The Energy Consumption and CO2 emission impacts of Fuel and Electric Vehicles in China

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Abstract. Vehicle electrification has been seriously considered as an industrial revolution to achieve sustainable transportation in China. With the development of the electric system, electric vehicles and railway systems are utilizing and generalizing. To accurately and adequately evaluate the energy consumption and CO2 emission effects of fuel and electric vehicles, this study focuses on these two kinds of vehicles, including buses and cars, and analyses their environmental impacts. Results show that electric vehicles consume less heat energy and release less CO2 emission than fuel vehicles do at the same distance. Public vehicles consume much less heat energy than private cars no matter which kind of fuel they use. In addition, the CO2 emission of fuel cars is larger than that of fuel buses. Moreover, electric energy is cheaper than gasoline and diesel. Therefore, the electric power will benefit the environment and society. The power should be recommended to substitute oil in the future. Although electric vehicles still have some limitations, such as prolonging the life of batteries, developing new energy, and green energy can guarantee energy security and benefit the environment and reduce the emission of CO2.

1 Introduction

A surge of the vehicle population in China since the 1990s has been primarily due to rapid economic growth and urbanization and has triggered great concern about energy security in the country. The associated CO_2 and air pollutant emissions increase pose a severe challenge to CO_2 mitigation and urban air quality improvement.

Using new energy has become a developmental trend, from industry to daily life. The energy use of road traffic is a considerable part of it, and it is closely related to environmental problems, so the government is immensely concerned about this issue. The main environmental contribution of road traffic is the energy use of fuel vehicles. To reduce the impact of fuel vehicles, electric-powered vehicles are more and more widely used. Furthermore, carbon neutrality is another essential topic: to calculate the total amount of CO_2 emissions and then absorb these emissions by planting trees to achieve the purpose of environmental protection. It is believed that using new energy can also make contributions to the reduction of CO_2 emissions.

To accurately and adequately evaluate vehicle systems' energy and CO_2 emission effects, this research focuses on conventional energy (fuel: gasoline and diesel) and new energy (electricity) vehicles. Using two representative types of vehicles, including cars and buses, this study analyzes the environmental impacts and differences of the two vehicles from the perspectives of energy consumption, CO_2 emission cost, and energy safety.

2 Energy Crisis in China

2.1 Oil dilemma in China

China is a poor-oil country compared with the USA and Russia and is the largest oil importer in the world. The oil reservation in China just can meet the demand for 40 days when the routes of oil importing are blocked, although 9 bases of oil reserve have been constructed and put into operation. Hu et al. analyzed that the geo-oil security index steadily increased from 3 to 10 between 1995 and 2010. It means that China is increasingly at a disadvantage in energy security and energy politics. 5 billion tons of oil were imported by China in 2019 [1]. According to China Energy Statistical Yearbook [2], Beijing does not produce crude oil and diesel oil, so it is necessary to transport diesel and petroleum from other regions or other countries. To guarantee oil supplement in Beijing and China, most cities have to import oil from other countries. However, the oil production or oil price is fluctuant due to geopolitics. For instance, a political dispute in which a senior official was murdered in Iran in 2020 had impacted the oil price in the world. Then the oil price dramatically increased to 70 dollars per barrel.

