ARTICLE IN PRESS

Research in Transportation Economics xxx (xxxx) xxx

Contents lists available at ScienceDirect

Research in Transportation Economics

journal homepage: http://www.elsevier.com/locate/retrec

A comprehensive charging network planning scheme for promoting EV charging infrastructure considering the Chicken-Eggs dilemma

Lefeng Shi [a,*], Ying Hao [b,**], Shengnan Lv [a], Liana Cipcigan [c], Jun Liang [c]

[a] School of Economics and Management, Center for Intelligent Energy Management and Applications, Chongqing Normal University, Chongqing, China
[b] Department of Automation, Beijing Institute of Technology, Beijing, China
[c] School of Engineering, Cardiff University, Cardiff, CF24 3AA, United Kingdom

ARTICLE INFO

Keywords:
Electric vehicle
Charging network
Charging convenience
Government subsidies

ABSTRACT

The development of electric vehicles (EVs) cannot separated with the support of charging infrastructures. However, there has always been a paradox between them, especially in the initial phase of EVs development: the low uptake of EVs often hinders the investment enthusiasm of investors for charging infrastructure and vice versa, making them drop into a chicken-egg dilemma. For resolving the problem, a comprehensive planning scheme for EV charging networks is proposed in this paper. In the scheme, the influence mechanism of charging networks along with the developing of EVs is analyzed theoretically first, in which an inclusive analysis framework is proposed; and then around how to solve the current chicken-egg dilemma, a series of propositions and planning models are set forth and built, which not only consider the impact of charging network layout on the EVs' charging convenience, but also discuss the cost pressure brought by the charging network construction on investors and the subsequent impact on the charging price; last, based on analytic results, aiming to promote the social uptake of EVs effectively, a relevant government subsidy scheme is proposed for charging facilities.

1. Introduction

1.1. Research background

There is a dynamically interdependent relationship between electric vehicles (EVs) and its charging infrastructure. Especially in the initial stage of EVs development, a reasonable layout of the charging network and an adequate provision of charging services are crucial to promoting the uptake of EVs (Springel, 2016). However, in its preliminary stage, due to the minor volumes of EVs, the investors of EVs charging infrastructures often experience a cold business period, in which the low charging demand might not satisfy their business expectation and even not make up their up-front investment. As Springel (2016) argued, in the early phase of EVs development, it was difficult for investors to make profits due to the significant initial investment for charging infrastructure and the low utilization rate of the majority of these chargers; especially when the recovery of this investment was always difficult, the investment enthusiasm of related investors for EVs' charging infrastructures would hardly be inspired. However, contradictorily, an adequate EVs charging service provision usually is the prerequisite to promote the large-scale social uptake of EVs (Haustein & Jensen, 2018; Javid & Nejat, 2017). Arguably, in reality, residents' purchase decision for EVs to a large degree depends on the density of the EV charging network of their area and the resulting charging convenience, as Sierzchula, Bakker, Maat, and Van Wee (2014) and Kuby and Lim (2005) pointed out that the key step propelling the EVs development is how to solve the contradiction of unsure charging demand and the requirement of large up-front investment for charging infrastructure. Hence, how to properly solve the contradiction between the investment motivation lack of charging infrastructure investors and the requirement of EVs potential buyers considering their EVs charging convenience, is a core issue in the charging network planning, especially in the early stage of the EVs widespread popularization. This hard problem often is labeled as the chicken-and-egg dilemma.

1.2. Literature review

Currently, though numerous suggestions have been put forth around the topic of EVs charging infrastructure planning or operating, little of them refer to the above issue. A large of relevant literature view the EVs

* Corresponding author.
** Corresponding author.
E-mail addresses: shilefeng@foxmail.com (L. Shi), hyxp1019@163.com (Y. Hao).

https://doi.org/10.1016/j.retrec.2020.100837
Received 7 December 2019; Received in revised form 3 February 2020; Accepted 10 March 2020

charging infrastructures planning as an optimization issue, in which the amount of EVs and their demand have been predetermined, and the planning goals largely are searching an approach of meeting the charging demand and meanwhile minimizing the investment cost of charging facilities or reducing relevant operational cost concerning the EVs' charging impact of the power system, or both (Huang, Yang, Chen, Jiang, & Cao, 2015; Jia, Hu, & Song, 2016; Ren, Shi, Zhang, Han, & Huang, 2011). For example, some studies, assuming the EVs charging behavior predictable, suggest that comprehensive considering both the charging demand of EVs and the power output of nearby renewable power resources, could decrease the operational cost and even could bring benefits for charging infrastructures (Jin, Sheng, & Ghosh, 2014; Kamankesh, Agelidis, & Kavousi-Fard, 2016; Wu, Zeng, Lu, & Boulet, 2017. In addition, other studies design a series of management schemes of charging facilities based on the same assumption, which aimed to exploit the potential value of EVs by coordinating them with the local power system operation (Huang et al., 2019; Zhou, Qian, Allan, & Zhou, 2011). Overall, taken the existing studies together, it is known that although the studies are feasible and effective in certain contexts, the majority of them often limited a special situation wherein a considerable number of EVs have existed, neglecting a vital issue that how to layout EVs charging infrastructures can enhance the social uptake rate of EVs effectively.

Indeed, the crux existing many relevant studies lies in that they did not take into account the dynamic relationship between the deployment of charging infrastructure and the development of EVs, thus leading to their invalidation or unreasonable when confronting the chicken-and-egg dilemma. For example, some studies suggested that the modern information and on-line control system could be employed to change the EVs charging choice, thereby to decrease the operational cost of charging facilities and enhance their utilization rate, and even to bring some benefit to EV users through vehicle-to-grid (V2G), so as to inspire the participating motivation of relevant stakeholders (Erden, Kisacikoglu, & Erdogan, 2018; Mehta, Srinivasan, Khambadkone, Yang, & Trivedi, 2016), whereas they neglected that the viability of the visions should be in basis of the premise that there are adequate EVs. Despite parts of studies recognized the problem, and argued that building an charging network ahead of EVs development is important for increasing the confidence of the potential EV buyers and reducing "range anxiety" of existing EVs owners as well as is helpful in the realization of the deliberated visions such as V2G (Lin & Greene, 2011; Tamor, Moraal, Reprogle, & Milačić, 2015; Lefeng, Tong, & Yandi, 2019), their effectiveness still are limited approaches in terms of resolving the chicken-and-egg paradox.

1.3. Research purpose and organization

In view of the above discussion, this paper aims to resolve the chicken-and-egg dilemma by designing a comprehensive planning mix.

Compared with the current studies, the novel points of this paper include as follows:

① A comprehensive charging network planing scheme accounting for promoting the EV social uptake is introduced;
② A areal charging network planing scheme and construction priority method is proposed;
③ A government subsidy scheme for EVs charging network is put forward.

The main content of this paper is organized below: in Section 2, the inner mechanism between the development of charging network and EVs market diffusion is analyzed theoretically; in Section 3, the dynamic function based on the Logistic model is built to depict the impact of charging service supply on the EV development; then in Section 4, the relevant models of Section 3 is extended to describe the dynamic relationship between areal EV charging demand and the whole charging network construction; based on the results of Section 4, a policy mix is proposed in Section 5 to coordinate the developing of EVs and charging network constructing; in Section 6, the corresponding planning process is put forward and applied to a practical case of Chongqing China; and finally, Section 7 presents concluding remarks.

