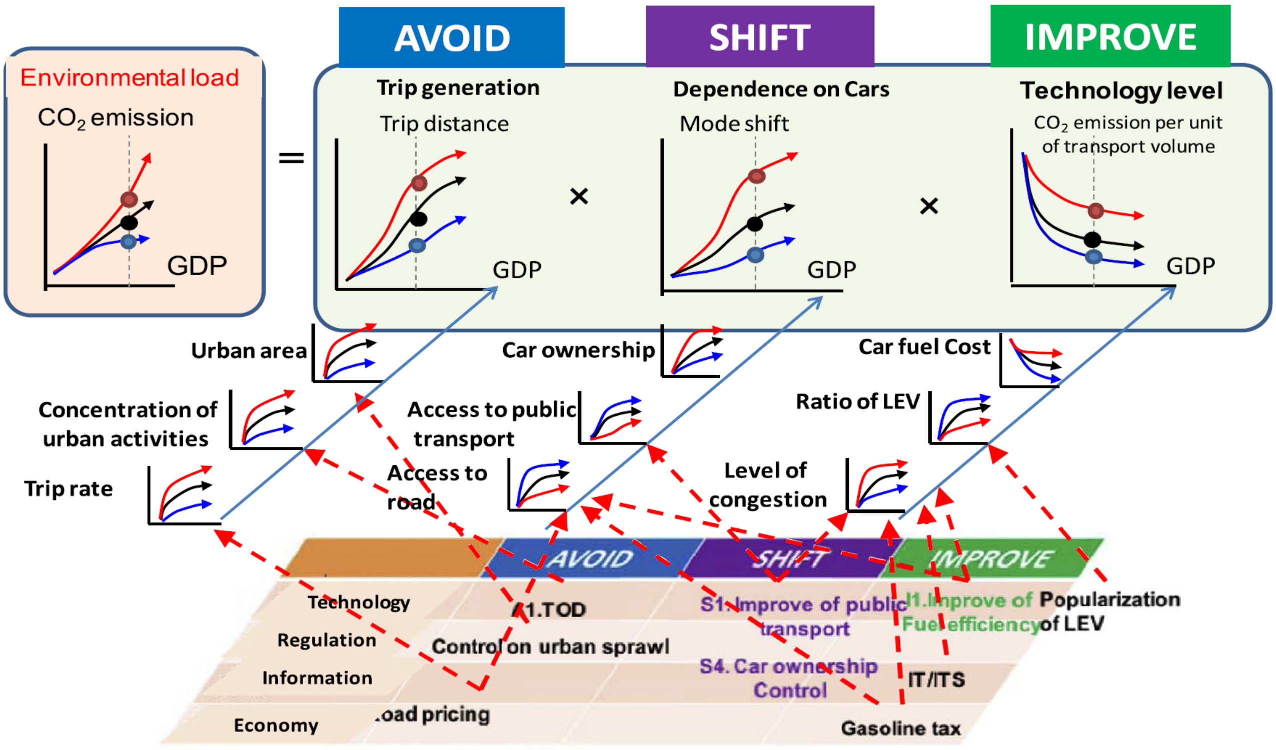

Figure 2: Dynamic tracking of transport-related emission mechanism

This study attempts to summarize the causal mechanism in an integrated causality map. The map consists of 3 parts horizontally: (1) AVOID: In this part, we describe the relationship between the factors with the traffic demand, which is mainly caused by suburbanization and the job-housing imbalance. The factors are marked as A1, A2…, and the related policies are marked as AP1, AP2… (2) SHIFT: In this part, we mainly describe the competition in different modes and describe how different policies affect the mode share. The factors are marked as S1, S2…, and the related policies are marked as SP1, SP2… (3) IMPROVE: In this part, we mainly describe how each policy affects the improvement of the transport system, such as the occupancy rate and the engine technology improvement. The factors are marked as I1, I2…, and the related policies are marked as IP1, IP2…, etc.

On the other hand, the phenomenon in the causality diagram are vertically divided into 5 stages: (1) Background: Economic development and population growth; (2) Direct cause: the deeper level of cause; (3) Land use and Transport phenomenon: the phenomenon in land use and transport phenomenon; (4) Direct Impact on CO_2 emissions: Increase of travel, trip rate, travel distance, mode shift, fuel efficiency and occupancy rate. (5) Social problem: global warming.

2.2 Causal mechanism investigation

The index decomposition method is powerful tool for tracing driving forces and influential factors for stakeholders to address specific measures. In the transport sector, a number of studies regarding factors that affect emissions growth have been conducted over the past few years. Eom et al. (2012) decomposed passenger transport in South Korea between 1986 and 2007 into transport activities, mode sharing, and energy intensity. Kwon (2006) used the LMDI method to research car travel in UK, where they decomposed the factor into population, vehicle trip distance, occupancy rate, fuel

efficiency and fuel structure. Lu et al. (2007) analysed the changes in highway vehicle CO_2 emissions in Japan, Germany, South Korea and Taiwan between 1990 and 2002, and they decomposed the factors into emission ratios, fuel intensity, car ownership, population coefficient and economic growth. Timilsina and Shrestha (2009) applied the LMDI method analysis for CO_2 emissions to entire transport sectors in different Asian countries and found different driving forces of CO_2 emissions in these countries. Zhang et al. (2011) identified the relationship between transport sector energy consumption and the changes of the transport mode, passenger-freight share, energy intensity and transport activity in China between 1980 and 2006. However, on the whole, no studies have combined a decomposition analysis with a causal mechanism analysis.

In this research, the prevailing decomposition approach, LMDI (Log Mean Divisia Index method), is applied to trace the driving factors of urban transport CO_2 emissions. The total CO_2 emissions can be obtained by Eq. (1). This method is the most commonly used one and has the advantage of lacking redundancy. Based on the analysis of Fig. 2, three factors affect CO_2 emissions: AVOID (trip generation), SHIFT (mode shift) and IMPROVE (technology level). Population, trip generation rate and travel distance are the components of trip generation; the mode shift describes the dependence of cars and the load factor, and fuel efficiency is a component of the technology level.

$$C^t = POP \times TN_i \times MS_i \times DT_i \times LF_i \times EF_i \quad (1)$$

POP : population of the year t; unit: person

TN_i : trip generation rate; unit: trip/person

DT_i : average travel distance of i mode; unit: km/passenger

MS_i : mode share; unit: %

LF_i : load factor, number of people who use car/bus/transport equipment; unit: vehicle-km/passenger

EF_i : emission factor; unit: CO2 / vehicle-km

Each individual factor that affects CO2 emissions from the base year to the year t can be calculated, as Eq. (2) shows:

$$\Delta C_{tot} = \Delta C_{pop} + \Delta C_{TN} + \Delta C_{MS} + \Delta C_{DT} + \Delta C_{LF} + \Delta C_{FE} \quad (2)$$

Each variable in this equation can be calculated by using the LMDI method as follows:

$$\Delta C_{POP} = \sum_i \Delta C_{POP,i} = \begin{cases} \Delta C_{POP,i} = 0, & \text{if } C_i^t \times C_i^0 = 0 \\ \Delta C_{POP,i} = \sum_i L(C_i^t, C_i^0) \ln\left(\frac{POP_i^t}{POP_i^0}\right), & \text{if } C_i^t \times C_i^0 \neq 0 \end{cases} \quad (3)$$

$$\Delta C_{TN} = \sum_i \Delta C_{TN,i} = \begin{cases} \Delta C_{N,i} = 0, & \text{if } C_i^t \times C_i^0 = 0 \\ \Delta C_{TN,i} = \sum_i L(C_i^t, C_i^0) \ln\left(\frac{TN_i^t}{TN_i^0}\right), & \text{if } C_i^t \times C_i^0 \neq 0 \end{cases} \quad (4)$$

$$\Delta C_{MS} = \sum_i \Delta C_{MS,i} = \begin{cases} \Delta C_{MS,i} = 0, & \text{if } C_i^t \times C_i^0 = 0 \\ \Delta C_{MS,i} = \sum_i L(C_i^t, C_i^0) \ln\left(\frac{MS_i^t}{MS_i^0}\right), & \text{if } C_i^t \times C_i^0 \neq 0 \end{cases} \quad (5)$$

$$\Delta C_{DT} = \sum_i \Delta C_{DT,i} = \begin{cases} \Delta C_{DT,i} = 0, & \text{if } C_i^t \times C_i^0 = 0 \\ \Delta C_{DT,i} = \sum_i L(C_i^t, C_i^0) \ln\left(\frac{DT_i^t}{DT_i^0}\right), & \text{if } C_i^t \times C_i^0 \neq 0 \end{cases} \quad (6)$$

$$\Delta C_{LF} = \sum_i \Delta C_{LF,i} = \begin{cases} \Delta C_{LF,i} = 0, & \text{if } C_i^t \times C_i^0 = 0 \\ \Delta C_{LF,i} = \sum_i L(C_i^t, C_i^0) \ln\left(\frac{LF_i^t}{LF_i^0}\right), & \text{if } C_i^t \times C_i^0 \neq 0 \end{cases} \quad (7)$$

$$\Delta C_{EF} = \sum_i \Delta C_{EF,i} = \begin{cases} \Delta C_{EF,i} = 0, & \text{if } C_i^t \times C_i^0 = 0 \\ \Delta C_{EF,i} = \sum_i L(C_i^t, C_i^0) \ln\left(\frac{EF_i^t}{EF_i^0}\right), & \text{if } C_i^t \times C_i^0 \neq 0 \end{cases} \quad (8)$$

Each component in Eqs. (3) through (8) represents different factors that affect CO_2 emissions. ΔC_{pop} states how much the population affects the CO_2 emissions of the urban transport sector; ΔC_{TN} describes how much the average trip generation rate affects the CO_2 emissions of the urban passenger transport sector,; ΔC_{CF} describes how much the mode shift affects the CO_2 emissions of the urban passenger transport sector; ΔC_{DT} describe how much the average travel distance affects the CO_2 emissions of the urban passenger transport sector; ΔC_{CF} describe how much the load factor affects the CO_2 emissions of the urban passenger transport sector; and ΔC_{EF} describes how emissions efficiency affects the CO_2 emissions of the urban passenger transport sector.