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2.2 Main routes and problem

China is facing the crucial challenge of providing sustainable energy because there is no adequate energy sustaining the general utilization in China. In terms of the Report on Chinese Energy Strategy to the Year of 2030 [3], the total of fossil fuel resources that could be utilized only is 3600 mtce/a, including 4100 Mt/a coal and 300 Gm^3 /an oil. China highly relies on oil importation from western Asia, Russian, and Western Africa with ocean shipping and pipelines because China is facing oil depletion in main oil fields, especially in the Karamay oil field and Daqing oil field. Moreover, the degree of oil dependency in China rapidly increases from 1.39% to 70.83% during 1996 to 2018 [4]. There is the largest oil transport from Western Asia to China from the Strait of Hormuz with the Strait of Malacca. In contrast, the political situation, wars, and religious conflicts in the strait region cannot be predicted. By 2021, fortunately, China and Iran have signed a 25-year cooperation agreement involved oil importing, the investment of constructing ports, and the new payment system of CNY. Additionally, the investment of Gwadar Port in Pakistan will be beneficial to break the dilemma for guaranteeing oil security via pipeline or trains in the future. As the closest oil importing country, the relationship between China and Russia is not only at the peak and will maintain a friendly relationship several years later. Oil has been transmitted by pipeline from Russia. The infrastructure of an oil pipeline in China is improving and needs cooperation to construct the pipeline in different countries, especially Russia. Importing oil from Russia to Beijing and other regions may reduce shipping costs and may guarantee oil security. However, China should facilitate the pipeline's construction and maintain the mutually beneficial relationship between Russia and China. However, the emission of CO_2 will be increased by transporting and mining oil, and the environment also will be destroyed with mining.
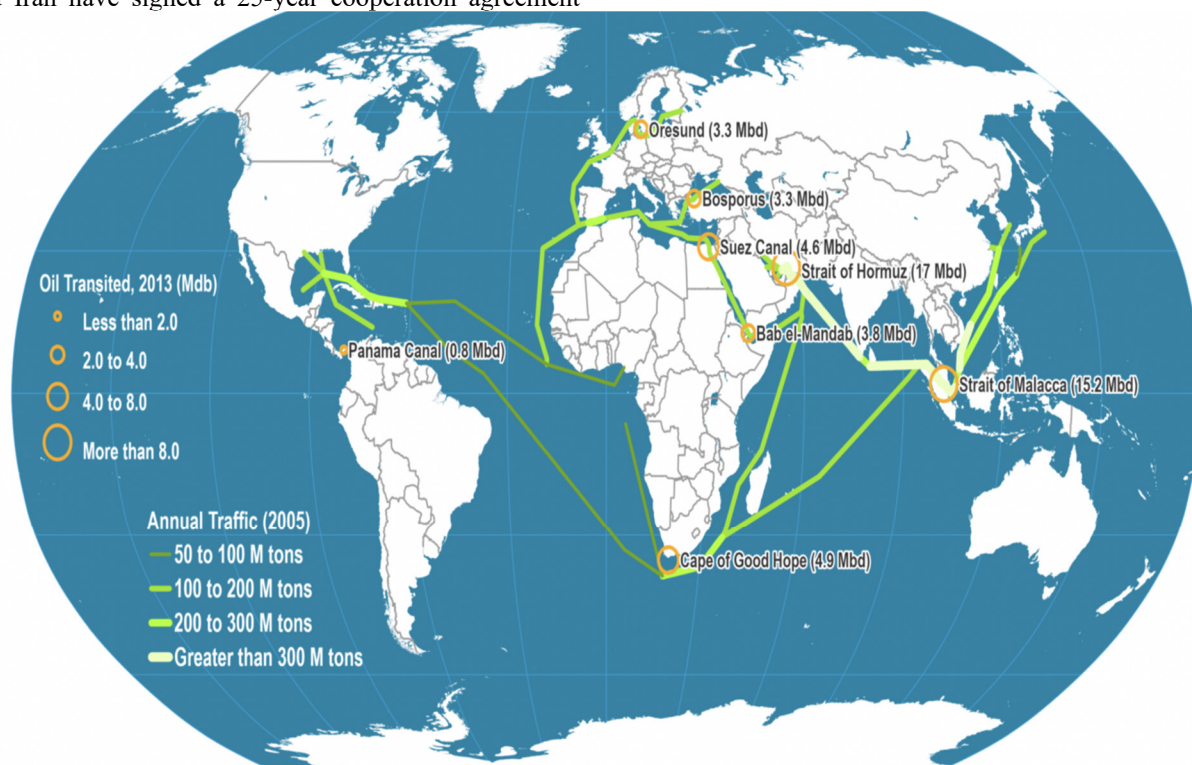

Figure 1. Major Oil Flows and Chokepoints [5]

