Economic Analysis of Battery Electric Vehicle Fast Charging Mode and Battery Swapping Mode in China

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Abstract. In China, energy-supplying industry has shown a trend of "charging as the mainstay, supplemented by battery swapping". In this paper, we study and construct the Total Cost of Ownership (TCO) model including capital cost, power battery rental cost, electricity cost, time cost, and maintenance cost. Taking the TCO model as a carrier, we quantitatively analyze the economics of fast charging mode and battery swapping mode in two application scenarios of taxis and private cars, study the impact of the battery swapping unit price on the economics of different modes for taxis and private cars, and discuss the critical price of the battery swapping unit price that is economical for battery swapping mode in different scenarios. We find that, compared with the fast charging mode, the battery swapping mode is more economical and has greater advantages for the taxis.

Keywords: Total Cost of Ownership · fast charging · battery swapping · economic analysis

1 Introduction

In recent years, the global economy has developed rapidly. At the same time, energy security issues, climate issues, and environmental issues have become more and more serious, drawing widespread attention from the whole society. According to data released by the International Energy Agency, among carbon emission sources of China in 2020, the carbon emissions generated by the transportation industry accounted for about 10% of the national total carbon emissions. Among them, the carbon emission in the road transportation sector alone accounts for 8% of the national total carbon emission, which is the most important emission source in the transportation industry. In the future, with the continuous growth of car ownership, the carbon emission situation in the domestic road transportation sector will become more and more severe.

Reducing the use of fossil fuels and reducing emissions of greenhouse gases and atmospheric pollutants plays an important role in alleviating energy security issues and addressing climate and environmental issues. Therefore, the development of new energy vehicles has become a strategic direction for the transformation of the automotive industry, and governments and OEMs around the world have issued electrification implementation strategies and goals. Many countries, regions/cities have successively proposed

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the ban on the sale of fuel vehicles, for example, Norway will ban the sale of fuel vehicles in 2025, Austria and Slovenia will ban the sale of fuel vehicles in 2030, and parts of the United Kingdom and the United States will ban the sale of fuel vehicles in 2035[1]. Many car companies around the world have also announced the end time of their fuel vehicles, such as Nissan plans to stop selling fuel vehicles after 2025, Mercedes-Benz will stop selling fuel vehicles in 2030, and Honda will stop selling fuel vehicles in 2040.

Driven by both policies and markets, new energy vehicle industry in China has developed rapidly. Statistics from the Ministry of Public Security show that by the end of March 2022, the number of new energy vehicles in China has reached 8.915 million[2]. In the first quarter of 2022, the number of newly registered new energy vehicles reached 1.11 million, with a year-on-year increase of 138.2%, showing a rapid development trend.

Although new energy vehicle industry of China is currently showing an optimistic form, it is undeniable that the development of electric vehicles is still constrained by factors such as power battery energy density and energy supply. At present, the vast majority of electric vehicles supply electric energy through charging, and there is a problem of long charging time. Especially for taxis, online car-hailing and other operating vehicles, the charging time will reduce the efficiency of vehicle use. At the same time, due to the high price of power batteries, the initial purchase cost of electric vehicles in charging mode is high, and the initial purchase cost increases with the driving mileage.

In order to reduce the initial cost of purchasing electric vehicles for users and improve the car experience, NIO, BAIC New Energy, Geely and other companies have launched electric vehicles with battery swapping mode. In battery swapping mode, users can choose to purchase the electric vehicle without battery, which significantly reduces the initial purchase cost. When the battery runs out of power, users can go to the swapping station to replace the depleted battery with a charged battery, and the replaced depleted battery enters the swapping station for charging, waiting for the next swapping cycle. Compared with the fast charging mode, the energy replenishment time of the battery swapping mode is shorter, the fastest can be as short as one minute, which can greatly improve the efficiency of the vehicles.

The battery swapping mode has the advantages of low initial purchase cost and short energy replenishment time, but users need to pay additional battery rental. Moreover, due to the high operating cost of the swapping station, swapping service fee is higher than that of the fast charging mode. Economic factors is an important consideration for users to purchase electric vehicles. Therefore, an objective analysis of the life cycle cost of electric vehicle in fast charging mode and battery swapping mode is of great significance for the further development of new energy vehicles and the innovation of business models.

