Original research paper

Analyzing the role of public transportation in reducing CO_2 emissions: a case study of Beijing

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Abstract

Public transportation systems are now believed to play more important role in reducing carbon dioxide emissions (i.e. CO_2 emissions) from the transportation sector in Mega-cities of China since the vehicle occupancy of such systems is usually higher than other modes. However, the real role of the public transportation system in mitigating CO_2 emissions has remained under-investigated at the city level in China, which is one of greatest barriers to achieving low/zero carbon urban mobility in China. This paper presents a systematic analysis of effects of different public transportation development scenarios on

CO_2 reductions. A total of 180 potential development scenarios of the public transportation system, including different shifts, different travel demand levels, and different prospective scenarios for the bus and subway, are identified and tested based on a case study in Beijing. A method for estimating CO_2 emissions suitable for complicated vehicle classes and operating patterns in the developing countries is established to assess the effect of the public transportation system on CO_2 emissions. The results indicate that the public transportation system has a great potential to reduce the total CO_2 emissions as well as the average CO_2 emissions per capita in Beijing. The modal share values of 61-64% are turning points at which CO_2 emissions begin to decline in the year 2020.

Keywords:

public transportation system; bus; subway; CO_2; emissions; scenario

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1 Introduction

The urbanization and economic growth in Asia in recent years has been unprecedented. In this context, controlling CO_2 emissions while meeting the growing demand for mobility is becoming an enormous challenge for many Asian cities. The continuous increase of CO_2 emissions into the Earth's atmosphere is now recognized as a predominant cause of the greenhouse effect and global warming. Under most circumstances when the vehicle occupancy is high, public transportation systems can play an important role in reducing CO_2 emissions from the transportation sector because they deliver low carbon CO_2 trips per capita. Public transport operators are striving to provide cities with a low carbon future by combining their mobility packages to provide a real alternative to the car (International Association of Public Transport et al., 2012).

In China, the intensive land use and dense population in large cities means that a passenger transportation system that heavily relies on cars is unsustainable. The public transportation system embracing bus and subway systems are backbones for the urban passenger transportation system in China. Mega-cities such as Beijing have been facing a great challenge of mitigating the greenhouse gas (GHG) emissions while the number of trips, the number of private vehicles, and their use are continuing to rise. Although the transportation sector is one of the main sources of anthropogenic CO_2 emissions, it is widely accepted that public transportation offers low-carbon and energy-efficient mobility solutions. However, the role of the public transportation system in mitigating CO_2 emissions remains under-investigated for cities in China, in which the average occupancy for bus and subway systems is generally high. A question to be answered is what would be the environmental significance of shifting from passenger cars to the mass transit system during the critical time when the private car ownership and usage rise so quickly in China. It is also important to understand whether there is a turning point of the modal shift at which CO_2 reductions can be achieved? In this context, this research is intended to conduct a systematic analysis of the role of the public transportation system on CO_2 reductions based on a case study in Beijing. Three travel demand levels are considered. Potential development scenarios for the public transportation system are designed in light of uncertain economic, sociological, and technological developments. A method for estimating CO_2 emissions suitable for complicated vehicle classes and operating patterns is established to assess how the future CO_2 emissions might change under different development scenarios of the public transportation system. Analysis results are discussed and recommendations of strategies for increasing the contributions of the public transportation system to the sustainable growth are provided.

2 Existing Studies

Some studies were conducted over the last decade regarding the role of the public transportation system on reducing CO_2 emissions or GHG emissions. The following summarizes several typical studies.

Paravantis and Georgakellos (2007) developed a regression model to forecast car ownership and bus fleet models, which is used to compare CO_2 emissions from passenger cars and buses in Greece. They concluded that passenger automobile will emerge as the dominant CO_2 source in road passenger transport considering the decline in bus travel.

McDonnell et al. (2008) analyzed a Quality Bus Corridor (QBC), implemented in Dublin, Ireland, in 1999 and estimated CO_2 emissions associated with differing levels of bus priority for the period 1998-2003 and for the Kyoto commitment period (2008-2012). They found that, in the absence of a QBC, peak-time emissions for the sample population would have been 50% higher than in the factual scenario.

The work of Zhai et al. (2008) estimated roadway link average emission rates for diesel-fueled transit buses based on link mean speeds, using vehicle specific power (VSP) modes from data gathered by a portable emissions monitoring system. Besides CO, NOx, and HC emissions, the relationship between VSP and CO_2 emissions were investigated, modeled and validated. The study concluded that VSP is a useful explanatory variable for estimating the variability in CO_2 emissions for diesel buses.

Hodges (2010) analyzed the role of public transportation in responding to climate changes. Average emissions per passenger mile of U.S. transit services were estimated. National averages demonstrate that public transportation produces significantly lower GHG emissions per passenger mile than private vehicles. Heavy rail transit systems, such as subways and metros, produce 76% less in GHG emissions per passenger mile than an average single-occupancy vehicle. Light rail systems produce 62% less and bus transit produces 33% less.

Gallivan and Grant (2010) summarized the current practices in GHG emissions reductions from the transit in the United States. They reviewed the literature on transit's impact on GHG emissions and on transit strategies to further reduce GHG emissions, and surveyed agencies about their current efforts to reduce GHG emissions. The research concluded that GHG emissions are still a peripheral concern for transit agencies and more research is needed on methodologies to estimate changes in emissions from specific improvements to transit.

