The effect of policy planning, population and age structure on carbon emission under different city scale

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Abstract. In recent years, air pollution has become more and more serious in the world. The transportation system in cities made a large contribution to carbon emission. Therefore, the problem of urban traffic pollution needed to be solved urgently. The city scale, population, the age structure of population and policy planning would influence the energy consumption and carbon emission of transportation systems. This article compared three different transportation systems: private motor vehicles, buses and subway in three cities. Beijing, Nanjing and Shijiazhuang were selected as the main cities which represented the different city scale. By reading the article about carbon emission from the transportation system and analyzing the research methods used before, this article analyzed the carbon emission from transportation in Beijing, Nanjing and Shijiazhuang. The article mainly included the following parts. First of all, 'engineering technical model' was used in this article. Using the ‘engineering technical model’ based on the data, which includes amounts of transportation tools, total miles, energy consumption and carbon emission factors, the carbon emission would be taken. Besides that, this article also predicted the carbon emission in 2035 based on 'The Fourteenth Five-Year Plan for the National Economic and Social Development of the People Republic of China and the Outline of the Long-range Goals to 2035' to detect the effect of policy on carbon emission. At last, the cities with advanced transportation systems would have less carbon emission, but the super cities like Beijing still had the largest carbon emission. The age structure of the population also influenced carbon emission. Government policy was also the main influence factor for carbon emission. Under the government policy, the carbon emission of the transportation system decreased sharply.

1 Introduction

The intensity of carbon emission had increased constantly in the world. It had become a hot issue in each country. According to the International Energy Agency (IEA) [1], transportation occupied a large proportion of energy consumption. Besides that, transportation also emitted more carbon dioxide than other areas. In recent years, China’s economy had developed rapidly, the citizens’ mode of travel had changed a lot. More citizens preferred to choose private cars as their transportation system. After 2015, the carbon emission of road traffic exceeded 80% of the whole transportation industry in China. With the introduction of China's 14th Five-Year Plan, motor vehicles were particularly important in environmental sustainability. With China's 14th Five-Year Plan, the Carbon emissions pattern of China will change dramatically within 15 years. At the same time, different daily travel modes of residents' daily, age structure, and urban spatial development pattern would affect the urban carbon emissions and the electric drive plan.

Previous studies had improved that the daily travel of residents in different city scales could influence carbon emission. [2] As Liu et al. [3] pointed, private cars, taxis, buses, and subways were the major mode of transportation for citizens in China. Based on this condition, there were many kinds of transportation systems for citizens to choose from. People have a different choice in different cities. The research indicated that travel distance, population density, and age structure significantly affected carbon emission. [3] The study on the travel carbon emission behavior of individuals in different cities at the scale of onlookers was helpful to accurately and effectively specify policies for different cities. After the policies come up, the research of carbon emissions should be limited to the study of the upgrading of vehicles and the impact of the built environment on carbon emissions in different types of cities and different spatial scales. Detecting the carbon emission and energy consumption of the different transportation systems is necessary to solve this problem. According to the research and comparison of different transportation systems' carbon emission and energy consumption, it would provide a better solution to improve transportation systems in cities. Besides that, it would also provide the direction of planning and evidence for the local government.

There are many researches about low carbon transport in the world. Vasiliki et al. [4] used the LCA to estimate carbon emission of Road and railway. They found that the road construction had less carbon emission than the construction of the railway, and the carbon emission of railway emission was less than the road operation. Zhang

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et al. [5] used the IPCC carbon accounting approach to analyze the carbon emission from passenger transport systems. They also used the CEPA method to detect the lowest demand of carbon energy requirement. And they concluded that clean energy would reduce the carbon emission from vehicles. Mao et al. [6] used the CMI model to predict the emission dynamic of CO2 and local air pollutants in China from 2008-2050. They concluded that the energy taxes and fuel taxes were the two most promising tools to reduce carbon emissions. Duan et al. [7] used the LCA method to calculate the carbon emission from the whole transport system in Shenzhen city. Based on the previous research, common methods were used. The one was the "engineering technical model", and another was the "energy-economy model" [8]. Until now, a large proportion of articles combined the two approaches. Markiewicz [9] used a technical engineering model to analyze the carbon emissions from road transport in cities. Meanwhile, he also used FCD methods and GPS to collect road data. Yuan and Yang [10] made Taiyuan city the target city to analyze the carbon emission of urban traffic system by IPCC approach. And they found that the usage of multiple energy resources would reduce carbon emissions. Becky and Li [11] used the "energy-economy model" to analyze the carbon emission from passenger transportation since 1949 in China. Wang et al. [8] used the "engineering technical model" to analyze the carbon emission in Xian and Bangalore. In conclusion, the LCA method, emission factor method, mass balance method, and CDM method were the main carbon emission research methods.

