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Article

Impacts of Urban Transportation Mode Split on CO_2 Emissions in Jinan, China

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Abstract: As the world's largest developing country, China currently is undergoing rapid urbanization and motorization, which will result in far-reaching impacts on energy and the environment. According to estimates, energy use and carbon emissions in the transportation sector will comprise roughly 30% of total emissions by 2030. Since the late 1990s, transportation-related issues such as energy, consumption, and carbon emissions have become a policy focus in China. To date, most research and policies have centered on vehicle technologies that promote vehicle efficiency and reduced emissions. Limited research exists on the control of greenhouse gases through mode shifts in urban transportation—in particular, through the promotion of public transit. The purpose of this study is to establish a methodology to analyze carbon emissions from the urban transportation sector at the Chinese city level. By using Jinan, the capital of China's Shandong Province, as an example, we have developed an analytical model to simulate energy consumption and carbon emissions based on the number of trips, the transportation mode split, and the trip distance. This model has enabled us to assess the impacts of the transportation mode split on energy consumption and carbon emissions. Furthermore, this paper reviews a set of methods for data collection, estimation, and processing for situations where statistical data are scarce in China. This paper also describes the simulation of three transportation system development scenarios. The results of this study illustrate that if no policy intervention is implemented for the transportation mode split (the business-as-usual (BAU) case), then emissions from Chinese urban transportation systems will quadruple by 2030. However, a dense, mixed land-use pattern, as well as transportation policies that encourage public transportation, would result in the elimination of 1.93 million tons of carbon emissions—approximately 50% of the BAU scenario emissions.

Keywords: urban transportation system; mode split; CO_2 emissions; scenario analysis

1. Background

China has experienced rapid urbanization during the last two decades. Since 2002, the urbanization rate has been 1% to 1.2% annually, and the number of cities has increased from 193 to 661 over the last three decades. At the end of 2006, China had 577 million people living in urban areas, which accounted for 44% of its total population [1]. It is predicted that the Chinese urban population will reach 1.12 billion between 2025 and 2030, thereby accounting for 70% of the country's total population [2]. With the brisk urbanization, the demand for mobility and motorization has increased dramatically. Shanghai, where the total trips increased from 28.3 million person-trips per day in 1995 to 41 million in 2004, the travel intensity increased from 1.97 trips per day per person in 1995 to 2.36 in 2004, and the average travel distance increased from 4.5 km per trip in 1995 to 6.9 km in 2004, provides an example of this trend. More significantly, the total car trips increased from 1.5 million per day in 1995 to 5 million in 2004 [3]. Along with the increase in travel, the structure of transportation modes has also changed. Taking Shanghai as an example again, from 1986 to 2004 the share of non-motorized transportation (NMT), which includes mainly biking and walking, decreased from 72.0% to 59.8%, while private car use increased from less than 3% to 16.5% [3]. In Beijing, the city with the largest vehicle population in China, the mode share of private cars increased from 5% in 1986 to 23.2% in 2000 and to 29.8% in 2005 [4].

Two main approaches facilitate the reduction of carbon emissions from the urban transportation sector: producing improvements in vehicle technology and shifting the urban transport modes to public transit and NMT. While the estimation of energy and emission effects derived from improved vehicle technology is straightforward, the estimation for the latter is more complicated, and the impacts are more difficult to identify. Lee *et al.* have calculated that, in European countries, an efficient bus could replace 5–50 cars in terms of energy use and land occupancy [5]. Wright and Fulton have developed a methodology that calculates the carbon emissions as the product of vehicle population, average travel distance, and fuel efficiency standards. They have applied this methodology for the bus rapid transit (BRT) system in Bogota, with the assumption that the private transportation mode remains stable [6]. Another way to address this issue is to use the Long-range Energy Alternatives Planning (LEAP) methodology to project vehicle mileage and carbon emissions. With the LEAP model, Chen *et al.* have predicted carbon emissions in Shanghai in 2020 and have recommend policy solutions to transportation energy problems [7]. In addition, R.K. Bose and the Institute of Global Environmental Strategy (IGES) have taken similar approaches to study the carbon impacts from mode splits in Dehli, India and Katmandu, Nepal, respectively [8]. Finally, other researchers have relied on linear planning measures for transportation structure optimization. Lu and Shen have used the concept of environmental capacity to optimize the transportation structure for Beijing [9,10].

The above-mentioned approaches present challenges. First, little data are available in developing countries, so most of the studies have used general data from developed countries. As a consequence, the findings are not city- or country-specific. Second, also because of limited data, some simplistic assumptions have been made during the studies; for example, many parameters were assumed to be constant over time. Third, it is difficult to link the results to specific policy implications because: (a) the analyses are not local-specific, and (b) the scenarios are defined in a general way. Since transportation energy consumption is one of the greatest contributors to carbon emissions, it is critical to quantify the impacts in order to guide city policies toward reducing the carbon emissions from urban transportation.

