frontiers | Frontiers in Energy Research

TYPE Original Research
PUBLISHED 15 May 2024
DOI 10.3389/fenrg.2024.1257121

OPEN ACCESS

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RECEIVED 12 July 2023
ACCEPTED 22 March 2024
PUBLISHED 15 May 2024

CITATION
Chen X-P, Jiang X, Yu X-C, Hao P and Xie B-C (2024), What factors affect the development of public charging infrastructures? a study from the perspective of potential users.
Front. Energy Res. 12:1257121.
doi: 10.3389/fenrg.2024.1257121

What factors affect the development of public charging infrastructures? a study from the perspective of potential users

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The rapid development of the electric vehicle market has greatly stimulated the demand for public charging infrastructure (PCI) and made it a pertinent topic to improve its charging service quality in the industry. Data from perceived preference, PCI and electric vehicles cannot reflect the factors influencing potential users' anxiety. This study designed a PCI development evaluation framework to investigate the impact of economic, technological, market, policy, and social environmental factors on PCI development from the perspective of potential users. We collected a dataset including 386 potential users in Tianjin, China, and employed structural equation model to survey the implementation of PCI. The following conclusions were drawn from this study: 1) Reducing operating costs will not significantly increase PCI charging user demand and improve use efficiency for potential users; 2) Technical factors cannot directly promote the development of PCI but will reverse lag the development of the market; 3) The growing market demand is the main impetus to the development of electric vehicle industry, and the incentive policy and social environment can indirectly incentivize PCI development. The policy implications suggest that the PCI industry can experience sustainable development by continuously innovating market-oriented business models, and improving policy systems and industry mechanisms. This study provides analytical foundation and decision support for policymakers and pertinent industry participants, promotes the development of electric vehicle-related industries, and helps achieve the strategic goal of carbon neutrality.

KEYWORDS

perspective of potential users, public charging infrastructures, structural equation model, impact factors, electric vehicle

1 Introduction

As the concept of sustainable urban development gains traction, electric vehicles (EVs) are considered green transportation tools that are expected to replace traditional fuel vehicles, owing to their advantage of zero emissions (Xue et al., 2021). Worldwide efforts to aggressively encourage the development of EVs have resulted in a sharp rise in both the quantity and popularity. In 2021, global total vehicle sales grew by only 4.7% year on year, whereas EVs grew by as much as 108% year on year, with battery electric vehicles (BEVs) accounting for 71% of total EVs sales and plug-in hybrid electric vehicles (PHEVs) accounting for 29% (EV-Volumes, 2023). Global EV ownership increased from 4.2% in 2020 to 8.3% in 2021 (EV-Volumes, 2023).

The total sales volume of electric vehicles in China surpassed all other countries worldwide in 2014. By September 2022, the number of electric vehicles in China had reached 11,490,000 and maintained a rapid growth trend (Ministry of Chinese Public Security, 2022), which also greatly stimulated user demand for charging infrastructure. However, insufficient charging infrastructure, potential users' anxiety about driving range, and long charging times have become the main issues impeding the development of electric vehicles (Nie et al., 2016; Wolinetz and Axsen, 2017). Among these, the construction process of public charging infrastructure (PCI) has become a key factor that affects the large-scale promotion and industrial development of electric vehicles (Jensen et al., 2013; Nocera and Cavallaro, 2016; Melliger et al., 2018).

With the continuous development of EVs and charging infrastructures, the potential users of PCI and potential charging demand is continuously increasing. However, in 2022, the cumulative number of PCI in China is only 1.8 million (Central Government of the People' s Republic of China, 2023). Their development level still lags behind that of electric vehicles. The pile ratio is significantly lower than the planned 1:1 target, seriously hindering the rapid expansion of electric vehicle (Fu et al., 2021). In addition, the difficulty of building piles in residential communities, uneven development of PCI, poor charging experience of users, and lack of quality and safety make it difficult for potential users to alleviate their anxiety. It is urgent to speed up operating models and mechanisms and further improve the ability to charge service guarantees to allay the charging anxiety of potential users.

The vigorous development of PCI is considered an effective means to address the difficulty of charging EVs (Hardman et al., 2018). PCI is particularly important for long-distance driving and frequent users of electric vehicles. This can reduce the relevant social costs of electric vehicles (Nie and Ghamami, 2013) and serve as the ultimate guarantee that users will be able to charge (Dong et al., 2014; Bonges and Lusk, 2016), which is of vital significance for improving the purchase intention of potential users. Studies have shown that the average utilization rate of a single PCI in China's major cities is less than 10% (Zhang et al., 2020). By the end of 2022, ownership of PCI was even lower than that of private charging infrastructure, which brought severe usage anxiety to potential users and seriously hindered the transition of potential users into actual users.

It can be seen that the immaturity of the PCI market not only reduces users' charging experience but also weakens potential users' purchase intention to EVs. Therefore, this study selects PCI as the research object to explore the key factors influencing its slow development and low utilization rate. This study analyzes the factors influencing the development of PCI in a more comprehensive framework, including policy, economy, technology, social environment, and other dimensions. Tianjin is selected as the study area because Tianjin is a pilot city for the promotion of new energy vehicles, with the rapid development of electric vehicles, and has similar urban characteristics to most cities in China. This study may provide a reference for policy adjustments in other cities with similar situations in China and even globally.

The remainder of this paper proceeds as follows: Section 2 reviews the literature on PCI-related issues. Section 3 explains the theoretical framework of this study. Section 4 sets out the research design and methodology. Section 5 presents the empirical results and discussion of the mathematical model. Section 6 summarizes the conclusions, offers policy implications, and provides directions for future research.