Bradley and Associates LLC (2014) estimated average energy use and CO_2 emissions by mode. They estimated that transit buses produce a 136-gram of average emissions per passenger mile.

Hill et al. (2014) provided the methodological approach and the key data sources used to define the emission factors, which are used to estimate CO_2 emissions. CO_2 emissions from the average local bus are 100.7 grams per passenger mile under an average passenger occupancy of 10.8.

Waraich et al. (2016) developed a methodology for simulating transit bus ridership and GHG emissions (in CO_2 equivalent) across a network of 200 buses in the city of Montreal, Canada. They observed the effect of a 20% system-wide increase in ridership, a 1.7% increase in total emissions, and a 28% decrease in per capita emissions.

Studies identified in the literature review have offered insights into the quantified assessment of the role of the public transportation system in reducing CO_2 or GHG emissions and factors contributing to the CO_2 or GHG reductions. They suggested that the modal shift is a key factor. Emission factors for individual operators and services vary significantly depending on the local conditions, the specific vehicles used, and the typical occupancy achieved (Hill et al., 2014). A methodology to estimate expected CO_2 reductions from the public transportation system is needed. However, little effort has been made to analyze the potential of the public transportation system to mitigate the CO_2 emissions at a city level in China, especially in Beijing. The work in this paper is to expand the previous research on assessing the role of public transportation in reducing CO_2 emissions by using the densely populated Beijing as a case study bed. The methodology of the modal-share-based estimation of CO_2 emissions for different modes is implemented. In the modal-share-based estimation of CO_2 emissions, modal shares for different modes are the key parameter to the estimation of CO_2 emissions, which allows analysis of CO_2 emissions by mode. In a combination with other parameters, such as, residential trips across all modes, average trip distance, and CO_2 emissions per capita per km for different modes, CO_2 emissions can be derived. Based on the analysis, recommendations for development strategies for the public transportation system in Beijing are presented.

3 Method and approach

3.1 Estimation method for CO_2 emissions

The transportation system is highly interconnected. CO_2 emissions from transportation sector are influenced by a group of factors, such as the driving cycle, fuel category, modal structure, passenger travel activities, etc. The relative importance of each factor to total changes in emissions varies with different levels of the estimation (Schipper et al., 2008). At a city level, only the most important and easy-to-monitor factors should be used, including the modal share, load factor, and CO_2 emission factor (Hook et al., 2010). The function to estimate CO_2 emissions from different modes at the city level is formulated in the following Eq. (1):

$$E_i = N * F_i * D_i * M_i \tag{1}$$

where the indices E_i, N, F_i, D_i, M_i describe the CO_2 emissions for the mode *i* (metric tons), residential trips (trips), modal share for mode *i* (%), average trip distance for mode *i* (km), and average CO_2 emissions per capita per km for mode *i* (g).

Average CO_2 emissions per capita per km for different modes can be derived from the CO_2 emission factor, load factor, and rated passenger capacity, as shown in the following Eq. (2):

$$M_i = \frac{EF_i}{L_i * P_i} \tag{2}$$

where EF_i, L_i, P_i, represent CO_2 emissions factor for mode *i* (g/km), load factor for mode *i*, which determines the average occupancy (%), and the rated passenger capacity for mode *i* (persons).

Therefore, the total CO_2 emission in a city can be further calculated in Eq. (3):

$$E = \sum_{i} N * F_i * D_i * \frac{EF_i}{L_i * P_i} \qquad (3)$$

3.2 Approach to determine emission factors

In this research, several modes including the bus, subway, taxi, and car are considered. A carbon dioxide emission factor can be calculated using the standard Intergovernmental Panel on Climate Change (IPCC) coefficients or other energy conversion factors to convert fuel (or electricity) consumption to carbon emissions. In developing country cities, vehicle numbers are growing rapidly, and their patterns of usage are changing as cities sprawl outwardly. Except for well defined, centrally operated vehicle fleets, transport sector fuel consumption is physically difficult to be collected due to the highly decentralized decision making process for transport activities (Schipper et al., 2008). Hence, we use the electricity-consumption-based-method to estimate the CO_2 emission factor only for the subway, which uses the electricity as the power. A methodological tool to calculate CO_2 emissions from the fossil fuel combustion provided by the clean development mechanism is based on the quantity of the fuel combusted and its properties (United Nations Framework Convention on Climate Change, 2013). However, we do not choose a fuel-consumption-based approach to estimate the CO_2 emission factor for the fuel-intensive modes of transportation (i.e., bus, taxi, and car) because such data are not easily collected and not reliable in Beijing. An emission-model-based approach to determine the emission rate and the emission factor for fuel-intensive modes of transportation has been used in this research. This approach can capture the speed, idling, or acceleration characteristics of vehicles, which reflects real operating patterns in the roadway network.

