Analysis on the Development Path and Potential of Electrification Level in the Field of Transportation in China

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Abstract. In view of the current low level of electrification in global and Chinese transportation, this paper selects five key areas to improve the level of electrification, such as electric vehicle, urban rail transit, electrified railway, ship shore power and airport bridge equipment, carries out technical and economic analysis, and studies and evaluates the future development trend of the five technologies. Finally, according to the situation in 2020 and 2030 respectively, this paper carried out the calculation of electrification improvement potential. The research results provide a key path for improving the electrification level in the field of transportation, and analyze the feasibility and future potential of the path, providing a reference for the global and Chinese governments to improve the electrification level in the field of transportation.

1. Introduction
In recent years, with the rapid development of China's economy, the transportation industry has developed rapidly and energy consumption has increased significantly. However, as the main energy consumption in the field of transportation is oil, it leads to the serious aggravation of environmental pollution[1]. At the same time, with the acceleration of China's urbanization process and the increase of car ownership, the proportion of carbon emissions in the transportation sector is expected to keep rising. China's commitment to carbon intensity in 2030 on the basis of 2005 by 60% - 65% of the target and the global temperature control of 2 ℃. Under the pressure of this scenario, accelerating the electrification in the field of transportation is already imminent.

At present, the level of electrification in the global transportation sector has been at a low level for a long time, only 1.3% in 2015 and only 0.1 percentage point higher than 2010. But in 2016, China's terminal energy consumption in the transportation sector was 370 million tons of coal, accounting for 11.6 percent of the country's total terminal energy consumption. Among them, electricity consumption is 153.8 billion KWH, accounting for 4.2% of the traffic terminal energy consumption, and the level of electrification is still low. With the improvement of electrification level in the field of transportation has become the consensus of the governments and industries of all countries, the future development space is huge[2].

2. Research on key technologies for improving electrification level in the field of transportation
The major electric power technologies in China's transportation sector include electric vehicles, urban rail transit, electrified railways, ship shore power and airport bridge equipment, which are analyzed respectively in terms of technical economy and environmental protection. The results show that all th
five technologies are technically feasible. In terms of economy, electric vehicles, electrified railways and airport bridge equipment are more economical. Due to the impact of huge initial investment and high operation and maintenance costs, urban rail transit is poor in economy[3]. However, due to social and environmental benefits, the driving effect of government investment and non-economic constraints, the state has issued mandatory environmental protection policies and switched to light oil, which will highlight the economy of electricity. The specific analysis is as follows:

2.1. Electric Cars
Electric vehicles are characterized by high efficiency, energy saving, low noise and zero emission, and have incomparable advantages in environmental protection and energy saving. Developing electric vehicles is an important means to solve energy crisis and environmental problems, and an effective way to implement energy security strategy, promote low-carbon economic transformation and promote ecological civilization construction[4].

Electric cars use less energy than fuel cars. If the electric passenger car is selected, it can be calculated according to the annual driving distance of 10,000km, the power consumption of 100km is 20 KWH, and the electricity price is 0.52 RMB/KWH (not considering the cost of battery replacement within the life of the vehicle). The fuel oil vehicle can be calculated according to the fuel consumption of 8 liters per 100km and the oil price of 5.77 RMB/liter (currently the highest retail price of 92# gasoline released by the national development and reform commission). Even if the charging is considered in the operating charging facilities, the charging cost will still be lower than the fuel consumption cost.

2.2. Urban Rail Transit
Urban rail transit system is a kind of vehicle transportation system which is located in the city or between the city and the suburb, including subway, light rail, fast rail, tram and so on. Rail transit takes electric power as its energy source, featuring large volume, fast speed, safety, punctuality, environmental protection and energy conservation. It is an effective way to solve urban traffic problems[5].

Urban rail transit is not economic, but the significant social benefit is the main driving force of its development. The investment in urban rail transit is quite huge. From the perspective of construction cost, China invested 220 billion RMB in the construction of urban rail transit in 2014. From the perspective of the average cost per kilometer of urban rail transit, tram is about 20 million RMB, light rail is about 200 million RMB, and subway is about 500 million RMB. Under the influence of urban scale, economic development level, land price and other factors, the construction cost of some cities is higher. From the perspective of operating cost, the operating cost is estimated to be 2—6 times of the construction cost based on the calculation of vehicle scrapping after 30 years of depreciation. Therefore, the high investment of rail transit makes it not economical compared with other traditional modes of transportation. However, due to its unique characteristics of comfort, efficiency, rapidity and environmental protection, the huge social benefits have become the fundamental driving force for its rapid development.