2 Literature review

2.1 Research on the development of public charging infrastructure

Charging infrastructure is an indispensable supporting facility for electric vehicles, which directly affects the acceptance of consumers to electric vehicles (Zhao et al., 2022). PCI refers to the infrastructure planned and constructed in public places, such as public parking lots and transportation hubs, to provide charging services for all electric vehicles in society. Previous studies have shown that the density of PCI is gradually becoming an important reference factor to purchase electric vehicles, and its quantity will greatly promote the development of electric vehicles (Franke and Krems, 2013; Neves et al., 2019). Chen and Lin, (2022) analyzed the preferences of different users to charging infrastructure and found that charging prices, charging station locations, and availability of charging stations during charging peak periods can affect consumers' choices of CPI. Therefore, the construction of PCI should consider station density, charging technology, and operating profit.

The existing research on the development of PCI focuses on exploring its layout. As for technology, the construction of charging stations needs to consider the actual needs of electric vehicle users and reduce social costs (Shen et al., 2019). Morrissey et al. (2016) believes that building fast charging stations is necessary to alleviate consumer concerns about charging time. But the large-scale construction of fast charging stations needs to consider the load capacity of the power grid. In terms of construction position, it needs to provide visibility to potential users while reducing electric vehicle users' range anxiety. The optimal location for PCI should be near the city center, shopping malls, or parking lots (Bailey et al., 2015). However, the construction cost in these areas is high, and profit are limited. Investors often pursue profit maximization rather than social welfare maximization, resulting in the current quantity of PCI in China not being able to cover the charging need of electric vehicle users (Wang et al., 2023).

To reduce the construction and operation costs of PCI, the minimization of the economic cost of operators, government urban planning, charging demand, and other factors must all be taken into account during scientific and reasonable planning and location selection of PCI. Liu et al. (2018) analyzed the key factors affecting the planning and allocation of charging stations by using a dynamic system model from the perspective of user charging satisfaction. Kong et al. (2019) built a discrete selection model and fully measured the impact of traffic flow density, power cost, road networks, and other factors on the site selection of the charging infrastructure from the perspectives of operators and managers. To meet increasing charging demands and improve the use efficiency of the charging infrastructure, a heuristic optimization algorithm is widely applied to optimize the PCI layout (Awasthi et al., 2017). Some scholars are inclined to conduct demand-oriented planning, site selection, and layout optimization of PCI and have always believed that these are crucial for the market penetration of electric vehicles (Philipsen et al., 2018). Therefore, charging demand prediction has gained importance in both academia and industry (Davis and Bradley, 2012; Amini et al., 2016; Majidpour et al., 2016).

2.2 Research from the perspective of potential users

Since the development of PCI is slow currently, finding a way for promoting its development has gradually become a topic of much discussion. However, most existing studies have explored planned site selection (He et al., 2019; Kong et al., 2019), layout optimization (Davidov and Pantoš, 2017; Liu et al., 2018), and demand prediction (Majidpour et al., 2016; Frendo et al., 2020) from the perspectives of cost reduction and efficiency improvement. In addition, a lot of academics have shifted from modeling analysis to descriptive and explanatory empirical research in an effort to better understand the developmental dilemma of PCI.

Based on the theory of diffusion of innovation (DIT), PCI is a new concept, and potential users are mainly late followers (Axsen et al., 2016). However, the lack of PCI has a significant negative impact on the consumption willingness of potential users (Pamidimukkala et al., 2023). Asxen et al. (2017) have found that consumers have a low level of understanding and awareness of the charging mode of BEVs. Building and promoting PCI can further stimulate the consumption of EVs. If potential users have sufficient knowledge of CPI, it may further promote the expansion of NEVs (Bailey et al., 2015). Existing studies have noted that potential users have a low degree of cognition of PCI: most of them are still unable to clarify basic information and have no clear or stable preference for using PCI, while policy support (Rezvani et al., 2015), technological progress (Plötz et al., 2014b; Globisch et al., 2019), and economic development (Krupa et al., 2014) will give potential users confidence.

Considering that charging through PCI is a major and necessary channel for potential users, the implementation of policies such as free parking will significantly improve their willingness to buy electric vehicles (Wolbertus et al., 2018). Other studies have noted that users who have not purchased NEVs have less understanding of charging options and are more concerned about the quantity of PCI (Hardman et al., 2018). And potential users are more likely to accept the controlled charging policy than users because users have more charging experience, and they believe that controlled charging will bring more inconvenience, so they need more compensation to adopt it (Axsen et al., 2016). In addition, the location, layout, and charging time of PCI will have an impact on the potential users' choices, and potential users have varying preferences for PCI (Jensen et al., 2013; Zhao et al., 2022). Zhao et al. (2022) believe that compared to users, potential users have stricter requirements for influencing factors of EVs, pay more attention to the quantity and charging time of PCI, while users are more concerned about the position and distribution density of PCI. Therefore, it is necessary for policymakers to consider the interest demands of the two target groups when designing promotional policies, which will be conducive to the rapid development of PCI and encourage potential users to become electric vehicle owners and users of PCI (Plötz et al., 2014a; Plötz et al., 2014b).