In order to compare and analyze the economics of electric vehicle fast charging mode and battery swapping mode in the whole life cycle, we construct an electric vehicle economic analysis model based on the total cost of ownership (TCO). We calculated the economics of EV Model A, and discussed the impact of the battery swapping unit price on the economy. The analysis results have strong reference value for new energy vehicle users and charging and battery swapping operators.

2 TCO Model

TCO was proposed by Gartner in the 1980s. It includes the initial purchase cost of assets and the cost of subsequent operation and maintenance. It is used to evaluate all costs related to an asset or technology for more effective management and decision-making. As an important indicator to measure the economics of an asset or technology, TCO analysis has been used many times in the automotive industry [3–9]. However, in the field of electric vehicles, there are few economic research results on different energy supply methods for the same vehicle.

The total cost of ownership of an electric vehicle includes vehicle purchase cost and usage costs. The usage costs include electricity cost, time cost, and maintenance cost. For battery swapping mode, the use cost also includes battery rental cost.

For battery swapping mode, the total cost of ownership in the ith year can be expressed as

$$TCO_i = CV_i + BR_i + PC_i + TC_i + MC_i \tag{1}$$

where CV_i represents the apportioned purchase cost in the i^{th} year, BR_i represents the battery rental cost in the i^{th} year, PC_i represents the cost of electricity cost in the i^{th} year, TC_i represents the time cost of taxis in the i^{th} year, and MC_i represents the maintenance cost in the i^{th} year.

For fast charging mode, the total cost of ownership in the ith year can be expressed as

$$TCO_i = CV_i + PC_i + TC_i + MC_i \tag{2}$$

2.1 Vehicle Purchase Cost

The purchase cost of electric vehicles in charging mode includes vehicle body cost and battery cost, while the purchase cost of electric vehicles in battery swapping mode only includes body cost.

When calculating the total cost of ownership of electric vehicles, the purchase cost is discounted to each year in the entire life cycle through cash flow discount, expressed as.

$$CV_i = \frac{CV \times r \times (1 + r)^n}{(1 + r)^n - 1} \tag{3}$$

where CV_i represents the apportioned purchase cost in the ith year, CV represents the initial purchase cost, r is the discount rate, and n is the total service life of the vehicle.

2.2 Battery Rental Cost

In battery swapping mode, the swapping stations purchase batteries, and charge battery rent on a monthly basis. With the continuous growth of the electric vehicle industry and the increase in the production and assembly of power batteries, the manufacturing cost of power batteries will gradually decrease, and the battery swapping station will adjust the battery rent according to the cost of power batteries. According to the learning rate curve [10–11], the annual battery rental cost can be expressed as

$$BR_i = BR_1 \times \left(\frac{N_i}{N_1}\right)^{\log_2 lr} \tag{4}$$

where BR_i represents the battery rental cost in the ith year, BR_1 represents the battery rental cost in the first year, N_i is the production of electric vehicles in the ith year, N_1 is the production of electric vehicles in the first year, and lr is the learning rate of the power battery.

2.3 Electricity Cost

The cost of electricity consumption can be calculated from fast charging unit price, battery swapping unit price and the annual electricity consumption. The specific calculation method is as follows

$$PC_i = p_i \times EC_i \tag{5}$$

where PC_i represents the cost of electricity cost in the i^{th} year, p_i represents the fast charging or battery swapping unit price in the i^{th} year, and EC_i represents the total electricity consumption in the i^{th} year.

2.4 Time Cost

During the charging waiting period, the taxi drivers cannot get out of the car for operation, which causes the loss of drivers. Private car users can work normally without loss during the charging waiting period. Therefore, we calculate the time cost of taxis without considering the time cost of private cars. The time cost of taxis can be expressed as

$$TC_i = In_i \times t_i \tag{6}$$

where TC_i represents the time cost of taxis in the i^{th} year, In_i represents the revenue per unit time of taxi drivers in the i^{th} year, and t_i is the total charging time in the i^{th} year.