For the subway, the CO_2 emission factor is determined in following steps. The subway operation needs to consume the electricity, which is measured in the unit of the standard coal. The standard coal here is the coal equivalent to measuring the amount of electricity used in China. The electricity data used by the subway operation and the total subway mileage from 2009 to 2013 in Beijing are collected (Beijing Mass Transit Railway Operation Corporation, 2014) (Beijing Mass Transit Railway Operation Corporation, 2012). A total of 2.834 tons of CO_2 will be emitted when one ton of the standard coal burned (U.S. Energy Information Administration, 2007) (Beijing Municipal Commission of Development and Reform, 2010). Multiplying the 2.834 by the standard coal consumption for each year, we can derive the total CO_2 emissions annually for the subway system in Beijing. Further, dividing the annual CO_2 emissions by the total subway mileage gives us the annual CO_2 emissions per kilometer. Here, an average of these values is used as the emission factor for the subway, which is 1143.6 grams of CO_2 per kilometer.

For the bus, taxi, and car, a portable emissions measurement system (PEMS: OEM-2100) has been used to collect the real time CO_2 emission data and a GPS device to collect driving activity data. More than 500 million groups of driving activity data were collected in recent years. A micro-scale VSP approach is used to establish the emission estimation model, which determines the CO_2 emission factor (Xu et al., 2008). The VSP approach can readily connect the driving modes with emissions, which results in accurate emission estimations by giving a close attention to high emissions in high VSP bins (Beijing Jiaotong University, 2011; Beijing Jiaotong University and Energy Foundation, 2009, 2010; Beijing Jiaotong University and Ministry of Transport of China, 2011; Beijing Jiaotong University and Natural Science Foundation of China, 2004; Hao et al., 2010; Liu et al., 2009; Song et al., 2009). CO_2 emission factors for different modes can be calculated by using Eq. (4):

$$EF_i = \frac{\sum_m ER_{im} * K_m}{v} * 1000 \tag{4}$$

where ER_{im} *represents* the average emission rate of mode i under VSP bin m (g/s), K_m represents the percentage of the driving time under VSP bin m (%), and v is average travel speed (km/s).

CO_2 emission factors for different modes are shown in Table 1.

Table 1 CO_2 Emission factors for different modes.

Modes	**Bus**	**Subway**	**Taxi**	**Car**
CO_2 emission factors (g/km)	682.832	1,143.609	231.953	303.767

4 Design of development scenarios for public transportation system

4.1 Analysis of potential prospects for public transportation's development

The bus and subway are two primary modes in the public transportation system in Beijing. The future economic, sociological, and technological developments always involve some degree of uncertainties. Factors of the economy, fare policy, demographics, land use, regional planning, vehicle technologies, and urban transport goal may all influence the future development of public transportation in Beijing. Currently, the economic growth slows down; a population of greater than 21 million people means a faster growth than what has been forecasted in the urban planning for 2020 (Beijing Municipal Commission of Urban Planning, 2011), which motivates the measures to curb the growth of the population; the land price has increased to a very high level; plans to build a new administrative center adjacent to the city have been announced in order to better integrate the Chinese capital with its surrounding areas; and non-capital functions including manufacturing, logistics, wholesale markets, and partial functions of the public service will be gradually moved out of the city (Beijing Youth Daily, 2015). Meanwhile, the reality of the limited roadway space and rapidly deteriorating traffic congestion has pressured the government to reconsider transit priority strategies and more strict license plates controlling policy. Fuel-efficient technologies and clean fuel technologies will be implemented gradually with the 2020 as the target year (State Council, 2012). Since a wide range of factors influence the public transportation demand, no single study could comprehend all the demand determinant factors of the public transportation system in a single context (Polat, 2012). In view of the complicated influencing factors of the public transportation demand and modal share in an urban passenger transportation system, a wider range of modal share of public transportation system should be considered. Further, due to the fact that the total modal share of the public transportation system of 46% in 2013, a range of modal share from 46% to 65% is set in this study. Moreover, three travel demand levels are considered. For each travel demand level, three possible development prospects for the bus and subway in the public transportation system are identified for up to 2020 in Beijing.

According to the forecasting results (Beijing Transportation Research Center, 2015), three travel demand levels are considered. With high, medium, and low population levels, the residential trips that do not include walking are forecasted as 17,842, 19,002, and 20,162 billion trips respectively.

For each travel demand level in 2020, three possible development prospects for the bus and subway in the public transportation system, which reflect potential modal share for the bus and subway, are identified as follows.

(1) Prospect A: modal share of the bus is equal to that of the subway

In the public transportation system, the bus and subway are dominant modes for passenger trips. Both companies that operate the bus and subway systems make efforts to enhance the service quality, thus a better intermodal connectivity is achieved. The passenger market of public transportation is divided equally by the mode of the bus and the subway. So, a modal share ratio of the bus to subway is assumed as 1:1 for all three travel demand levels.

(2) Prospect B: modal share of the subway slightly exceeds that of the bus

Although Beijing Public Transportation Company adopts more measures to improve operating conditions and the service quality that can have a positive influence on the bus usage, it is likely that the subway attracts slightly more passengers than the bus due to its higher operating speed, reliability, and better network reach. In this context, the modal share ratios of the bus to the subway are assumed to be 1:1.28, 1:1.44, and 1:1.32 for three travel demand levels, according to the forecasting results of the transportation planning from 2015 to 2020 in Beijing (Beijing Transportation Research Center, 2015).