The environmental protection advantages of urban rail transit are significant. Since metro and light rail account for up to 81.9% of urban rail transit, this paper selects metro and light rail as the representative of urban rail transit system to conduct comparative analysis of energy consumption and pollutant emissions with fuel cars and buses. The results show that under different load rates, the energy consumption and pollutant emission of urban rail transit are far lower than that of traditional fuel transportation, with the lowest energy consumption and the highest environmental protection.
2.3. Electrified Railways

Electrified railway is a kind of modern transportation vehicle with electric energy as traction power. It takes electric energy as power source and has the characteristics of large volume, fast speed, safety and comfort. It has entered the high-speed development stage in China.

Electric traction is more economical than fuel traction. The main traction for electrified railway traction power, compared with traditional diesel traction in the economy is mainly manifested in the operating costs associated with traction, mainly includes: energy cost, locomotive maintenance cost, depreciation cost, material, manpower and power supply system operation and maintenance cost needed for locomotive traction, of which the first three items account for the highest proportion.

In terms of energy cost, the electric energy cost of electric locomotive is about 83 RMB per 10,000 tons and kilometers, and the fuel cost of diesel locomotive is about 147-196 RMB. The higher the oil price, the more obvious the energy cost advantage of electric locomotives will be. In terms of maintenance and depreciation cost of locomotives, the maintenance cost of electric locomotives is lower than that of diesel locomotives due to the length of fixed inspection kilometers, long maintenance cycle and less relative maintenance amount. There is little difference in purchase price between electric locomotive and fuel locomotive when their technical performance is close to each other. Therefore, the expected residual value of electric locomotive is higher than that of diesel locomotive, and the annual depreciation cost of electric locomotive is lower than that of diesel locomotive. In terms of consumables, operation and maintenance, and labor cost, the cost of electric locomotive is lower than that of diesel locomotive due to less consumables and labor allocation. Overall, electric traction has obvious advantages over internal combustion traction. According to the calculation by China Railway Corporation, the standard fuel consumed by electric traction is 15% lower than internal combustion traction, the efficiency of electric locomotive is 54% higher than that of diesel locomotive, and the transportation cost of electric traction is 60% lower than that of internal combustion traction[6].

Table 2. Economic comparison of electric traction and internal combustion traction.

| Cost type       | Electric traction | Diesel traction |
|-----------------|-------------------|-----------------|
| Energy costs    |                   |                 |
| Energy consumption (2014) | 103.3kWh/ Wan ton-km | 27.2kg/ Wan ton-km |
| Energy prices   | 0.8RMB/ Kwh       | 5.4-7.2RMB/kg   |
| Depreciation cost | Low              | High            |
| Material cost   | Low               | High            |
| Operational costs | Low              | High            |
| The human cost  | Low               | High            |
| The total cost  | Low               | High            |
2.4. Electric Cars

Shore power of a ship means that during the period when the ship is in port, the generator on the ship is stopped and the onshore power supply is used instead. The specific technical scheme includes three types: low-voltage shore power technology with small capacity, low-voltage shore power technology with large capacity and high-voltage shore power technology with large capacity. All three technical schemes have been adopted in various demonstration projects of ports and wharfs in China.

The economy of ship shore power is poor. Based on 4250TEU ship power supply and single berth 1000kW power, port electricity price is 0.7RMB/kWh. The fuel consumption rate of Wartsila four-stroke diesel engine is 0.216kg/kWh. According to the heavy oil (IFO380) price reported by Alphazone on March 9, 2016, it was 1822 RMB/ton, equivalent to 1.82 RMB/kg. Marine light diesel (MGO) oil price is 7194 RMB/ton, equivalent to 7.19 RMB/kg. Under the same circumstances, it costs 0.39 RMB for a Marine generator to generate kilowatt-hour power with IFO380, 1.55 RMB for MGO, and 0.7 RMB for direct shore power. It can be seen from the calculation that when ships use IFO to generate electricity, the cost is lower than that of shore power, and when they use MGO to generate electricity, the cost is much higher than that of shore power. See table 3 for details.

The ship shore electricity environmental protection benefit is remarkable. According to the calculation, the discharge status of a 4250TEU container during the port stop is PM10:221kg/year, PM2.5:177kg/year, NOX: 2340kg/year, SOX: 1240kg/year, CO: 198kg/year, CO2:123t/year. But the application ship shore power supply has the discharge almost[7].

Table 3. Comparison of the cost of marine diesel power generation and shore power generation.

| Marine diesel generator set | Shore power |
|----------------------------|-------------|
| IFO380 fuel consumption | MGO style fuel consumption |
| The unit price | The unit price | The unit price |
| Cost | 0.216kg/kWh | 0.216kg/kWh | 7.19RMB/kg |
| 1.82RMB/kg | 0.7RMB/kWh |
| Compared with the price of shore Power | Cheaper than 0.81 RMB | More expensive than 0.35 RMB |

2.5. Airport Bridge Equipment

Bridge equipment (GPU) mainly uses airport static transformer power supply and aircraft ground special air conditioning, the purpose of which is to provide electrical energy for the aircraft during its stay on the ground. The aviation industry uses bridge equipment to replace APU, which is an important energy saving and emission reduction technology and electric energy replacement technology, and has significant economic and environmental benefits.

