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An Economic Evaluation of Electric Vehicle Charging Infrastructure in Public Places in China

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Abstract. The electric vehicle market has witnessed a big growth spurt as a result of the promotion of the transportation electrification in the global. Among electric vehicles, electric passenger cars are the most promising fleet to achieve the global climate target in the next decades, which will lead to a vast potential public charging market. Therefore, evaluating the economy of operating the charging infrastructure from the operator's perspective is especially required. The paper aims at providing an economic evaluation of charging infrastructure in public places in China. In the proposed method, the initial investment cost, the subsidy, the operating revenue and the operating cost are all modeled in detail. Using the proposed model, two scenarios representing the electric vehicle charging in the work place and in the fast charging station are assumed, and the cost and revenue of charging operators are calculated and compared. It is shown that under our assumption the payback period of the charging infrastructure in the work place is much shorter than that of fast charging station. Because the calculated payback period of fast charging station is more than ten years, current fast charging stations are unlikely to profit, and the promotion of the fast charging stations requires further policy support and smart grid technology development.

1. Introduction

Electric vehicle provides a crucial opportunity to promote the low-carbon energy transition of the transportation sector [1], [2] and has had a good run as the substitution of conventional vehicle, but it still faces a lot of barriers to widespread adoption. Among several main obstacles, from user's perspective, poor public charging infrastructures is the largest barrier after the technological barriers [3], [4]. With the development of electric vehicles, charging infrastructure is the obvious substitute for petrol station accompanied by the transition from conventional vehicle to electric vehicle. Additionally, the possibility of charging at home, work place or other public places [5] is becoming another superiority for the energy refilling of electric vehicles. Destination charging could save the unnecessary time used for driving to the petrol station and waiting for refilling the fuel tank of conventional vehicles, which even could solve technical problems, for example range anxiety [6].

On the basis of those, charging infrastructures are heavily invested by national governments [7] as well as enterprises so as to be networked and widely used. In China, the development of electric vehicles, the construction of charging infrastructures is given high priority, and policies for charging infrastructure constructions have been issued by governments. Constructing charging infrastructures in public places is one of great urgency to promote the adoption of electric cars.

The economy of constructing and operating charging infrastructures is significant for charging operators; therefore, an economic evaluation of electric vehicle charging infrastructures is given in this paper. A profit model is proposed in terms of several major costs and revenues to evaluate the annual profit and the payback period of various charging ways. Two scenarios representing the electric vehicle charging in the work place and in fast charging station are assumed, and the cost and revenue of charging operators are calculated, compared and discussed. The results show that because of very low initial investments, slow charging infrastructures are easier to profit, however, fast charging stations are unlikely to profit currently [7], and further policy and technical support are required.

The paper is arranged as follows. After introduction, the method of the charging infrastructure economic evaluation is proposed. Based on that, two charging scenarios are calculated and compared. Conclusions are discussed in the last section.

2. Method Proposed

The economy of charging infrastructures from the perspective of charging service operators includes the initial investment cost, the subsidy, the operating revenue, the operating cost. The net investment cost in the initial stage is calculated by the initial investment and the subsidy; the annual profit is the difference between the annual operating revenue and the annual operating cost. Payback period is the time when the accumulated annual profit equals to the net investment and operating cost.

2.1. Initial Investment Cost Model

For the charging infrastructure operator, the initial investment cost (*IIC*) includes land purchasing cost (*LPC*), building construction cost (BCC), power-supply system cost (*PSC*), monitoring system cost (*MSC*) and charging infrastructure cost (*CIC*), which is expressed as

$$IIC = LPC + BCC + PSC + MSC + CIC(n) \tag{1}$$

where, *LPC* is the total cost of the land where the charging infrastructure sits. The area of the land is related to the area of each section of the charging infrastructure including charging spaces, carriageways, power-supply room, monitoring room and other land for example a certain amount of reserve land which will be used in the future. LPC represents a significant portion of the initial investment cost and highly depends on the location in the city. *BCC* is the total construction cost of the related building and ground. PSC and MSC represent the costs of purchasing equipment, installing equipment and hiring labor in initial stage respectively, which is related to the scale of the charging infrastructure. Land purchase cost, building construction cost, powered-supply system cost and monitoring system cost will be saved if the charging infrastructure is constructed based on the existing public parking lots. *CIC* is the function of the number of the charging systems and the price of the charging equipment related to the charging demand. Fast charging is preferred for EV users when the battery is low and the users only stay a short time; and slow charging is a better selection for extending the battery lifespan and further incorporate within the control of smart grid. The charging infrastructure cost could be calculated by