The purpose of this study was to establish a methodology to analyze carbon emissions from the urban transportation sector at the city level. The key technical contents include collecting data and surveying upon the local availability, calculating measures to be refined for adaption to local situations, and linking with the policy developments. It should be noticed that we try to utilize as much as of the available data from various sources and purposes. The sizes of the data set we collected do not necessarily match the need of our study. We have selected Jinan as the case study for this analysis. Jinan, the capital city of Shandong Province, China, has a population of 6.0 million within its metropolitan area. The total area of the Jinan metropolitan area is about 8100 square km, and the urban area is 3257 square km. According to the urban development plan for Jinan (Jinan City Master Plan, 2005–2020), the urban population is projected to increase from 3.4 million in 2004 to 4.5 million in 2020—and this is viewed as a very conservative projection. The rapid urbanization in Jinan is a reflection of the city growth in China. Therefore, the government views the development of a sound transit system as the key element for sustainable urbanization.

2. Methodology

2.1. Framework for the Modeling System

We used a modeling framework similar to those developed by Wright and Fulton to calculate the energy consumption and carbon emissions. However, we tried to refine the detailed data collection and calibration to ensure that the calculation reflected the local situation. The key equation of the calculation is as follows:

$$Ec(Em) = \sum_{i,j} \frac{T \times P_{i,j} \times D_{i,j}}{C_{i,j}} \times Fe_{i,j}\left(Ef_{i,j}\right) \tag{1}$$

Ec: total fuel consumption from the urban transportation sector (tons);
Em: total carbon emissions from the urban transportation sector (tons of CO_2);
T: total number of trips;
$P_{i,j}$: mode split (%);
$D_{i,j}$: travel distance for each mode (km);
$C_{i,j}$: load factor (persons);

$Fe_{i,j}$: fuel efficiency factors for different modes (L/100 km or kWh per 100 km traveled);

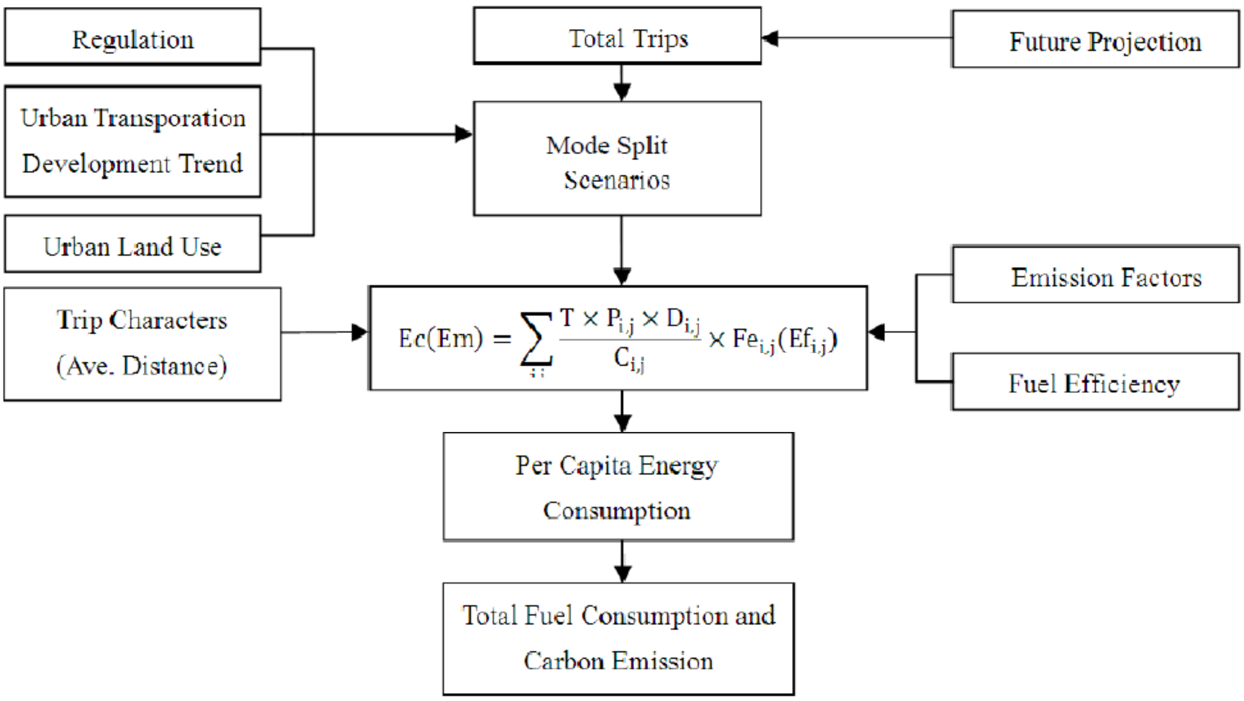
$Ef_{i,j}$: emission factors (g/km);