This study offers a new perspective on the relationship between PCI and electric vehicle consumption by quantitatively analyzing the factors influencing PCI from the viewpoint of potential users within a more comprehensive framework. First, it reveals the factors affecting the development of electric vehicles from the perspective of potential users. Second, it elaborates on a theoretical framework based on Theory of Public Goods (TPG). As an infrastructure for providing charging services for electric vehicles, PCI possesses the fundamental qualities of a public benefit (Oakland, 1972). Third, this study adopts DIT to explain the relationship between the economic environment and development status factors. DIT describes the process of diffusion of a new thing, idea, or technology through mass communication in society, which mainly includes five stages: knowledge, persuasion, decision, implementation, and adoption (Rogers et al., 2014). Inspired by DIT, this study posits that PCI as the basic service facility of electric vehicles is a new concept, and potential users are mainly late followers (Axsen et al., 2016). In summary, from the perspective of potential users, this study integrates the theories of TPG and DIT to provide a comprehensive and in-depth discussion of the key factors affecting the development of PCI.

3 Theoretical frameworks

3.1 Definition of influencing factors

Based on the perspective of potential users, this study divides influencing factors into five categories of environmental factors: economic, technological, market, policy, and social. The development of charging infrastructure will be directly impacted by economic environment (EE) factors involving the operation and maintenance costs of charging infrastructure, market environment (ME) factors involving market supervision and maintenance strength, and technical environment (TE) factors involving the charging process and charging instructions. In addition, favorable macro-political environments (PE) will also be conducive to the development of the industry, such as central- and local-level overall construction planning, incentives, industry standards, and other policies. Social environments (SE) involving the rapid development of charging supporting facilities often indirectly affects the development of PCI.

Previous research on the development status of charging infrastructure has illustrated that PE, ME, TE, SE, and EE are key factors affecting the development of PCI. In terms of PE factors, policy coordination and operator subsidies will affect the degree of development of charging infrastructure (Fang et al., 2020). The quantity of electric vehicles and standards of industry construction also have an impact on the investment and construction of charging infrastructure (Hopkins et al., 2023). Therefore, we take into account factors including pile-to-car ratio planning target, construction incentive criteria and industry standards. We set the reserved installation standard as an additional factor according to the status of charging

TABLE 1 Definition of variables in the structural equation model.

Latent variable	Explicit variable	Variable definition
Development status (DS) factors	Quantity	Perception of the amount of PCI
	Ratio of quick charge	Perception of fast charging ratio of PCI
	Utilization rate	Perception of utilization and availability of PCI
Policy environment (PE) factors	Operator subsidy	Construction subsidies and operation subsidies for operators
	Reserved installation standard	Building charging infrastructure in public places or reserving installation conditions
	Pile-to-car ratio planning target	Central/local planning target for pile-to-car ratio
	Construction incentive standard	National reward standard for local governments to build charging infrastructure
	Industry standard	Uniformity of design specifications and industry standards for charging infrastructure
Market environment (ME) factors	Supporting service facilities	Convenience of supporting service facilities and internal environment of charging place
	Maintenance support strength	Maintenance feedback, timeliness and accuracy of troubleshootingetc.
	Strength of supervision	The intensity of daily supervision, frequency of daily inspection and safety inspections
	Professional norms of maintenance	Maintenance standards and professionalism of maintenance personnel
Technical environment (TE) factors	Charging process complexity	The complexity of the charging process
	Visualization degree of charge	The degree of visualization of the charging process, including charging speed, amountetc.
	Readability of charging instructions	Readability of charging procedure instructions
Social environment (SE) factors	Charging power	Charging power of charging infrastructure (fast or slow charge)
	Convenient of payment methods	Convenience and diversity of payment methods after charging
	APP information sharing degree	Interconnection of charging APP, accuracy and timeliness of release information
Economic environment (EE) factors	The price of the land	The price of land where the charging infrastructure is built
	Average cost of charging infrastructure	Average cost of a single charging infrastructure
	Running cost	The cost of electricity and labor required for the operation of charging infrastructure
	Maintenance cost	The cost of maintaining the charging infrastructure

infrastructure construction. Regarding ME considerations, charging duration and queue time, infrastructure distance and location, charging cost, and the current development status of PCI will all play a significant role in influencing potential new energy vehicle users to choose PCI. The features of market environmental will affect the rate of development of charging piles (Philipsen et al., 2016; Chen and Lin, 2022). Supporting service facilities and maintenance support strength also influence the development of PCI (Hardman et al., 2018; Hecht et al., 2020).

In terms of TE and SE factors, the portability of charging is an important reference point for potential users regarding of TE and SE considerations (Zhang et al., 2018). Potential users' decision to choose PCI will be influenced by the portability, availability, reliability, and payment services of charging infrastructure when taking into account the differences among potential user groups. Advances in PCI's technology is beneficial for improving the satisfaction of potential users with charging infrastructure (Liu and Wei, 2018; Hopkins et al., 2023). Therefore, we consider the charging process complexity, visualization degree of charge and readability of charging instructions as proxy variables for the TE factors. With regard to EE factors, the construction cost of PCI is relatively high. In order to recoup the investment swiftly, investors will consider the construction cost, operating cost, and maintenance cost to decide the location for PCI (Wang, et al., 2023). The land price, the average cost of charging infrastructure, running costs, maintenance costs, and other factors related to investment and operation are intimately linked to the profits of PCI operators and have a significant impact on site selection decisions and construction scale (Zhang et al., 2018).

With reference to the existing literature on the measurement of the above latent variables, the explicit variables involved in this study are defined in Table 1.

