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Charge pricing model for electric vehicle charging infrastructure public-private partnership projects in China: A system dynamics analysis

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ABSTRACT

The design of charge price is essential to the financial viability of electric vehicle charging infrastructure public-private partnerships (EVCI-PPPs). This study proposes a system dynamics (SD) technique to develop a charge pricing model based on pro forma financial statements developed during the feasibility study period. Pricing parameters are first identified. A charge pricing model using the SD approach is then developed based on charge pricing parameters. This charge price not only ensures charge operators gain the anticipated minimum attractive return of rate, but also not exceed the government-regulated price. Subsequently, an ongoing EVCI-PPP project in Anqing is selected to verify the applicability and effectiveness of the model proposed in this study. Sensitivity analysis results indicate that operating costs, electricity price, and charge volume are the main determinants of feasible charge price. Several suggestions to improve charge operators' profits and reduce charge price, including increasing charge volume, negotiating with power companies for preferential electricity price, broadening profit channels, and improving operational capabilities, are put forward. This research framework can also be used as reference to study other infrastructure's pricing models.

1. Introduction

1.1. Background of EVCI-PPPs

Considering the sound performance of electric vehicles (EVs) in reducing fossil energy consumption and greenhouse gas (GHG) emissions (Ma et al., 2017), an increasing number of countries have introduced policies to encourage EV adoption (Verma et al., 2015; Xu et al., 2017). Providing an effective EV charging infrastructure (EVCI) is an important step in popularizing these vehicles (Sehar et al., 2017). Supported by the government, the scale of charging facilities has almost satisfied EV charge demand in some regions in China.

However, due to a lack of operational management experience, charge services are inefficient, and the actual utilization of urban public charging stations is below 15% (Li et al., 2018). China's government faces tremendous financial and management pressures (Madina et al., 2016). In 2015, considering the lower charge service efficiency and disorder charging market, the public-private partnership (PPP) mode was introduced to increase the participation of social capital to accelerate the progress of the EVCI industry and make up for the infrastructure deficit of the government, to reach a win-win situation (Zhang et al., 2014). However, despite combining the advantage of private sector funding, advanced technology, and efficient management, the development of EVCI-PPPs remains slow (Yang et al., 2016). At the end of 2017, China had only 17 PPP projects in vehicle charging infrastructure. Only two projects have entered the implementation stage. The primary reasons include that the operational mode of charging facilities and charge price remain uncertain. On April 1, 2018, Beijing cancelled the government regulation on charging service fees. Charge operators now have more autonomous rights over pricing. Thus, it is recommended that a systematic charge pricing model be established for charge operators.

A reasonable charge price is essential to EVCI-PPPs success, as it determines the commercial viability and profitability of a charging

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facility project (Guo and Chan, 2015; Shen et al., 2007). For EVCI-PPPs, the characteristics of government-led regulatory mechanisms and government-specified highest charge price add to the complexity of pricing from the perspective of charging operators (Maia et al., 2015). Therefore, how to determine a reasonable charge price based on the costs and benefits of the charging infrastructure and then decrease charge price are the key issues for the development of EVs and EVCI projects.

1.2. Literature review

Few studies pointed out that the participation of private charging operators can progress the development of EVCI projects (Liu and Wei, 2018; Yang et al., 2018). Moreover, additional infrastructure could be developed through private investment as the EV adoption rate increases (Colmenar-Santos et al., 2014). Yang et al. (2016) explained the PPP model is an effective way to supply charge services from a macroscopic perspective. Li et al. (2016) argued the Shenzhen model can be enhanced through a private investment charging infrastructure using PPPs. Although an increasing number of studies indicated the PPP model is an effective way to increase the scale of charging piles, to the best of our knowledge, they did not thoroughly analyze the main factors affecting the smooth development of charging facility PPPs (Li et al., 2016; Yang et al., 2016), especially the importance of charge price on the success of EVCI-PPPs.

However, some scholars analyze the relation of charge price and charging behaviors (Langbroek et al., 2017; Motoaki and Shirk, 2017). For instance, Burnham et al. (2017) illustrated that an acceptable price for consumers is key to popularizing charging projects, Motoaki and Shirk (2017) pointed out that different pricing affects recharging behavior, and Langbroek et al. (2017) showed the importance of temporal price differentiation in influencing charging behavior patterns and how this type of price is effective for those who use EVs regularly. Based on two scenarios, of cooperation and non-cooperation, Hu et al. (2016) simulated how to set a reasonable charge price to guide users to participate in power grid dispatching and reduce electricity cost.