i: modes that include private cars (including business cars), motorcycles, e-bikes, rail, BRT, normal buses (including business shuttles), bicycles, and walking;

j: fuels that include gasoline, diesel, natural gas, and electricity; and

The overall approach for the analysis is shown in Figure 1.

Figure 1. Technical Approach.



2.2. Data Collection and Calibration

2.2.1. Total Trips (T)

We defined total trips as all travel activities, including both motorized trips and non-motorized trips (walking and biking). Based on the survey of current urban transportation modes in China, we included the following trips in this study: private cars, business cars, motorcycles, e-bikes, rail, BRT, normal buses, business shuttles, bicycles, and walking. We then sorted the trips into seven categories for the results.

Typically, we would use results from household travel surveys on per-capita trips and then multiply those by the total population to obtain the total trips for various transportation modes. There are two challenges with this approach: the lack of samples to statistically represent the real situation, and the uncertainties regarding the migrated population in Chinese cities. In this study, we obtained the results of household surveys that were conducted by local organizations in Jinan in 2004. We then calibrated the results based on the electronic card (IC card) data for public transit, as well as some supplementary household survey data from 2009.

For future trips, we simply used the activity numbers (per-capita daily trips) of more economically developed Chinese cities to project the future trips in Jinan. For example, based on the current Jinan social and economic development plan, it is predicted that Jinan's urban scale and economy will reach the current level of Shenzhen by 2020. Therefore, we used the current transportation activity numbers for Shenzhen to project the future activity numbers for Jinan. The population projection for Jinan was obtained from the Jinan Urban Planning Master Plan. These projections are shown in Table 1.

Table 1. Projection of Jinan Total Trips.

	2009	**2018**	**2025**	**2030**
Urban population (in 1000 s)	3754	4365	4838	5177
Per-capita daily trips	2.1	2.4	2.7	2.8
Total annual trips (in millions)	2927.4	3877.2	4707.6	5349.8

2.2.2. Mode Splits

Mode splits reflect the contribution of various transportation modes in an urban transportation system. It is a function of urban scale, urban geography, economy, urban land use, and personal behavior. At the same time, public polices play a very important role in determining city transportation mode splits. In European and Asian countries, public transit plus NMT can contribute as much as 80%, whereas typical US cities have a car share of more than 50%.

We obtained the current mode splits data for Jinan from comprehensive surveys taken over the past 10 years. In addition, we conducted supplementary surveys of 2000 households to calibrate the previous data to generate the mode splits in 2009. We also examined the trends of change in mode splits to the project future changes in mode splits to be used as our BAU case for the future projections. The data are shown in Table 2.

Table 2. Jinan Mode Splits in 2004 and 2009.

	2004	**2009**
Walking	32.7%	25.0%
Biking	30.6%	12.0%
Bus	14.5%	18.0%
BRT	0.0%	5.0%
Company shuttle	2.8%	2.0%
Rail	0.0%	0.0%
Company car	1.8%	1.9%
Private car	2.2%	13.3%
Taxi	1.1%	2.8%
Motorcycle	6.6%	2.0%
E-bike	7.6%	18.0%

Mode splits are the most sensitive component in urban transportation public policies, and they could be greatly improved through national and local policies and financial incentives. In this analysis, we attempted to link policy implications with the shift of mode splits and then estimated energy use and carbon emissions from the mode split changes.

2.2.3. Average Travel Distance

Average travel distance is defined as the single trip distance between origin and destination with various transportation modes. It is a function of urban scale, urban development pattern, land use, and population distribution.

2.2.3.1. Walking and Biking

We conducted a local survey with questionnaires about walking and biking in nine neighborhoods in Jinan, which covered various typical urban settings. We collected over 2000 survey samples, and the survey results indicated that the average bike travel distance in Jinan is about 4.4 km. International studies show that most people accept up to about a half hour of walking and biking during a commute. This conclusion implies that the average travel distances are about 2 km for walking and 6 km for biking [11], which are consistent with the survey in Jinan. Biking and walking do not cause any fossil fuel consumption, and their contribution to carbon emissions is zero. Consequently, biking and walking are the most ideal transportation modes in terms of carbon mitigation.