2. Analysis of the complementary relationship between EVs and charging network

2.1. Complementarity between EVs and charging network

The relation between EVs and their charging network belongs a complementary one, like computers and the internet, mobile phones and apps (Saloner & Shepard, 1992; Katz & Shapiro, 1994). The main characteristic of complementary commodities is that consumers must buy both in order to get the maximum benefit. If one of them is missed, consumers not only will not obtain the maximum consumption benefits but also even due to the inconvenience, may abandon the purchase or turn to buy the other alternatives (Winebrake & Farrell, 1997; Lee, 2013). The same goes for EVs and charging networks. In holistic view, to advance the developing of EVs onwards, apart from the technical progress of EVs themself, it is necessary to be accompanied with a proper layout and scale of charging network. However, at present, the construction of charging networks is far insufficient in a lot of regions. Although many automobile manufacturers such as Tesla and the Chinese BYD promise to install the private chargers for EV buyers, the travel distance of EVs users still is greatly limited by the scarcity of an adequate public charging network (Morrissey, Weldon, & O'Mahony, 2016; Traut, Cherng, Hendrickson, & Michalek, 2013).

From a dynamic perspective, when the developing process of a commodity always lies in coordination with the development of its complementary, the latter will, in turn, stimulate its further development. This mutual positive feedback-coordination process between complementary commodities is called as **Network Effect** (Katz & Shapiro, 1985). Consistent with the characteristic of the network effect, the development of EVs charging network may well bring network benefit to EV development (Li, Tong, Xing, & Zhou, 2017; Zhou & Li, 2018n Fig. 1. In a microlevel, because the EVs charging facilities of different areas which compose a charging network, not only can meet the charging demand of EV users of the local area but also can meet the charging demand of the users from other areas; therefore, once the EVs charging network is constructed up, the travel range of EV users in all areas will be extended, and thanks to the feedback-reinforcing effect of the network effect, the EVs' convenience of charging will be enhanced too, whereby the alleviation of EV users' range anxiety and improving the acceptance

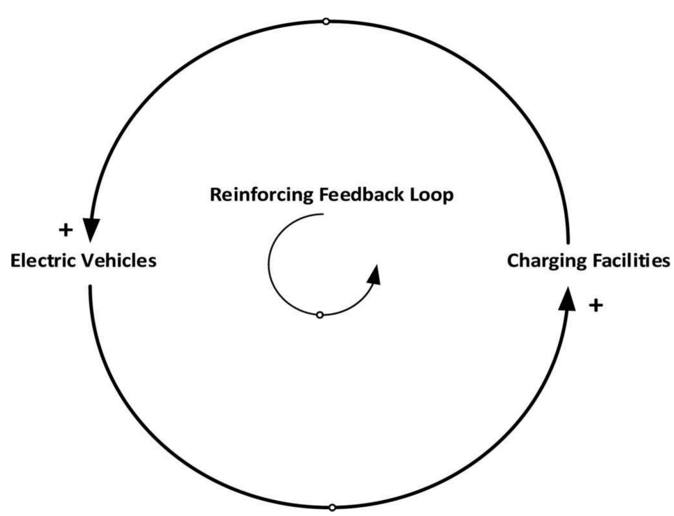

Fig. 1. Feedback relations between EVs and charging facilities.

of EV in the market could be achieved.

2.2. Network effect description between EVs and charging network

2.2.1. Influence of EVs adoption

Generally, the main factors that hold up the development of vehicles, include the purchase cost of vehicles, fuel cost and the convenience of refueling. To EVs, except for the purchase cost having a direct relation with its technical level, the other two factors (i.e., fuel cost and refueling convenience) all relate with the charging network. In EVs charging network, the density and location rationality of charging facilities determine the charging convenience and its investment cost that would affect the EVs charging price setting to a large degree (Sierzchula et al., 2014; Zhang et al., 2018). Based on the above logic, Proposition 1 can be got:

Proposition 1. *the layout of an EVs charging network not only should consider how to enhance EVs charging convenience but also ought to take the related charging prices as well as its impact of EVs uptake rate into account meanwhile.*

Moreover, despite EVs charging networks, other factors relevant to the EVs development could be categorized into two kinds: uncontrollable factors and controllable factors. As demonstrated in Fig. 2 and shown in Table 1, the uncontrollable factors contain the technical progress level of EVs as well as the social environment-protection consciousness, fuel price and other uncontrollable factors (located at the bottom half of Fig. 2). On the other hand, the operation situations of the entire electric power system and the subsidy from government (located at the top half of Fig. 2) as well as the situation of charging network layout, belong to the controllable factors (Chandra, Gulati, & Kandlikar, 2010). In some degree, the controllable factors could exert more effectiveness than the uncontrollable. For example, notwithstanding the breakthrough of EV battery technology could reduce the sale price of EVs, extend EVs driving distance, and remove the range anxiety of EV users effectively (Li & Ouyang, 2011; Nie & Ghamami, 2013), but due to its unpredictability, if aiming to promote the EVs developing in short time, advancing the construction of EVs charging network would be more effective, compared with anchoring all hope on the technological progress. Hence, Proposition 2 can be got:

Table 1
Effectiveness classification of the factors influencing the development of EVs.

Factors	Effectiveness
Charging network	Direct and controllable effectiveness
EV technological level	Direct but uncontrollable effectiveness
Power system development, Subsidy	Indirect and controllable effectiveness
Consciousness of resident, Fuel price	Indirect but uncontrollable effectiveness

Proposition 2. *in the context of the current EV technologies and the consciousness of resident, in the short term, improving the charging network and designing the corresponding subsidy scheme is an effective way to promote the development of EVs.*

2.2.2. Influence of charging network layout

According to Proposition 2, it is known that promoting layout of charging network will be more effective to the development of EVs than other factors in the short term, but how to plan a charging network in conjunction with EVs marketization to resolve the chicken-and-egg