2.5 Maintenance Cost

At present, there is no research result showing that electric vehicles of fast charging mode and the battery swapping mode have significant differences in maintenance costs. Therefore, we assume that the maintenance costs of the fast charging mode and the battery swapping mode of electric vehicles are the same.

3 Vehicle TCO Analysis

In this paper, we select EV model A as the research object. The vehicle price of this model is 129,000 RMB, and the body price in the swapping mode is 79,800 RMB. The power battery has a power of 45kWh and a cruising range of 300km. The monthly battery rent of this model is 458 RMB, and the of battery swapping unit price is 2.3 RMB/kWh. In this paper, we take the average price of 1.6 RMB/kWh as the fast charging unit price, and take the average income in Shanghai of 56 RMB/hour as the revenue per unit time of taxi drivers. The learning rate of the power battery is 16% with reference to the relevant literature, and the discount rate is 5%. The annual mileage of taxis is 100,000km, and the annual mileage of private cars is 14,000km.

3.1 Taxi TCO Analysis

In the taxi TCO, the electricity cost accounts for the highest proportion in both the fast charging mode and the battery swapping mode, as shown in Fig. 1. In 2021, the TCO per kilometer of taxis in fast charging mode is 0.655 RMB/km, and the TCO per kilometer of taxis in battery swapping mode is 0.599 RMB/km. The battery swapping users can save 0.056 RMB per kilometer. In fast charging mode, the electricity cost has obvious advantage, and the users can save 0.105 RMB per kilometer. In battery swapping mode, the vehicle purchase cost and time cost have advantages, and users can save 0.077 RMB and 0.1396 RMB per kilometer respectively.

With the development of fast charging technology, the power of fast charging will gradually increase, and the charging time of users will be shortened, and the time cost of taxi drivers will be reduced year by year. According to the learning rate curve, the battery rental cost will show a decreasing trend year by year. Therefore, in both the fast charging mode and the battery swapping mode, the TCO of taxis show a gradually decreasing trend, as shown in Fig. 2. However, the reduction of battery rent in battery swapping mode is lower than the reduction of the time cost in fast charging mode, so the TCO in fast charging mode decreases more significantly.

Before 2025, the TCO per kilometer in battery swapping mode is lower than that in fast charging mode. In 2026, the TCO in two modes will be close to the same. After 2027, the TCO in fast charging mode is slightly lower than that in battery swapping mode, showing a slight advantage. The TCO per kilometer in the whole life cycle of taxis in fast charging mode is 0.607 RMB/km, and it is 0.585 RMB/km in battery swapping mode. In battery swapping mode, taxi drivers can save about 3.6% of the cost.

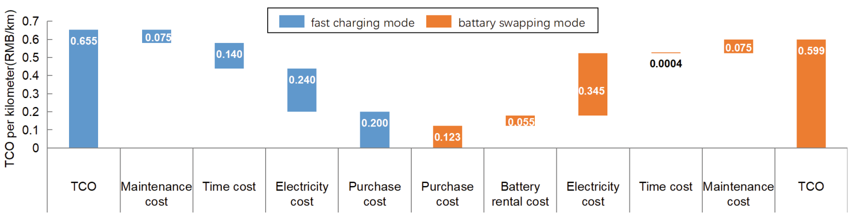


Fig. 1. TCO comparison between fast charging mode and battery swapping mode of taxis in 2021

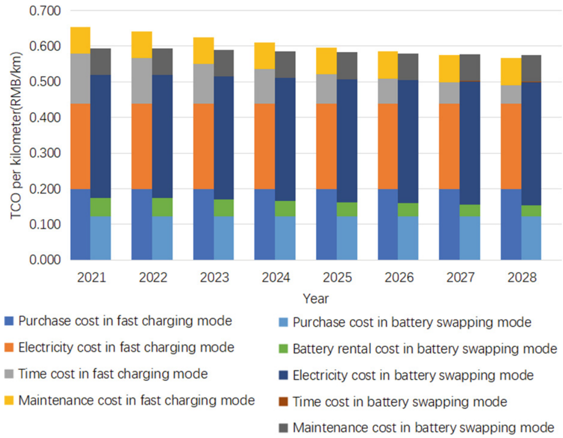


Fig. 2. Development trend of TCO per kilometer in fast charging mode and battery swapping mode of taxis