2.3 Data

The data used in this study are obtained from two channels: (1) first-hand data from surveys and reports and (2) second-hand data from statistical yearbooks. Compared to past studies, we obtain newer and innovative first-hand data.

For Shanghai, the population data is from Shanghai statistical yearbooks; the data of the railway energy efficiency is from a report on the Shentong Group,[1] which operates Shanghai's metro system, and the data for car fuel efficiency is from other local researchers' reports and papers[2]. The data of the Shanghai mode share, trip rate and travel distance in this study is from the Shanghai Investigation report of comprehensive transportation in Shanghai in the years 1995, 2004 and 2009[3].

For Tokyo, the data for car energy efficiency is from the Japanese automobile statistical yearbook[4,5] and the data for railway efficiency is from Japanese railway statistical yearbooks[6,7]. The data for the Tokyo mode share and trip rate are from the Tokyo personal trip research conducted in 1968, 1978, 1988, 1998 and 2008[8]. The travel distance data are drawn partly from the statistical yearbooks and partly from the personal trip research on Tokyo in each corresponding year.

3. Case introduction

3.1 Socio-economic condition of Shanghai and Tokyo

We select two Asian mega cities as case studies: Shanghai, China and Tokyo, Japan. The location information is presented in Fig. 3. From a development stage perspective, Shanghai is a developing mega city, and it faces significant conflicts of traffic demand and supply. While Tokyo is a developed city, it has experienced high-speed economic development and socio-economic change from the 1950s to 1980s. In its developing stages, Tokyo has also experienced similar conflicts of traffic demand and supply, but Tokyo has successfully overcome this dilemma. Tokyo is now famous for its public transport system, especially its railway system. Hence, it is necessary to identify the deeper reason for Tokyo's experience, find useful policies in Tokyo, and combine the experience with the local situation in Shanghai to draft an appropriate policy system to make the transport system more sustainable in Shanghai. Fig. 4 summarizes the GDP per capita change in Shanghai and Tokyo.

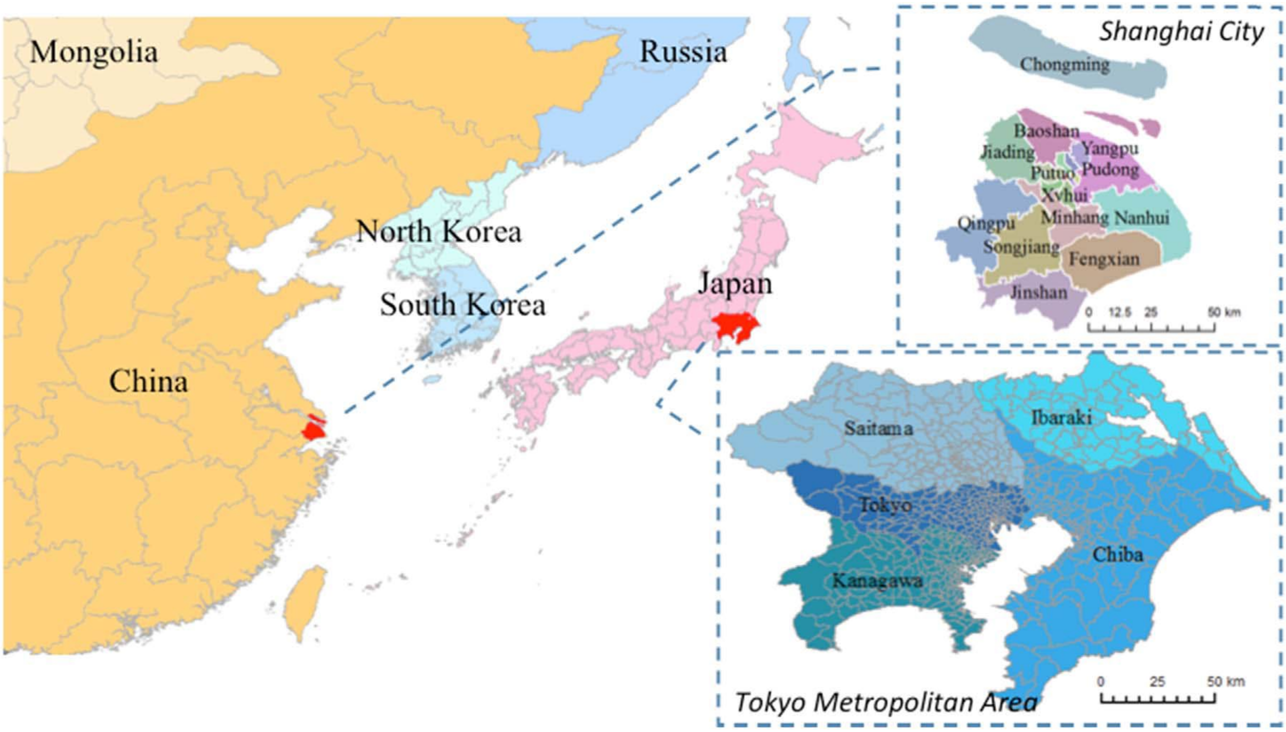

Figure 3: Location of Shanghai and Tokyo.

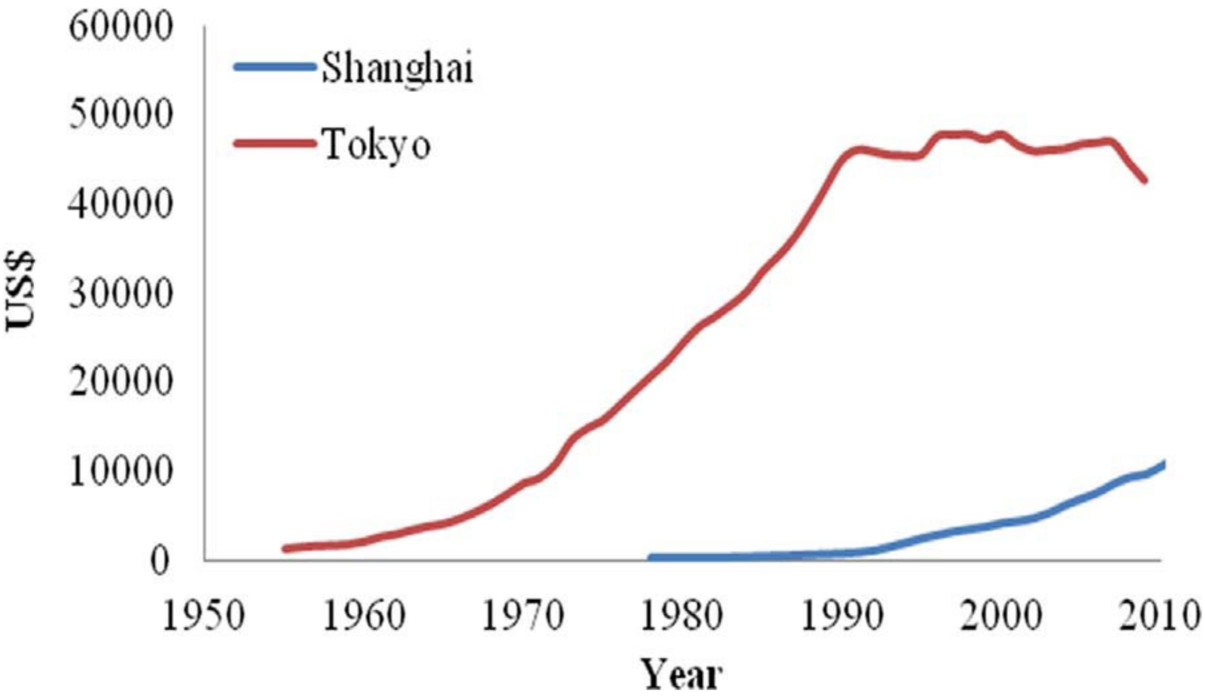

Figure 4: Per capita GDP of the Shanghai and Tokyo metropolitan areas.

Source: MOIAC, 2013; NBS, 2012.

Shanghai is the largest mega city in terms of GDP as well as the financial centre of China. The total area of Shanghai was approximately 6340 km^2 in 2011. The total population in Shanghai has increased constantly due to the rapid migration of people from other parts of China who sought work opportunities and a higher quality of life. The population grew quickly from 1978 to 2011. With rapid economic development, the residents' traffic demand has grown rapidly. Due to the 3rd and 4th Comprehensive Travel Survey of Shanghai, the total trip volume generated by the urban passenger transport approached 50 million per day by 2009, meaning that the daily generation rate of trips reached 2.43 per person (NBS, 2012).