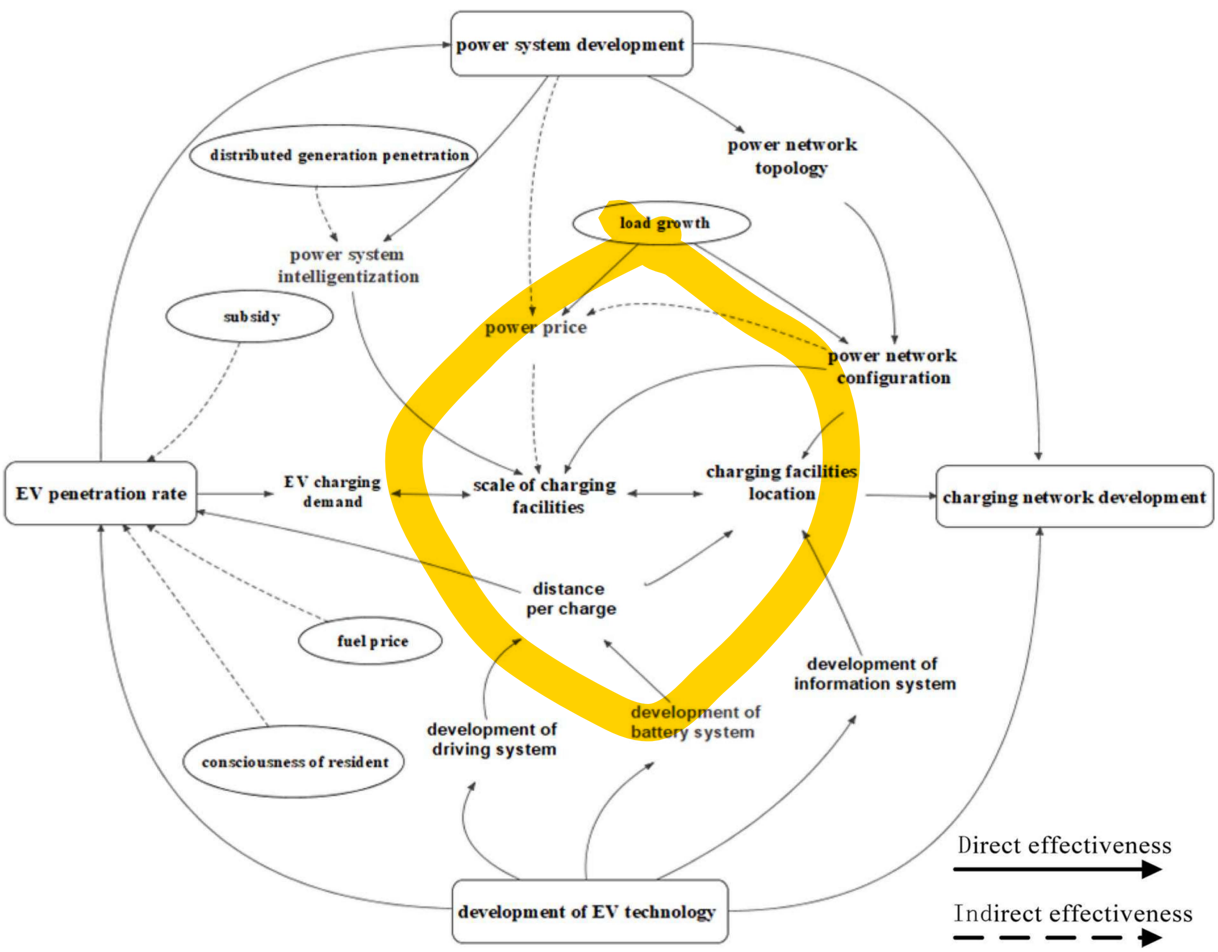

Fig. 2. Dynamic relation between EVs and charging network.

dilemma still is an open question. The answer might be obtained if we stand on a holistic perspective combining the EVs technology progress, the layout of the charging network and the EVs development. As illustrated in Fig. 3, regarding the related technology progress and the market penetration level, the EVs development process could be divided into multi-periods (Lefeng et al., 2019), in which the trajectory of EV diffusion presents a trend that EVs develop with the enlarged scale of charging network because more charging facilities will bring about better-charging convenience. However, restricted by the short-term technical level and the situation of charging service supply, the potential market capacity of EVs of each phase is different, e.g. due to the technology progress, the potential market capacity of EVs in period *t*, *Qt,* is larger than the *Qt-1* of period *t-1,* distinctly.

In the respect of charging network, as Fig. 3 shows, when the charging network layout is nonoptimal, like the charging network 1, the market acceptance quantity of EVs, *Q1*, is less than the quantity of the charging network 2, *Q2*, whose layout is more optimal (for instance, the layout strategy of charging network 2 may take into account other factors better, such as power grid operation, road traffic conditions and other factors illustrated in Fig. 2), but for investors, a theoretically more optimal charging network often requires more investments in reality, which will lead to higher charging price for EV users and thus depressing EV purchase willing of the public (Shao et al., 2017).

Furthermore, even when the same planning strategy is executed, the market acceptance of EVs will be affected by the supply of charging facilities as well. For example, in Fig. 3, when the supply of charging facilities (shown in the horizontal coordinate), *Sa* less than the optimal supply *S*, the market acceptance quantity of EVs (shown in the vertical coordinate), *Qsa,* will be less than the quantity, *Qs*. Similarly, when the supply quantity of charging facilities *Sb* higher than *S*, the market acceptance quantity of EVs is not necessarily higher than *Qs* at this time, as the higher investment cost and the lower utilization rate of EVs charging facilities would make the charging network investor set a higher charging electricity price to recover its cost (Feng & Figliozzi, 2013), while the high charging price might well impact the market purchase of EVs (Dong, Ma, Wei, & Haycox, 2019; Wirges, Linder, & Kessler, 2012). In this situation, the market acceptance quantity of EVs will be *Qsb*, small than *Qs*. Therefore the intersection between 'Trajectory of EV diffusion' and 'charging network' usually is a compromise of the contradiction described above, attaining the optimal scale of charging network. According to the above ratiocination, Proposition 3 can be obtained:

Proposition 3. *the layout form of EVs charging network and the scale of each charging point affect the social uptake of EVs jointly.*

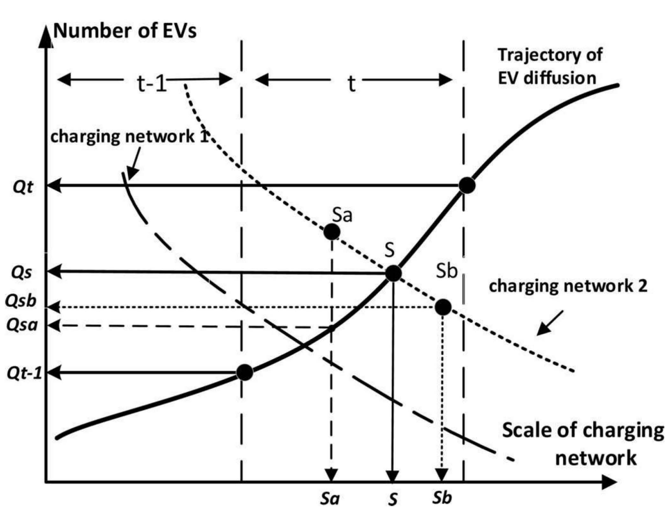

Fig. 3. Dynamic relation between EV development and charging network layout.

In light of Proposition 3, the conclusion can be obtained that when formulating an EV charging network, the key point is to choose an optimal layout form and determine a proper quantity of charging facilities at each point. During the process, to reconcile this contradiction between the demand for charging convenience of EVs users and the requirement of cost-effectiveness of the related investors, the support from government is needed (Eid, Guillén, Marín, & Hakvoort, 2014). *However, what a policy the government should follow has been discussed rarely as we know. The rest of this paper will address this problem systematically.*

3. Charging network impact on EVs development

3.1. EVs diffusion

The current models describing the diffusion process of a new technology product based on the two basic models: Logistic model and Bass market model (Dissanayake & Morikawa, 2010; Al-Alawi & Bradley, 2013). The Bass model considering the technical innovation and the social imitating rate of the selected product, will be more effective in the case of predicting the diffusion trajectory of a new technology product in a long terms, while the Logistic model can directly predict its market diffusion increment in a short term, which assumes that in some period the related technical level of the selected product remains static, thus excel in measuring the impact from external factors other than technology factor in respects of the diffusion increment (Naseri & Elliott, 2013). Considering the goal of the charging network planning is to meet the incremental charging demand and accordingly to promote EVs social uptake, this paper, therefore, adopts Logistic model to describe the EV market diffusion process:

$$\widehat{E}^{t} = \frac{\mathrm{d}N(t)}{\mathrm{d}t} = \alpha^{t}\cdot\mu^{t}\cdot[m - E(t)] \tag{1}$$

Where $N(t)$is the total number of EVs until in period $t,t \in [0,1,2,\dots,T]$; $\widehat{E}^{t}$represents the increment of EVs of period t; $E(t)$is the cumulative ownership of EVs by time t; m is the largest theoretic market volume of EVs in future; $\alpha^{t}$and $\mu^{t}$are the market response coefficients to the technological level of EVs and to charging convenience in period t respectively.

In Eq. (1), it can be seen that, under certain circumstances, the convenience of charging and the technological level of EVs can substitute each other. For example, when the battery power density is not high, a complete charging network still can promote the development of EVs. This inference is in line with Proposition 2. In this paper, the EVs technical level, α^{t}, is set as an exogenous variable, which can be obtained through referring other relevant studies or reports such as Global EV Outlook of international energy agency, and the EV charging convenience level, μ^{t}, is set as an endogenous variable.