2.2.3.2. E-bikes

We conducted surveys at main intersections in Jinan and collected about 6000 samples for the e-bike. The results showed that the average travel distance of an e-bike is about 5.1 km.

2.2.3.3. Buses (Including BRT)

We used a specific OD (origin and destination) survey to estimate the average bus travel distance. In 2006, as requested by the Jinan Municipal Government, Shandong University conducted a detailed survey on the OD of Jinan bus-system ridership for the purpose of optimizing the bus operation system. More than 80,000 samples were obtained during that survey. From that survey, we concluded that the average bus travel distance in Jinan is about 7.1 km.

Compared with international cities, the average bus travel distance is longer in Chinese cities. We found that the bus travel distance in Jinan is similar to those in large metropolitan cities such as Beijing and Shanghai.

The BRT is rapid transit provided by buses. A good BRT system generally involves a number of features, including bus stations with amenities, well-designed vehicles, a mechanism for rapid fare payment, use of Intelligent Transportation Systems, dedicated roadway space, and frequent all-day service.

2.2.3.4. Rail

Jinan does not yet have a metro or light rail system, but a rail development plan has been approved by the Central Government. Based on the plan, Jinan will develop its first rail corridor by 2015 and expand to three lines by 2020. However, because a rail network is not yet formed, we do not expect that by 2020 a rail system could play an important role in Jinan's transportation system. Nevertheless, we used the Shenzhen data as the reference for the Jinan metro and assumed an average travel distance of 7 km.

2.2.3.5. Taxis

We used the statistics from the Jinan Transportation Management Authority to estimate the travel distance for the taxi. In Jinan, the average cost for a taxi trip is about 15 RMB per trip. The fare scheme is 7.5 RMB for the first 3 km, and then averages 1.5 RMB per km. Thus, the 15-RMB average taxi fare results in an average travel distance about 6 km. One important factor for the Chinese taxi is the lack of a systematic dispatching system. As such, the Chinese taxi typically is driven for very long periods in a dawdling mode. According to a survey of taxi drivers, the non-occupancy driving rate in Jinan is about 50%. Therefore, we calculated the average travel distance for the taxi as follows:

$$D_r = D_{taxi} / F_{Pa} \tag{2}$$

D_r: actual travel distance;
D_{taxi}: average travel distance with passengers, and
F_{Pa}: non-occupancy rate.

2.2.3.6. Private Cars and Motorcycles

We used the same questionnaires in the nine neighborhoods to obtain the average travel distance for cars and motorcycles. The results established a distance of 12.6 km for cars and 5.8 km for motorcycles.

2.2.4. Average Load Factors

Average load factors represent the average number of passengers carried by various transportation modes. Obviously, the average load factor is 1.0 for bikes, e-bikes, and motorcycles. We used the following equation to calculate the average load factor for buses from the available data:

$$\bar{C} = \frac{\sum C_v \times N_v}{\sum N_v} \times L_f \tag{3}$$

$\bar{C}$: average load factor (persons);
C_v: capacity of bus type V (persons);
N_v: *t* number of buses type V, and
L_f: average occupancy (%).

Table 3. Jinan Bus Statistics by Category.

Bus Length (m)	**8**	**10**	**12**	**18**	**Double-Deck**
Stock	102	1462	2240	167	86
Maximum load	53–64	68–80	96–116	167–180	93

The data for buses, shown in Table 3, were collected from the Jinan Bus Company. Average occupancy rates were obtained from on-site surveys. The Jinan Bus Company conducted a bus occupancy survey at 24 bus stations and collected over 20,000 samples. On the basis of the survey, we estimated the average occupancy of a Jinan bus to be 44.7%, thus implying an average load factor of 45 persons. With the same method, we estimated the average load factor of BRT to be 85 persons.

The average load factor for the taxi was set as 2.2, based on statistics from the Jinan Transportation Management Authority. The load factor for a private car was set as 1.4, based on the household survey. We assumed that the load factor would remain stable over the time period being investigated.

2.2.5. Fuel Consumption and CO_2 Emission Factors

Fuel consumption and CO_2 emission factors are defined as the energy consumed and the CO_2 emissions per 100 km of travel. We surveyed real-world fuel consumption at the Jinan Bus Company and obtained the fuel consumption factors for buses, as presented in Table 4.

Table 4. Fuel Consumption Rates for Jinan Buses.

Length (m)	**8**	**10**	**12**	**18**	**Double-Deck**	**BRT (12 m)**	**BRT (18 m)**
Number of vehicles	102	1462	2240	167	86	60	107
Fuel consumption (L/100 km)	22	28	30	50	45	30	50

We calculated the average fuel consumption rates for regular buses and BRT buses with the following equation. The results for the two are 30 L/100 km and 43 L/100 km, respectively. The equation is shown below:

$$\overline{F}_e = \frac{\sum F_e \times N_v}{\sum N_v} \quad (4)$$

$\overline{F}_e$: average fuel consumption rate (L/100 km),

F_e: fuel consumption by bus type (L/100 km), and

N_v: vehicle number by bus type.