Tokyo is the capital of Japan. The Tokyo metropolitan area includes the Ibaraki Prefecture, Saitama Prefecture, Chiba Prefecture, and Kanagawa Prefecture. It has an area of 19651 km2. The total population was 36.4 million in 2008 (1853 person/km^2). Tokyo's 23rd ward has a population of 8 million along with 58% of large company headquarters, 47% of the financial departments, and 84% of foreign companies. The total number of jobs in the 23rd ward is 6.7 million, which means that most jobs are in the city centre, while most people live in the peripheral area. Hence, high-volume travel can be frequent and concentrated in the city centre (MOIAC, 2013).

3.2 Urban Transport development in Shanghai

With economic growth and urbanization, the built-up area in Shanghai increased quickly from 203 km2 in 1986–2303 km^2 in 2009, an annual increase rate of 11%. The population and average travel times in Shanghai increased constantly; the population increased from 12.49 million in 1986 to 20.13 million in 2009, and the daily average trip generation increased from 1.70 to 2.42 times per person. The increase of the population is uncontrollable because economic development draws more people to move to Shanghai for opportunities. More detailed information is shown in the Supporting information.

The travel objectives are primarily commuting, and the share for entrainment increases. The population of the central area decreased from 1986 to 2004 from 4.85 million to 4.05 million, and the share of the total population decreased from 37.4% to 23%. The average travel distance increased from 4.3 km in 1986 to 6.9 km in 2009, and the average travel time increased from 25 min in 1986 to 33.2 min in 2004. Detailed travel distance information by mode can be seen in Fig. 5. We can see that the average distance for rail increased because of the rail decrease. Although the railway expanded into the suburban areas, the travel distance did not change significantly. The mode share change is shown in Fig. 6.

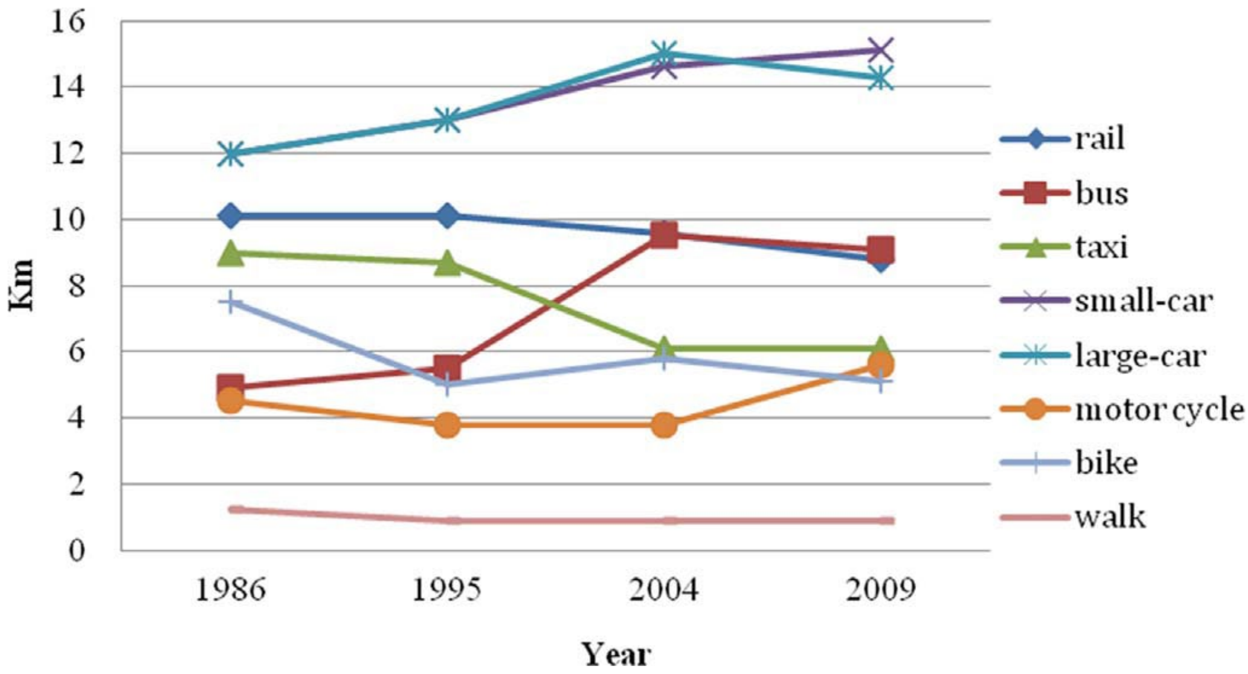

Figure 5: Travel distance by mode in Shanghai.

Source: Report on the Shanghai Transportation Survey in 2009, 2004, 1995.

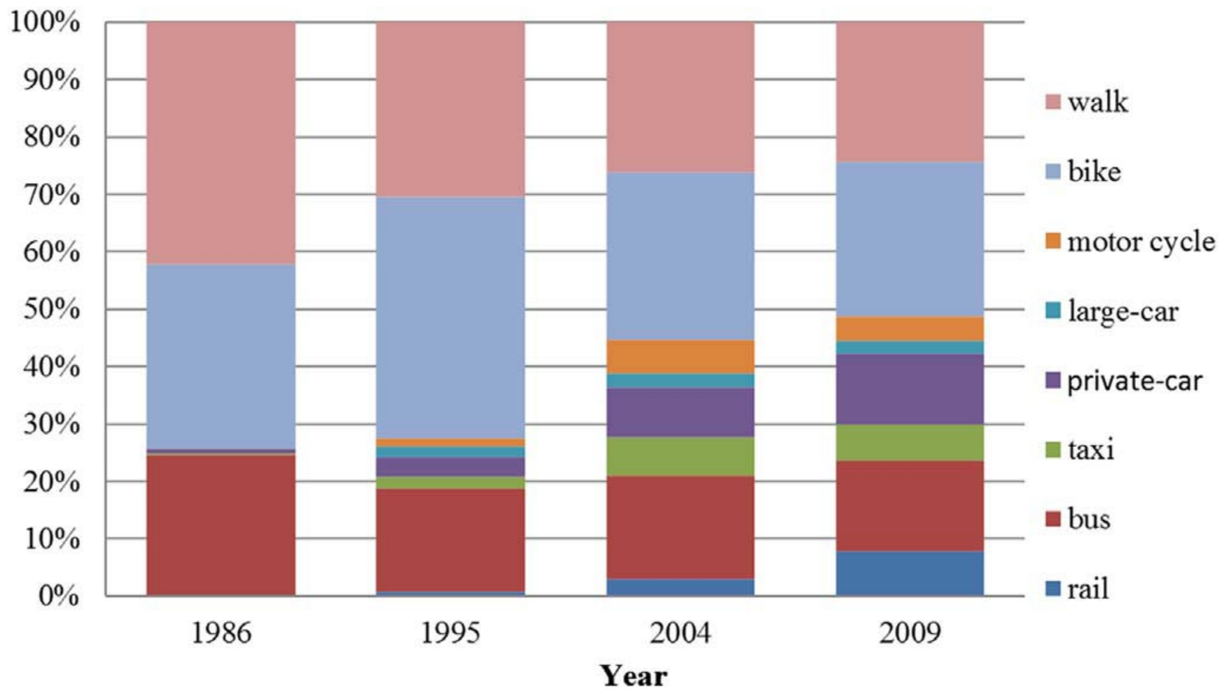

Figure 6: Mode share change in Shanghai.

Source: Report on the Shanghai Transportation Survey in 2009, 2004, 1995.

3.3 Urban transport development in Tokyo

In Tokyo, the population increased constantly due to increased work opportunities, so the population increased at a high speed. The trip generation rate of Tokyo increased from 2.24 to 2.45 from 1968 to 1978, decreased slightly to 2.41 and then maintained a constant value. The urban area expanded from 1965 to 2005, but the expansion maintained good TOD because the convenience factor of the railway system was high. Therefore, even with the development of the urban area and the trend of suburbanization, the travel distance of buses did not increase. It decreased slightly in 2 periods due to the oil crisis between 1968 and 1978 and the railway system improvements between 1998 and 2008. However, the main job opportunities were in the inner part of Tokyo. As a result, more than 90% people use the railway to commute longer distances, and thus the rail travel distance increased constantly. More detailed information on the land use and transport system change is shown in the Supporting Information section.

As with Shanghai, Figs. 7 and 8 illustrate the average trip generation and travel mode share in Tokyo. It is noted that with the longer travel distance, the greater share is rail, mainly because of the convenience of the railway and the high usage costs for cars (oil prices, parking fees).