3.2. Charging network impact

Eq. (1) describes a generalized market diffusion model of EVs. In practices, the development of EVs has obvious areal characteristics. When charging facilities will be placed in area $ii \in N$, the charging convenience is reflected by μ_{i}^{t}:

$$\mu_{\mathrm{i}}^{t} = \mathrm{w}_{\mathrm{i}}^{\mathrm{C}}/T_{i}^{C} + \mathrm{w}_{\mathrm{i}}^{\mathrm{P}}/P_{i}^{C} \tag{2}$$

Whereμ_{i}^{t} is the charging convenience of EV users in area i, which is decided by charging waiting time $T_{i}^{C}$and charging price P_{i}^{C}; $\mathrm{w}_{\mathrm{i}}^{\mathrm{C}}$and $\mathrm{w}_{\mathrm{i}}^{\mathrm{P}}$are the psychological weights of $T_{i}^{C}$and $P_{i}^{C}$for EVs users charging in area i. As discussed, charging time $T_{i}^{C}$and charging priceP_{i}^{C} are related to the scale of the charging network of i area Z_{i}^{t}, where $T_{i}^{C}$is inversely proportional to $Z_{i}^{t}$and $P_{i}^{C}$is positively proportional to Z_{i}^{t}. Integrating Eq. (1) and Eq. (2), the function of the impact of charging network on the EVs development of area i can be derived:

$$\widehat{E}_i^t = \frac{dN_i(t)}{dt} = \alpha^t \cdot \left(w^C / T_i^C + w^P / P_i^C\right) \cdot [m_i - E_i(t)] \tag{3}$$

Where $N_i(t)$is the EVs scale of area i until in period t; $\widehat{E}_i^t$represents the increment of EVs of area i in period t; $E_i(t)$is the cumulative ownership of EVs by time t; $m_i$is the area i's largest theoretic EVs market volume in future. As Eq. (3) describes, under the condition of a certain EV technology, reducing charging waiting time or charging electricity cost will be conducive to promoting the EVs uptake, which corresponds to Proposition 2. Section 4 probes the influence of the two aspects further.

Notably, though $w_i^C$and w_i^Pas well as $m_i$belongs to exogenous variable, their values determine the aeral characteristic of EVs adoption. For obtaining as accurate the values as possible, diverse methods can be employed. For instance, Scobit model is usual to be chosen to evaluate the citizens' psychological factors and to estimate the potential scale of alternative urban trip modes accordingly (Zhang, Xu, & Fujiwara, 2012). Nevertheless, their estimation has gone beyond the scope this paper focus on. We has written another paper to address this issue in detail. Besides, we assume that the planned public chargers follow the same technical criteria, namely including the same charging power. Thus for every charging point, the charging time of EVs is not different, compared with the difference brought by the geographical elements and the scale element of charging points. So, the influence of EVs charging time is neglected in the paper.

4. Charging network impact on EVs charging

4.1. EVs charging demand

As argued in Proposition 1 and Proposition 3, planning a charging network cannot be separated from the analysis of the layout and scale of charging facilities in different areas. Considering the situation of each area, the entire charging network can be described as:

$$Z^t = \left[z_{ir}^t\right]_{N\times M} = \begin{pmatrix} z_{11}^t & z_{12}^t & \cdots & z_{1M}^t \\ z_{21}^t & z_{22}^t & \cdots & z_{2M}^t \\ \vdots & \vdots & \vdots & \vdots \\ z_{N1}^t & z_{N2}^t & \cdots & z_{NM}^t \end{pmatrix}_{N\times M} \tag{4}$$

In Eq. (4), $z_{ir}^t \in \{0,1\}$denotes whether charging facility is built in area i, $i \in N$; the maximum of M chargers could be constructed in each area. In rush hour, the potential charging demand of EVs is:

$$Q^t = \left[q_{ig}^t\right]_{N\times E_i^t} = \begin{pmatrix} q_{11}^t & q_{12}^t & \cdots & q_{1w}^t \\ q_{21}^t & q_{22}^t & \cdots & q_{2w}^t \\ \vdots & \vdots & \cdots & \vdots \\ q_{N1}^t & q_{N2}^t & \cdots & q_{Nw}^t \end{pmatrix}_{N\times E_i^t} \tag{5}$$

Where $q_{ig}^t$is the charging demand of EV user in the area i, $g \in E_i^t$,where the EVs amount is $E_i^t = E_i(t) + \widehat{E}_i^t$.

Theoretically, the EV user's charging convenience coefficient of area i, $\mu_{ig}^t$is influenced by the number of charging facilities $z_i^t = \sum_M z_{ir}^t$and the charging demand $q_i^t = \sum_{E_i^t} q_{ir}^t$. However, as in real life vehicles always are in a mobile state, EVs from other areas such as j ($j \in N, j \neq i$), possibly drive to area i and charge, and vice versa. Accordingly, the EV charging demand of area i can be divided into two parts: the demand in area i, q_{ii}^t, and the demand in other areas, q_{ij}^t. The demand in area i, q_{ii}^t, means that the EV users of area i choose to charge their EVs in area i; q_{ij}^t, represents that the some EVs of area i is charged in other area such as j. Thus the charging demand of from the EVs of area i,q_i^t is:

$$q_i^t = p_{ii}q_{ii}^t + p_{ij}q_{ij}^t = \sum_N p_{ij}q_{ij} \tag{6}$$

Eq. (6) describes the expectation of EV charging demand of area i. $p_{ii}$is the probability that the EVs of area i choose to charge in area i; $p_{ij}$is the probability that the EVs of area i choose to be charged in the area j, $\sum_{i,j\in N} p_{ij} = 1$. At this time, the charging demand in area i,$\tilde{q}_i^t$,is:

$$\tilde{q}_i^t = p_{ii}q_{ii}^t + \sum_{j\neq i} p_{ji}q_{ji}^t \tag{7}$$

Where$p_{ii}q_{ii}^t$ is the inherent charging demand from EVs of area i; $\sum_{j\neq i} p_{ji}q_{ji}^t$is the charging demand of EVs from other areas. So, the actual charging demand in each area can be expressed as:

$$Q_i^t = \left[\tilde{q}_i^t\right]_N = \left[p_{ii}q_{ii}^t + \sum_{j\neq i} p_{ji}q_{ji}^t\right]_N \tag{8}$$

Based on Eq. (6) to Eq. (8), Proposition 4 can be got:

Proposition 4. *even though the amount of EVs in the area i is greater than area j, it is not sure that the actual charging demand in the area i must be necessarily greater than area j, because of the areal mobility of EVs. The same is true of the scale of charging facilities in different areas.*

4.2. EVs charging convenience

As the core indicator assessing EVs charging convenience, the charging time in area i can be obtained through Eq. (9):

$$\tilde{T}_i^C = \beta_i^t \cdot \frac{\tilde{q}_i^t}{z_i^t \cdot \gamma \cdot \zeta} \tag{9}$$

Where $\beta_i^t$is the coefficient of charging time of area i, which is affected by the charging network layout in area i and its road traffic condition, $\beta_i^t \geq 1$; z_i^trepresents the scale of charging facilities in area i; $\gamma$is the rated charging power of a single charger; $\zeta$is the daily charging peak time ratio, which is the proportion of the rush hour throughout the day (because a larger peak time ratio should correspond to a longer charging time).