(3) Prospect C: modal share of the subway moderately exceeds that of the bus

The environment for public transportation is dynamic and even interactive. Due to the traffic congestion, Beijing government will possibly invest more in the construction of the subway system and provide more subsidies for subway operations in comparison with Prospect B. In the future, the subway may attract even more passengers than the bus. Therefore, the modal share ratios of the bus to subway are assumed as 1:1.57, 1:1.87, and 1:1.62 for three travel demand levels, which represent the possibilities that the modal share of the subway moderately exceeds that of the bus.

4.2 Scenario design under different prospects for public transportation development

Due to the uncertainty of the future development of the public transportation system, a scenario analysis is used. This paper relies upon the ridership, modal shift, and other parameters in Eq. (3) to design scenarios. These parameters will be estimated under different prospects of public transportation development in the year of 2020. Actual operational and performance data are collected to estimate these parameters. Based on the estimated parameters, 20*3*3 (i.e., 180) development scenarios will be designed and their resulting CO_2 emissions will be analyzed when the modal share is changed at a step of 1%. Turning points on CO_2 emission reductions will be identified.

In Eq. (3), the parameters including residential trips N, average trip distance D_i, CO_2 emission factor EF_i, and rated passenger capacity P_i, are assumed to be constant values for the 180 scenarios in 2020. All these parameters need to be estimated for 2020. The load factors L_i under different scenarios are determined depending on the increase of the modal share of the bus and the subway.

As mentioned in the section of 4.1, the residential trips N for 2020 are 17.842, 19.002, and 20.162 billion trips under three different travel demand levels.With the increase of the residential travel demand, the average trip distance will increase due to the extension of the urban rail transit network. According to the planning of the urban rail transit network in Beijing from 2010 to 2020 (Beijing Municipal Commission of Urban Planning and Beijing Infrastructure Investment Co., Ltd, 2011), there will be 30 lines and 450 stops of the urban rail transit to be developed by 2020. In 2020, the total track length will extend to 1050 kilometers from 465 kilometers in 2014. Suburban areas will be connected with downtown by new radial lines, according to the plan. We analyze the average trip distance in 2000, 2005, and 2010. From 2000 to 2010, the average trip distance for the bus and taxi did not change significantly with only a slight fluctuation and the average trip distance for the car and subway increased by 12.75% and 15.40% respectively. These data have been used for estimating the average trip distance from 2010 to 2020. So the average trip distance for the bus and taxi will not change and the average trip distance for the car and subway will increase according to the increasing rates of 12.75% and 15.40%. Therefore, we can obtain the average trip distance D_i for all modes for 2020.

Beijing has begun to introduce Phase 5 emission standard since September, 2013. In order to strengthen the energy conservation and emission reductions, a plan on accelerating the development of the energy-saving and new electric automobile industry has been formulated for the period of 2012-2020. The CO_2 emission factor EF_i under all scenarios will be lower in consideration of the enhancement of the fuel efficiency, the improvement of engine technologies, and the implementation of stringent emission control standards. The fuel economy will be improved significantly in 2020, according to the plan for the development of the energy-saving and new energy automobile industry (State Council, 2012). The fuel consumption per hundred-kilometers of new produced passenger vehicles in 2020 will be reduced to 5 liters per 100 kilometers, which is a significant reduction compared with the current one. However, due to the fact that the full implementation of the fuel economy improvement in this plan and the vehicle replacement still takes a long time, the CO_2 emission factor EF_i will be reduced by only 7% in different scenarios in contrast with the one in 2010. Considering the energy saving target for the cost control of Beijing Subway Company and the decrease level of CO_2 emission factor in recent years, a decrease of 7% of the CO_2 emission factor for subway in 2020 is assumed.

The rated passenger capacity P_i is related to the vehicle design. We assume that this parameter will not change in the near future since no significant changes on vehicle seats or the space size are predicted.

The load factor L_i in 2020 was also assumed. In the future, Beijing will invest more in the public transportation system considering the severe traffic congestion and air quality issues. A multimodal public transportation network with a better coverage and punctuality will be provided. More travel demand management measures to control the use of cars, such as the congestion toll collection and the low emission zone, will be implemented in the future. The measures on the congestion toll collection and the low emission zone are included in the clean air action plan from 2013 to 2017 in Beijing and its implementation scheme is being studied (Beijing Municipal Government, 2013) (Beijing Municipal Commission of Transport, 2014). All of these measures will likely attract more passenger trips to use the public transportation system. Hence, with the increase of the modal share of the bus and the subway, the load factors L_i under different scenarios are increased by 0% to 22%.

The modal shares F_i in Eq. (3) are different under 180 scenarios. As mentioned in the section of 4.1, different modal share values for public transportation (46% to 65%) are tested in this study and three modal share ratios of the bus to the subway for each travel demand level are assumed for 2020.

Table 2 shows these parameters used for scenario analysis in 2020.

Table 2 Parameters for different scenarios in 2020.