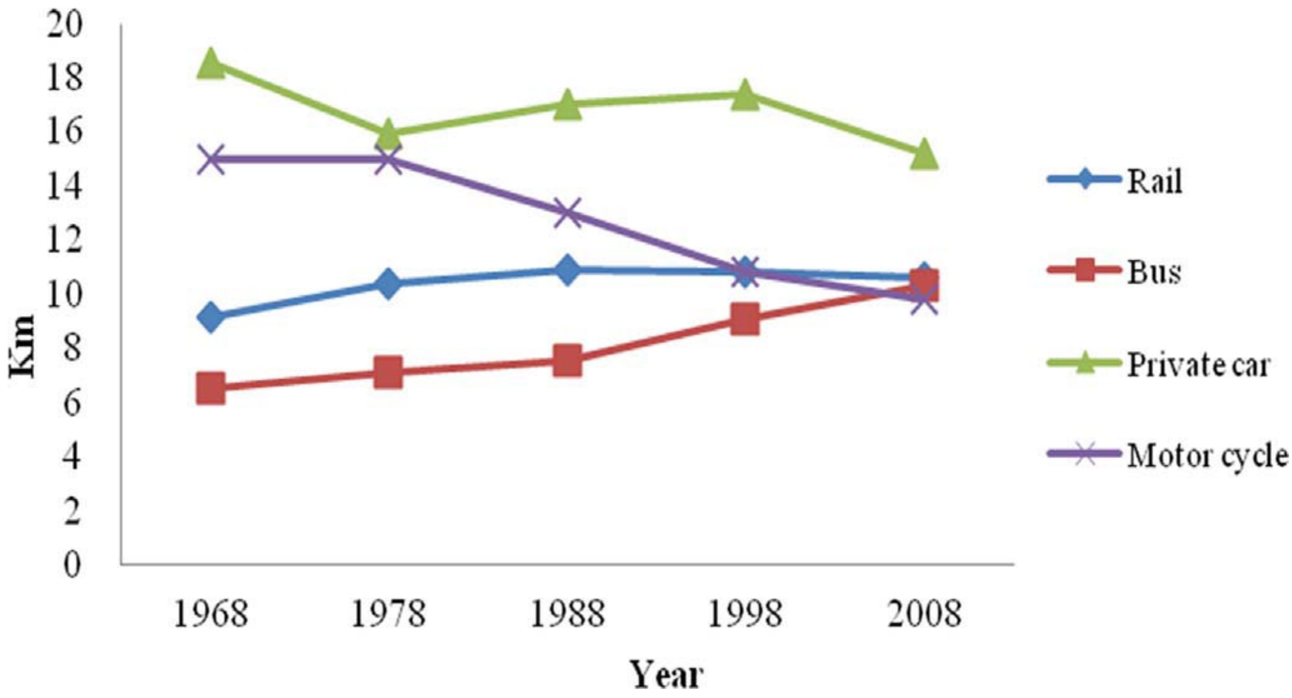

Figure 7: Travel distance by mode in the Tokyo metropolitan area.

Source: Rail travel distance data are from the Annual Report of Rail Transportation Statistics89; data on bus, private car and motorcycle travel distance are from the Motor Vehicle Transport Statistical Yearbook.

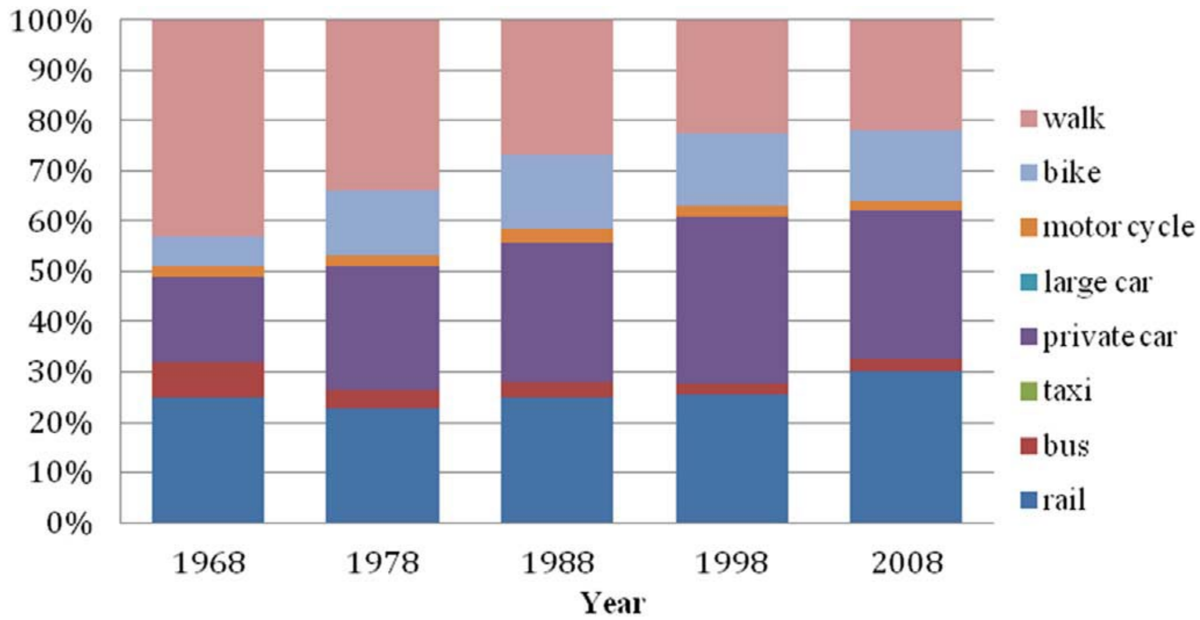

Figure 8: Mode share in the Tokyo metropolitan area.

Source: PT investigation of Tokyo in 1968, 1978, 1988, 1998, 2008.

4. Results and discussion

4.1 Analysis on Shanghai

4.1.1. Urban transport CO_2 emissions

Based on the established methodology, urban transport CO_2 emissions in Shanghai were calculated and the affecting factors were decomposed. All parameters, i.e., car ownership, number of passengers, travel distance, and fuel efficiency have been presented in the Supporting Information section.

Fig. 9 shows the CO_2 emissions change in the passenger transport sector in Shanghai. It is noted that total CO_2 emissions increased from 1.4 thousand-t in 1986 and 3.4 thousand-t in 1995 to 11.7 thousand-t in 2004 and 16.7 thousand-t in 2009; the increase ratio is 12% yearly. At the same time, the GDP of Shanghai was $561 in 1986, $2525 in 1995, $6284 in 2004, and $9724 in 2009. The increase ratio is 13%, and the total transport sector CO_2 emissions increase ratio is similar to that of economic development.

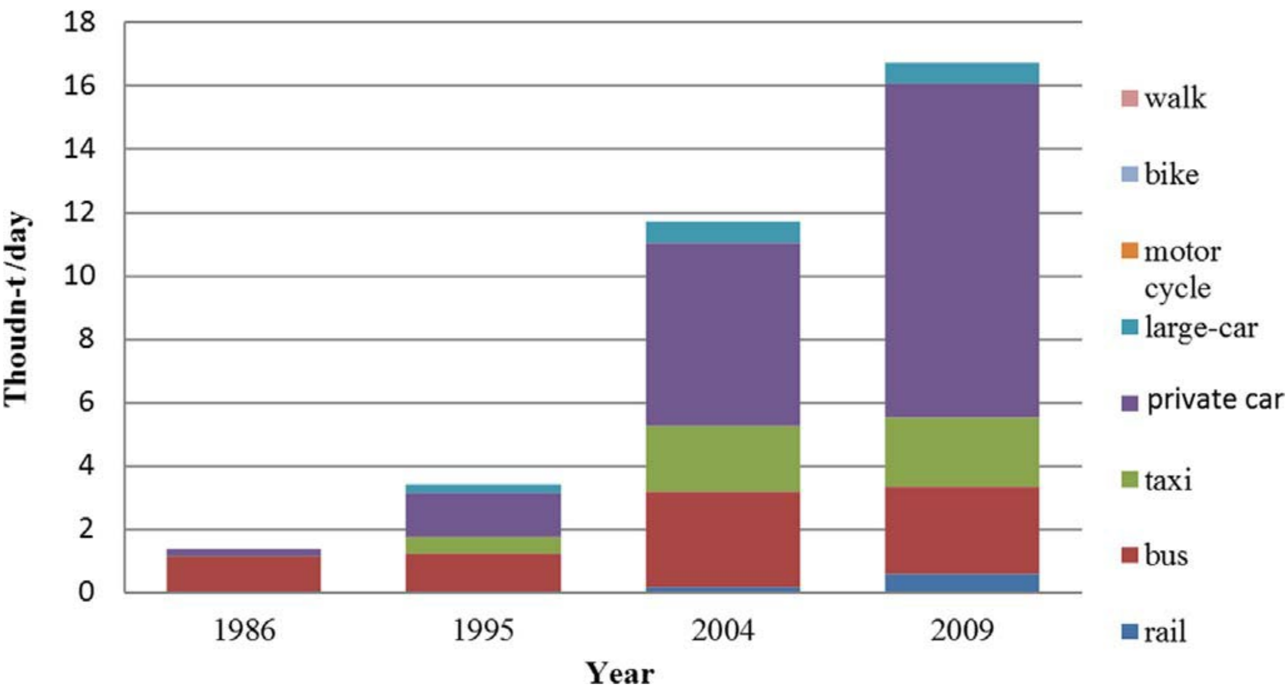

Figure 9: CO_2 emissions of the passenger transport sector in Shanghai.

4.1.2. Decomposition analysis

Based on the emissions calculations, a decomposition analysis is conducted to investigate the driving forces. The result is illustrated in Fig. 10. For the year 1995, we find that the main contributors of CO_2 emissions are small vehicles and buses; in 2004, the share of small vehicles and buses increased; and in 2009, the share of small vehicles increased significantly but the share of buses decreased. The number of vehicles increased significantly; hence, the use of small vehicles is more frequent.