2.3. **Electricity generation of different vehicles**

2.3.1. Electricity generation. In terms of the China Energy Statistical Yearbook [2], the power generation in Beijing is only 451×10^8 kWh in 2018. The generation cannot meet the demand for electricity in Beijing. Electricity should be transmitted from peripheral provinces, like Hebei, Shanxi, and Inner Mongolia. The electricity in Hebei, Shanxi, Inner Mongolia is mainly generated by thermal power, so generating electrical power has to utilize fossil fuel. Therefore, the approach for generating electricity is not sustainable and will damage the environment. The development of green and sustainable energy in Beijing and peripheral provinces cannot meet consumption in a short-term time even if there are several projects of green energy in Inner Mongolia and Hebei.
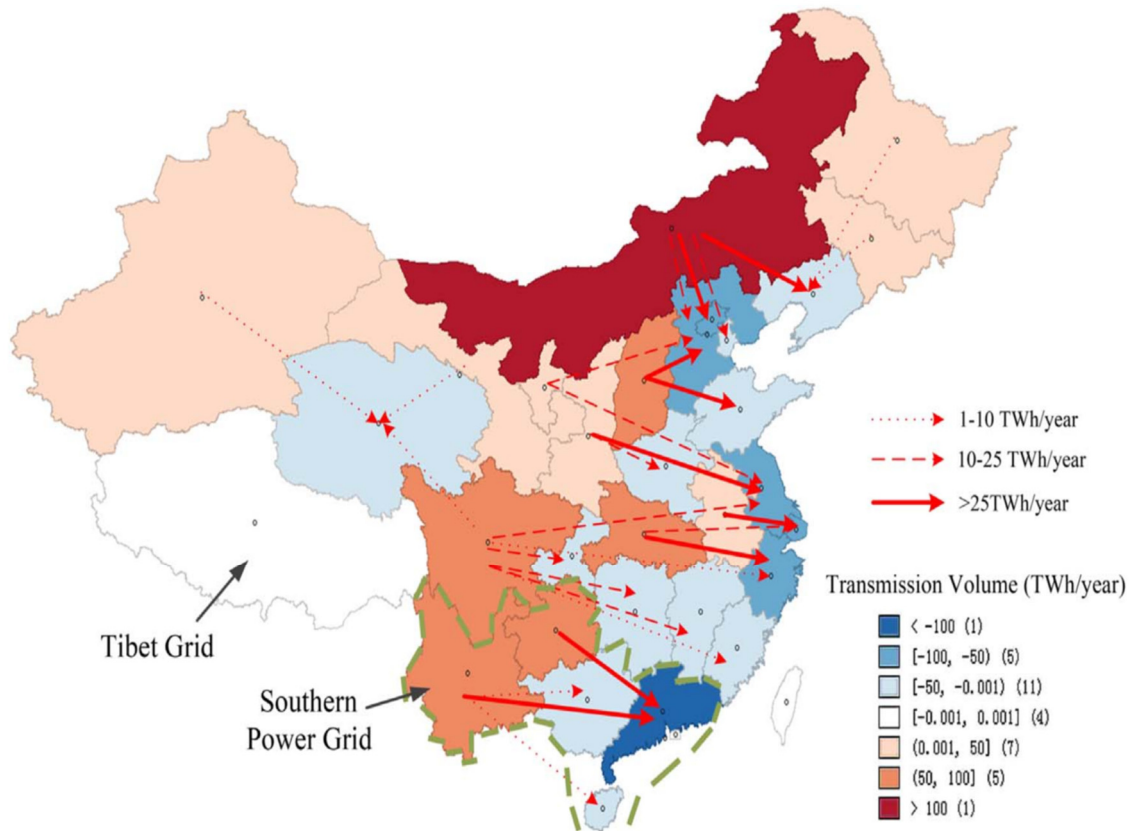
Figure2. The electric transmission paths [6]