However, the previous researches only focus on the transport systems and specific cities. There were very limited articles focus on the comprehensive comparison of transport systems in cities with different levels of development. And there were also a few articles to compare the variance of carbon emission based on China’s 14th Five-Year Plan. This article would focus on comparing energy consumption, carbon emission of the different transportation systems in Beijing, Nanjing, and Shijiazhuang city, and conclude the best transport system to reduce carbon emission.

2 method

2.1 Carbon emission accounting methods in the transportation system

To detect the carbon emission from the transportation system, the methods that contain collecting relevant data about transportation tools, index, and emission factors are used. The methods of carbon emission calculation have matured among the world.

In this article, the "engineering technical model" was used, based on the total miles, the volume of transport tools, and energy consumption to calculate the carbon emission in Beijing, Nanjing, and Shijiazhuang. This article assumed that private cars are dominated by fuel cars, buses are dominated by electrical buses, and subway are provided the energy by electricity [12].

2.2 Carbon emission

2.2.1 Vehicle carbon emission

This article uses equation 1, which was from IPCC 2006, based on the types of cars, total miles of cars, the energy consumption of cars, and Carbon emission factor to detect the carbon emissions of private cars. The following shows the equation of carbon emission [12].

\[
P_{\text{CO}_2} = \sum \sum C_{ij} V_{ij} S_{ij} PF_j
\]

- \(P_{\text{CO}_2}\) — Total carbon emission (10^4 tons)
- \(V_{ij}\) — Type of cars I which use type of gasoline
- \(S_{ij}\) — Total miles of the car i which use type of gasoline
- \(C_{ij}\) — Energy consumption per hundred kilometers (L/100KM)
- \(PF_j\) — Carbon emission factor of gasoline j

2.2.2 Electrical vehicles contain subway and buses

Like private cars, the equation 2, 3 and 4 were all from IPCC 2006, which were based on the energy consumption for each car, the carbon emission factor of China's power grid to detect the carbon emission of buses and subway. The following shows the carbon emission calculation process of electrical buses and subway [12].

\[
P_{\text{ele}} = W_{it} \times EF_{grid,i}
\]

- \(P_{\text{ele}}\) — Total carbon emission (10^4 tons)
- \(W_{it}\) — Total energy consumption of the routes for each car (kW*h)
- \(EF_{grid,i}\) — Carbon emission factor of China power grid (kg CO2/kW*h)

\[
W_{it} = S_{ij} \times D_r \times C_r
\]

- \(V_{ij}\) — Type of cars I which use type of gasoline
- \(S_{ij}\) — Total miles of the car i which use type of gasoline
- \(C_r\) — Energy consumption per hundred kilometers (k*Wh/100km)
- \(D_r\) — Average annual running of rail transit

2.3 Methods of data collection

This article mainly used two types of collection. One method to collect data is to search the data directly in government articles. The data from the government articles was more convincing. Besides that, the data from the government articles would help this article analyzed and used. The methods of data collection are provided the energy by electricity [12].
transportation tools was from the reasonable prediction from experts or relevant guilds.

3 Result

3.1.1 total mile of the different transportation system in three cities

Table 1. Total miles of the transportation system in three cities [13-15]

|                     | Beijing          | Nanjing          | Shijiazhuang      |
|---------------------|------------------|------------------|-------------------|
| private cars (km)   | 6.69×10^{10}    | 2.14×10^{10}    | 3.37×10^{10}     |
| Buses (km)          | 1.28×10^{9}     | 6.32×10^{9}     | 2.21×10^{9}      |
| Subway (km)         | 6.57×10^{8}     | 2.81×10^{8}     | 1.70×10^{8}      |

Table 1 shows the total miles of the different transportation systems in Beijing, Nanjing, and Shijiazhuang. From a macro perspective, the total mile of private cars was the largest among three transport systems in different cities. It meant that private cars were still the first choice for people to travel in the first-tier city, second-tier city, and third-tier city. The total mile of buses was higher than the subway in three cities. It meant that buses were the second choice for people to travel in different tier cities. The total mile of private cars in Beijing is much higher than in the other two cities. And the total mile of private cars in Shijiazhuang was larger than in Nanjing. This article assumes that the private cars in each city are running 14432 kilometers on average. According to the statistical bulletin [13], Beijing had the largest motor vehicle population, and Shijiazhuang had fewer motor vehicle population than Beijing but is still higher than Nanjing. Nanjing had the least motor vehicle population among the three cities. As for the buses, the total mile of buses in Beijing was much higher than in the other two cities, and the total mile of buses in Nanjing was higher than in Shijiazhuang. The contribution of the subway in three cities had the same condition as buses. Beijing had the longest operation length of the subway, and the value of Nanjing is higher than Shijiazhuang.