3.2 Research hypothesis of PCI development

3.2.1 Relationship between EE factors and DS factors

According to the DIT, at the beginning of the development of emerging technologies, they are always in a disadvantageous position compared to traditional technologies in terms of use experience and payment prices because they cannot quickly reach the needed scale (Adner, 2002). In terms of PCI, high investment costs, low utilization rates, and low profit margins have led to poor economic performance in the industry. High construction costs, operation costs, and land shortages have become important factors hindering the development of PCI (Fu et al., 2021). Minimizing construction costs including land price, equipment, and equipment maintenance costs can promote the rapid development of PCI (Kong et al., 2019). It is evident that PCI can achieve significant cost savings, and widespread adoption is anticipated. Therefore, we propose the following hypothesis:

H1a. Reducing the economic cost of PCI has a significant positive impact on promoting its development.

3.2.2 Relationship between TE factors and DS factors

Improving the technical level of PCI is important for improving its supply capacity and use efficiency. The low technical level of the charging infrastructure is the main obstacle limiting the development of PCI (Fang et al., 2020). Advanced technologies can effectively improve the charging performance and service levels of PCI (Liu and Wei, 2018). It is anticipated that new technologies will impact PCI's design and functionality by lowering costs or raising customer demand for charging, leading to a breakthrough in the technology's development (Zhang et al., 2018). Therefore, we propose the following hypothesis:

H2a. An advanced technology level has a significant positive impact on promoting the development of PCI.

3.2.3 Relationship between ME factors and other factors

Comprehensive impact analyses of various factors, including the market environment, have been the focus of numerous studies. First, the market environment directly affects PCI development potential. The professional maintenance, reliability, and stability of charging are important indicators for measuring the quality of charging services (Zhang et al., 2020). Second, supporting service facilities also affect the utilization rate of PCI to a certain extent (Hecht et al., 2020). Not only can a strong business model and aggressive development of supporting charging facilities increase the utilization rate of PCI, but they also increase charging operators' profits (Madina et al., 2016; Zhang et al., 2018; Yang et al., 2020). Third, by strengthening market supervision and maintenance, and improving technical reliability, the use of PCI can be further promoted (Hardman et al., 2018). Therefore, we propose the following hypotheses:

H3a. A favorable market environment has a significant positive impact on improving PCI efficiency.

H3b. Sound supporting infrastructure has a significant positive effect on improving the economic environment of the PCI industry.

H3c. Strict market supervision and guarantees have significant positive impacts on technical reliability.

3.2.4 Relationship between PE factors and other factors

Based on the theory of public goods (TPG), it is evident that depending solely on the market is insufficient to attain the equilibrium between supply and demand in an economic society. This could result in market failure, inefficient use of resources, and low efficiency. In order to maximize resources, accomplish the best allocation, and make up for the market flaws in the charging infrastructure, the government must therefore utilize a variety of regulatory measures to interfere in the market behavior of PCI. The government's moderate subsidies reduce the charging cost, which inevitably stimulates the charging demand of users and the purchase desire of potential users, creating a favorable market environment for potential users (Zhang et al., 2019). In addition, according to the construction quality and utilization rate of the charging infrastructure, the formulation of scientific and reasonable incentive policies is of great significance for reducing the economic cost of PCI and charging prices, and forming a good economic environment (Globisch et al., 2019). Therefore, we propose the following hypotheses:

H4a. Positive supporting policies have a significantly positive impact on improving the market environment in the PCI industry.

H4b. Scientific and reasonable incentives, subsidy policies, and industry standards have significant positive impacts on reducing the economic cost of PCI and creating a favorable economic environment.

3.2.5 Relationship between SE factors and other factors

First, social environmental factors often indirectly affect the development of PCI by influencing market and technological environmental factors (Guo and Zhao, 2015). Second, high-power charging infrastructure can meet the charging demand in future charging networks and shorten charging time, thus improving the use efficiency of PCI (Zhang et al., 2021). However, due to the barriers between different charging infrastructure operators in terms of charging standards, payment methods, and information sharing, the convenience of payment methods cannot be guaranteed. Therefore, it is necessary to establish a unified information sharing platform to realize interconnection and improve the visualization of the charging process (He et al., 2016). Third, unified industry standards and planning objectives can reduce the complexity and uncertainty faced in PCI construction, reduce manufacturing and research and development costs, and improve the efficiency of charging services (Zhang et al., 2020). In addition, reasonable planning of charging resources and establishment of a scientific efficiency evaluation system can effectively improve the charging service quality (Neaimeh et al., 2017). It can be seen that the government can improve the market penetration of PCI by exerting social influence, and social factors will in turn influence the introduction of relevant policies (Zhang et al., 2011). Therefore, the following hypotheses are proposed:

H5a. Social and environmental benefits have a significantly positive impact on improving the market environment in the PCI industry.

H5b. Achieving connectivity and information sharing has a significant positive effect on improving the technical level of PCI.

H5c. A positive policy environment can improve social and environmental benefits, whereas a favorable social environment

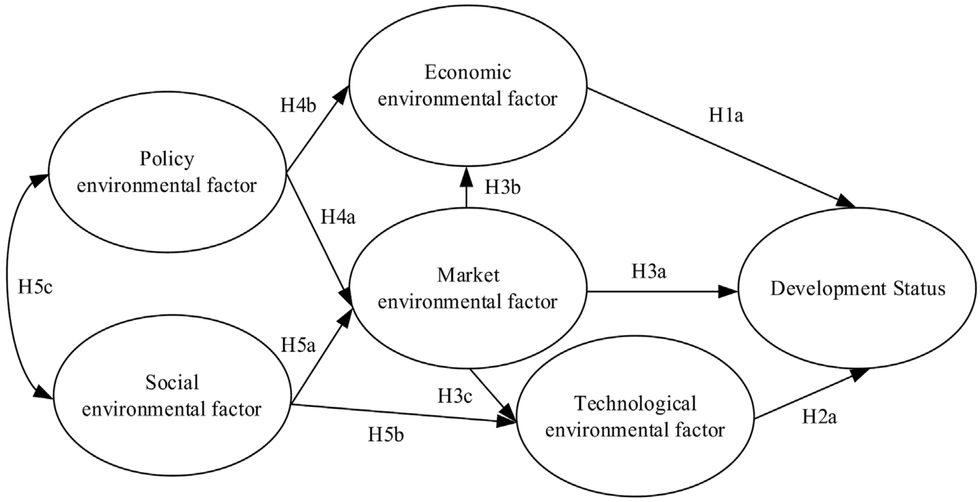

FIGURE 1
Theoretical framework presenting the linkage among influencing factors.

can promote the introduction of supporting policies. A significant two-way positive correlation was observed between these two variables.