Under a given scale, the theoretical charging price in area i is:

$$\tilde{P}_i = \tilde{P}_i(z_i^t) = \frac{F_i(z_i^t)/\zeta}{\tilde{q}_i^t} = \frac{F_i(z_i^t)}{\tilde{q}_i^t \cdot \zeta} \tag{10}$$

Where $F_i(z_i^t)$ represents all the input costs of the charging facility in area i. The shared cost of a single charging facility is:

$$f_i = C_{0i} + C_{1i} + C_{2i} + C_{3i} \tag{10.1}$$

where $C_0 C_1 C_2, C_3$ respectively represent the construction cost of a single facility in area i, parking space rental cost, amortization cost of local power system upgrade and the ordinary maintenance and management cost of charging facility. Their calculation functions are as follows:

$$C_{0i} = a_1 + a_2 \tag{10.2}$$

$$C_{1i} = T_i \tag{10.3}$$

$$C_{2i} = a_3 \cdot \varepsilon_{1i} + a_4 \cdot \varepsilon_{2i} + a_5 \cdot \varepsilon_{3i} \tag{10.4}$$

$$C_{3i} = (C_{0i} + C_{1i} + C_{2i})^* \rho \tag{10.5}$$

Where $a_1$and $a_2$are the purchase cost and the building cost of the charging facilities of area i; $T_i$is the rental fee for the parking space in area i; a_3, $a_4$and $a_5$are the amortization value of adding transformer cost, the amortization value of adding power line and the amortization value of adding other electrical equipment respectively in the area; $\varepsilon_{1i}\varepsilon_{2i},\varepsilon_{3i}$

are 0/1 variables; ρ is the maintenance and management cost coefficient of charging facility and relevant equipment.

$$F_i(z_i^t) = z_i^t \cdot f_i \tag{10.6}$$

According to Eq. (9) and Eq. (10), the influence of the whole EV charging network of area i can be obtained by the weighted average:

$$T_i^C = \sum_{j \in N} p_{ij} \cdot \tilde{T}_j^C \tag{11}$$

$$P_i = \sum_{j \in N} p_{ij} \cdot \tilde{P}_j \tag{12}$$

Where T_i^C is the average charging time of the EVs of area i in the charging network; P_i is the average charging price paid by the EV users of area i in the charging network.

Based on Eq. (3), Eq. (11) and Eq. (12), the increment of EVs of area i, influenced by the whole charging network, can be expressed as follow:

$$\widehat{E}_i^t = \alpha^t \cdot \left(w^C \Big/ \left(\sum_{j \in N} p_{ij} \cdot \tilde{T}_j^C \right) + w^P \Big/ \left(\sum_{j \in N} p_{ij} \cdot \tilde{P}_j \right) \right) \cdot [m_i - E(t)] \tag{13}$$

5. Comprehensive charging network planning scheme

5.1. Planning scale and priority

5.1.1. Optimal scale of areal charging facilities

From the perspective of charging network operation, the acceptance situation of EVs will affect both the cost and the profitability of the charging facilities of each area (Morton, Anable, Yeboah, & Cottrill, 2018). Therefore, the main goal of the construction of the EV charging network is to balance the interests between the EV users and the charging infrastructure investors, and eventually to realize the coordinated development of EVs and charging infrastructure. To achieve this goal, the scale of charging facilities in each planning area should be considered, where the charging facilities of each area constitute the whole charging network jointly.

Depending on Eq. (1), the potential EV theoretical increment of each area in future period t can be obtained, assuming that all the charging demand of EVs can be satisfied. After knowing the increment of EVs in each area, the optimal scale of charging facilities in each area can be deduced reversely through referring to Eq. (9) to Eq. (13):

$$z_i^S = \arg\left(\max \widehat{E}_i^t\right), i \in N \tag{14}$$

Eq. (14) indicates that the layout of charging facilities of area i aims to maximize the development of EVs.

5.1.2. Priority of areal charging facilities construction

Combining Eq. (9) with Eq. (13), it is clear that the development of areal EVs is positively correlated with the number of charging facilities, $\widehat{E}_i^t \propto z_i^t$, and the scale of charging facilities is positively correlated with the charging demand, $z_i^t \propto \tilde{q}_i^t$, so it can be deduced that the increment of EVs in period t is positively correlated with the charging demand of each area, $\widehat{E}_i^t \propto \tilde{q}_i^t$.

Moreover, due to the construction of charging facilities in the areas with greater charging demand, it would make a greater contribution to the uptake of EVs, based on which the inference could be got that the construction sequence of the charging facilities in different areas may lead to different effects of stimulating the EV development. The charging network is first laid out in the area where the charging demand of EVs is larger, and the development of EVs can be more promoted, that is:

$$\tilde{q}_j^t \geq \tilde{q}_i^t, i, j \in N \Rightarrow z_j^t \succ z_i^t \tag{15}$$

Eq. (15) indicates that if the charging demand of area j is higher than the charging demand of area i, the deployment of charging facilities of area j should take precedence over that of area i. Hence Proposition 5 can be obtained:

Proposition 5. *it is favorable to promote the uptake of EVs when the facilities of the area with higher charging demand are deployed at priority.*

5.2. Government subsidies for charging network

5.2.1. Behavior of the charging network investor

The objective function of EV charging network investor is the profit maximization as usual, which can be defined as:

$$z_i^I = \operatorname{argmax} \pi_i = \operatorname{argmax} \eta \cdot F_i(z_i^t), i \in N \tag{16}$$

Where $\pi_i = \eta \cdot F_i(z_i^t)$ is the revenue function of charging facilities; $\eta, \eta \geq 1$ is the revenue coefficient. When the revenue function is converted to the revenue of each kilowatt-hour, the charging price of area i can be obtained. Eq. (10) can be changed into:

$$\tilde{P}_i = \frac{\eta \cdot F_i(z_i^t)}{\tilde{q}_i^t \cdot \zeta} + P^G \tag{17}$$

Where P^G is the electricity cost, which is the price when the investor of charging network buys electricity from the upstream grid.

According to the economic theory, when the investor's marginal cost is equal to the marginal benefit, the maximum benefit can be obtained (Baumol & Bradford, 1970; Yang and Huang, 1998). Assume that the investor of charging network is rational. For a rational investor, when its marginal revenue is set as the EV users' psychological expectation charging price P_i^V (which is the highest charging price EV users are willing to pay), its revenue will be the largest:

$$\tilde{P}_i = P_i^V = \frac{\eta \cdot F_i(z_i^t)}{\tilde{q}_i^t \cdot \zeta} + P^G = \frac{\eta \cdot z_i^t \cdot f_i}{\tilde{q}_i^t \cdot \zeta} + P^G \tag{18}$$

Based on Eq. (18), if the EV user's psychological expectation charging price has been known, in the area i, the optimal scale of charging facilities placed by the investor will be:

$$z_i^I = \frac{(P_i^V - P^G) \cdot \tilde{q}_i^t \cdot \zeta}{\eta \cdot f_i} \tag{19}$$

5.2.2. Government subsidies scheme

The "chicken-and-egg" dilemma arising from the development of EVs and the layout of charging network, lies in the interest conflict between EV users and charging network investor. EV users expect that the charging network should be as convenient as possible, and simultaneously the charging prices are acceptable, whereas the charging network investor needs to consider its cost and profit, as argued in Proposition 1. To reconcile this contradiction, the government needs to mediate (Corradini, Costantini, Markandya, Paglialunga, & Sforna, 2018; National Research Council, 2015).

At current stage, the promotion of EVs is the main goal of many governments (Cazzola, Gorner, Munuera, Schuitmaker, & Maroney, 2017). In order to achieve $\widehat{E}_i^t$, the goal of EV growth in area i in future period t, the number of EV charging facilities built by the charging network investors is at least equal to the expected number of EV charging facilities (the optimal scale) $z_i^S = z_i^I, i \in N$. However, when the charging network meets the charging requirements of EV users, the charging network investors may face two situations:

Situation 1: when the charging network is built, the charging network investor can get a certain profit, and its charging price is not higher than the psychological expectations of EVs, $P_i^C \leq P_i^V$. Obviously, this is the best expectation of the whole society.