3.1.2 energy consumption of different transportation system in three cities

Because of the lack of data about the average energy consumption of different transport systems in each specific city, this article used the data about the average energy consumption of China to substitute the specific data.

Table 2. Energy consumption in three cities [13-15]

|                     | Beijing          | Nanjing          | Shijiazhuang      |
|---------------------|------------------|------------------|-------------------|
| private cars (gasoline, kg) | 5.19×10^{11}    | 1.66×10^{11}    | 2.61×10^{11}     |
| Buses (electricity, kW·h)  | 6.10×10^{8}     | 3.01×10^{8}     | 1.06×10^{8}      |
| Subway (electricity, kW·h) | 1.34×10^{8}     | 5.74×10^{8}     | 3.48×10^{8}      |
| Total (Heat value)  | 2.39×10^{12}    | 7.63×10^{11}    | 1.20×10^{12}     |
| person/year         | 5.80×10^{4}     | 4.69×10^{4}     | 5.71×10^{4}      |

According to table 2, the energy consumption of each transport system in Beijing was the highest among the three cities. Compare with Nanjing and Shijiazhuang, the energy consumption of buses and subway in Nanjing was higher than in Shijiazhuang. Still, the energy consumption of private cars in Shijiazhuang was higher than in Nanjing. That was mainly because the motor vehicle population of Nanjing is less than Shijiazhuang. From table 1, the total energy consumption of Beijing is the highest. Although the energy consumption of buses and subway in Nanjing is higher than in Shijiazhuang, the total energy consumption of transport systems was less than Shijiazhuang.

Figure 1 shows total energy consumption and energy consumption per person per year in three cities. According
to figure 3, Beijing had the highest value among the three cities, and the value of Shijiazhuang was less than Beijing but higher than Nanjing.

3.1.3 carbon energy consumption

Figure 2. Carbon emission in three cities [13-15]

According to equation 1, the carbon emission of private motor cars would be got. And the equation 2,3,4 could get the carbon emission of buses and subways. Figure 2 shows the total carbon emission and carbon emission per person in three cities, the carbon emission of Beijing had reached $1.2 \times 10^{12}$ kg. Because of the population and city scale, the carbon emission of Beijing was the highest. The total carbon emission of Shijiazhuang has reached $1.2 \times 10^{12}$ kg. However, the city scale of Shijiazhuang was smaller than Nanjing. The total carbon emission is much higher than in Nanjing. The total carbon emission of Nanjing only had $3.74 \times 10^{11}$ kg. Although the city scale of Shijiazhuang was smaller than Nanjing, the population and private motor vehicle population were higher than Nanjing. Therefore, the carbon emission of Shijiazhuang was higher than Nanjing.

The red line shows the carbon emission per person per year. From figure 5, Beijing and Shijiazhuang had the near value of carbon emission, and Nanjing had the least carbon emission per person per year among the three cities. Because the city scale and population of Beijing were larger, the carbon emission of Beijing was larger than Nanjing.

3.2 policy effect on carbon emission

According to the 14th five years' plan of China, the government put the development of public transportation as the first position. Meanwhile, the government was planning to develop clean energy in transportation to reduce the carbon emission from cities.’ The Fourteenth Five-Year Plan for the National Economic and Social Development of the People Republic of China and the Outline of the Long-range Goals to 2035 also pointed that establish a new energy structure is necessary for the development of vehicles. Besides that, the government would also accelerate automobile consumer goods from purchase management to use management. It meant the amounts of private cars in China would increase, but this action limited the development of motor vehicles, and it only focuses on electric vehicles. This action ensured that the expansion of the market for automobile consumption with low carbon emission. In 2035, the government aims to achieve 4.2L/km gasoline consumption.
Figure 3 shows the comparison of total carbon emissions in 2019 and 2035. The value of 2035 was a prediction based on the government policy. From figure 4, the carbon emission of 2035 was much less than 2019, especially in Beijing. The carbon emission of Shijiazhuang and Nanjing also had a significant reduction.