The theoretical framework of this study is shown in Figure 1.

4 Methodology and data sources

4.1 Survey area and questionnaire design

Questionnaires were issued in Tianjin for data collection. Tianjin is extremely representative in terms of its economic development, population density, development prospects, and relevant policy support. First, as a pilot city of the project "Thousands of vehicles in ten cities", Tianjin has always been the key national demonstration city for the development of new energy vehicles, giving relatively high local subsidies to electric vehicle buyers and implementing policies such as tax exemption and unlimited license plates. With the support of these policies, the new energy vehicle sales in Tianjin accounted for 3% of China's total sales in 2021, ranking sixth in the cities. The rapid development of electric vehicles can provide important experience for promoting electric vehicles in other cities. Second, Tianjin has a high population density and its development model has been imitated by many cities in underdeveloped areas (She et al., 2017). By the end of 2020, Tianjin had a permanent population of 13.866 million, ranking second in terms of population density in China, but the GDP ranking 23rd. The research results of Tianjin have reference significance for small and medium-sized cities. Third, Tianjin has formulated several PCI supporting policies and planning schemes. By the end of 2020, 27,800 PCIs had been built and put into operation in Tianjin; thus, the charging market has huge potential. Combining the above factors, it is more practical to conduct research on the development of PCI in Tianjin than in Beijing, Shanghai, Guangzhou, or other cities. The conclusions provide a reference for other cities with similar levels of development. Finally, the potential users in our survey covered a variety of professions, including drivers, students, company employees and service personnel, which can represent the views of the majority of people in Tianjin on the development of PCI.

To expand the survey scope and enhance the credibility of our research, the data on potential users were collected online. First, we divided the influencing environmental factors into five categories: policy, market, technological, social, and economic. A questionnaire was developed to measure various influencing factors. Second, to address the deficiencies in the questionnaire scale and improve its quality, we visited the two largest public charging stations in Tianjin and consulted research institutions to evaluate the initial questionnaire structure. And two rounds of pilot surveys have been set up on a small scale. First, we conducted preliminary survey on two groups of people. One was actual users at public charging stations, and the other was potential users of EVs near companies, bus stations, and residential areas. Based on their feedback on the questionnaire, we adjusted the questionnaire structure and content. Second, we conducted in-depth interviews with the respondents and further adjusted the specific questions in the questionnaire to enhance its pertinence and effectiveness. The final questionnaire used in this paper consists of three parts (see Supplementary Appendix SA for details). The first part was used to study the perceptions and understanding of potential users of the PCI. The second part was used to analyze the factors that potential users believe affect the development of PCI. The third part was the basic information of the respondents, which was used to analyze their demographic characteristics. Finally, this study investigated the shortcomings of the current development of PCI by adding an open question to collect relevant opinions.

4.2 Data collection and descriptive statistics

Most survey studies use third-party platforms for online survey. And many researchers have chosen the professional platform Wenjuanxing. (Zhou et al., 2022; Li J. et al., 2023). Wenjuanxing is a large data research platform that covers

TABLE 2 Descriptive statistics.

Background variables	Type	Potential user frequency	Percentage of effective potential user (%)
Gender	Male	153	39.6
	Female	233	60.4
Age	≤25	201	52.1
	25–35	103	26.7
	35–45	45	11.7
	45–55	25	6.5
	>55	12	3.1
Education	High school, technical secondary school, and below Junior college	27	7.0
		28	7.3
	Undergraduate	144	37.3
	Master	152	39.4
	Doctor's degree or above	35	9.1
Vocation	Professional	36	9.3
	Taxi/ride-hailing driver	5	1.3
	Worker	12	3.1
	Company employee	69	17.9
	Service personnel	8	2.1
	Freelancer	10	2.6
	Administrative personnel	30	7.8
	Student	204	52.8
	Others	12	3.1
Family members	1	12	3.1
	2	29	7.5
	3	182	47.2
	4	106	27.5
	≥5	57	14.8
Annual household disposable income	100,000 yuan or less 100,000 to 200,000 yuan	126	32.6
		148	38.3
	200,000 to 300,000 yuan	69	17.9
	300,000 to 500,000 yuan	30	7.8
	500,000 yuan or above	13	3.4

approximately 3 million enterprises and 90% of universities in China, with a total of approximately 246 million questionnaires released. Therefore, we conducted an online survey using the professional questionnaire distribution platform, Wenjuanxing. The questionnaire link was open for 30 days. A total of 477 questionnaires were issued and 472 were recovered. To ensure the quality of the questionnaire collection, we screened the questionnaires and eliminated those with contradictory answers and the same selection of eight consecutive items on a Likert scale. Finally, 386 valid questionnaires were obtained, with an effective recovery rate of 81.78%.