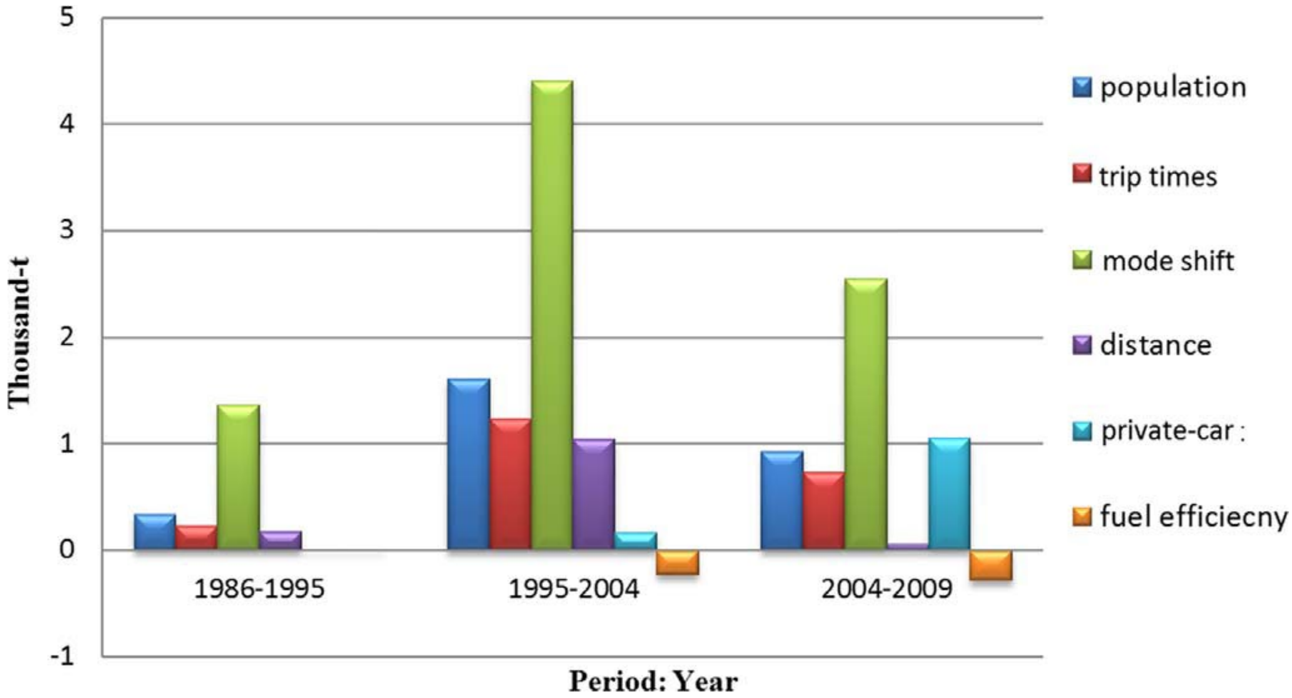

Figure 10: Decomposition result of Shanghai.

The results highlight all the influence factors except for fuel efficiency that have a positive impact on CO_2 emissions. On the whole, the largest contributor is the mode share, followed by the population increase, the average trip times, and the travel distance. From 1986 to 1995, the mode shift effect shows the strongest positive effect on CO_2 emissions, which contributed to 73% of the total change. From 1995 to 2004, the mode shift also shows the strongest positive effect, contributing 56% of the total change; the trip generation rate and population contribute 15% and 19% to the total change, respectively. From 2004 to 2009, the mode shift also shows the strongest positive effect, contributing 52% of the total change, and the trip generation rate and population contribute 14% and 18% to the total change, respectively. While fuel efficiency constantly contributes negatively to CO_2 emissions, the contributions in the periods from 1986 to 1995, 1995 to 2004, and 2004 to 2009 2004–2009 are −0.1%, −3% and −6%, respectively.

4.1.3. Causal mechanism analysis

With the decomposition analysis and the dynamic tracking on the urban transport system, causal mechanism is further analysed, and a causality map is drawn in Fig. 11.

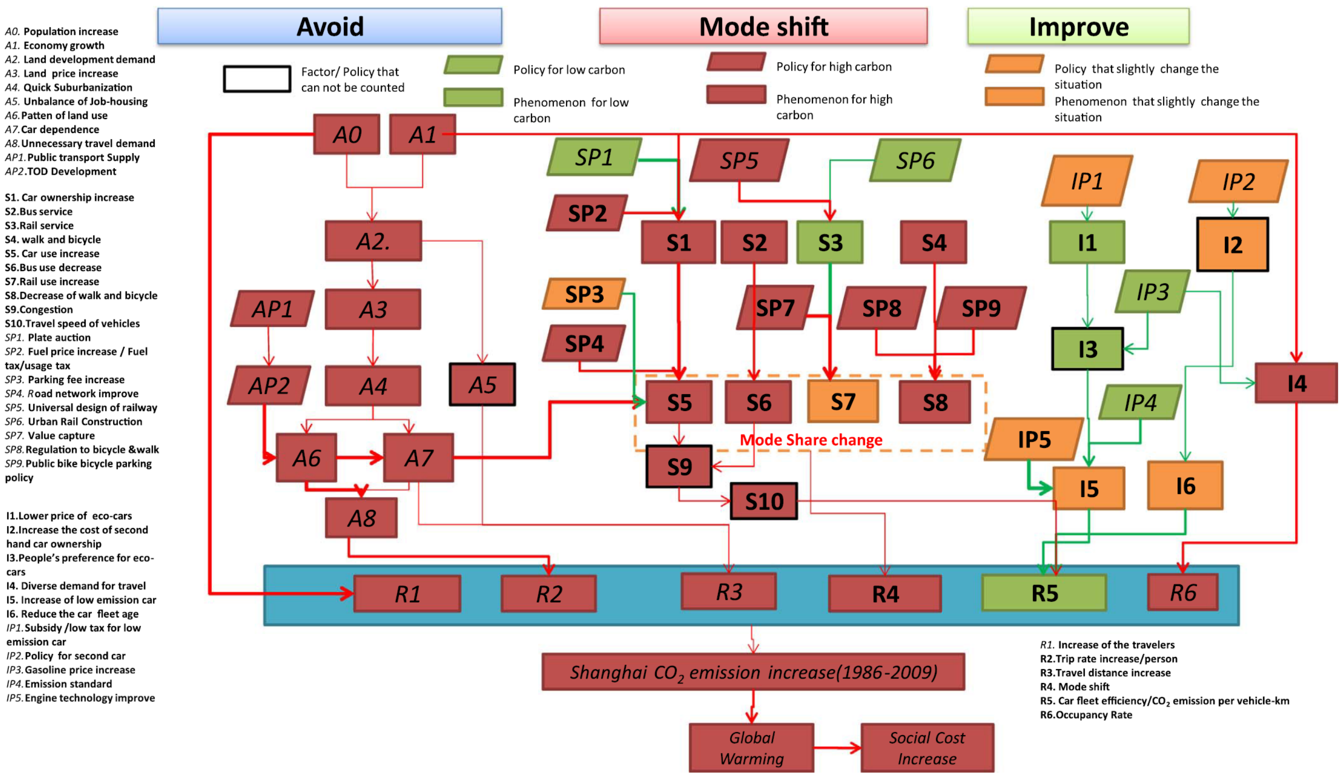

Figure 11: Causal mechanisms of Shanghai's urban transport CO_2 emissions.

In the causality map of Shanghai, it is noted that in the rapid economic growth era for Shanghai, land development causes an imbalance of jobs and housing, and the rapid urbanization and weak public development lead to detrimental patterns of land use; thus, car dependence increases. These factors cause an overall increase in the travel distance and trip rate. In such periods, even with a strong car ownership control policy (plate auctions), given the economic growth, car ownership increases significantly, and the improvement of the road network also encourages people to use cars. At the same time, the urban railway length increased significantly, which led to an increase in railway users. Because the universal design of the railways is not optimal, this reduces the attractiveness of rail usage. The share of bus service level declined due to competition with railway and car usage. Walking and bicycling decreased significantly due to the poor travel environment, strict policies for these modes and the increased travel distance. Gasoline price increases and emission standards, together with better engine technology, caused an increase in low-emission cars, which allowed car fuel efficiency to improve. With economic growth, the diversity of travel demand occurs, which leads to the occupancy rate decrease. All of these factors resulted in CO_2 emissions increasing from 1986 to 2009, which consequently caused global warming and increases in social cost.

4.2 Analysis on Tokyo

4.2.1. Urban transport CO_2 emission

CO_2 emissions are calculated first in Fig. 12. The CO_2 emissions increase from 1968 to 1998 and decrease from 1998 to 2008 are highlighted. The main contributor is private car usage, the secondlargest contributor is rail usage, and the third-largest contributor is bus usage. Each year, cars contributed more than 90% of the total CO_2 emissions, and the absolute value of car-oriented CO_2 emissions maintained a steadily increasing trend.