Previous studies found the charge price influences users' driving behaviors, EV operation costs, and the development of EVs (Yu et al., 2017) and EVCI-PPPs (Zhang et al., 2017a). Therefore, an increasing number scholars pay more attention to charge prices. For example, Yu et al. (2017) designed a robust flexible-probabilistic programming method to help plan the municipal energy system while considering the peak-electricity price and EV. The results demonstrated that the RFPP method is effective, and that it ensures lesser electricity expenses and lesser CO_2 emissions in the municipal energy system. Wei et al. (2018) designed an intelligent charging management mechanism to maximize the interests of both customers and charging operators. Li and Ouyang (2011) calculated a charge price range from the perspective of EV users and station operators and made suggestions to shrink pricing shortfalls, such as increasing energy prices, reducing battery cost, state subsidies. Lu et al. (2014) considered the main determinants of charging stations and developed a cost-benefit model to calculate a reasonable charge price. Overall, scholars have emphasized the acceptable charge price from the relative viewpoints of all participants. An appropriate charge price not only ensures profit for station operators but also helps reduce EV users' expenditures compared to traditional combustion engine vehicles. The cost-benefit of charging operators is thus key to determining charge price. On the other hand, China's government have released incentive policies to subsidy public and private charge facilities, which adds to the complexity of the pricing process.

For specific charge prices, the time-of-use (TOU) charge price is considered consistent with the development path of a charging infrastructure. In this respect, Zhang et al. (2017c) developed a peak-valley TOU charge pricing model for private charging piles (PCPs). However, only PCPs were considered, while pricing models for public charging facilities have not yet been evaluated. Cao et al. (2012) studied the effects of a TOU charging mechanism on reducing costs for EV users, but the actual interests of public charging facility operators have not been thoroughly analyzed. Zhang et al. (2017a) proposed a SD model to develop a real-time charge pricing mechanism for EVs, However, as opposed to ordinary charging stations, EVCI-PPPs have specific cost-benefit rules and regulations.

Regarding EVCI-PPPs from the viewpoint of private investors, it is necessary to set a charge price as low as possible to win the concessionaire and adequate charge volume. On the other hand, high prices can maximize profits. Therefore, the goal of private investors is to determine a charge price that will guarantee winning the bid and achieving a reasonable profit (Xu et al., 2012). An appropriate charge price is thus essential for the financial viability of PPPs (Yang et al., 2018). For EVCI-PPPs, the government-led regulatory, government-specified price, and operating subsidies add the complexity of charge pricing. However, there are few methods available for calculating the value of this variable in EVCI-PPPs, which this study adds to.

1.3. Research objectives

EVCI has a large potential market and can provide electric power to EV users. Therefore, it is necessary to propose a framework to determine an acceptable charge price from the perspective of charge operators. This study aims to determine a rational charge price for private investors based on a SD model and also uses a cost-benefit model to identify the main determinants of charge prices. Such a model computerizes and simulates the dynamic relationships between charge prices estimated using causal loops. Furthermore, the model can help charge operators identify the main determinants to charge prices. In other words, the main contribution of this paper is the SD model proposed for charge operators to determine rational charge prices in increasing EVCI-PPP projects.

The rest of this paper is structured as follows. Relevant incentive policies related to financial subsidies and charge prices are introduced in Section 2. The SD model for charge prices of EVCI-PPPs is established in Section 3. In Section 4, taking as an example a charging infrastructure PPP project in China that has entered the implementation stage, a sensitivity analysis is conducted to test model's effectiveness. Section 5 offers suggestions to increase charge benefits and reduce charge price based on the simulated results and Section 6 presents conclusions. Generally, this study provides reference for charging infrastructure operators to design a rational charge price based on the SD model and the price parameters proposed in this study.

2. Charging infrastructure policies in China

2.1. Construction of charging infrastructure and policy subsidies

An adequate and effective EV charging infrastructure is essential for popularizing the use of EVs (Yang et al., 2018). To increase the scale of vehicle facilities, China has issued various subsidies and guides for charge prices from the macro viewpoint, which can directly and indirectly reduce vehicle charge price.

Due to the different levels of economic and social development, as well as the distribution of EV manufacturers, provincial charging facilities develop at varying speeds. As such, the uncoordinated