Table 2 lists the personal statistical information and characteristics of potential users. Female respondents (60.4%) occupy the majority of the sample of potential users, most potential users are aged 25 or below (52.1%), and the education level of potential users is generally higher. Most of them have an undergraduate degree or a higher degree (accounting for 85.8%). Previous studies have demonstrated that users with a higher degree

TABLE 3 Descriptive statistics of influencing factors.

Latent variable	Explicit variable	Mean	Standard deviation
Development status factors	Quantity	1.19	0.833
	Ratio of quick charge	1.52	1.034
	Utilization rate	1.61	1.104
Policy environment factors	Operator subsidy	3.48	0.958
	Reserved installation standard	3.50	0.977
	Pile-to-car ratio planning target	3.44	1.010
	Construction incentive standard	3.65	1.034
	Industry standard	3.60	0.927
Market environment factors	Supporting service facilities	3.41	0.901
	Maintenance support strength	3.60	0.815
	Strength of supervision	3.65	0.872
	Professional maintenance norms	3.62	0.937
Technical environment factors	Charging process complexity	3.27	1.146
	Visualization degree of charge	3.32	1.070
	Readability of charging instructions	3.09	1.160
Social environmental factors	Charging power	3.89	1.015
	Convenient of payment methods	3.66	1.139
	APP information sharing degree	3.70	0.942
Economic environmental factors	The price of land	3.49	1.103
	Average cost of charging infrastructure	3.41	1.039
	Running cost	3.55	1.019
	Maintenance cost	3.48	0.994

and stronger environmental consciousness are more inclined to purchase electric vehicles and experience new things (Zhao et al., 2022). Higher educated users are more capable of recognizing technology, environment, and economic environment, and young people can have a deeper comprehension of charging infrastructure (She et al., 2017; Chen and Lin, 2022), which further ensures the accuracy of our results.

From the perspective of occupation, students (52.8%) occupy the main position. College students, with a higher level of education and strong ability to understand and accept new things, are the main group of future electric vehicle owners and users of PCI. Most respondents' families consist of three people (47.2%), indicating that most potential users' families are the only child, and their annual income is typically less than 200,000 yuan (70.9%). Less than two member families typically consist of elderly adults who are employed and have some financial stability. If members of this group do not purchase electric vehicles, it indicates their low willingness to consume electric vehicles and will not pay attention to the development of electric vehicle supporting facilities—PCI. The group with more family members and lower annual income has a stronger willingness to buy electric vehicles since we investigate potential users of electric vehicles (She et al., 2017; Li G. D. et al., 2023), and is more likely to have a better understanding of PCI.

From the perspective of potential users, the scores of the five influential factors were all greater than the median value of 3 points, and the scores of the development status were also far less than 3 points. Referring to the Likert 5-point scale scoring method, a score below 3 is generally considered low or poor, a score between 3–3.75 is average, a score between 3.75–4.25 is high, and a score above 4.25 is very high. The social environment and hardware settings are the two main factors that potential users believe have a significant influence. They are dissatisfied with the current development of PCI and believe that it cannot meet the charging demand well, and there is much room for progress. Descriptive statistics of the influencing factors are listed in Table 3.

In the open question of our questionnaire (not mandatory), a total of 104 valid feedback items were collected from potential users regarding the current problems with PCI development. We found that "quantity," "popularization," "convenience," "location," and "management" appeared more frequently. Potential users who have not used a PCI believe that the number of PCIs is still too small, leading to a long waiting time. They believe that the penetration rate of PCI needs to be improved, and that policy guidance and capital promotion are needed to improve public recognition. Simultaneously, public opinion needs to be widely absorbed, and mass media publicity should be increased. In

TABLE 4 KMO value and Bartlett's sphericity test.

KMO value		0.894
Bartlett's sphericity test	Chi-square value	4512.971
	Degrees of freedom	231
	Significance	0.000

addition, most potential users think that the current charging is not sufficiently convenient, the charging speed is slow, and thus it is inconvenient to travel long distances. Therefore, the charging speed, charging efficiency, and endurance should be fundamentally improved. Additionally, the distribution of PCI locations was uneven. Charging stations in most suburbs are distant and difficult to locate and there is a lack of adequate public charging piles around communities and other public places. The identification of the PCI is not clear, which makes it difficult to locate charging piles in unfamiliar places.

Other concerns have primarily focused on management and services. Most potential users believe that the current operation and maintenance level of PCI is not high and that maintenance is poor. Therefore, standardized management should be strengthened, intelligent management and services should be provided, and supervision of the frequent occurrence of fueled car-occupying situations should be strengthened. Only by effectively solving the concerns of potential users can the popularization of electric vehicles be further promoted and the use efficiency of PCI be improved, thus promoting the rapid and healthy development of PCI.

5 Results and discussion

To analyze the factors influencing the development of PCI and verify the hypotheses between different factors, we used a Structural Equation Model (SEM) to analyze the data. Referring to previous research, we use IBM SPSS Amos software for analysis (Deng et al., 2013; Bai et al., 2023). SPSS and Amos can allow researchers to perform click operations and output analysis results based on their research purpose. According to the operating procedure, first, we used SPSS to perform some necessary tests, including factor analysis, common method deviation test, and reliability test, to ensure that the samples meet the requirements of further statistical analysis. Second, based on the results of factor analysis, we constructed a SEM and applied Amos for confirmatory factor analysis and validity testing to analyze the adaptability of the questionnaire and model. Finally, we inputted the data into Amos for computation and conducted path analysis to test the relationship and influence degree between various factors. We conducted tests before analyzing the results.