Situation 2: due to the high input cost of the charging network, the charging price is set to be higher than the psychological expectation

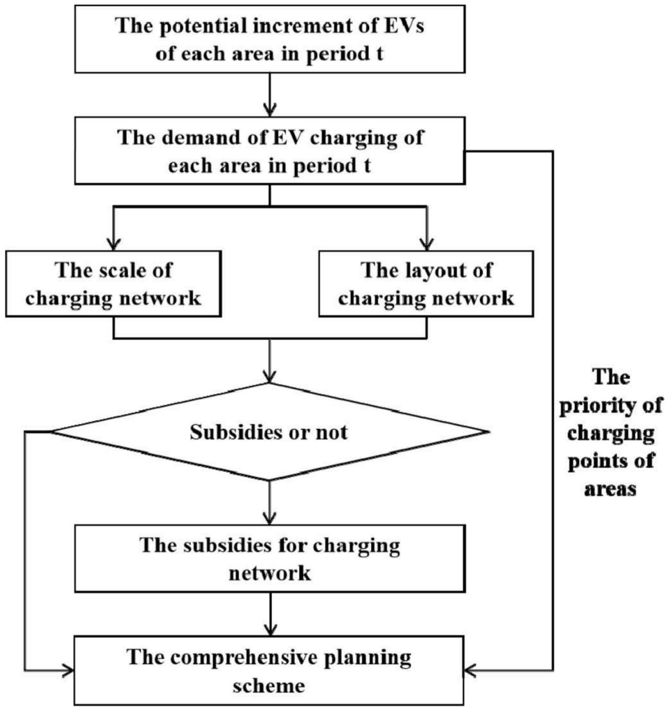

Fig. 4. Planning procedures of charging network.

of EV users, $P_i^C > P_i^V$. Referring to Eq. (19), it is known that if the price of charging network is fixed at a level acceptable to EV users, charging network investor would endure losses. In this situation, for making profit, the rational choice of the charging network investors, is to reduce the scale of the charging network, which will lead to the scale of the deployed charging network smaller than the optimal scale that EV users expect, $z_i^S > z_i^I, i \in N$. Due to the reduction of the charging network scale, as such a chain effect will be triggered, e.g., that the charging convenience of EVs will decrease; the market acceptance of EVs will also decline. Therefore, in order to better promote the development of EVs, the government needs to give a certain subsidy to the charging network investors to compensate for their loss. Only in this way, both the layout and the scale of the charging network can meet the optimal expectations of society. The government subsidies for charging network should be:

$$S_i = \tilde{P}_i - P_i^V = \frac{\eta\cdot\left(z_i^S - z_i^I\right)\cdot f_i}{\tilde{q}_i^t} \tag{20}$$

6. Planning guideline and case study

6.1. Planning procedures

From this analysis, it was found that a complete EV charging network planning should take into account the impact of charging network layout on EV uptake, and eventually develop a comprehensive planning scheme that includes the scale and layout of charging network, government subsidies for charging network and layout priority of the charging facilities of different areas. Fig. 4 summarizes the proposed steps of charging network planning:

① The potential increment of EVs of each area in period *t* should be estimated first, assuming the charging demand is fully met.

② Based on the increment of EVs in each area and the traffic flow characteristics of EVs between areas, the charging demand of EVs in each area can be estimated.

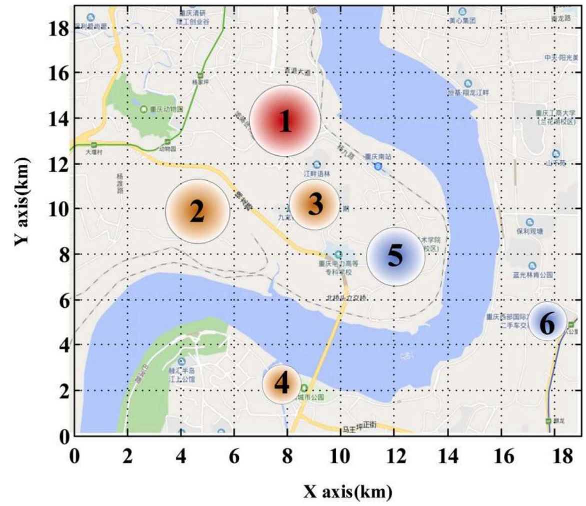

Fig. 5. Charging network planning area.

Table 2
Planning areas classification.

areas	Function
1	Medical, shopping, social, etc
2,3,4	Residence
5,6	Workplace

③ According to the network effect and the charging demand of EVs in different areas, the priority of charging points in each area is determined.

④ The scale and layout of charging facilities of each area can be obtained, which is determined based on its charging demand and the charging time requirements of EV users in different areas.

⑤ According to the scale and layout of the charging network, the reasonable charging price set by investors in the charging network is calculated.

⑥ Comparing the charging price set by the charging network investor with the psychological expectation charging price of EV users, the excess is the subsidy that the government needs to give to the charging network investor.

⑦ Combining the scale and layout of the charging network, the priority of the charging points of areas and the government subsidy, a comprehensive planning scheme of the charging network can be introduced.

6.2. Case study

In this paper, a charging network is planned in an area of 19 km in both length and width of Chongqing city, China. As shown in Fig. 5, the charging facilities in 6 different areas constitute a charging network. Each area is classified into residential area, industrial area and commercial area, as shown in Table 2. In order to obtain the potential increment of EVs in each area in the planning period, a survey in these areas was first conducted. After obtaining the ideal increment of EVs in these areas and the travel characteristics of residents driving between areas, the comprehensive planning scheme of EV charging network in the planning areas is obtained according to the planning procedures in Fig. 4.

Table 3
Diffusion of the EV market.

Parameter	Value					
	1	2	3	4	5	6
$\widehat{E}^t$	27,000	16,000	10,670	5,330	13,800	9,200
$E(t)$	1100,000	650,000	433,330	216,670	540,000	360,000
m	1700,000	1000,000	666,670	333,330	840,000	560,000
q_i^*	135,000 kWh	80,000 kWh	53,350 kWh	26,650 kWh	69,000 kWh	46,000 kWh
w^C	0.5	0.5			0.5	
w^P	0.5	0.5			0.5	
P_i^V	1.2Yuan	1.0Yuan			1.1Yuan	
P^G	0.8Yuan	0.6Yuan			0.7Yuan	

6.2.1. *Potential increment of EVs*

We predict that in the next year, there will be 8,2000 potential increments of EVs in the planned area. The response coefficient of the market to the technical progress of EVs, is $\alpha^t = 0.045$. Table 3 shows the increments, the current EV holdings, and the maximum market volume in the 6 areas. The electricity purchase price from the grid $P^G$and the expected charging price of EV user $P_i^V$are also listed in Table 3. The average charging demand is 5 kWh per day for each EV (Zhong & Weiyu, 2018). The q_i^*in Table 3 is the charging demand in the 6 areas.

6.2.2. *Charging demand of EVs*

In this case study, China traffic database is referred to calculate the frequency at which cars travel between areas based on different starting area in one day (Gaode, 2019); and based on the driving frequency, the transition probability of EVs between areas (shown in Eq. (21)) is derived (Ma et al., 2017). In addition, considering the possibility that EVs in the 6 areas may travel outside the planning area and be charged, we add the last row and the last column in Eq. (21) to represent that possibility.

$$P = [p_{ij}]_{7\times7} = \begin{pmatrix} 0.1705 & 0.5824 & 0.0034 & 0.0314 & 0.1279 & 0.0655 & 0.0189 \\ 0.2100 & 0.0128 & 0.0366 & 0.1544 & 0.3307 & 0.2322 & 0.0233 \\ 0.6589 & 0.0752 & 0.0323 & 0.0377 & 0.1294 & 0.0583 & 0.0084 \\ 0.6126 & 0.0853 & 0.0144 & 0.1044 & 0.0964 & 0.0794 & 0.0095 \\ 0.0934 & 0.5618 & 0.0032 & 0.0282 & 0.2426 & 0.0604 & 0.0104 \\ 0.1118 & 0.5887 & 0.0056 & 0.0446 & 0.1330 & 0.1039 & 0.0124 \\ 0.2936 & 0.1951 & 0.1301 & 0.0650 & 0.1683 & 0.1122 & 0.0329 \end{pmatrix} \tag{21}$$

In accordance of the description in Section 4.1, the charging demand in each area $\tilde{q}_i^t$can be calculated using Eq. (1), Eq. (7) and q_i^*:

$$\tilde{q}_i^t = [1.32440.78140.52900.26450.68280.4243] \times 10^5 \tag{22}$$

6.2.3. *Comprehensive planning scheme*

The charging power of a single charging facility is $\gamma = 37.5$kWh, the daily charging peak time ratio is $\zeta = 1/12$, and the costs of a single charging facility are list in Table 4. Because the depreciation period of the charging facility is assumed to be 5 years, the average cost for one year of a single charging facility is:

$$f_i^* = f_i/5 \tag{23}$$

Building charging facilities in the area with larger charging demand will have a greater contribution to the development of EVs. Therefore, when the EV charging demand in area *j* is higher than that in area *i*, the layout priority of area *j* should be higher than in area *i*. Based on Eq. (22), the priority of the 6 areas is:

$$Pr_i^t = [0.32810.19360.13110.06550.16920.1125] \tag{24}$$

The results of Eq. (24) describe the probability that a rational charging network investor will invest in charging facilities in each area in the period of constructing the charging network.