2.3.2. Problems and measures. Since there are a lot of factories in Northern China and Northeastern China, generating electricity in Northern China, however, highly relies on thermal power, and the amount of electricity is not adequate to maintain the normal industrial and agricultural development in Beijing and the whole Northern China. Moreover, the population in Beijing is 21.53 million, so the demand for electricity for life, business, and industry are astonishing. In comparison, Southwestern and central China, Yunnan, Sichuan, and Hubei, which have too much surplus power for life and industry, can mainly utilize abundant hydropower to generate electricity. With the West-East Power Transmission project application, hydropower provides more sustainable and green energy for eastern China. Actually, the hydropower industry is rapidly developing in western and central China, while the technology and power transmission are not available to transmit hydropower from Yunnan and Sichuan to Beijing. In addition, solar power generation and wind power generation also provide power supplements for Beijing from Hebei and Inner Mongolia. Still, solar power and wind power are very low, although the powers are more sustainable. It is unnecessary to rely on the electronical importing from other countries as oil, so electricity transmission will not be controlled. If electricity becomes essential energy in the future instead of oil, the cost for generating electricity will be lower and more sustainable than oil. Most citizens could afford electricity bills in the future, and the electricity bill definitely will be lower than

petroleum.

3 Energy consumption and cost of different vehicles

Consumption of gasoline cannot directly compare with consumption of electricity because they are different substances. Therefore, to analyse the consumption of energy, energies consumed by buses and private cars are transformed into heat energy (1kWh equals 3600 kJ). To differentiate the energy consumption of buses and cars more clearly, the energy consumption per person is figured out. All the calculations will be based on assuming that one car takes 5 persons and one bus takes 85 persons.

3.1 Energy consumption of cars

3.1.1. Electric cars. For electric cars, the total electricity consumption per 100 km is 15 kWh [7]. The equations are as following:

$$ECEC = TECEC \times 3600 \qquad (1)$$

$$ECEC_0 = ECEC/P \qquad (2)$$

Where *ECEC* is energy consumption per 100 km of one electric car (kJ); *TECEC* is total electricity consumption per 100 km (kWh); *P* is how many people one vehicle can take at one time. Table 1 shows the calculated energy consumption of electric cars.

Table 1. Energy consumption of electric cars

Types	Energy consumption
Total electricity consumption per 100 km	15 kWh
Energy consumption (kJ/100 km·car)	54000 kJ
Energy consumption (kJ/100 km·people)	10800 kJ

3.1.2. Fuel cars. For fuel cars, they use gasoline as their power supply. The total volume of gasoline per 100 km is 10.49 L [8]. The calorific value of gasoline is 44200 kJ/kg, and the density of gasoline is 0.725 kg/L [9]. The equations are as following,

$$m = d \times v \tag{3}$$

$$ECCC = CVG \times m \tag{4}$$

$$ECCC_0 = ECCC \div P \tag{5}$$

Where *m* is the total mass of gasoline per 100 km (kg); *d* is the density of gasoline (kg/L); *v* is the total volume of gasoline per 100 km (L); *ECCC* is Energy consumption per 100 km of one fuel car (kJ); *CVG* is Calorific value of gasoline (kJ/kg). Table 2 shows the calculated energy consumption of fuel cars.

Table 2. Energy consumption of fuel cars

Types	Energy consumption
Total volume of gasoline per 100 km	10.49 L
Total mass of gasoline per 100 km	7.61 kg
Energy consumption (kJ/100 km·car)	336362 kJ
Energy consumption (kJ/100 km·people)	67272 kJ

3.2 Energy consumption of buses

3.2.1 Electric buses. For electric buses, total electricity consumption per 100km is 120 kWh [7]. So,

$$ECEB = TECEB \times 3600 \tag{6}$$

$$ECEB_0 = ECEB \div P \tag{7}$$

Where *EEC* is energy consumption per 100 km of one electric buses (kJ); *TECEB* is total electricity consumption per 100 km (kWh). The calculated energy consumption of electric buses is presented in table 3.