5.1 Testing of validity and reliability

Table 4 presents the results of the exploratory factor analysis The KMO value was 0.894, which is greater than 0.8. This result is much higher than the value obtained by others using the same method (0.640) (Bai et al., 2023). The *p*-value of Bartlett's spherical test is less than 0.001, which indicates that the sample data of potential users are suitable for factor analysis. The factors extracted from potential user data are listed in Table 5.

Six factors with characteristic values greater than 1, namely, market environment factors, economic environment factors, policy environment factors, technical environment factors, social environment factors, and development status, were also extracted from the data of potential users, as shown in Table 6. The factor loading of all items met the standard, the attribution of each item was clear, and a 70.735% variance was explained. The rate of interpretation of variance was relatively high.

The reliability evaluation showed a relatively good performance. Draw from previous research, we set the cut-off loading as 0.3 (Howard, 2023). As shown in Table 6, Cronbach's alpha coefficient

TABLE 5 Factor extraction.

Item number	Extract value	Item number	Extract value
A1. Quantity	0.766	B3_1. Charging process complexity	0.775
A2. Ratio of quick charge	0.703	B3_2. Visualization degree of charge	0.686
A3. Utilization rate	0.692	B3_3. Readability of charging instructions	0.701
B1_1. Operator subsidy	0.553	B4_1. Charging power	0.716
B1_2. Reserved installation standard	0.715		
B1_3. Pile-to-car ratio planning target	0.587	B4_2. Convenience of payment methods	0.736
B1_4. Construction incentive standard	0.612	B4_3. APP information sharing degree	0.736
B1_5. Industry standard	0.596		
B2_1. Supporting service facilities	0.583	B5_1. The price of the land	0.699
B2_2. Maintenance support strength	0.728	B5_2. Average cost of charging infrastructure	0.787
B2_3. Strength of supervision	0.796	B5_3. Running cost	0.792
B2_4. Professional maintenance norms	0.807	B5_4. Maintenance cost	0.795

TABLE 6 The factor load matrix after rotation.

Item number	Factor load					
	Economic environment	Market environment	Political environment	Technical environment	Development status	Social environment
B5_2. Average cost of charging infrastructure	0.828			0.311		
B5_3. Running cost	0.802					
B5_1. The price of the land	0.786					
B5_4. Maintenance cost	0.779					
B2_3. Strength of supervision		0.809		0.334		
B2_4. Professional maintenance norms		0.805				
B2_2. Maintenance support strength		0.744				
B2_1. Supporting service facilities		0.625				
B1_2. Reserved installation standard	0.322		0.797			
B1_3. Pile-to-car ratio planning target			0.730			
B1_4. Construction incentive standard			0.729			
B1_1. Operator subsidy			0.660			
B1_5. Industry standard			0.511			
B3_1. Charging process complexity		0.319		0.818		0.320
B3_2. Visualization degree of charge				0.712		
B3_3. Readability of charging instructions				0.702		
A1. Quantity					0.860	
A2. Ratio of quick charge					0.814	
A3. Utilization rate					0.814	
B4_1. Charging power		0.302		0.327		0.749
B4_2. Convenience of payment methods						0.749
B4_3. APP information sharing degree						0.656
Cronbach's Alpha	0.890	0.858	0.807	0.806	0.771	0.801
Characteristic root	7.958	2.311	1.749	1.590	1.012	0.941
	13.999	13.720	12.987	10.630	9.852	0.957

(Continued on following page)

TABLE 6 (*Continued*) The factor load matrix after rotation.

Item number	Factor load					
	Economic environment	Market environment	Political environment	Technical environment	Development status	Social environment
Variance interpretation rate (%)						
Cumulative variance interpretation rate (%)	13.999	27.719	40.706	51.336	61.188	70.735
Total Cronbach's Alpha coefficient	0.895					

TABLE 7 Fitness test.

Fit index	χ^2/df	RMSEA	RMR	GFI	CFI	NNFI
Inspection result	2.872	0.070	0.062	0.882	0.915	0.901

was above 0.771, and the total Cronbach's alpha coefficient was 0.895. Compared with other studies, the total Cronbach's alpha coefficient is significantly higher (Zhang and Lin, 2018). As they are far beyond the standard of 0.7, the reliability of the total scale and the subscales both meet the judgment standard of the ideal reliability coefficient, indicating that potential users' data have good reliability. And research has shown that when Cronbach's alpha coefficient is higher than 0.8, the analysis results are highly acceptable (Yang et al., 2016). In addition, the maximum factor interpretation rate of the potential user data is 13.999%, which is far less than 30%, indicating that the common method deviation is not significant and can be tested for validity. The validity test was based on three aspects: structural, convergence, and discrimination validity. As shown in Table 7, χ^2/df equals 2.872, which fits the criteria >1 and <3. The RMSEA and RMR values were 0.070 and 0.062, respectively, which are less than 0.08, indicating good adaptation. Other indicators, such as GFI, CFI, and TLI (NNFI) values, were larger than 0.8. The model was considered suitable for the data, and the degree of fit was relatively good.

Next, we test the convergent validity of the model based on factor load, average extraction variation (AVE), and combination reliability (CR). As can be seen from Table 8, *p* values of all explicit variables corresponding to development status, economic environmental factors, society environmental factors, political environmental factors, technological environmental factors, and market environmental factors are all less than 0.001, showing significant statistical significance. Standardized factor loads are all larger than 0.6, T-value is much higher than 2, and CR value is greater than 0.7. The results are similar in reliability and validity to other literature, indicating that the quality of our questionnaire is relatively high (Bai et al., 2023; Jing et al., 2023). Except for political environment, the AVE values of the other exceed 0.45, showing acceptable performance. The results of the above indicators indicate that the questionnaire scale has good convergence validity.