Airport bridge equipment can save half of the cost compared with APU. By replacing APU with ground bridge equipment, airlines can reduce aviation fuel consumption and effectively reduce operating costs. The cost of APU mainly includes fuel consumption and operation and maintenance. The cost of aviation fuel is calculated at RMB 7,700 per ton, and the maintenance cost is provided by the airport maintenance department. As can be seen from table 17, the total cost of using APU for the three models is 1151 RMB, 2081 RMB and 3592 RMB respectively. The total cost of switching to the bridge equipment is about 600 RMB, so the operation cost can be saved by 551 RMB, 1481 RMB and 2992 RMB per hour for the three models using the bridge equipment. Compared with the APU, it can save at least half of the operation cost, and the larger the model, the greater the profit.
Table 4. Cost-benefit analysis of airlines using bridge equipment instead of aircraft APU.

| Model | Fuel costs (RMB/h) | Maintenance cost (RMB/h) | Total cost (RMB/h) | Power supply charge (RMB/h) | Air conditioning charge (RMB/h) | The total cost (RMB/h) |
|-------|-------------------|--------------------------|-------------------|---------------------------|-------------------------------|------------------------|
| A320  | 1001              | 150                      | 1151              | 240                       | 360                           | 600                    |
| MD11  | 1856              | 225                      | 2081              | 240                       | 360                           | 600                    |
| B747  | 3142              | 450                      | 3592              | 240                       | 360                           | 600                    |

3. Estimation of development potential of electrification level in the field of transportation.

In the future, the main way to improve the level of electrification in the field of transportation is through the development of electric cars, rail transit and electrified railways, while the ship shore power and airport bridge equipment is an important supplement. It is estimated that in 2020, about 295.6 billion kilowatt-hours of electricity will be consumed in the national transportation sector, and the electrification level of transportation will be about 6.5 percent, according to the national and transportation related planning and industry statistical bulletin. With the rapid development of electric cars, rail transit and electrified railways, about 596.6 billion kilowatt-hours of electricity will be used in the national transportation sector by 2030, and the electrification level of transportation will be about 8.7%.

Table 5. Development potential of major technology electrification level in the field of transportation in China.

| The mode of transportation | The main technical             | National replacement potential |
|----------------------------|--------------------------------|-------------------------------|
|                            |                                | In 2020                       | In 2030                       |
| highway                    | The electric car               | 343                           | 1875                         |
| Low-speed electric vehicle |                                | 1596                          | 2377                         |
| rail traffic               |                                | 400                           | 875                          |
| railway                    | Electrified railway            | 449                           | 630                          |
| waterway                   | Shore power technology         | 160                           | 192                          |
| aviation                   | Airport bridge equipment       | 8                             | 16.7                         |
| combined                   |                                | 2936                          | 5966                         |

3.1. Electric Cars

China has given strong support to the development of electric vehicles, offering subsidies and exempting vehicle purchase taxes. Cities that have implemented total vehicle license control have also introduced policies such as separate license plates for electric vehicles and free license plates, giving a strong boost to the large-scale application of electric vehicles. The replacement space for pure electric vehicles will gradually expand. By 2015, China had produced nearly half a million pure electric vehicles and plug-in hybrid vehicles, and by 2020, China will have more than 5 million electric vehicles, using about 34.3 billion kilowatt-hours of electricity. It is expected that by 2030, with the rapid development of electric vehicles, the electricity consumption of electric vehicles will reach 187.5 billion kilowatt-hours.

It is worth noting that the rapid development of domestic low-speed electric vehicles in recent years can't be ignored. By 2015, China's low-speed electric vehicle ownership reached 21 million, with an annual sales volume of more than 30 million and a growth rate of about 50%, showing a rapid development. It is estimated that by 2020, the total number of low-speed electric vehicles will reach about 280 million, and the country's electricity consumption will reach about 159.6 billion KWH. By 2030, the number of low-speed electric vehicles will total about 440 million, and the country's electricity consumption will reach 237.7 billion kilowatt-hours.