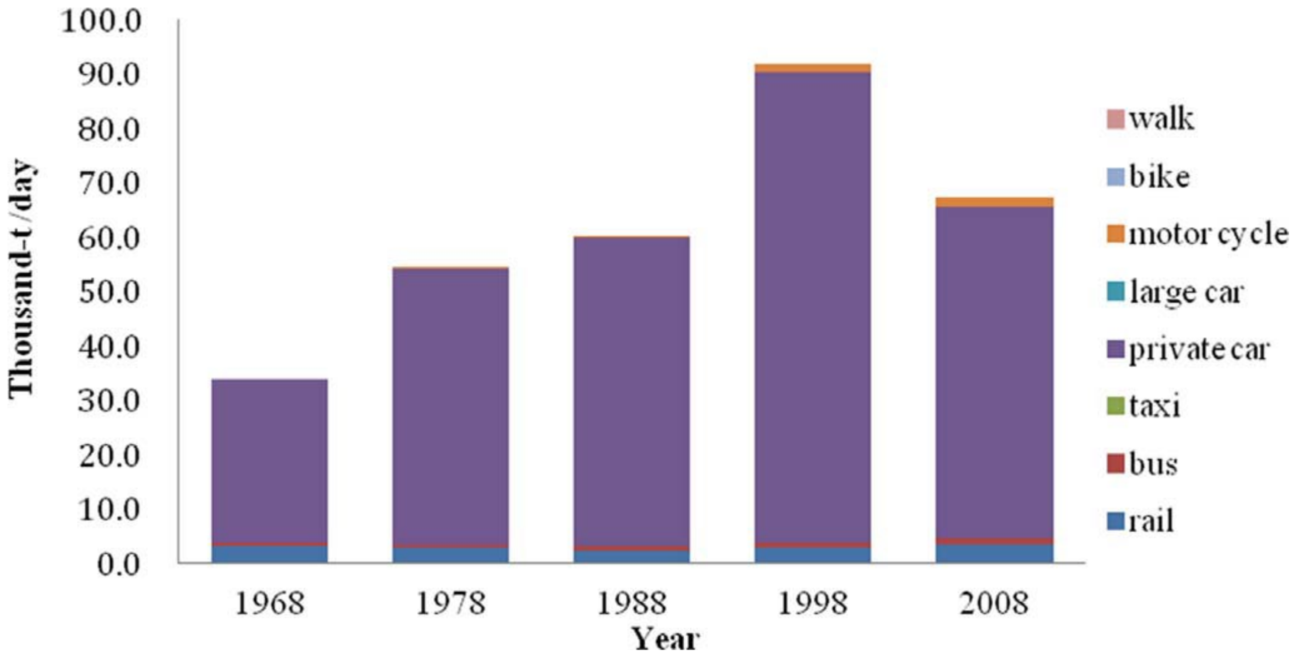

Figure 12: CO_2 emissions in Tokyo's urban passenger transport sector.

4.2.2. Urban transport CO_2 emission

The contributions of each influencing factor on CO_2 emissions in Tokyo are shown in Fig. 13.

Generally, the population consistently shows a positive effect, and mode shift and fuel efficiency are sensitive factors for CO_2 emission change. Specifically, it is noted that the population effect constantly maintained a positive effect on CO_2 emissions. The effect of the trip rate is positive from 1968 to 1978, negative in the periods 1978–1988 and 1988–1998, and then positive from 1998 to 2008. The mode shift effect appears to be positive in the previous 3 periods and shows a negative effect in the last period. The load effect always shows a negative effect because of the improvement of the occupancy rate. It is worth noting that fuel efficiency shows a small negative effect from 1968 to 1978, a stronger negative effect from 1978 to 1998, a sudden positive effect from 1988 to 2008, and a sudden negative effect from 1998 to 2008. These shifts are mainly due to energy technology improvements and people's preferred changes with cars. The distance effect shows a negative effect from 1968 to 1978, a positive effect from 1978 to 1988 and 1988–1998, and then shows a negative effect again from 1998 to 2008.

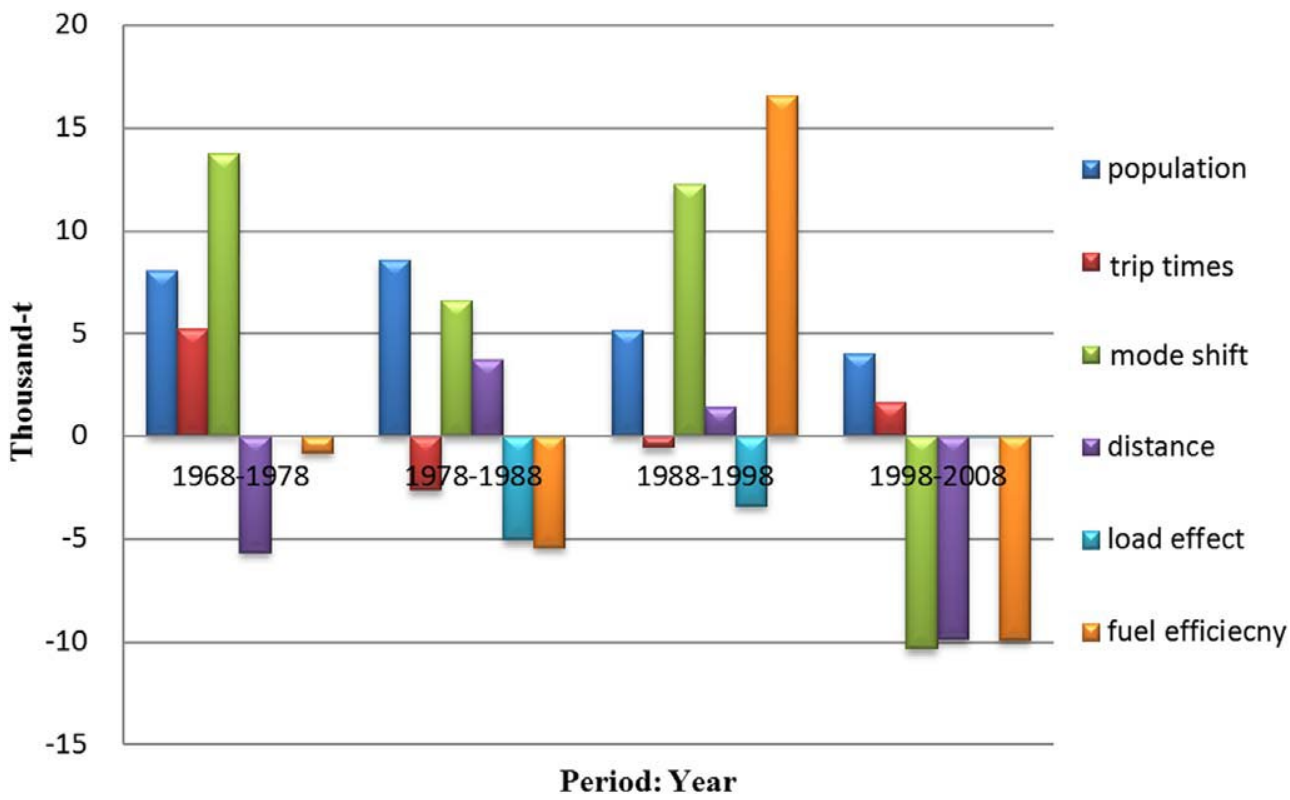

Figure 13: Decomposition result of Tokyo.

4.2.3. Causality analysis

A similar causality map is drawn for Tokyo. Fig. 14 presents causality in the surging economic development era (1968–1988) of Tokyo. The population explosion leads to a surge in travel. The land development caused an imbalance between jobs and housing, even with the rapid urbanization. However, a well-designed public transport system and TOD development mode offered Tokyo a good pattern of land use and lack of strong dependence on cars. Consequently, unnecessary travel demand did not increase significantly. The travel distance increased mainly for rail; hence, the total effect on CO_2 emissions was small. With the growth of the economy, car ownership increased quickly in that period, and thus car use increased quickly. The railway system in Tokyo is well designed, and the value capture allows the operator to continually improve railway services. However, bus service was weak because of the competition from rail service. Because of the long travel distance, the share of walking and biking decreased. Additionally, the subsidy and gasoline prices increased, and the engine technology improvements increased the number of low emission cars. Finally, car efficiency improved significantly. With economic growth, a diversity of travel demand occurs, which leads to an occupancy rate decrease. All of these factors drive the CO_2 emissions to increase from 1968 to 1988, which consequently causes global warming and increases in social cost.