$$CIC(n) = n_p \gamma_c (\gamma_f P_f + \gamma_s P_s) \tag{2}$$

where, n_P is the number of parking spaces in the public, γ_c is the ratio of the number of charging spaces and the number of parking spaces, γ_f is the ratio of the number of fast charging spaces and the number of charging spaces, γ_s is the ratio of the number of slow charging spaces and the number of charging spaces, P_f and P_s are the allocation prices of the total purchase cost of charging systems per fast charging space and per slow charging space respectively, including the purchasing cost, the freight

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cost, the installation cost, the material cost, the test cost, and the labor cost according to the charging infrastructure supplier.

2.2. Subsidies
The relationship between the electric vehicle and the charging infrastructure pose a chicken-or-egg conundrum. Hence, in the early phase of development of electric vehicles, it is difficult to benefit from operating charging infrastructures [8]. To promote electric vehicles, it is necessary to provide subsidies to support the construction and the operation of the charging infrastructure. And the way of the subsidy is various and depends on the national and local policies from the government. The total subsidies are expressed as

$$SUB = S_c + S_l + S_o \tag{3}$$

where S_c is the subsidy for purchasing the charging infrastructure, S_l is the subsidy for purchasing the land of the charging infrastructure, S_o is the subsidy by other forms such as according to the number of the new registered electric vehicles locally and the tax reduction.

2.3. Operating Revenue Model
Operating revenue (OPR) in the i th year is divided into several parts: electricity revenue (ER), service revenue (SR), other revenue (OR), expressed as

$$OPR(i) = ER(i) + SR(i) + OR(i) \tag{4}$$

EV batteries are assumed to be charged during the parking time. And electricity revenue in the i th year from the EV users is calculated by

$$ER(i) = 365 \times 24 \times n_p \gamma_c (\gamma_f \beta_u^f \beta_p^f p^f + \gamma_s \beta_u^s \beta_p^s p^s) P_e \tag{5}$$

where β_u is the utilization rate of time, β_p is the utilization rate of charging spaces, p is the rated output power of the charging equipment, P_e is the electricity selling price per kWh, including the electricity cost and the extra charging service profit.
Service revenue is gained by providing extra service except charging for example parking, management and scheduling of EVs providing by parking lot operator. If the charging operator also plays the role of parking lot operator, service revenue in the i th year is evaluated by

$$SR(i) = 365 \times 24 \times n_p \gamma_c (\gamma_f \beta_u^f \beta_p^f + \gamma_s \beta_u^s \beta_p^s) I_s \tag{6}$$

where I_s is the service fees per hour.
Other revenue such as the advertisement revenue from business cooperation is a large extra revenue for charging operators.

2.4. Operating Cost Model
The operating cost (*OC*) includes electricity purchasing cost (EPC), charging infrastructure maintenance cost (*CMC*), management cost (*MC*) and other operating cost (*OOC*). And the operating cost in the i th year is given by

$$OC(i) = EPC(i) + CMC(i,n) + MC(i) + OOC(i) \tag{7}$$

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The charging infrastructure operator is a medium between the gird and EV users exactly. The electricity is purchased from the power gird and sold to EV users. And it is assumed the electric energy is transmitted from the power gird to the EV users directly without energy storage systems. Then the electricity purchasing cost is calculated by

$$EPC(i) = 365 \times 24 \times n_p \gamma_c \left(\frac{\dfrac{\gamma_f \beta_u^f \beta_p^f p_f}{\eta_c^f} + \dfrac{\gamma_s \beta_u^s \beta_p^s p_s}{\eta_c^s}}{\eta_P} \right) P_P \tag{8}$$

where η_c is the charging equipment efficiency, η_P is the power-supply system efficiency, P_P is the electricity purchasing price per kWh.
The charging infrastructure maintenance cost per year including the labor cost, related equipment repairing and replacement cost, assumed to be 10% of initial cost of the charging infrastructure.