3.2. Urban Rail Transit

The urban rail transit system is an effective way to solve the urban traffic problems at present and has a huge development space in the future. By 2014, China had opened 3,173 kilometers of urban rail transit lines, up 15.5 percent year-on-year. Annual electricity consumption was about 9.4 billion kWh, up about 20% year-on-year. According to the national Urban Rail Transit 2013 Annual Statistical Analysis Report, considering the converted turnover of six major modes of urban rail transit and the
average energy consumption of 100 people kilometers and other parameters, it is estimated that in 2020, China's rail transit operating mileage will reach 13,400 kilometers, and the national rail transit electricity consumption will reach about 40 billion KWH. By 2030, China's rail transit will have an operating mileage of 30,000 kilometers, and the country's rail transit will use about 87.5 billion kilowatt-hours of electricity.

3.3. Electrified Railways
China's electrified railways have entered the stage of high-speed development. By 2014, the length of China's electrified railways reached 65,000 km, an increase of 16.9% over the previous year, and the electricity consumption was about 39.7 billion kWh, an increase of 10.9% over the previous year, accounting for more than 70% of the total electricity consumption in the transportation industry. According to the National Medium and Long Term Railway Network Planning (2008), taking into account such parameters as the converted turnover of electrified railways and the comprehensive power consumption of electric locomotives, it is estimated that the operating mileage of electrified railways in China will reach 72,000 km by 2020, and the electricity consumption of electrified railways in China will reach about 44.9 billion KWH. By 2030, China will have 110,000 kilometers of rail transit in operation, and the country's electrified railways will use about 63 billion kilowatt-hours of electricity.

3.4. Ship Shore Power
Ship shore power is mainly used in the coastal ports, along the river and along the river port terminals. By the end of 2014, China had 5,834 coastal ports and 2,871 ports along rivers and inland waterways, handling 12.452 billion tons of cargo. If ship shore power is popularized and applied in large and major ports, it is estimated that China's ship shore power consumption will be about 16 billion KWH by 2020. It is estimated that by 2030, China's offshore electricity consumption will be about 19.2 billion kilowatt hours.

3.5. Airport Bridge Equipment
According to the 2014 National Civil Aviation Flight Operation Efficiency Report, in 2014, the proportion of bridge equipment replacing APU technology in major domestic airports was about 40%, and remarkable economic benefits and energy-saving and environmental benefits have been achieved. Based on the calculation of using ground bridge equipment and shutting down APU for one hour per flight, it is estimated that the total number of aviation flights will increase to 11.9 million by 2020, among which 6.04 million will be provided by airport bridge equipment, which will consume about 800 million kilowatt hours of electricity. By 2030, the total number of flights will increase to 13.1 million, of which 9.11 million will be served by airport bridge-mounted equipment, using about 1.67 billion kilowatt-hours of electricity.

4. Conclusions and suggestions
To popularize the concept of "replacing oil with electricity" in the field of transportation and improve the level of electrification in the field of transportation are important means to advocate the concept of ecological civilization and realize green development. China should constantly explore the electrification path of transportation and accelerate the electrification process in the field of transportation.

4.1. Differentiated Promotion of Electric Energy Alternative Technology in The Field of Transportation
The Chinese government needs to strengthen overall planning, and promote the implementation of "replacing oil with electricity" in the transportation sector with goals and priorities to improve the level of electrification. For electric vehicles, it is necessary to speed up the establishment of the "seven vertical, four horizontal and two grid" expressway quick charging service network in key cities,
deepen the application of the Internet of vehicles platform, and promote the large-scale development of electric vehicles. For rail transit and electrified railways, it is necessary to strengthen the communication and connection with power grid enterprises and other related subjects, accelerate the construction of power distribution network, and meet their development needs. It is necessary to promote the popularization and application of port power and airport bridge technology in ports and airports, and give priority to the construction and operation of projects with large power load, high equipment utilization rate and good economic benefits.

4.2. Strong Support Policies Will Be Introduced
We will strengthen coordination and linkage between the state energy administration, the ministry of environmental protection, the ministry of communications and other relevant state departments, strengthen research on electrification in the field of transportation, and bring electrification in the field of transportation into the national and departmental development plans at an early date. We will further introduce mandatory environmental protection policies in the transportation sector, raise emission standards, and reduce pollutant emissions. At the same time, we will improve fiscal, taxation and subsidy policies to create a favourable market environment for the development of electrification in the transportation sector.

4.3. Strengthening The Construction of Technical Standard System
We will strengthen the development of technical standard systems for electric vehicles, port power supplies, and bridge equipment, supplement and improve the content of technical standards according to actual conditions, promote the formulation of industry and national standards, and guide the development of related technologies and industries. The research and development of a group of key technical equipment and overall solutions with great market potential and good economy by concentrating superior resources will lay a foundation for the development of transportation electrification.

Acknowledgments
Thanks to the State Grid Corporation Science and Technology Project "Research on the Structural Decomposition and Potential Evaluation Model of Energy Saving in China's Whole Society" (Contract No. 5202011600UA).

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