Modes	**Bus**	**Subway**	**Taxi**	**Car**
***N'*(trips)**	17,841,565,000 (population=26 million)			
	19,001,535,000 (population=28 million)			
	20,161,505,000 (population=30 million)			
D_i(km)	10.8	20.77	9.3	12.97
P_i(persons)	112	310	5	4
EF_i(g/km)	635.03	1,063.56	215.72	282.50
L_i	44%, 48%, 50%	35%, 38%, 40%, 42%, 45%	30.20%	33.50%

Note： The total modal share of the public transportation system (including bus and subway) is changed from 46% to 65% with a step of 1%. When the population is 26 million, the modal share ratios of the bus to subway are assumed as 1:1, 1:1.28, and 1:1.57. When the population is 28 million, the modal share ratios of the bus to subway are assumed as 1:1, 1:1.44, and 1:1.87. When the population is 30 million, the modal share ratios of the bus to subway are assumed as 1:1, 1:1.32, and 1:1.62.

5 Result and analysis

5.1 CO_2 emissions in 2010

The year of 2010 has been chosen as the base year considering the data availability. The 2010 Beijing Household Travel Survey shows that Beijing residents made 16.538 billion annual trips in 2010 (Beijing Transportation Research Center, 2011). Other parameters are listed in Table 3 and results on CO_2 emissions are shown in Table 4.

As presented in Table 4, the total CO_2 emissions for the transportation sector in Beijing have achieved 12,117.629 metric kilotons, an average CO_2 emission per capita of 1,052.741g/person. Cars emit 84.69% of CO_2 emissions, which are substantially larger than those from the bus and the subway. The CO_2 emissions from the subway are the smallest among all modes. It can be observed that the public transportation system has a great potential for reducing CO_2 emissions.

Table 3 Parameters for estimating 2010 Beijing CO_2 emission in Beijing.

Modes	**Bus**	**Subway**	**Taxi**	**Car**
F_i	28.20%	11.5%	6.8%	34.2%
D_i**(km)**	10.8	18	9.3	11.5
EF_i**(g/km)**	682.832	1,143.609	231.953	303.767
L_i	44%	35%	30.2%	33.5%
P_i**(persons)**	112	310	5	4

Note: Modal share F_i and average trip distance D_i are from 2010 Beijing Household Travel Survey. Load factor L_i are from the survey by public transport agency in Beijing.

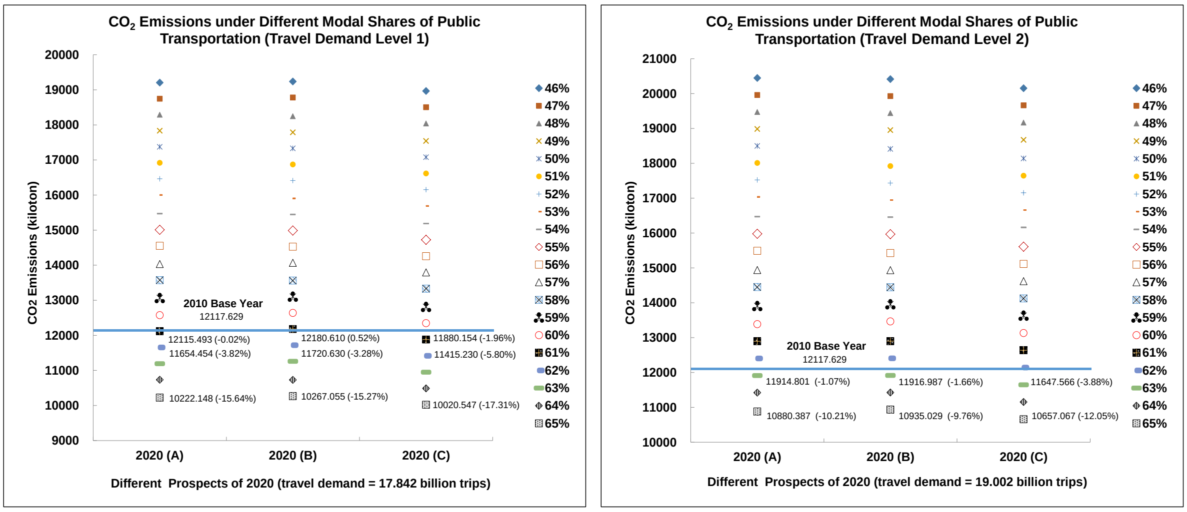
Table 4 CO$_2$ emission results for different modes in 2010.

Modes	**Bus**	**Subway**	**Taxi**	**Car**	**Total**
CO$_2$ emission (metric kiloton)	485.749	251.139	1,118.178	10,262.563	12,117.629
Percentage	4.01%	2.07%	9.23%	84.69%	100.00%
CO$_2$ emission per capita (g/person)	42.200	21.818	97.144	891.579	1,052.741
Percentage	4.01%	2.07%	9.23%	84.69%	100.00%