Table 3. Energy consumption of electric buses

Types	Energy consumption
Total electricity consumption per 100 km	120 kWh
Energy consumption (kJ/100 km·bus)	432000 kJ
Energy consumption (kJ/100 km·people)	5082

3.2.2 Fuel buses. For fuel buses, they use diesel as their power supply. The total volume of diesel per 100 km is 35

L [7]. Calorific value of diesel is 42500 kJ/kg and density of gasoline is 0.84 kg/L [9]. The equations are as following,

$$ECCB = CVD \times m \tag{8}$$

$$ECCB_0 = ECCB \div P \tag{9}$$

ECCB is energy consumption per 100 km of one fuel bus (kJ); *CVG* is the Calorific value of diesel (kJ/kg). The calculated energy consumption of fuel buses is presented in table 4.

Table 4. Energy consumption of fuel buses

Types	Energy consumption
Total volume of diesel per 100 km	35 L
Total mass of diesel per 100 km	29.4 kg
Energy consumption (kJ/100 km·bus)	1249500 kJ
Energy consumption (kJ/100 km·people)	14700 kJ

3.3 Cost of different vehicles

After calculating the differentiation of energy consumption, the cost of using buses or cars is figured out through a simple assumption. The calculation only considers the cost of recharging energy through petrol stations (fuel transportation) or charging piles (electric transportation) to see which type of vehicles is more sustainable from an economic perspective to users.

For electric cars and buses, the price of electricity through the charging pile is 1.71 yuan/kWh [10] (average of all periods and locations, including 0.8 yuan/L service charge). After the oil price adjustment in 09.04.2021, for fuel cars, the price of gasoline (92) is 6.6 yuan/L, and for fuel buses, the price of diesel (0) is 6.26 yuan/L. The equation is as follows,

$$C = Pe \times TEC \tag{10}$$

Where *C* is the cost of different transportation; *Pe* is the price of different energy; *TEC* is the total energy consumption of different transportation per 100 km. The calculated cost of different transportation is presented in table 5.

Table 5. Cost of different transportation

Types	Cost/yuan
Cost of fuel cars (100 km)	$10.49 \times 6.6 = 69.23$
Cost of electric cars (100 km)	$15 \times 1.71 = 25.65$
Cost of fuel buses (100 km)	$6.26 \times 35 = 219.1$
Cost of electric buses (100 km)	$1.71 \times 120 = 205.2$

4 CO₂ emission of different vehicles

In this study, the calculation does not consider the CO_2 emission of the energy-producing process. Only an easy calculation of the CO_2 emission during the process of energy consumption is considered.

4.1. CO2 emission of cars

4.1.1 Electric car. Similar to the electric bus, it is considered that no CO2 is released during the electricity-consuming process. The CO_2 emissions of electric buses are presented in Table 6.

Table 6 CO$_2$ emission of electric cars

Types	Electricity consumption&CO$_2$ emission
CO$_2$ emission per 100km of one car	0 kgCO$_2$
CO$_2$ emission per 100km of one person	0 kgCO$_2$

Obviously, even though consuming electricity does not discharge CO_2, producing and transporting process will discharge CO_2 [11]. If we consider the whole life cycle of electricity, the carbon emission factor is 1.246 kg/kWh [12], the value of which is provided by the North China Power Grid (NCPG). It is obtained through the CO_2 emissions from all power plants of NCPG (kg) divided by the whole power supply of these power plants(kWh). Therefore, the CO_2 emission of one electric bus is 149.52kg, and that of one electric car is 18.69kg.

4.1.2. Fuel car. For fuel cars, it is assumed that these cars use gasoline as their power supply. The CO_2 emission factor of gasoline is 2.26kg CO_2/L, which means that consuming 1 liter of gasoline will discharge 2.26kg CO_2 into the atmosphere. The equation of CO_2 emission per 100 km of one fuel car is as follows.

$$m_C = F_g \times V_g \qquad (11)$$

where m_C is CO_2 emission per 100 km of one car (kg); F_g is the CO_2 emission factor of gasoline (kg CO_2/L); V_g is the volume of gasoline per 100km of one car (L).

In this calculation, it is assumed that one fuel car can take 5 people. Therefore, CO_2 discharged by a fuel car per person per 100km can be calculated. The equation to calculate the CO_2 emission of a fuel car per person per 100km is equation (11). Table 7 presents the calculated CO_2 emission of fuel cars.