$$CMC(i,n) = 10\% CIC(n) \tag{9}$$

Management cost is required including the labor cost for guidance and scheduling, the energy cost for lighting and cleaning and other related cost. But for the charging infrastructure based on the existing parking lot, the cost of this part will be included in the business cooperator cost within OOC.
Other operating cost per year includes the business cooperation cost paid for the service from other operators to manage the charging infrastructure, the maintenance cost for power-supply system and monitoring system, and other labor cost.

2.5. Profit Model
The revenue model is established by the initial investment cost, subsidy, operating revenue and operating cost. And yearly profit (YP) and payback period is expressed by

$$YP = OPR(i) - OC(i) \tag{10}$$

$$m = \frac{IIC - SUB}{YP} \tag{11}$$

where m is the payback period when the accumulated annual profit of the charging infrastructure in the past m years has covered the total cost to construct and operate the charging infrastructure.

3. Case Studies
Fast charging and slow charging are two typical charging ways at present, which is suitable for different charging requirements. Based on the different travel habits, two scenarios representing the two charging ways respectively are analyzed.

3.1. Work Place
According to the travel habits of working people, their electric cars usually be parked at the work place during their 8-hour work time. Therefore, the parking lot of the work place is a promising choice for charging electric vehicle, and slow charging is preferable due to the long-time parking behavior. In this analysis, it is assumed that the charging operator in the work place constructs the charging infrastructure based on the existing parking lot and cooperates with the parking lot operator; therefore, the land purchase cost and the building construction cost is saved, besides, the power-supply system and the monitoring system rely on the existing system. Because the parking and charging behaviors

are approximately constant, the number of charging systems can be accurately planned according to the number of electric car owners in the work place. The initial investment cost is only the purchase cost of the slow charging systems. Business cooperation cost is considered within the other operating cost. Since the charging operator does not own the parking lot, it has no gain in service revenue and only makes revenue from electricity selling and advertising.

3.2. Fast Charging Station

Fast charging infrastructures are necessary to complete the charging network for emergency charging, where most EVs could be fully charged within one hour or less. Charging station is an independent charging infrastructure, and the land purchase cost and building construction cost are needed and take a great proportion in the initial vestment cost. Power-supply system and monitoring system are also necessary. The planning of the number of charging spaces is a complex optimization problem, relating to different parameters of EV owners' driving behavior, driving route planning, charging stations distribution in the neighborhood, etc. We simply use 10 charging spaces in this analysis according to the size of the current charging stations in China. The management cost is used for hiring employees to carry out the daily management of the charging station and the maintenance of the equipment. Electricity revenue and service revenue are gained and the advertising revenue will increases compared with charging infrastructure in the work place due to the larger service flow.

3.3. Results and Discussions

The results of the two scenarios are shown in Fig. 1 and Fig. 2 respectively. The payback period is calculated by the initial investment cost model, subsidy, operating cost model and operating revenue model. Due to the absolute value differences between the two types of charging infrastructures, the results are represented using normalized costs. The 15-year total cost of each scenario is used to normalize all the calculation results of each scenario respectively. The 15-year total cost in the work place is approximately 820,000, however, it is as high as 18,000,000 for the fast charging station. In Fig. 1 and Fig. 2, y-axis represents the normalized cost or revenue and x-axis represents the duration that the charging infrastructure is operated. The projection of the difference between the normalized revenue line and the normalized cost line on the y-axis in the given year is the net normalized annual profit that year, and the projection of the intersection of the normalized accumulated cost line and the normalized accumulated revenue line on the x-axis is the payback period for the charging infrastructure.