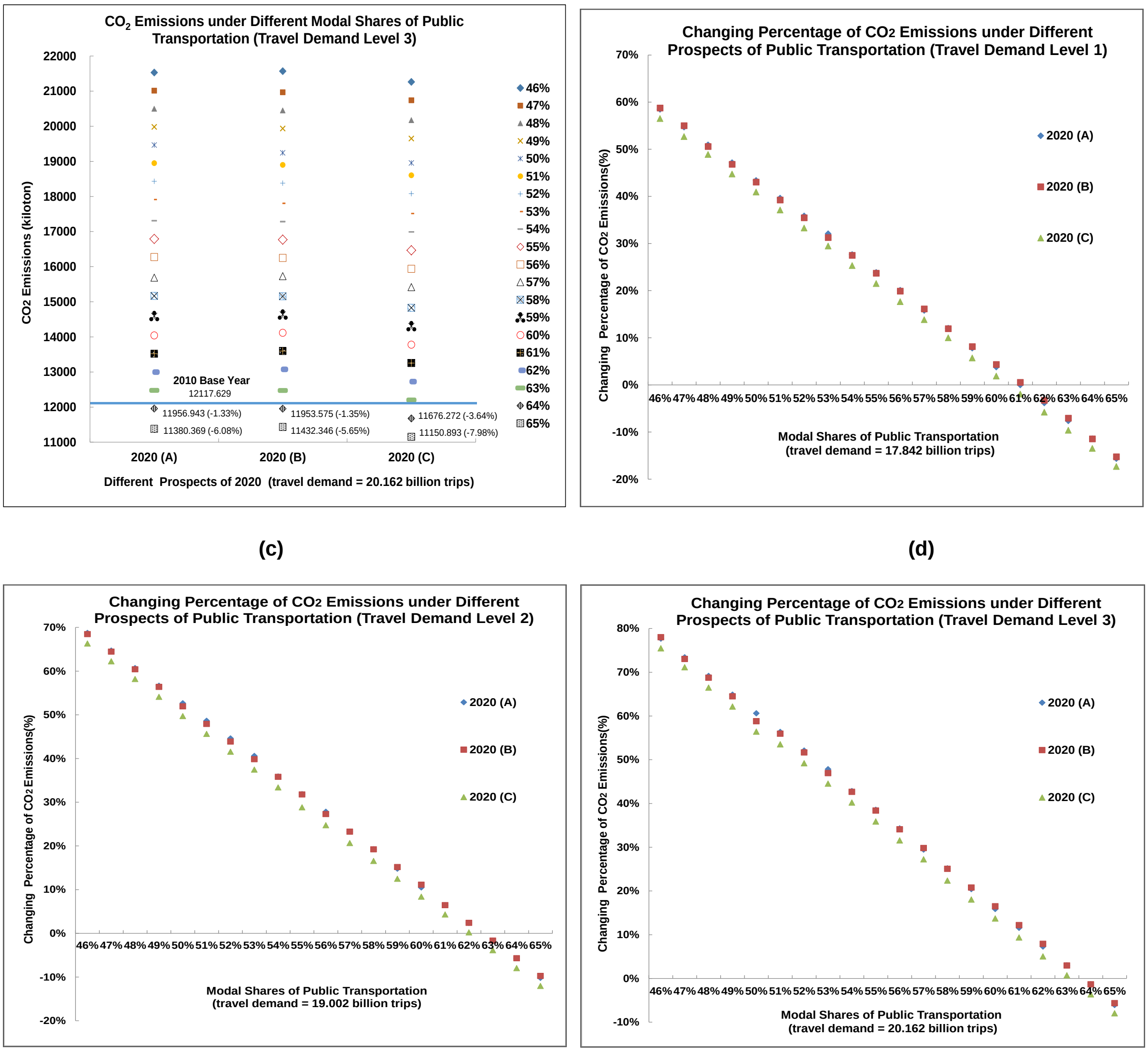
5.1 CO$_2$ emissions under different scenarios for the public transportation system

CO$_2$ emissions under different shifts, different travel demand levels, and different prospective scenarios are calculated using Eq. (3). Fig. 1(a) to 1(f) and 2(a) to 2(f) illustrate the results of different scenarios for 2020.

Fig. 1(a) to 1(c) illustrate the change of CO$_2$ emissions and Fig. 1(d) to 1(f) show the changing percentages of CO$_2$ emission under different scenarios. As shown in Fig.1(a) to 1(c), under travel demand level 3 in which the travel demand is larger than that of travel demand levels 1 and 2, the higher CO$_2$ emissions are produced. For each travel demand level, there are no significant differences of CO$_2$ emissions or changing percentages among Prospects A, B, and C. For Prospect C under which the modal share of the subway moderately exceeds that of the bus, slightly less CO$_2$ emissions are released to the atmosphere. In Fig. 1(d) to 1(f), when the modal share of public transportation increases, CO$_2$ emissions are in a declining trend for all three travel demand levels. A modal share value of 61% or 62% is a turning point that results in the reduction of CO$_2$ emissions in 2020 for travel demand level 1. For Prospects A and C, CO$_2$ emission reductions are 0.02% and 1.96% with a modal share value of 61%. For Prospect B, the CO$_2$ emission is reduced by 3.28% with a modal share of 62%. When the modal share of public transportation increases to 65%, the CO_2 reduction could range between 15.27% and 17.31%. Under travel demand levels 2 and 3, the turning points for the CO_2 emissions reduction in 2020 are 63% and 64% respectively. For Prospects A, B, and C, CO_2 emissions in 2020 could decrease by 1.07%, 1.66%, and 3.88% with a modal share of 63% under travel demand level 2. Further, the CO_2 reduction could fall within a range of 10.21%-12.05% corresponding to a 65% modal share. Under travel demand level 3, the CO_2 reduction can be 1.33%, 1.35%, and 1.64% for Prospects A, B, and C when the modal share is 64%. When the modal share increases to 65%, CO_2 emissions in 2020 can decrease by 6.08%-7.98%. It can be observed from the results that a sufficient modal shift to public transportation from the higher-emitting car mode can result in the positive environmental benefit for the society despite the massive overall increase in the number of trips made in urban areas.