Table 7 CO$_2$ emission of fuel cars

Total volume of gasoline per 100 km of one car	10.49 L
CO$_2$ emission per 100km of one car	23.74kgCO$_2$
CO$_2$ emission per 100km of one person	4.75kgCO$_2$

4.2. CO2 emission of buses

4.2.1 Electric bus. For electricity-powered vehicles, it is considered that no CO2 is released during the energy-consuming process. The electricity itself does not discharge any CO_2 into the atmosphere. Thus, the CO_2 emission of electric buses is presented in Table 8.

Table 8. CO$_2$ emission of electric buses

Types	Electricity consumption&CO$_2$ emission
Total electricity consumption per 100 km of one bus	120kWh
Carbon emission per 100km of one bus	0kgCO$_2$
Carbon emission per 100km of one person	0kgCO$_2$

4.2.2 Fuel bus. For fuel buses, it is assumed that they use diesel as their power supply. The CO_2 emission factor of diesel is 2.61kg CO_2/L, which means that consuming 1 liter diesel will discharge 2.61kg CO_2 into the atmosphere. The equation of CO_2 emission per 100 km of one fuel bus is as follows.

$$m_B = F \times V \qquad (12)$$

where m_B is CO_2 emission per 100 km of one bus (kg); F is CO_2 emission factor of diesel (kg CO_2/L); V is the volume of diesel per 100km of one bus (L).

In this calculation, it is assumed that one fuel bus can take 85 people at one time. Then the amount of CO_2 discharged by a fuel bus per person per 100km is known.

$$m_P = m_B/P \qquad (13)$$

where m_P is CO_2 emission per 100 km of one person. Table 9 shows the calculated CO_2 emission of fuel buses.

Table 9. CO$_2$ emission of fuel buses

Types	CO$_2$ emission
CO$_2$ emission per 100km of one bus	91.21kg CO$_2$
CO$_2$ emission per 100km of one person	1.07kgCO$_2$

5 Discussion

5.1 Energy Consumption

Through comparing the consumption of heat energy of different transportation, the electric vehicles (buses and cars) consume less heat energy than fuel vehicles do in same distance. This means that vehicles use electric energy more effectively than ones using gasoline or diesel. Furthermore, gasoline and diesel are non-renewable resources and consider the strong dependency of gasoline and diesel in China's industries. Energy reserves are not abundant. But electric energy is renewable resources. Due to its high efficiency and renewable property, electricity is a more ideal vehicle than gasoline and diesel. Government should accelerate the transformation of energy structure in the transportation system.

Compared with fuel vehicles, the energy consumption of electric vehicles is less than fuel vehicles (Figure 3). Therefore, electric vehicles are assumed to be more energy sustainable. If the government focuses on promoting energy transformation in vehicles, a great number of fuel energies will be saved. Taking Beijing as an example,

according to the Beijing transportation development annual report [13], the number of private cars is 4970300, the annually total miles of a private car in Beijing is 14332 km, and the buses run 1278600000 km a year in total. If 10% of these fuel cars transform into electric cars, about 0.7 billion liters of gasoline and 44.8 million liters of diesel will be saved, which are definitely a tremendous number.
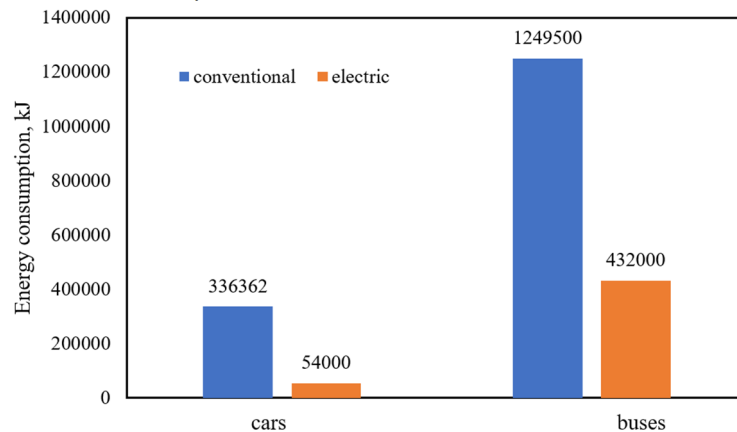