For cars and taxis, we relied on a study on fuel efficiency conducted by Tsinghua University. The study showed results of 9.1 L/100 km for both cars and taxis [12].

For e-bikes, we referred to the "General Technical Standards for E-bikes (GB17761-1999)." From this information, we adopted the fuel efficiency standard for the e-bike, which is about 1.2 kWh/100 km.

For rail, since there is no current rail operation in Jinan, we used the data in Beijing as a reference, which is 4 kWh/km [13].

2.2.6. CO_2 Emission Factors

For fossil fuels, we used the following equation to calculate CO_2 emission factors:

$$C_e = F_c \times C_c \times 44 \div 12 \quad (5)$$

C_e: CO_2 emission factor (g/100 km);

F_c: fuel consumption factor (L/100 km), and

C_c: carbon contents (g/L).

For electricity, we found that the energy source for Jinan electricity generation is 100% coal. By combining with the overall electricity generation efficiency of 33% in China, we estimated that the average CO_2 emission factor from electricity use is 1002 g CO_2/kWh.

3. Scenarios

As discussed above, mode splits are the most policy-sensitive component for urban transportation carbon emissions. We set up various urban transportation mode split scenarios that could be reached through public policies and incentive adoption. We then analyzed CO_2 emissions for various mode split scenarios.

3.1. Business-as-Usual (BAU) Scenario

According to the historic data on urban transportation development (Table 2), Jinan is experiencing very fast motorization. Over the last five years, the car trip share has increased from 2.2% to 13.3%. To the contrary, NMT, including walking and biking, has dropped dramatically. However, biking that includes the e-bike has remained almost stable. This trend is typical in Chinese cities, and we expect that the trend will continue, given the lessons learned in Beijing and Guangzhou, if there is no strong policy intervention.

In the BAU scenario, we assumed that there is no policy intervention and that the current trend of motorization would continue. Considering the national policy that supports car industry development, we assumed that car trips (including private cars, business cars, and taxis) will account for 35% of total trips, which is roughly the current situation in Beijing, but still much lower than that in U.S. cities. We also assumed that NMTs will continue to shrink, but public transit will continue a steady growth. The details for the scenario are listed in Table 5.

Table 5. Jinan Urban Transportation BAU Scenario: Shares of Different Transportation Modes.

	2009	**2018**	**2025**	**2030**
Walking	25.0%	23.0%	20.4%	17.0%
Biking	12.0%	8.8%	5.5%	3.5%
Regular bus	18.0%	18.5%	19.3%	20.0%
BRT bus	5.0%	7.0%	9.0%	12.0%
Company shuttle	2.0%	1.5%	1.2%	1.0%
Rail	0.0%	3.0%	5.5%	7.0%
Company car	1.9%	2.5%	3.0%	3.0%
Private car	13.3%	19.5%	23.5%	28.5%
Taxi	2.8%	3.0%	3.5%	3.5%
Motorcycle	2.0%	1.2%	0.6%	0.0%
E-bike	18.0%	12.0%	8.5%	4.5%

3.2. Policy Intervention Scenarios

We developed two scenarios for policy intervention. The scenarios are presented below:

The Low Policy Intervention Scenario: This scenario assumes that the current proposed urban transit development policies would be well implemented. From the requirement of the Central Government, the public transit share in key cities should reach 45% by 2030. We also assumed that the current BRT development policy in Jinan would continue to build a high-quality service network. At the same time, the rail construction would follow the already-adopted plan and would offer 7% of trips. These requirements would necessitate a large capital investment, as the costs for BRT and metro construction would be about RMB 30 M/km and 400 M/km, respectively. To reach these goals, the total capital requirements would be 20 billion RMB. With the great investment in public transit, we assumed that the car growth rate would be reduced, whereas the NMTs would continue to shrink. The details of the low policy intervention scenario are listed in Table 6.

Table 6. Low Policy Intervention Scenario: Shares of Different Transportation Modes.