(a) **(b)**

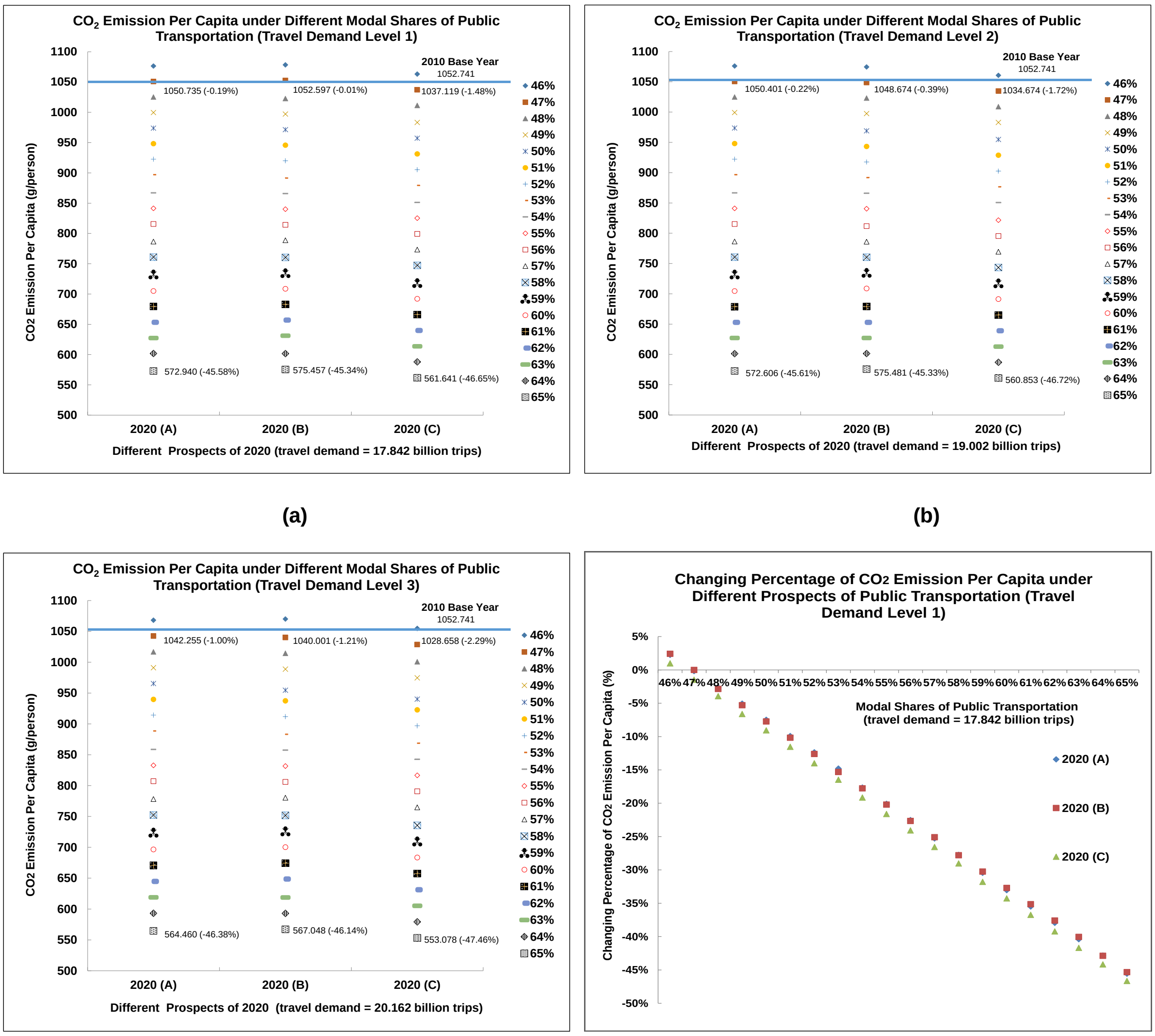


(c) (d)

(e) (f)

