Study on crowdfunding's promoting effect on the expansion of electric vehicle charging piles based on game theory analysis

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Abstract

The successful market penetration of electric vehicles (EVs) is subject to the capacity of charging infrastructure, and the development of charging infrastructure is mainly driven by economic incentives. This study analyzes the advantages of crowdfunding financing for promoting the construction of electric vehicle charging piles compared with other incentive methods. A three-level Stackelberg game is proposed to model the interactions between the electricity supplier, the charging infrastructure operator and crowdfunding. The results indicate that crowdfunding is an effective and efficient way to promote the penetration of charging piles, since it has the same effect as supplying a 20% subsidy with regards to the promotion of charging pile installation. Theoretical analysis finds that crowdfunding's performance is affected by crowdfunders' risk attitude, and less risk-averse crowdfunders have stronger incentives for charging piles investment. Sensitivity analysis is conducted on crowdfunding's performance in terms of repayment rate, unit construction cost, charging volume and risk tolerance. The results show that the effect of crowdfunding is most sensitive to construction cost, and when unit construction cost decreases from 0.03 to 0.01 USD/(watt·year), the total annual construction quantity under crowdfunding model increases from 18.8 MW to 56.6 MW, which provides managerial insights for the government to promote charging infrastructure related technologies.

1. Introduction

With growing concerns for environmental protection and considerations of possible energy transitions in the transportation sector, electric vehicles (EVs) have become one of the prevalent trends globally. The Chinese government has been making substantial efforts in promoting EVs’ penetration [1]. Electric vehicle (EV) sales in China were projected to reach 5 million in 2020 from the current 0.5 million in 2015. However, at present, only 3600 charging stations and 49 thousand public charging piles are available at the end of 2015, and there is a huge gap between the supply and the prospective demand of EVs [2]. Therefore, the Chinese government plans to construct 12 thousand charging stations and 4.8 million charging piles by 2020 [3]. At the same time, the Chinese government has also been using various methods to stimulate the construction of EV charging facilities, such as subsidizing the charging infrastructure operator and encouraging the entrance of private capital.

To-date, multiple participants have contributed to the construction of EV charging piles, including the government, the charging infrastructure operators, and customers. Charging piles are either constructed by a single participant or a group of these participants.
in existing studies. However, the role of private capital flows and the advent of crowdfunding have not yet been considered. In recent years, crowdfunding has attracted increasing attention in various industries and achieved tremendous successes as a new form of financing. Crowdfunding means connecting crowdfunding and fund raisers through the internet and it is widely used in art, business, and technology project funding. Crowdfunding can gather funds from a large number of participants, thereby a firm can gain a large amount of capital from many small clients. On 28th March 2016, crowdfunding for ‘Changdi’ intelligent charging pile obtained 75 thousand USD within 5 h, showing that there are promising prospects for crowdfunding to finance EV charging facilities. However, the benefits of crowdfunding to the expansion of charging facilities have rarely been discussed in previous studies, in part due to the lack of tools.

The existing studies about EV charging infrastructures have addressed problems in many aspects, including EV charging demand forecasting [4,5], economics performance of charging infrastructure [6,7], optimal location of charging infrastructure [8], and impact of EV charging on the power system [9]. Also, there are studies focusing on the government’s strategy for promotion of EV charging infrastructures. Li et al. [10] investigated the strength and weakness of EV deployment in Shenzhen, China. They found that the existing charging infrastructures are far from sufficient to meet the need of the booming EV market. Schroeder and Traber [11] found that investment for EV charging facility is hardly profitable at low EV adoption rates and traditional financing methods failed to work due to high initial capital and long payback period. Therefore, it is crucial to find a method to finance the construction of EV charging piles, which leads to expectations of the potential of crowdfunding.

Traditionally, government provide subsidies to facilitate the development of new technologies. Some recent publications have studied the subsidy policies and their impact on EV market penetration [2,12,13]. Han et al. [2] reviewed China’s EV subsidy scheme and concluded that vehicle purchase subsidy plays an essential role in starting up China’s EV market. However, the subsidy policy for EV charging infrastructure was not considered in their research. Qin and Zhu [12] developed a dynamic game model to analyze the government’s optimal subsidy policy for EVs, and the results showed that the recent subsidy policy hasn’t provide enough support for charging facility construction. However, some studies propose that subsidy is inadequate to boost an industry, and more innovative policies are required [13]. In previous studies, the enterprises participating in the construction of EV charging infrastructures are limited to the government, EV manufacturers, grid companies, and other big enterprises. However, few attention were given to absorb private investors into the charging market, although the absence of private investment is considered as a primary reason for the insufficient charging infrastructures [10]. Motivated by these investigations, in the present study crowdfunding are involved in the charging pile construction process, providing an innovative idea for policy makers to expand EV charging infrastructures. The effect of crowdfunding and the traditional subsidy policy would also be compared to evaluate the efficiency of crowdfunding.

Crowdfunding has recently been considered as a promising financing method with the fast development of internet based financing. Many researchers have focused on the advantages of crowdfunding and the applications of crowdfunding in various industries. In terms of the advantages of crowdfunding, Rubinton [14] demonstrated that crowdfunding is more efficient and can diversify risks when compared with traditional financing methods. Agrawal et al. [15] found that the spatial constraint of financing has been overcome by crowdfunding. Crowdfunding could also reduce cost of financing, enhance customer loyalty, and improve social welfare [16]. Models for crowdfunding applications in the new energy area have previously been developed. Zheng et al. [17] modelled the cooperation among the power grid, farm owners, and crowdfunding for investing in community solar farms, and showed that crowdfunding is an efficient method to promote solar power generation. Vasileiadou et al. [18] and Lam and Law [19] found that crowdfunding only accounts for a small proportion but exhibits huge potential through an empirical study. However, theoretical and quantitative studies on crowdfunding applied in the area of EV charging infrastructure have not been found in the previous literatures. Therefore, the present study will quantitatively analyze the effect of crowdfunding on promoting the construction of EV charging piles.

Game theory is widely used in the literature to model interactions among different stakeholders with various objectives. The Stackelberg game, which is a type of non-cooperative game that deals with hierarchical decision-making processes of multiple decision makers, has attracted great attention in the energy market [20,21]. Tushar et al. [20] proposed a Stackelberg game to study the problem of energy trading between a smart grid and a number of plug-in EV groups. The interactions between the utility supplier and multiple users in the electricity trading process are formulated into a Stackelberg game [21]. Therefore, a Stackelberg game method is used to model the crowdfunding process for EV charging pile construction.

The purpose of this study is to quantify the effect of crowdfunding in promoting EV charging pile construction using a proposed three-level Stackelberg game model in which the operator, crowd-
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