	2009	2018	2025	2030
Walking	25.0%	24.0%	23.0%	23.0%
Biking	12.0%	7.8%	4.4%	3.5%
Normal bus	18.0%	19.5%	21.3%	24.0%
BRT	5.0%	8.0%	10.5%	13.0%
Company shuttle	2.0%	1.5%	1.2%	1.0%
Rail	0.0%	3.0%	5.0%	7.0%
Company car	1.9%	2.5%	3.0%	2.5%
Private car	13.3%	17.5%	20.5%	17.5%
Taxi	2.8%	3.0%	3.5%	3.0%
Motorcycle	2.0%	1.2%	0.6%	0.0%
E-bike	18.0%	12.0%	7.0%	5.5%

The High Policy Intervention Scenario: In addition to the investment in public transit, if significant efforts are made to reform the urban development pattern to promote the transit-oriented development, together with a great urban NMT system and public space design, Jinan could reach much more sustainable urban transportation development results. Although our listing is not complete, such efforts and policies would establish the following: (1) high-density (overall, Floor Area Ratio greater than 6.0) development around metro stations and BRT corridors with highly mixed land use within walking and biking distance; (2) city renovation to support a safe and convenient walking and biking system; (3) a fine road network and smaller parcels of land use in newly developing areas; (4) a robust public spaces network to "invite" personal life in the city rather than in cars; (5) excellent accessibility to the public transit system; (6) highly mixed land-use development in areas of new development; and (7) robust car restriction policies, parking policies, congestion charging, and traffic-calming designs. Based on the experiences in Hong Kong and Singapore, we assumed that Jinan could control car usage to less than 20% of total trips, thereby maintaining the share of public transit and NMTs at more than 80% of total trips. Under this scenario, we assumed that public transit could cover 50% of total trips by 2030; the car trip share would peak in 2020 and then drop to 15% by 2030. Over time, the BRT system would form the backbone of the urban transportation system. The details for the high policy intervention scenario are listed in Table 7.

Table 7. High Policy Intervention Scenario: Shares of Different Transportation Modes.

	2009	2018	2025	2030
Walking	25.0%	24.0%	24.0%	22.0%
Biking	12.0%	5.8%	5.4%	5.4%
Normal bus	18.0%	21.0%	20.8%	20.0%
BRT	5.0%	10.0%	15.0%	20.0%
Company shuttle	2.0%	1.5%	1.2%	1.0%

Table 7. *Cont.*

Rail	0.0%	3.5%	6.0%	9.0%
Company car	1.9%	2.0%	2.5%	2.0%
Private car	13.3%	16.0%	13.0%	9.5%
Taxi	2.8%	3.0%	3.5%	3.5%
Motorcycle	2.0%	1.2%	0.6%	0.0%
E-bike	18.0%	9.0%	8.0%	7.5%

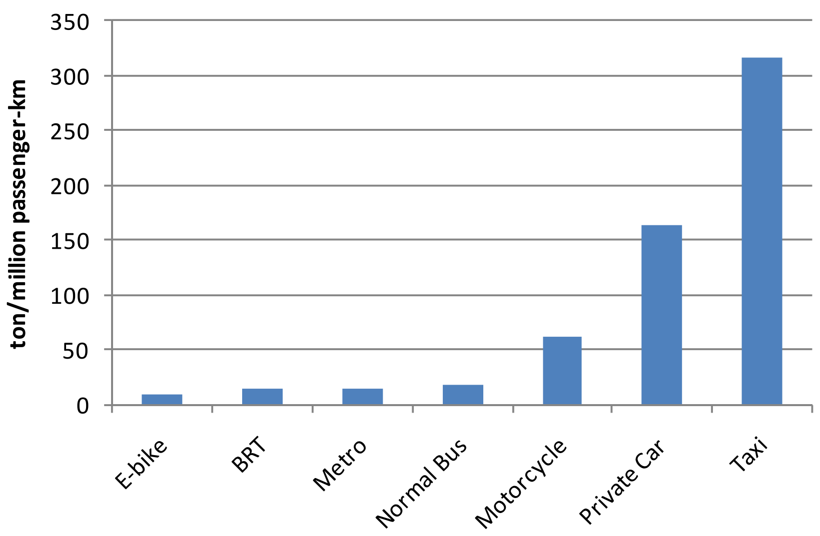
4. Results

4.1. Per Passenger-km CO_2 Emissions

The purpose of transportation is to move goods and persons, rather than to move vehicles. Thus, it is important to develop per passenger-km carbon emissions in order to best utilize transportation resources. We used the index of CO_2 emissions per million passenger-km to evaluate the efficiency of various urban transportation modes in Jinan.

The results are depicted in Figure 2, from which we can see that mass transits/systems are much more efficient than those of private transportation modes. For example, CO_2 emissions from transit modes are only about 10% of the emissions from private cars. The BRT is leading the public transit mode in terms of transport efficiency in Jinan. Not surprisingly, the taxi is extremely inefficient compared with other transportation modes, and the emissions are about 20 times as that from mass transit because of the high non-occupancy rate. Electric drive vehicles, including the metro and e-bike, have certain CO_2 emissions because of the coal-power generation for Jinan. The CO_2 emissions from the metro system are even higher than those from the high-efficient bus (BRT) system. Nevertheless, the e-bike is still the most carbon-efficient mode. Considering other advantages of the e-bike, such as road space occupancy, we believe that the e-bike is another good transportation mode that should be promoted in Jinan.