3.2 Private Car TCO Analysis

In the private car TCO, the purchase cost accounts for the highest proportion in both the fast charging mode and the battery swapping mode, as shown in Fig. 3. In 2021, the TCO per kilometer of the private car in fast charging mode is 1.672 RMB/km, and the TCO per kilometer of the private car in battery swapping mode is 1.774 RMB/km. The fast charging mode is economical and has an advantage of 0.102 RMB/km.

Figure 3 shows that the sum of purchase cost and battery rental cost in battery swapping mode is 1.036 RMB/km, which is close to the purchase cost in fast charging mode. The electricity cost in fast charging mode is significantly lower than that in battery swapping mode, with an advantage of 0.105 RMB/km.

Since the time cost is not considered, the TCO of the private cars in fast charging mode is not affected by the development of fast charging technology. In battery swapping mode, the battery rental cost changes according to the learning rate curve, and the TCO decreases year by year. As shown in Fig. 4, before 2024, the TCO per kilometer in fast charging mode is lower than that in battery swapping mode, which is economical. After 2025, TCO per kilometer in battery swapping mode will be lower than that in fast charging mode. From the perspective of the whole life cycle, the TCO per kilometer in fast charging mode of private cars is 1.672 RMB/km, and it is 1.642 RMB/km in battery

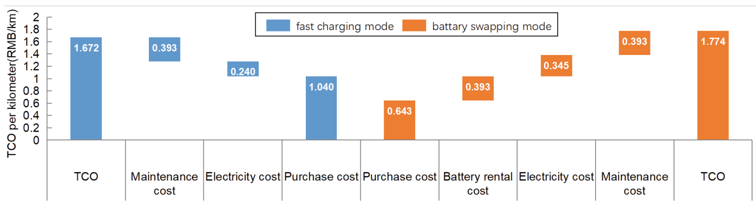


Fig. 3. TCO comparison between fast charging mode and battery swapping mode of private cars in 2021

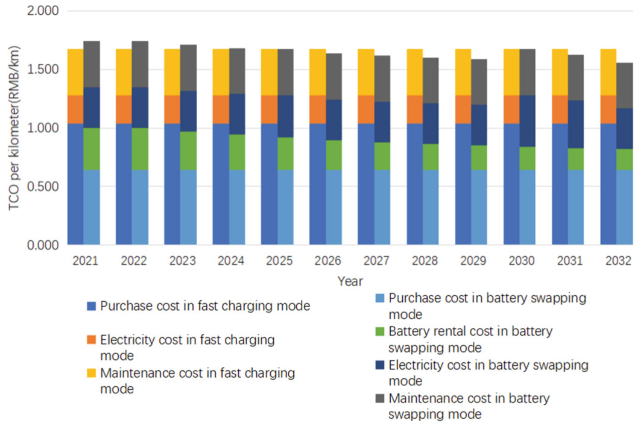


Fig. 4. Development trend of TCO per kilometer in fast charging mode and battery swapping mode of private cars

swapping mode. In battery swapping mode, private cars drivers can save about 1.8% of the cost.

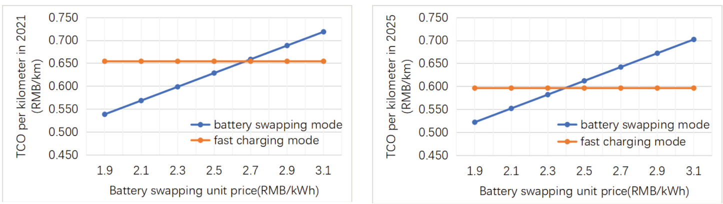
In battery swapping mode, the TCO per kilometer in the whole life cycle of taxis and private cars is lower than that in fast charging mode, and battery swapping mode is economical. Moreover, compared with the private car scenario, the battery swapping model in the taxi scenario is more economical and easier to promote.