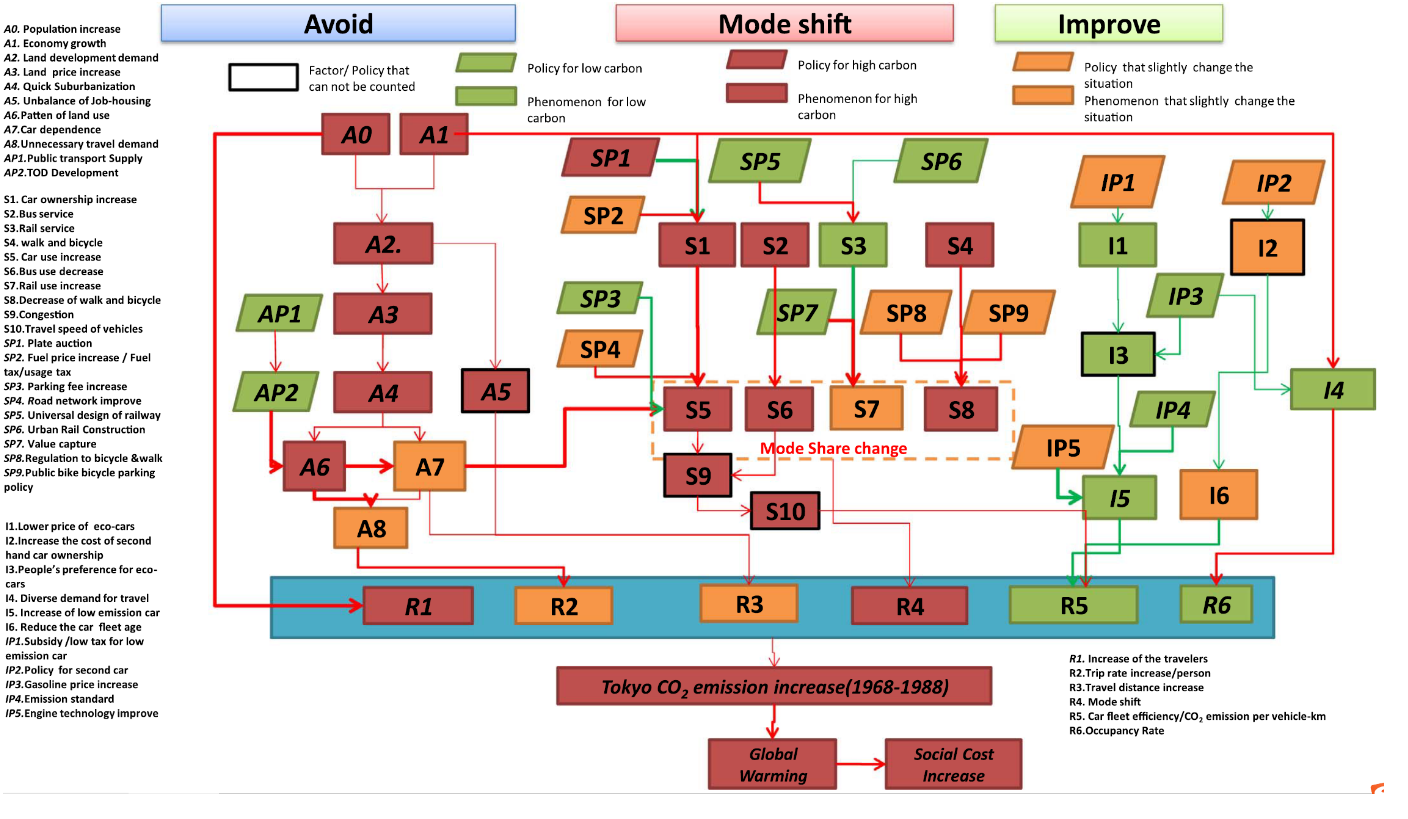

Figure 14: Causal mechanism for Tokyo's urban transport CO_2 emissions (1968–1988).

Fig. 15 illustrates the economically stable era (1988–2008) for Tokyo. Land demand was low, and effective public transport services and the TOD development mode allowed the trip rate and travel distance to remain almost unchanged. The population moved closer to railway stations, and an increasing number of people used rail for transport. Consequently, the share of modes shifted in an eco-friendly direction. Subsidies and gasoline price increases led to preferences for low-emission cars, and continual engine technology improvements caused fuel efficiency to improve. While economic development became stable, the diverse travel aims did not change significantly, and thus the occupancy rate did not change significantly. Finally, CO_2 emissions did not increase significantly, and global warming and social costs remained stable.

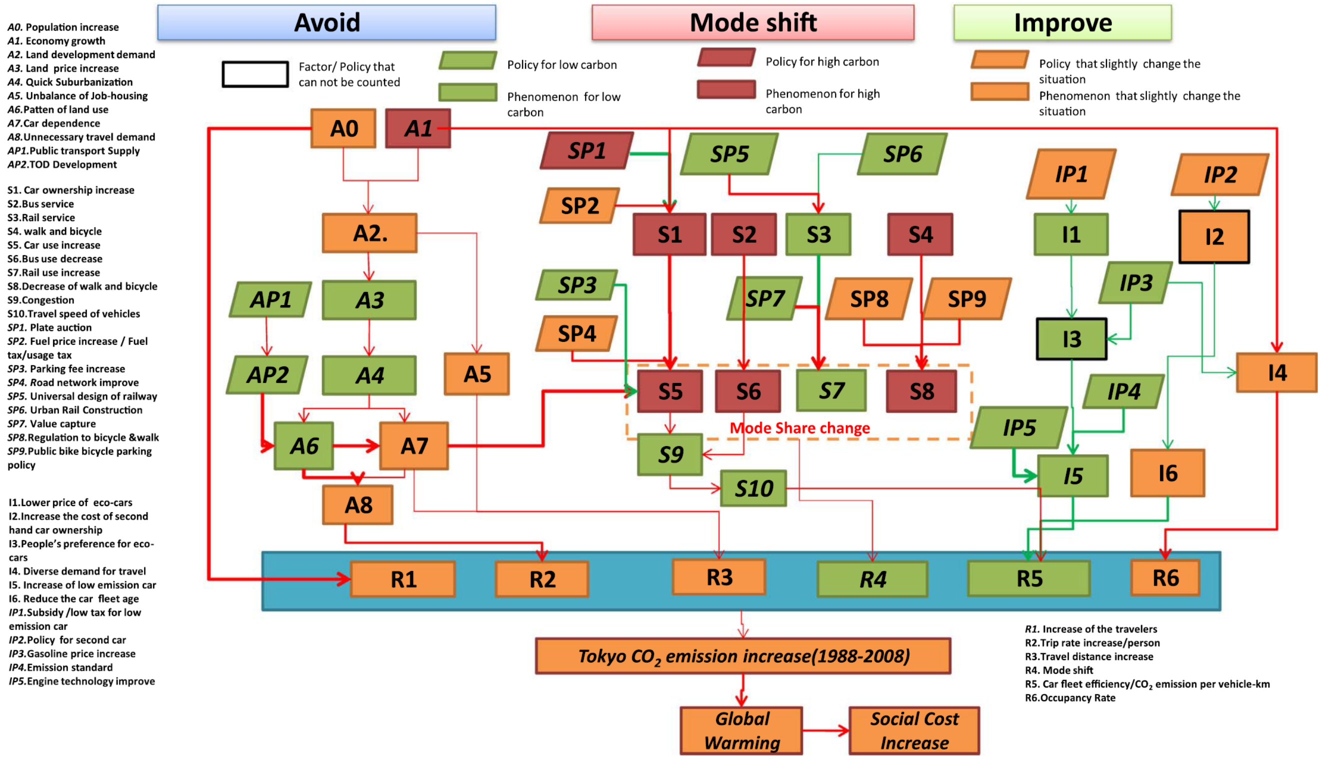

Figure 15: Causal mechanism for Tokyo's urban transport CO2 emission (1988–2008).

4.3 Discussions on the comparison of Shanghai and Tokyo

Based on the results of Shanghai and Tokyo, we further make a comparison so that some critical insights can be learned from Tokyo, some of similar results and experiences can also be founded in the research conducted in global passenger transport dynamics (Mittal et al.) for the ongoing improvement of Shanghai's sustainable urban transport system.

A comparison based on the decomposition analysis and the causality map is analysed in Fig. 16. The upper part is the CO_2 measurement equation, and the population is an individual factor. The total travel distance, mode share and travel fuel efficiency respectively represent the travel demand, mode shift and travel fuel efficiency and respectively relate to the policies of Avoid, Shift and Improve. The small figures below represent the performance of the deeper factors. The total travel distance is affected by the trip generation rate and travel distance, the travel distance is affected by the built-up area, and trip generation is affected by the TOD index9. The car mode share is affected by the car trip rate and car ownership, and the car trip rate is affected by the TOD index. The travel fuel efficiency is affected by the load factor and vehicle fuel efficiency. The lowest part shows the key transport policy, where the TOD policy affects the TOD index and built-up area, the plate auction affects car ownership, rail construction affects the TOD index, and the parking fee affects the car trip rate. The energy technology improvements and the low tax for LEV contributes to vehicle fuel efficiency improvement.