Figure 2. Per Million Passenger-km CO_2 Emissions from Various Transportation Modes in Jinan.

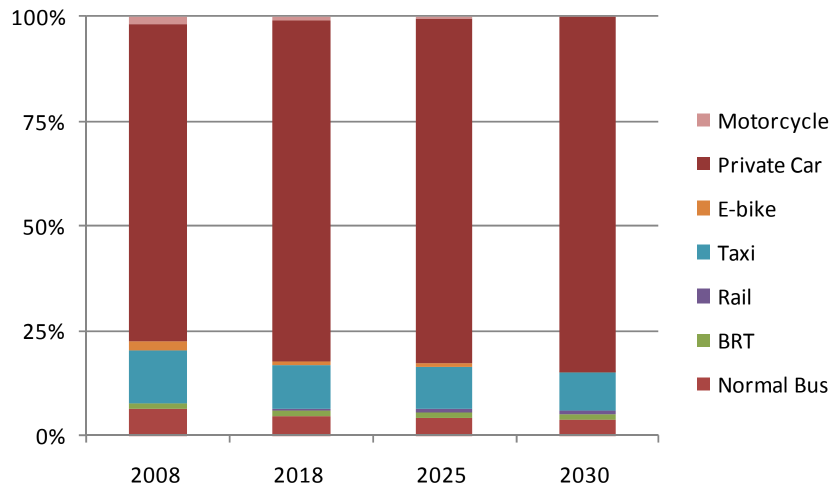


4.2. Emission Contributions from Various Transportation Modes

4.2.1. Emission Contributions under the BAU Scenario

The emission contributions from various transportation modes in Jinan are depicted in Figure 3, which shows that even though private transportation modes account for only 18% of the total trips, they contribute to about 90% of the CO_2 emissions. Under the BAU scenario, the emission contribution of private transportation modes continues to increase over time, which confirms that the key to urban transportation efficiency is to control the growth of private transportation. One noticeable factor regarding taxis is that, even though they represent only about 3.5% of the total trips, they contribute to about 10% of the CO_2 emissions. This implies an important challenge to improve taxi efficiency, especially by reducing the dawdling drive by establishing information systems and intelligent dispatching methods.

Figure 3. Emission Contributions from Various Transportation Modes under the BAU Scenario.



4.2.2. Emission Contributions under the Policy Intervention Scenarios

Figures 4 and 5 illustrate CO_2 emission contributions from various transportation modes under the two policy intervention scenarios. The emission contribution pattern under the low intervention scenario is very similar to that under the BAU scenario. Even though the public transit share increases by about 20%, the contribution from private transportation is still about 90%, which reflects the high efficiency of mass transit. Under the high policy intervention scenario (Figure 5), the contribution from private transportation drops due to the aggressive reform on urban land use and urban patterns. Biking and walking play an important role in forming the sustainable urban transportation pattern.

Figure 4. Emission Contributions from Various Transportation Modes under the Low Policy Intervention Scenario.