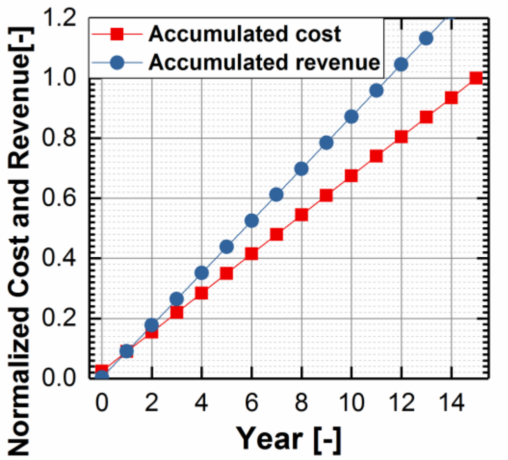

Figure 1. Normalized yearly accumulated cost and revenue (charging infrastructure in the work place).

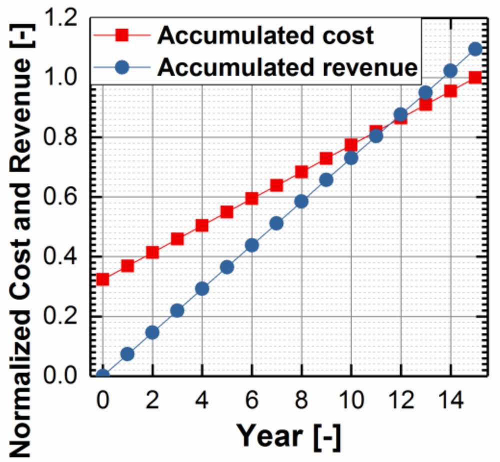

Figure 2. Normalized yearly accumulated cost and revenue (fast charging station).

According to the results shown in the figures, the net initial investment cost of the fast charging station is much higher than that of the charging infrastructure in the work place because of the costly related equipment, the building and the land. The payback period for the charging infrastructure in the work place is 1 year, which is far sooner than the payback period of 12 years for the fast charging station. However, the lifetime of the charging systems is not considered here.

Due to the characteristic of the charging way, fast charging could provide more effective service and gain higher electricity revenue and service revenue, but with the limitation of battery technology it faces the anxiety of battery capacity degeneration. On the contrast, slow charging provides an economical charging choice which is easier to be adopted. Although the charging process is time-consuming, slow charging is feasible to be promoted vigorously with inexpensive initial investment cost and wins on volume.

With the chosen assumption, the scale of the charging infrastructure, the utilization of the time and the number of the charging spaces is constant, as a result, the operating revenue and the operating cost is constant every year. As the market penetration of the electric car, the scale of the charging infrastructure, the utilization of the time, charging spaces as well as service efficiency will increase and the operating revenue including the business cooperation revenue will rise rapidly; then the payback period will be shortened. In addition, intangible resources are not calculated in the economic evaluation for example the increasing value of the land, gaining the market share and the brand cognitive, which will help operator benefit more.

4. **Conclusion**

A model to evaluate the economy of the electric vehicle charging infrastructure in the public place from the operator's perspective is built, including the initial investment cost model, subsidy, operating revenue model and operating cost model. Then two typical scenarios, the charging infrastructure based on the existing parking lot in the work place with slow charging way and the charging station with fast charging way, are calculated and compared. As a result, the payback period is 1 years for the charging infrastructure in the work place, but it is 12 years for the fast charging station. The results show that the initial cost of slow charging infrastructure is low and the corresponding investment is easy to recover in the short term, with further advantages such as very low impact on the power grid. Slow charging infrastructure is an economical choice for the large-scale promotion of electric vehicles. The initial cost of fast charging system is very high, the payback period is too long, therefore, the investment of fast charging station seems difficult to profit currently. Additionally, the planning of the fast charging station is also very complex [9], and global planning with the smart grid is needed [10]. However, fast charging station is necessary for the promotion of electric vehicles, because it is especially important to overcome the range anxiety of EV users. Therefore, on the one hand, vehicle and grid inter-connection techniques, energy storage techniques, novel business models should be applied to increase the profitability of the fast charging station; on the other hand, more favorable policy supporting is required for the operation of fast charging stations.

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