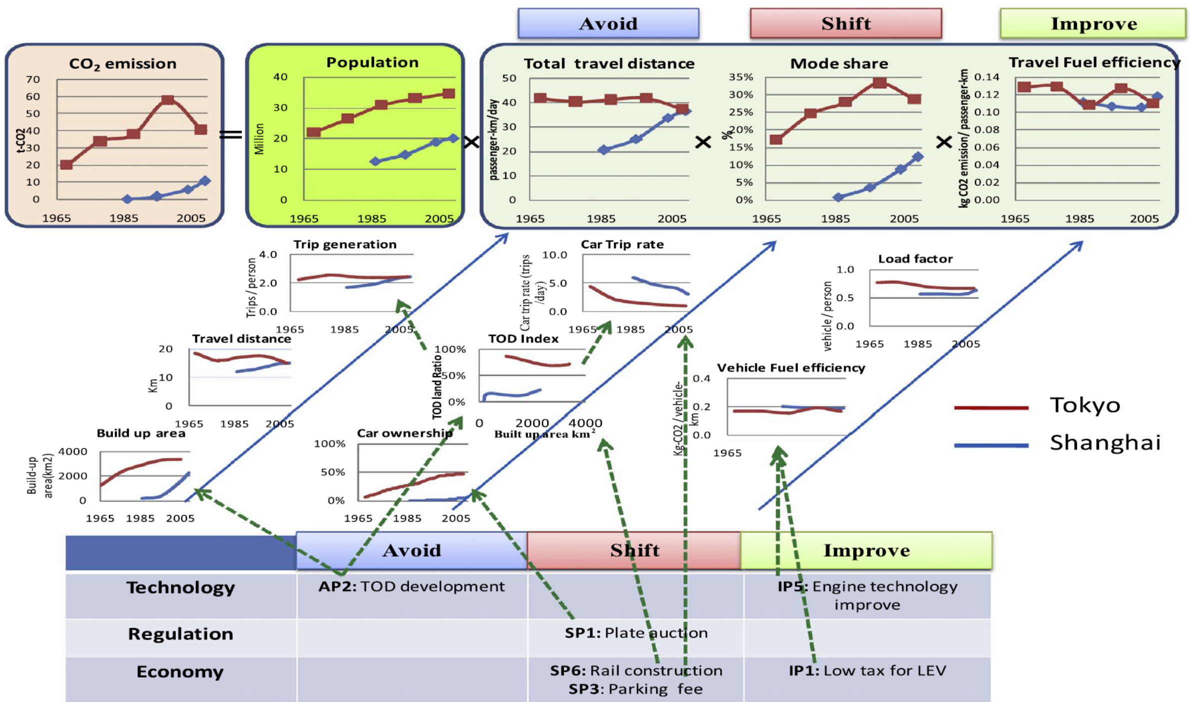

Figure 16: Dynamic tracking of transport-related emission mechanisms in Shanghai and Tokyo.

According to above analysis on Tokyo and Shanghai, several key findings are highlighted:

(1) Shanghai is in a rapid growth period in terms of population, travel distance, built-up areas and car ownership, together with its rapid economic growth and urbanization, while Tokyo has moved into a stable stage. Therefore, Tokyo's past experiences for TOD will be valuable for Shanghai, which is in a transitional stage.

(2) TOD is identified as a key strategy. The TOD index of Tokyo is much higher than that of Shanghai: in Tokyo, urban public transport infrastructures construction like the railway was done early, travellers are accustomed to using the railway system, and the TOD development also stimulates related mixed land use and reduces unnecessary traffic demand.

(3) Car ownership, the total car use and car travel distance in Shanghai is highlighted to be much lower than that of Tokyo, but the usage ratio is much higher than in Tokyo. In Shanghai, the car trip rate was 6 in 1986 and generally decreased to 3 in 2009; in Tokyo, the rate was 1 in 2008. As to the unit car travel distance, the number of Shanghai is much higher than that of Tokyo, which is 48 km/day and 15 km/day in 2008, respectively. The difference between Shanghai and Tokyo is mainly caused by the strict parking policy in Tokyo and other high usage fees, while in Shanghai, the parking fees have not yet increased as quickly as the CPI index, and the plate auction fee also encourages people to use cars more frequently once they are purchased. Another reason is the government's attitude towards road policies. In Tokyo, the road length has maintained a stable value that discourages people from using cars, while in Shanghai, the road length increased 3 times from 1995 to 2009. The uncontrolled urban sprawl of Shanghai also encourages more frequent car usage.

(4) In terms of “Railway service (S3)”, “Value capture (SP7)”, and “urban rail construction (SP6)”, the railway influence area in DID (density increased district) areas of Tokyo has maintained a high value and thus can provide good service. Moreover, good financial policy value capture

can help the government or railway owners capture the land value increase around the railway, which has seen great success in Japan and encouraged the development of new railways. In Shanghai, no similar policy exists, and the government is suffering from massive financial burdens from the railway system.

(5) Regarding the "Increase of low-emission cars (I5) (car fuel efficiency)", fuel efficiency increase is key factor for CO_2 mitigation in the urban transport sector of Tokyo. Tokyo has experienced a major fuel efficiency change from 1998 to 2008, and low taxes for low-emission cars have encouraged more people to buy these cars. Because the technology transformation is increasingly quicker, the fuel efficiency change may have a significant influence on CO_2 mitigation in Shanghai.

5. Conclusions and policy implications

5.1 Conclusions

This study conducts an innovative decomposition analysis on the urban transport sector in Shanghai and Tokyo combined with causal mechanism analysis. The main findings in this chapter are as follows:

Generally, during the progression of rapid development, the population, trip generation rate, mode shift, travel distance, and load effect show a strong effect on the CO_2 emission increase. Referred to Shanghai case, the mode shift to high emission vehicles leads to the strongest positive effect and contributed to more than half of the total emission increment, and the increasing trip generation rate and population contributed around 35% in total. By contrast, the reduction effect on emissions from increasing fuel efficiency is quite limited, no more than 10%. This phenomenon is also found in Tokyo Metropolitan Area until the end of rapid economic growth period by 1990s. When coming into steady growth, the pushing effect from population and trip generation obviously decreases, while mode shift to lower emission vehicles and decreasing travel distance contributed a determinant amount to reduce CO_2 emissions. With the fast popularization of low fuel consumption vehicles, fuel efficiency improvement also contributed significantly to reducing CO_2 emission.

On the other hand, according to the causality maps of both Shanghai and Tokyo cases, during the period of rapid economic growth, urban sprawl is indicated to be the main reason for the increase of travel distance, car ownership and mode shift to private cars. Especially in Shanghai, the low service level of public transport and lack of strong controls on car usage further increased the usage of private cars. However, Tokyo's experience supports TOD development as an effective approach to suppress the car usage and shift modes to the railway, including strict car parking policies and high usage fees for cars, and the high service level of rails. Additionally, it should be combined with financial tools such as value capture, and fuel efficiency improvements such as better emission standards and preferential low taxes on small-engine cars.

Based on the comparison, the advantage of the Tokyo transport sector is that the land use system and transport system are well coordinated, and TOD development in Tokyo is successful. Tokyo has a well-built rail system, and people are also accustomed to using the public transport system. Even though car ownership rates are high, the usage rate of cars is low. Shanghai has successfully controlled car ownership, and it has strong policies and the financial ability to construct subways quickly. The disadvantage in Shanghai is its high usage of cars and weak connection between the land use system and transport system, in addition to the generally deteriorating walking and bicycle system. Future policies should focus on a well-designed public transport system to enhance the TOD index, market measures to strengthen controls on car ownership and usage rates, and technical shift measures such as fuel efficiency enhancements.

5.2 Policy implications

Our main findings highlighted that Tokyo was a mature city that has experienced rapid development, and the developing speed was currently stabilizing, while Shanghai was a faster developing mega city. Hence, valuable experiences from Tokyo could be summarized and highlighted on policy implications for Shanghai's low-carbon transport system transition and sustainable urban development.

Tokyo's beneficial experiences included: (1) high level of public transport service (e.g., the major mode share in Tokyo was rail, mainly due to the effective transport system and compact city development), which help to promote the shift of the mode share and the energy efficiency enhancement; (2) Socioeconomic, market measures as well as well designed urban functions to control the car usage, such as, major investment in the transport system and high parking fees (push citizens to use public transport service); compact city strategy to enhance the accessibility to public service (attract people to use public transports); and capacity restrictions in the city centre, which brought the increased population allocated to suburban areas; (3) Low-carbon technologies promotion in transport sector: e.g., launching national laws and incentives to promote low-emission car/e-cars.

Based on above, the following implications are proposed and discussed for Shanghai and other similar fast developing mega cities in China, towards their TOD development.

(1) Mode share plays a significant role in CO_2 emissions in the urban transport sector of China. We suggest that China's urban administration vigorously promote TOD, in which a new increase in population is assumed around the railway stations. This implication requires an optimized public transport system, as well as better distribution of urban functional areas. In addition, we also suggest that China popularize new energy vehicles (electric vehicles and vehicles using non-fossil fuels), which have a significant effect on the mitigation of CO_2

emissions through a number of measures, e.g., tax discounts and subsidies for new energy vehicles, as well as more strict controls on fuel quality to promote the development of the new-energy vehicle industry.

(2) Average trip times and travel distance also play key roles in CO_2 emissions in the urban transport sector of China. We recommend a transition to green transportation and improvements in the public transport system to address these concerns. China should engage in advertising and educational activities for China's residents to decrease the average trip times per capita and reduce the travel distance per capita. More importantly, China should improve and optimize the urban rail/metro network to decrease the average trip times and reduce the travel distance according to the actual situations of the cities, i.e., city planning and travel habits of the residents.

(3) The load effect has become increasingly important in China for the mitigation of CO_2 emissions in the urban transport sector of China. We suggest that China use further control measures on car ownership and usage rates with market measures, i.e., high parking fees and license-plate lottery systems for car registrations.

(4) Fuel efficiency will certainly play a critical role for China to mitigate CO_2 emissions in the urban transport sector according to the experiences of Tokyo, Japan. Therefore, China should invest more in the R & D of high fuel efficiency transportation projects for the enhancement and improvement of fuel efficiency.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2017.02.049.

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