4 Sensitivity Analysis of Battery Swapping Unit Price Based on TCO

Based on the TCO model and the relevant parameters, the battery swapping unit price to ensure the economy of battery swapping mode can be discussed.

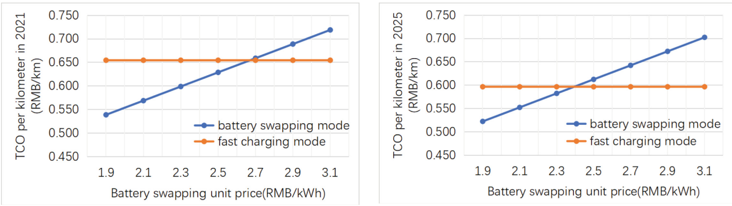
4.1 Sensitivity Analysis of Battery Swapping Unit Price of Taxis

Considering that the TCO per kilometer of taxis will decrease year by year before 2025 in Fig. 2, we select 2021 and 2025 for sensitivity analysis of battery swapping unit price of taxis.



(a)TCO in 2021 (b) TCO in 2025

Fig. 5. TCO comparison of taxis in fast charging mode and battery swapping mode under different battery swap unit prices in 2021 and 2025



(a) TCO in 2025 (b) TCO in 2030

Fig. 6. TCO comparison of private cars in fast charging mode and battery swapping mode under different battery swap unit prices in 2025 and 2030 (a) TCO in 2025 (b) TCO in 2030

The vehicle body price of taxi is 79,800 RMB, and the monthly battery rent is 458 RMB. As shown in Fig. 5, in 2021, when battery swapping unit price is lower than 2.675 RMB/kWh, the economy of taxis in battery swapping mode is higher than that in fast charging mode. In 2025, when battery swapping unit price is lower than 2.4 RMB/kWh, the economy of taxis in battery swapping mode is higher than that in fast charging mode.

4.2 Sensitivity Analysis of Battery Swapping Unit Price of Private Cars

Considering that the TCO per kilometer of private cars will increase year by year after 2025 in Fig. 4, we select 2025 and 2030 for sensitivity analysis of battery swapping unit price of private cars.

As shown in Fig. 6, in 2025, when battery swapping unit price is lower than 2.405 RMB/kWh, the economy of the private cars in battery swapping mode is higher than that in fast charging mode. In 2030, when battery swapping unit price is lower than 2.93 RMB/kWh, the economy of the private cars in battery swapping mode is higher than that in fast charging mode.

5 Conclusions

In this paper, we fully considered the vehicle purchase cost, battery rental cost, electricity cost, time cost, and maintenance cost, and established a TCO analysis model for fast charging and battery swapping mode. Based on the TCO analysis model, we analyzed the economic development trend of fast charging mode and battery swapping mode in two different application scenarios of taxis and private cars. Also, we studied the sensitivity of battery swapping unit price. Through the analysis in this paper, we draw the following conclusions.

With the innovation of fast charging technology and the large-scale promotion of electric vehicles, the time cost in fast charging mode and the battery rental cost in battery swapping mode will gradually decrease. And, the time cost in fast charging mode decreases faster.

Before 2026, the battery swapping mode of taxis is more economical. After 2025, the battery swapping mode of private cars is more economical. In terms of the whole life cycle, the battery swapping mode of both taxis and private cars is economical, and the battery swapping mode of taxis is more economical.

In TCO composition of taxis, the electricity cost accounts for the largest proportion, and in TCO composition of private cars, the purchase cost accounts for the largest proportion. The reason is that the annual mileage of taxis is large and the utilization rate is high.

For taxis, if the battery swapping unit price is lower than 2.675 RMB/kWh in 2021, and lower than 2.4 RMB/kWh in 2025, the battery swapping mode is economical. However, the economic of battery swapping mode will decrease year by year over time. For private cars, if the battery swapping unit price is lower than 2.405 RMB/kWh in 2025, and lower than 2.93 RMB/kWh in 2030, the battery swapping mode is economical, and the economy will become more obvious as time goes on.

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