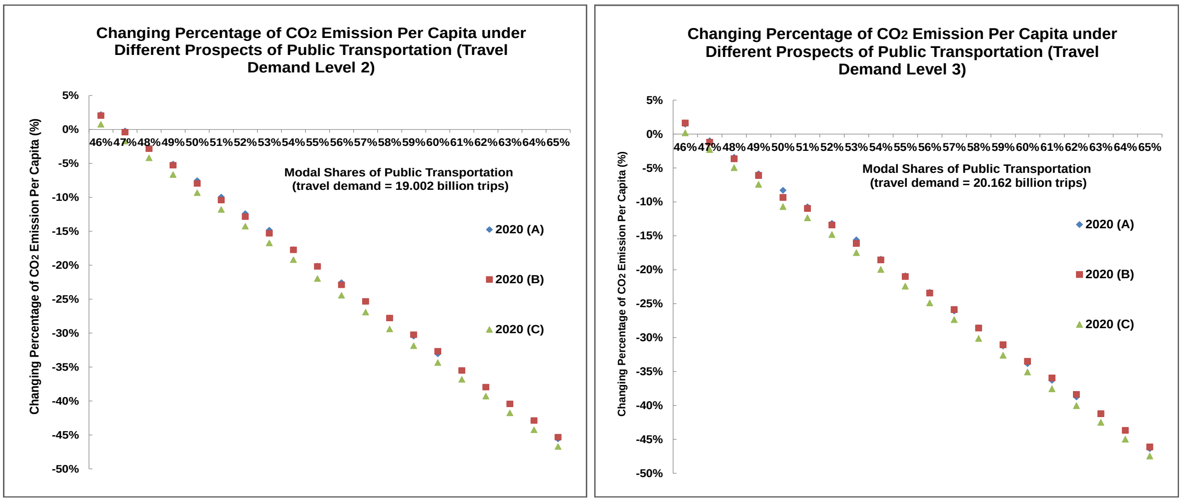
Fig.1 Comparison of CO$_2$ emissions or changing percentage between 2010 and scenarios in 2020 for three travel demand levels. (a) CO$_2$ emissions (travel demand level 1). (b) CO$_2$ emissions (travel demand level 2). (c) CO$_2$ emissions (travel demand level 3). (d) Changing percentages of CO$_2$ emission (travel demand level 1). (e) Changing percentages of CO$_2$ emission (travel demand level 2). (f) Changing percentages of CO$_2$ emission (travel demand level 3).

CO$_2$ emissions per capita and their changing percentage under different scenarios are presented in Fig. 2(a) to 2(f). The turning point for CO$_2$ emissions per capita to reduce is the modal share of 47%. Under travel demand level 1, the minimum value of the reduction percentage is 0.01% for Prospect B when the modal share of public transportation is 47%, while the maximum value is 46.65% for Prospect C when the modal share of public transportation is 65%. Under travel demand levels 2 and 3, the minimum value of the reduction percentage is 0.22% and 1.00% for Prospect A respectively with a modal share of 47%, while the maximum value is 46.72% and 47.46% for Prospect C with a modal share of 65%. It is suggested that the public transport can reduce CO_2 emissions per capita and has the capacity to contribute even greater CO_2 emission reductions per capita with the increased modal share of public transportation.



(a) **(b)**

(c) **(d)**



(e) **(f)**

Fig.2 Comparison of CO_2 emission per capita or changing percentage between 2010 and scenarios in 2020 for three travel demand levels. (a) CO_2 emissions per capita (travel demand level 1). (b) CO_2 emissions per capita (travel demand level 2). (c) CO_2 emissions per capita (travel demand level 3). (d) Changing percentages of CO_2 emission per capita (travel demand level 1). (e) Changing percentages of CO_2 emission per capita (travel demand level 2). (f) Changing percentages of CO_2 emission per capita (travel demand level 3).

6 Conclusions

The low carbon mobility with the low energy consumption is essential for a sustainable and competitive future for Asian cities. Different urban public transportation development policies and strategies implemented by the governments will yield different results in emissions of carbon dioxide from the urban passenger transport sector. In this paper, we employed a scenario analysis approach to assess the role of the public transportation system on CO_2 reductions using a case study of Beijing. A CO_2 emission estimation method suitable for Beijing has been established to assess the role of the public transportation system in reducing CO_2 emissions. Potential prospects for the development of the public transportation system in Beijing are analyzed. Accordingly, 180 scenarios for the target year of 2020 are designed and results are analyzed.

The increase of the urban travel demand in Beijing will bring a great challenge on mitigating CO_2 emissions. Three travel demand levels are considered in this research. Some of the most noteworthy findings from the analysis in this paper are as follows: 1) With the increase of modal shares of the public transportation system, the increase of CO_2 emissions is marginal. When the modal share of the public transportation system reaches 61-64%, the turning points will appear at which CO_2 emissions begin to decline. 2) CO_2 emission reductions per capita can be resulted by an increase of the modal share of the public transportation system. When the modal share of the public transportation system is greater than 47%, CO_2 emission reductions per capita can be achieved. We can conclude that the public transportation system has a great potential to reduce CO_2 emissions and average CO_2 emissions per capita in Beijing. As a result, it is recommended that policy strategies and measures to encourage shifting trips away from private modes be adopted in Beijing. Both bus and subway systems need infrastructure investments, financial subsidy, service level enhancement, and intermodal connectivity improvements that prioritize the transit over other modes since a 15-18% increase of the modal share of public transportation is needed if CO_2 emission reductions are to be achieved.

The methodology in this research is limited to estimating CO_2 emissions in cities of developing countries where detailed data on vehicle types and fuel consumption are difficult to be collected, partially due to the rapid replacement rate of vehicles. It should be noted that significant heterogeneity exists across cities. In the future, the CO_2 emission analysis for other cities that have different development patterns should also be explored. Moreover, the impact of the newly established “Xiong-An New District” to the south of Beijing on the population and transportation mode shares is not considered in this paper, in regard to the fact that the process of change will take a long time. So, a further investigation and analysis taking into account “Xiong-An New District” will be considered in the near future. In the meantime, it should be noted that the policy recommendation in this paper is mainly based on the CO_2 emission analysis. In the future studies, other potential impacts, such as the air quality, road safety, congestion, and energy consumption should be added to the analysis.

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