Figure 3. Energy consumption per bus/car (100 km)

When energy consumption is divided by the number of passages that vehicles can take at one time. Fuel cars consume about 5 times more energy than fuel buses, while electric cars consume about 2 times more energy than electric buses (Figure 4). This indicates the importance of promoting public vehicles because public vehicles consume much less heat energy than private cars, no matter which kind of energy they use. Therefore, how to attract people to take buses instead of using private cars requires more in-depth thoughts.
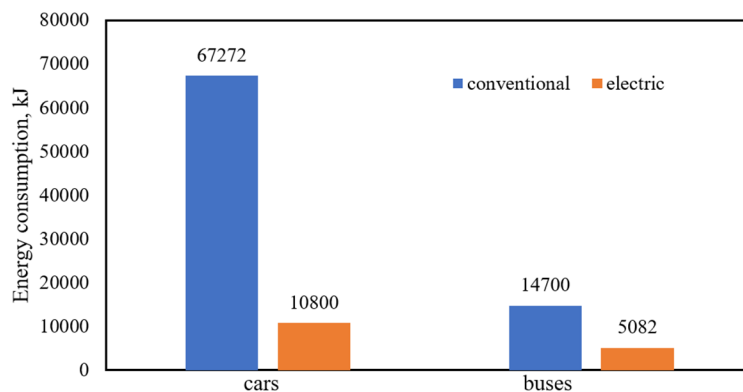

Figure 4. Energy consumption per person (100 km)

5.2. Cost

By comparing the cost (recharging energy) of different transportation, electric energy is cheaper than gasoline and diesel (Figure 5). This means that if government prompts energy reformation from fuel energy like gasoline and diesel to electric energy, the operating cost will decrease. This phenomenon is more remarkable in cars than in buses.

Therefore, it is necessary to accelerate the innovation of energy structure in private cars. Taking Beijing as an example, the number of private cars is 4970300, and the annual total miles of a private car in Beijing is 14332 km [13]. If 10% of these fuel cars transform into electric cars, it will save over 3 billion money in recharging gasoline every year.
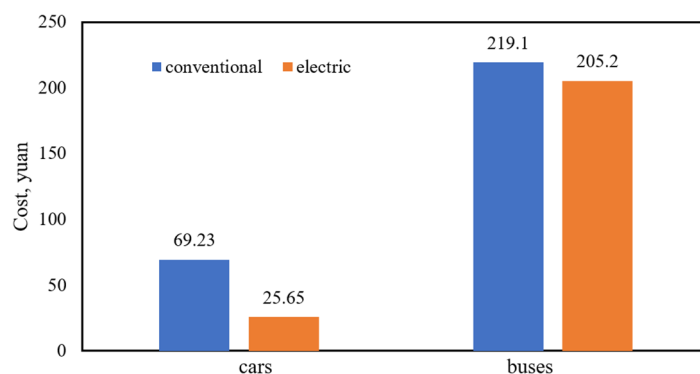
Figure 5. Cost of one bus/car (100 km)

From another perspective, the cost of one bus is higher than one car. This is because they can take different passengers at one time. Therefore, if the cost is divided by the number of passages which they can take at one time, for fuel vehicles, cars (13.58 yuan/person) will cost about 6 times more than buses (2.58 yuan/person). As for electric vehicles, cars (5.13 yuan/person) will cost about 2 times more than buses (2.41 yuan/person). This indicates that if the government wants to cut down costs in operating aspects, encouraging more people to take buses is viable.

In conclusion, to reduce the operating cost in transportation, the government should accelerate the speed of transforming energy structure and attract more civilians to choose buses as major transportation way instead of private cars.