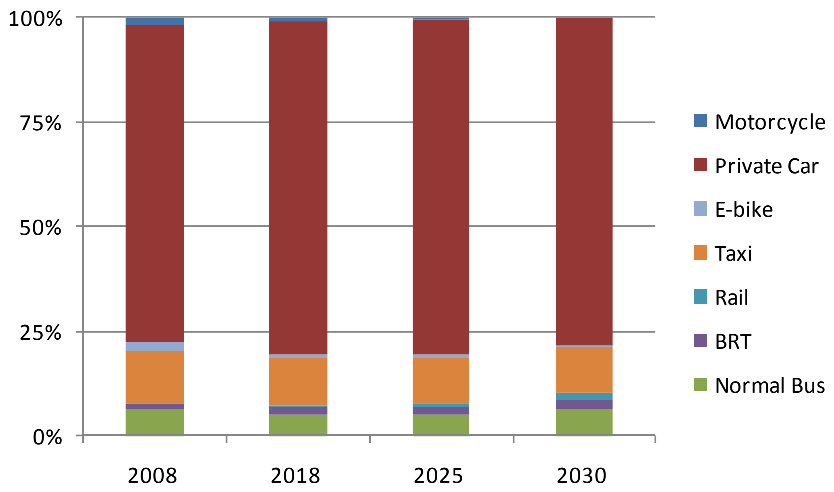
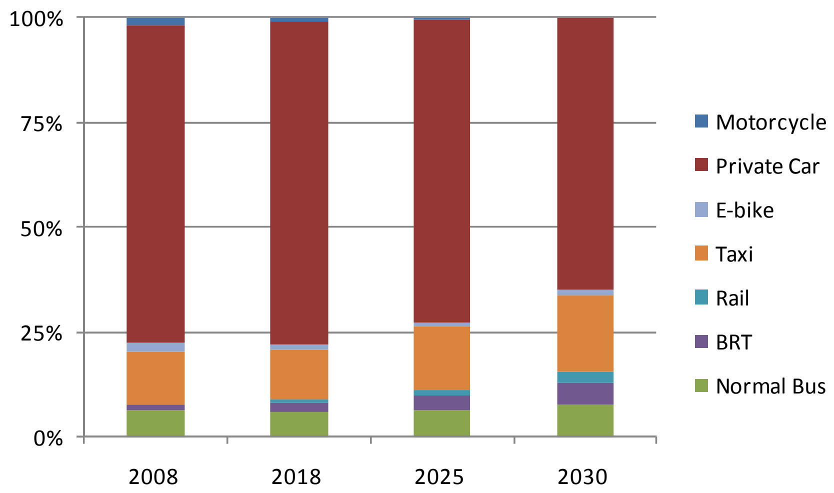


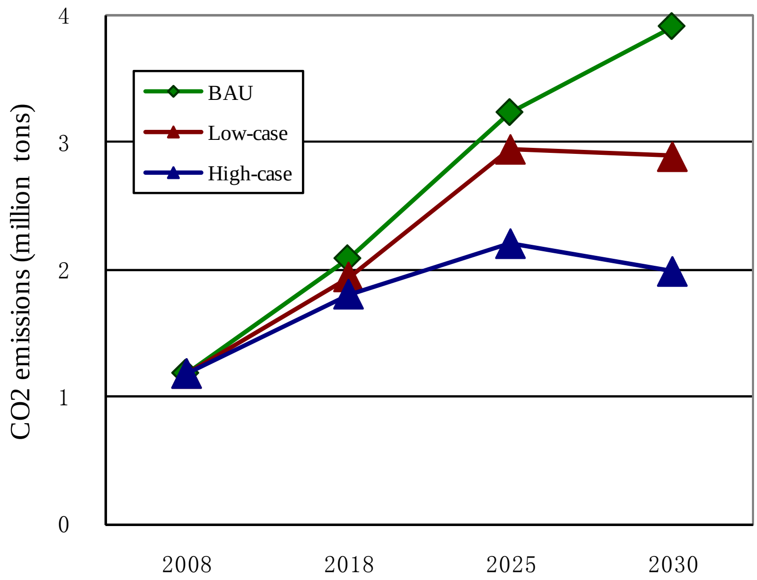
Figure 5. Emission Contributions from Various Transportation Modes under the High Policy Intervention Scenario.



4.3. Total CO_2 Emissions under the Three Scenarios

The total CO_2 emissions under the three scenarios are illustrated in Figure 6. If there is no policy intervention on the urban transportation system in Jinan, total CO_2 emissions from the urban passenger transportation sector will almost quadruple to 3.91 million tons over the 20-year period. On the other hand, aggressive policy intervention could dramatically spur efficiency improvements in urban transportation. Under the low policy intervention scenario, the CO_2 emission reduction would be 1.02 million tons, about 26% of the BAU scenario. Under the high policy intervention scenario, the CO_2 emission abatement would be 1.92 million tons, about 50% of the BAU scenario emissions.

Figure 6. CO_2 Emissions from Urban Transportation in Jinan under the Three Scenarios.



5. Conclusions

The purpose of this study was to establish a methodology to analyze carbon emissions from the urban transportation sector at the city level. This paper examines a modeling system to evaluate various urban transportation development scenarios by determining the energy use and CO_2 emission impacts from various mode split scenarios. During this study, we identified several issues that require further investigation. These issues are summarized below.

A significant challenge for this type of study is the lack of statistics about Chinese cities. In this study, we used data from various sources with different measures for data collection and calibration. However, we realize that a gap exists between these available data and the real-world data. Therefore, for China we recommend that considerable efforts should be directed toward overcoming both capacity and institutional issues and establishing comprehensive databases for urban development and evaluation.

The method used in this study provides a simple means to analyze the changes in transportation behavior over time, especially during the rapid urbanization process in China. Additional studies are necessary to link urban patterns and urban development policies. The model in this study is static. Further studies should address the dynamics of urban development policies, economic development, and personal behaviors (especially travel behaviors).

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