2) Charging facility scales of areas

The optimal scale of charging facilities in the 6 areas, $z_i^S$is be obtained, integrating function (13) and the parameters of both Tables 3 and 4. And the charging price $\tilde{P}_i$can be obtained using function (17), $\eta = 1.2$.

$$z_i^S = [483021102417] \tag{25}$$

$$\tilde{P}_i = [1.45241.23211.25351.22241.32861.3661] \tag{26}$$

The charging facility sale in Eq. (29) is the optimal that can realize the EV potential increment in the planning period. However, the practical scale, z_i^Ithat the investor of the charging network will layout, may be different with the optimal scale as illustrated in Eq. (25). According to Eq. (19), $z_i^I$is obtained:

$$z_i^I = [30191371510] \tag{27}$$

3) Government subsidies

Comparing the $z_i^S$and z_i^I,the practical scale of charging network is smaller than the optimal. That means enlarging their charging network to the optimal scale is not cost-effective to the investor of charging network. However, in the practical scale of charging network, the EV charging waiting time will increase, and thus the EV charging time requirement cannot be satisfied, which will reduce the market acceptance rate of EVs and lead to Chicken-Eggs dilemma. Hence, in this situation, the government needs to give the investor a certain subsidy to motivate it to enlarge the charging network to the optimal scale. According to Eq. (20), the subsidy for per kWh $S_i$is:

$$S_i = [0.24470.23180.24900.18670.21700.2437] \tag{28}$$

Table 5 shows the summary of the comprehensive planning scheme in this case study, from which we can get to know that the commercial

Table 4
The costs of a single charging facility.

Cost	Value		
	1	2, 3, 4	5, 6
a_1	20,000Yuan	20,000 Yuan	20,000 Yuan
a_2	100,000 Yuan	100,000 Yuan	100,000 Yuan
T_i	55,000 Yuan	25,000 Yuan	25,000 Yuan
$[a_3a_4a_5]$	[123]*10,000 RMB	[123]*10,000 RMB	[123]*10,000 RMB
$[\varepsilon_1\varepsilon_2\varepsilon_3]$	[100]	[100]	[100]
Y_i	5,500 Yuan	5,500 Yuan	5,500 Yuan
α_i	1	1	1

Note: Yuan is the monetary unit of China. One yuan is about $0.148.

1) Priority of the charging facility building

Table 5
Comprehensive planning scheme summary.

areas	Priority	Scales	Prices	Subsidies
1	0.3281	48	1.4524	0.2447
2	0.1936	30	1.2321	0.2318
3	0.1311	21	1.2535	0.2490
4	0.0655	10	1.2224	0.1867
5	0.1692	24	1.3286	0.2170
6	0.1125	17	1.3661	0.2437

area (area 1) is most important to the development of EVs in the planning area. Because of the characteristic of area 1, its input cost of the charging facilities is relatively high, so the charging price and the corresponding government subsidy is the highest.

7. Conclusion

The development of EVs cannot be separated from the supporting charging network. As the typically complementary commodities, the outcome of their mutual influence will determine their further development. Especially in the initial stage of EVs uptake, the development of charging network will directly affect the convenience of EVs charging and further affect EVs market diffusion. However, at present, because some practical obstacles such as the inmature of EVs relevant technologies and the diverge of social cognization, make the EVs development not smooth. Moreover, apart from the technical and cognitive factors and other hard-controlled factors, the supplying shortage of EVs charging services is an important factor. Nevertheless, the studies on the dynamic relation of EVs and charging services in terms of charging network planing is scare. To address the problem or rather to find a proper solution to the chicken-egg dilemma between EVs diffusion and charging network construction, this paper first analyzes the commodity attributes between them, then describes their dynamic development relationship theoretically, and finally proposes a comprehensive planning scheme of EV charging network. The scheme not only takes into consideration the promotion of EV development in the conjunction of charging network layout, but also regards the charging price decision made by the investor of the charging network and its impact on EVs development after the construction of the charging network. Additionally, this paper suggests that the government should subsidize the relevant charging facilities and proposes the subsidy calculation method. All the related methods and propositions of this paper compose an integrated EVs charging network planning scheme, providing a new perspective of how to promote charging network construction favoring the EVs developing effectively.

Acknowledgements

Funding: this project was fully funded by the National Social Science Fund of China (grant number: 19BJY077), the Humanities and Social Sciences Projects of the Ministry of Education of China (grant number: 18YJC790137), the project of science and technology research program of Chongqing Education Commission of China (grant number: KJ1703067), Chongqing social science planning and key think-tank project (grant number: 2018ZDZK06), and the Top Talent Plan of Chongqing Normal University (grant number: 020303070059).

References

Al-Alawi, B. M., & Bradley, T. H. (2013). Review of hybrid, plug-in hybrid, and electric vehicle market modeling studies. *Renewable and Sustainable Energy Reviews, 21*, 190–203.

Baumol, W. J., & Bradford, D. F. (1970). Optimal departures from marginal cost pricing. *The American Economic Review, 60*(3), 265–283.

Cazzola, P., Gorner, M., Munuera, L., Schuitmaker, R., & Maroney, E. (2017). *Global EV outlook 2017: Two million and counting.* Paris: IEA Publications-International Energy Agency.

Chandra, A., Gulati, S., & Kandlikar, M. (2010). Green drivers or free riders? An analysis of tax rebates for hybrid vehicles. *Journal of Environmental Economics and Management, 60*(2), 78–93.

Corradini, M., Costantini, V., Markandya, A., Paglialunga, E., & Sforna, G. (2018). A dynamic assessment of instrument interaction and timing alternatives in the EU low-carbon policy mix design. *Energy Policy, 120*, 73–84.

Dissanayake, D., & Morikawa, T. (2010). Investigating household vehicle ownership, mode choice and trip sharing decisions using a combined revealed preference/stated preference nested logit model: Case study in bangkok metropolitan region. *Journal of Transport Geography, 18*(3), 402–410.

Dong, G., Ma, J., Wei, R., & Haycox, J. (2019). Electric vehicle charging point placement optimisation by exploiting spatial statistics and maximal coverage location models. *Transportation Research Part D: Transport and Environment, 67*, 77–88.

Eid, C., Guillén, J. R., Marín, P. F., & Hakvoort, R. (2014). The economic effect of electricity net-metering with solar PV: Consequences for network cost recovery, cross subsidies and policy objectives. *Energy Policy, 75*, 244–254.

Erden, F., Kisacikoglu, M. C., & Erdogan, N. (2018). Adaptive V2G peak shaving and smart charging control for grid integration of PEVs. *Electric Power Components and Systems, 46*(13), 1494–1508.

Feng, W., & Figliozzi, M. (2013). An economic and technological analysis of the key factors affecting the competitiveness of electric commercial vehicles: A case study from the USA market. *Transportation Research Part C: Emerging Technologies, 26*, 135–145.