5.3 CO_2 Emission

By comparing electricity and fuels, electric energy is much cleaner than gasoline and diesel during the consuming process. To be more specific, for both bus and cars, which represent large vehicles and small vehicles, we can draw the same conclusion. That is, vehicles powered by electricity is much cleaner on the contrary, vehicles powered by gasoline or diesel discharge a certain amount of CO_2, which will cause the greenhouse effect. Therefore, electricity is a more ideal power of vehicles than gasoline and diesel.

From another perspective, the CO_2 emission of fuel cars is larger than that of fuel buses. According to this result, to protect the environment, the rate of taking buses should be increased. Compared with buses, private cars will discharge more CO_2 that will pollute the atmosphere more. Besides, the number of cars is usually huge, which means that the total amount of CO_2 emission will be an alarming statistic. Taking Beijing as an example, the number of private cars is 4970300, and the annual total miles of a private car in Beijing is 14332 km [13]. All these cars will discharge 3.3 million tons of CO_2. Because of this, to reduce CO_2 emission, the Chinese government could introduce effective policies to encourage more people to take buses instead of driving their cars.

5.4 Limitation of electricity

Electric vehicles indeed have advantages—it is more environmentally friendly than fuel vehicles. However, electric vehicles have some disadvantages. First, they have a limited driving range. Typically, electric vehicles have a range of about 150 km, while the actual range, taking into account factors such as weather, road conditions, and batteries, the capacity is about 100 km. It requires drivers to make driving plans ahead of time. Second, electric vehicles need support from charging infrastructures. The lack of public charging piles affects the experience of electric vehicles, and it takes about 5~8 hours to be fully charged. Finally, for electric vehicles, the battery is the source of power. The battery life is usually short because of the limitation of technology nowadays. After a long time of use, the batteries are bound to decay, which means their range is reduced. In general, the first year of the battery declines about 8%, and then it is 4% for the next two years, and after five or six years, it decays by about 1% a year [14]. Hence, there are some imperfections of electric vehicles that impede the development of electric vehicles.

In the future, the countries should devote the time and effort to research and develop the battery of electric vehicles, including extending the range of driving per charge, prolonging the life of batteries, and increasing the quality of charging infrastructures.

6. Conclusion and prospective

This study analyzes energy consumption, cost, and CO_2 emission of electric vehicles and fuel vehicles (gasoline-powered and diesel-powered ones).

The energy consumption, cost and CO_2 emission of electric vehicles, including buses and cars, are much smaller than gasoline and diesel vehicles. Fuel cars consume about 5 times more energy per person than fuel buses, while electric cars consume about 2 times more energy per person than electric buses. Moreover, the cost of one bus is higher than one car because they can take different passengers at one time. In addition, the CO_2 emission of fuel cars is larger than that of fuel buses. Therefore, to reduce the energy consumption, the operating cost in transportation, and the CO_2 emission, the Chinese government could introduce effective policies to encourage more people to take buses instead of driving their cars.

As China's capital, Beijing will rely on oil and thermal power for transportation in the long-term period. Oil and thermal power definitely impact the environment and is

not sustainable. Additionally, China is facing the challenge of energy security. To guarantee energy security and sustainable energy in China, facilitating the construction of new energy like hydropower and solar power will improve oil and thermal power dependency. Utilizing new energy to substitute oil and thermal power is impossible in the short term due to the consideration for the cost of new energy and technology. Developing new energy and green energy can guarantee energy security and benefit the environment and reduce the emission of CO_2. For electricity, hydropower is more sustainable than oil and thermal power. West-East Power Transmission and the development of ultra-high voltage transmission technology might effectively solve the lack of electricity in Beijing in the future. Moreover, peripheral regions develop green energy instead of fossil fuel for electricity will benefit the environment and can be sustainable to provide power for Beijing in the long term. Thus, electricity can benefit the energy security and cost and certainly can improve the environment and air pollution. Overall, the investment in electric vehicles and other transportation should be increased. Then electric transportation will be more beneficial for human beings.

Although the advantages of electricity, electric vehicles still have some limitations, especially the battery of electric vehicles, such as the range of driving per charge, prolonging batteries' lives, and increasing the quality of charging infrastructures. The government should also devote time and effort to the research and development of electric vehicles.

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