3.3 Urban architecture

Table 3. Population in three cities [16]

|                  | Beijing | Nanjing | Shijiazhuang |
|------------------|---------|---------|--------------|
| Population (10^4) | 2153.6  | 850     | 1039.42      |
| Urban population ratio | 86.5%  | 67.72%  | 53.32%       |
| Age structure (0-14 yr) | 10.47% | 13.73%  | 18.48%        |
| Age structure (14-65 yr) | 78.28% | 71.97%  | 68.83%        |
| Age structure (Above 65 yr) | 11.25% | 14.3%   | 12.69%        |

Table 3 shows the population in each city. According to table 3, Beijing had the largest population among the three cities. Although Nanjing was more popular than Shijiazhuang, the population of Shijiazhuang was larger than Nanjing. As table 3 shows, the urban population ratio of three cities. From table 3, the urban population of Beijing was the highest among the three cities, and Shijiazhuang had the lowest urban population ratio. Compare with three cities, people between 14-65 years old occupy a large proportion of the population. Beijing had the largest population between 14-65 years old among the three cities. Shijiazhuang had the largest proportion of 0-14 years old people, and Nanjing had the largest proportion of 65 years old people.

4 Discussion

Based on the result, Beijing had the largest energy consumption and carbon emission in each city. One of the reasons was that Beijing's population density and urban development were all the highest in China. Dense population and large city areas meant larger distance transportation and more transportation tools. Therefore, Beijing had the largest energy consumption and carbon emission. However, Nanjing had different conditions from Beijing. 14-65 years old people occupied the largest population ratio in Beijing. It meant that the requirements for transportation were larger than the other cities. Therefore, energy consumption and carbon emission were the largest.

Compare with the Shijiazhuang, Nanjing had less energy consumption and carbon emission than Shijiazhuang. As mentioned before, compared with Shijiazhuang, Nanjing had a more advanced urban public transport system. Because of the advanced urban public, private motor cars were less than Shijiazhuang. Private motor cars made the biggest contribution to the energy consumption and carbon emission, and the private motor cars in Shijiazhuang were higher than Nanjing. Therefore, the energy consumption and carbon emission of Shijiazhuang were higher than in Nanjing. According to the result, the Population of Shijiazhuang was higher than Nanjing, and the urban population ratio of Shijiazhuang was less than Nanjing. The proportion of the urbanized population reflected the development of cities to a degree. It also reflected the development of public transportation of Shijiazhuang was worse than Nanjing. Age structure also reflected the energy consumption and carbon emission. Nanjing had 14.3% of the elderly population, which was higher than the other cities. Elderly people preferred to choose public transportation or walked to the nearby blocks. Therefore, the energy consumption and carbon emission were less than the other two cities.

Shijiazhuang was not an advanced city compared with
Beijing, but the carbon emissions per capita of Shijiazhuang were near Beijing. Compare with the transportation system of the two cities, the transportation mode in Shijiazhuang was simple. Meanwhile, the degree of urbanization was not high compare with the developed city. This condition results in people would choose private motor vehicles as their main transportation tool in Shijiazhuang. Therefore, the value of carbon emission per capita of Shijiazhuang was near to the value of Beijing.

The government policy was an effective way to reduce carbon emissions. Based on 'The Fourteenth Five-Year Plan for the National Economic and Social Development of the People Republic of China and the Outline of the Long-range Goals to 2035', this article predicted the carbon emission in the next 20 years. According to figure 6 in result, the carbon emission would decrease sharply. Today, the country’s support for new energy vehicles and the control of fuel vehicles would significantly reduce carbon emissions.

5 Conclusion

This article was based on the 'engineering technical model' to analyze the carbon emission and energy consumption in Beijing, Nanjing, and Shijiazhuang in 2019. The research result indicated that the different city scales, amounts of population, and population's age structure determined the carbon emission and energy consumption. Beijing represented the super cities in China. These cities had the densest population, younger population, and largest requirements of transportation. Therefore, the densest population and younger population had a negative impact on carbon emission. However, because of the large requirements of transportation, the super cities always had advanced transportation systems. Advanced transportation would reduce carbon emissions per capita. This article also compared the energy consumption and carbon emission of second-tier cities in developed regions and second-tier cities in less developed regions except for the super city. This article found that the urban population ratio also determined energy consumption and carbon emission through the research. The higher urban population ratio had the lower energy consumption and carbon emission except for the super city. A higher urban population meant higher urban public transport coverage. Therefore, the total energy consumption and carbon emission were less in the cities with the higher advanced transport system.

Meanwhile, this article also found that private motor cars made the largest contribution to energy consumption and carbon emission. For example, as a developed city with an advanced transportation system, Nanjing, carbon emission of public transportation in Nanjing, was higher than Shijiazhuang. However, the amounts of private motor cars in Shijiazhuang were higher than in Nanjing, the total energy consumption and carbon emission were much higher than in Nanjing.

In addition, government policies influenced carbon emission deeply. Reduced carbon emission by controlling auto emissions was still in the 14th five years’ plan of China. Besides that, the advantage of the strategy of public transport priority was obvious, and this strategy would still be carried out among the whole country. All in all, reducing the carbon emission requires the joint efforts of the whole society.

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