Gaode. (2019). *Gaode map big data platform[EB/OL]*. https://report.amap.com/detail.do?city=500000.

Haustein, S., & Jensen, A. F. (2018). Factors of electric vehicle adoption: A comparison of conventional and electric car users based on an extended theory of planned behavior. *International Journal of Sustainable Transportation, 12*(7), 484–496.

Huang, Q., Wang, X., Fan, J., Qi, S., Zhang, W., & Zhu, C. (2019). June). V2G optimal scheduling of multiple EV aggregator based on TOU electricity price. In *2019 IEEE international conference on environment and electrical engineering and 2019 IEEE industrial and commercial power systems europe (EEEIC/I&CPS europe)* (pp. 1–6). IEEE.

Huang, X. Q., Yang, H., Chen, J., Jiang, L., & Cao, Y. J. (2015). Optimal planning of electric vehicle charging stations based on life cycle cost and quantum genetic algorithm. *Automation of Electric Power Systems, 39*(17), 176–182.

Javid, R. J., & Nejat, A. (2017). A comprehensive model of regional electric vehicle adoption and penetration. *Transport Policy, 54*, 30–42.

Jia, L., Hu, Z. C., & Song, Y. H. (2016). An integrated planning of electric vehicle charging facilities for urban area considering different types of charging demands. *Power System Technology, 40*(9), 2579–2587.

Jin, C., Sheng, X., & Ghosh, P. (2014). Optimized electric vehicle charging with intermittent renewable energy sources. *IEEE Journal of Selected Topics in Signal Processing, 8*(6), 1063–1072.

Kamankesh, H., Agelidis, V. G., & Kavousi-Fard, A. (2016). Optimal scheduling of renewable micro-grids considering plug-in hybrid electric vehicle charging demand. *Energy, 100*, 285–297.

Katz, M. L., & Shapiro, C. (1985). Network externalities, competition, and compatibility. *The American Economic Review, 75*(3), 424–440.

Katz, M. L., & Shapiro, C. (1994). Systems competition and network effects. *The Journal of Economic Perspectives, 8*(2), 93–115.

Kuby, M., & Lim, S. (2005). The flow-refueling location problem for alternative-fuel vehicles. *Socio-Economic Planning Sciences, 39*(2), 125–145.

Lee, R. S. (2013). Vertical integration and exclusivity in platform and two-sided markets. *The American Economic Review, 103*(7), 2960–3000.

Lefeng, S. H. I., Tong, L. V., & Yandi, W. A. N. G. (2019). Vehicle-to-grid service development logic and management formulation. *Journal of Modern Power Systems and Clean Energy, 7*(4), 935–947.

Lin, Z., & Greene, D. L. (2011). Promoting the market for plug-in hybrid and battery electric vehicles: Role of recharge availability. *Transportation Research Record, 2252*(1), 49–56.

Li, Z., & Ouyang, M. (2011). The pricing of charging for electric vehicles in China—dilemma and solution. *Energy, 36*(9), 5765–5778.

Li, S., Tong, L., Xing, J., & Zhou, Y. (2017). The market for electric vehicles: Indirect network effects and policy design. *Journal of the Association of Environmental and Resource Economists, 4*(1), 89–133.

Ma, X., Li, Y., Wang, H., et al. (2017). Research on demand of charging piles based on stochastic simulation of EV trip chain [J]. *Transactions of China Electrotechnical Society, 10*(32), 190–202.

Mehta, R., Srinivasan, D., Khambadkone, A. M., Yang, J., & Trivedi, A. (2016). Smart charging strategies for optimal integration of plug-in electric vehicles within existing distribution system infrastructure. *IEEE Transactions on Smart Grid, 9*(1), 299–312.

Morrissey, P., Weldon, P., & O'Mahony, M. (2016). Future standard and fast charging infrastructure planning: An analysis of electric vehicle charging behaviour. *Energy Policy, 89*, 257–270.

Morton, C., Anable, J., Yeboah, G., & Cottrill, C. (2018). The spatial pattern of demand in the early market for electric vehicles: Evidence from the United Kingdom. *Journal of Transport Geography, 72*, 119–130.

Naseri, M. B., & Elliott, G. (2013). The diffusion of online shopping in Australia: Comparing the Bass, Logistic and Gompertz growth models. *Journal of Marketing Analytics, 1*(1), 49–60.

National Research Council. (2015). *Overcoming barriers to deployment of plug-in electric vehicles.* National Academies Press.

Nie, Y. M., & Ghamami, M. (2013). A corridor-centric approach to planning electric vehicle charging infrastructure. *Transportation Research Part B: Methodological, 57*, 172–190.

Ren, Y., Shi, L., Zhang, Q., Han, W., & Huang, S. (2011). Optimal distribution and scale of charging stations for electric vehicles. *Dianli Xitong Zidonghua, 35*(14), 53–57.

Saloner, G., & Shepard, A. (1992). *Adoption of technologies with network effects: An empirical examination of the adoption of automated teller machines (No. w4048)*. National Bureau of Economic Research.

Shao, Y., Mu, Y., Yu, X., Dong, X., Jia, H., Wu, J., et al. (2017). A spatial-temporal charging load forecast and impact analysis method for distribution network using EVs-traffic-distribution model. *Proceedings of the CSEE: Smart Grid, 37*(18), 5207–5219.

Sierzchula, W., Bakker, S., Maat, K., & Van Wee, B. (2014). The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy Policy, 68*, 183–194.

Springel, K. (2016). *Network externality and subsidy structure in two-sided markets: Evidence from electric vehicle incentives*. Berkeley: University of California.

Tamor, M. A., Moraal, P. E., Reprogle, B., & Milačić, M. (2015). Rapid estimation of electric vehicle acceptance using a general description of driving patterns. *Transportation Research Part C: Emerging Technologies, 51*, 136–148.

Traut, E. J., Cherng, T. C., Hendrickson, C., & Michalek, J. J. (2013). US residential charging potential for electric vehicles. *Transportation Research Part D: Transport and Environment, 25*, 139–145.

Winebrake, J. J., & Farrell, A. (1997). The AFV credit program and its role in future AFV market development. *Transportation Research Part D: Transport and Environment, 2*(2), 125–132.

Wirges, J., Linder, S., & Kessler, A. (2012). Modelling the development of a regional charging infrastructure for electric vehicles in time and space. *European Journal of Transport and Infrastructure Research, 12*(4).

Wu, D., Zeng, H., Lu, C., & Boulet, B. (2017). Two-stage energy management for office buildings with workplace EV charging and renewable energy. *IEEE Transactions on Transportation Electrification, 3*(1), 225–237.

Yang, H., & Huang, H. J. (1998). Principle of marginal-cost pricing: How does it work in a general road network?[J]. *Transportation Research Part A: Policy and Practice, 32*(1), 45–54.

Zhang, Q., Li, H., Zhu, L., Campana, P. E., Lu, H., Wallin, F., et al. (2018). Factors influencing the economics of public charging infrastructures for EV–A review. *Renewable and Sustainable Energy Reviews, 94*, 500–509.

Zhang, J., Xu, L., & Fujiwara, A. (2012). Developing an integrated scobit-based activity participation and time allocation model to explore influence of childcare on women's time use behaviour. *Transportation, 39*(1), 125–149.

Zhong, W. A. N. G., & Weiyu, T. A. N. (2018). Spatialtemporaldistribution prediction ofchargingloadforelectric vehiclebasedon MDPrandompathsimulation. *Automation of Electric Power Systems, 42*(20), 59–66.

Zhou, Y., & Li, S. (2018). Technology adoption and critical mass: The case of the US electric vehicle market. *The Journal of Industrial Economics, 66*(2), 423–480.

Zhou, C., Qian, K., Allan, M., & Zhou, W. (2011). Modeling of the cost of EV battery wear due to V2G application in power systems. *IEEE Transactions on Energy Conversion, 26*(4), 1041–1050.