In addition, for the discriminative validity of the potential user data, as shown in Table 9, the square root of the average extraction variation of each latent variable was significantly greater than the correlation coefficient between this latent variable and the other latent variables, indicating good discriminative validity.

5.2 Structural equation model

The sample size of potential users is 386, and the ratio of sample to estimated path is as high as 38:1 and is larger than 5. The path coefficient diagram of this model (Figure 2) shows that the variance explanation rates (R^2) of the hypothesis model for the market environment factors, economic environment factors, technical environment factors, and development status are 55%, 41%, 55%, and 11%, respectively. Thus, the hypothesis model provides an ideal explanation for the variance in each latent variable. The significance level (T-value) for each path in the model is listed in Table 10. The results show that economic and environmental factors have no significant influence on development status.

5.3 Hypothesis testing

By exploring the influences of economic, technological, market, policy, and social environmental factors on development status from the perspective of potential users, this study determined the relationship and degree of their influence (Figure 1). As shown in Table 10, the standardized path coefficients between the economic environment factors, technical environment factors, market environment factors, and development status were 0.027 ($p > 0.05$), −0.434 ($p < 0.001$), and 0.298 ($p < 0.01$), respectively. Therefore, H3a is supported and H1a is not supported (the hypothesis testing results are shown in Table 11). Due to the results, the hypothesis of a positive impact of H2a is not supported by the results, which confirms a significant negative correlation between technological environmental factors and development status. Instead, it can be concluded that technological environmental factors have a significant negative impact on development status. From the perspective of the relative degree of influence, technological environment factors significantly negatively relate to development status. Among the potential causes are the fact that charging behavior usually depends

TABLE 8 Test of validity of convergence.

Latent variable	Explicit variable	Standardized load	Non-standardized load	S.E.	C.R. (T-value)	p	SMC	CR	AVE
Development status factors	A1. Quantity	0.840	1.000	0.097	11.658	***	0.706	0.790	0.561
	A2. Ratio of quick charge	0.767	1.132	0.089	11.017	***	0.588		
	A3. Utilization rate	0.623	0.982				0.388		
Economic environmental factors	B5_1. The price of the land	0.687	1.000	0.076	14.811	***	0.472	0.892	0.677
	B5_2. Average cost of charging infrastructure	0.817	1.119	0.078	15.377	***	0.667		
	B5_3. Running cost	0.887	1.192	0.076	15.185	***	0.787		
	B5_4. Maintenance cost	0.883	1.157				0.780		
Social environmental factors	B4_3. APP information sharing degree	0.859	1.126	0.078	14.518	***	0.738	0.808	0.586
	B4_2. Convenient of payment methods	0.720	1.141	0.089	12.791	***	0.518		
	B4_1. Charging power	0.708	1.000				0.501		
Policy environment factors	B1_1. Operator subsidy	0.609	1.000	0.112	10.953	***	0.371	0.807	0.457
	B1_2. Reserved installation standard	0.735	1.231	0.113	9.995	***	0.540		
	B1_3. Pile-to-car ratio planning target	0.653	1.130	0.116	10.396	***	0.426		
	B1_4. Construction incentive standard	0.682	1.209	0.108	10.153	***	0.465		
	B1_5. Industry standard	0.694	1.101				0.482		
Technical environment factors	B3_3. Readability of charging instructions	0.742	1.000	0.073	13.094	***	0.551	0.808	0.584
	B3_2. Visualization degree of charge	0.774	0.961	0.075	13.754	***	0.599		
	B3_1. Charging process complexity	0.776	1.033				0.602		
Market environment factors	B2_4. Professional maintenance norms	0.845	1.000	0.046	20.734	***	0.714	0.865	0.619
	B2_3. Strength of supervision	0.862	0.950	0.046	17.852	***	0.743		
	B2_2. Maintenance support strength	0.793	0.816	0.056	12.803	***	0.629		
	B2_1. Supporting service facilities	0.625	0.711				0.391		

Note: *** means $p < 0.001$, ** means $p < 0.01$, * means $p < 0.05$.

on charging time and charging cost (Morrissey et al., 2016). Advancements in technology will result in faster charging and shorter charging time, which will enhance PCI utilization efficiency. A quantity of PCI can meet potential user needs. In addition, technological advancements will also simplify the charging process, thereby shortening the usage time of PCI and improving its efficiency. In this case, there is no need to build too many PCI. Technological environmental factors have the largest direct influence on the status of development, followed by market environmental factors; however, the impact of economic environmental factors is not significant.

The specific reasons are as follows: 1) The views of potential users on economic, technological, and market environment factors were analyzed at the macro level. Consequently, the degree of the relative impact varied little despite the large difference in the absolute impact value. 2) The influence of economic and environmental factors on the development status is not significant. According to the principle of scientific simplicity, the model must be updated and this path removed from it before the analysis. However, the parameter could not have a significant impact, which could not prove that the path was not important in the model, or it may have been caused by the small sample size

TABLE 9 Discriminative validity test.

Latent variable	Social environmental factors	Policy environment factors	Market environment factors	Technical environment factors	Economic environmental factors	Development status factors
Social environmental factors	0.766					
Policy environment factors	0.641	0.676				
Market environment factors	0.721	0.603	0.787			
Technical environment factors	0.714	0.501	0.661	0.764		
Economic environmental factors	0.487	0.581	0.569	0.414	0.823	
Development status factors	−0.082	−0.022	0.026	−0.226	0.016	0.749

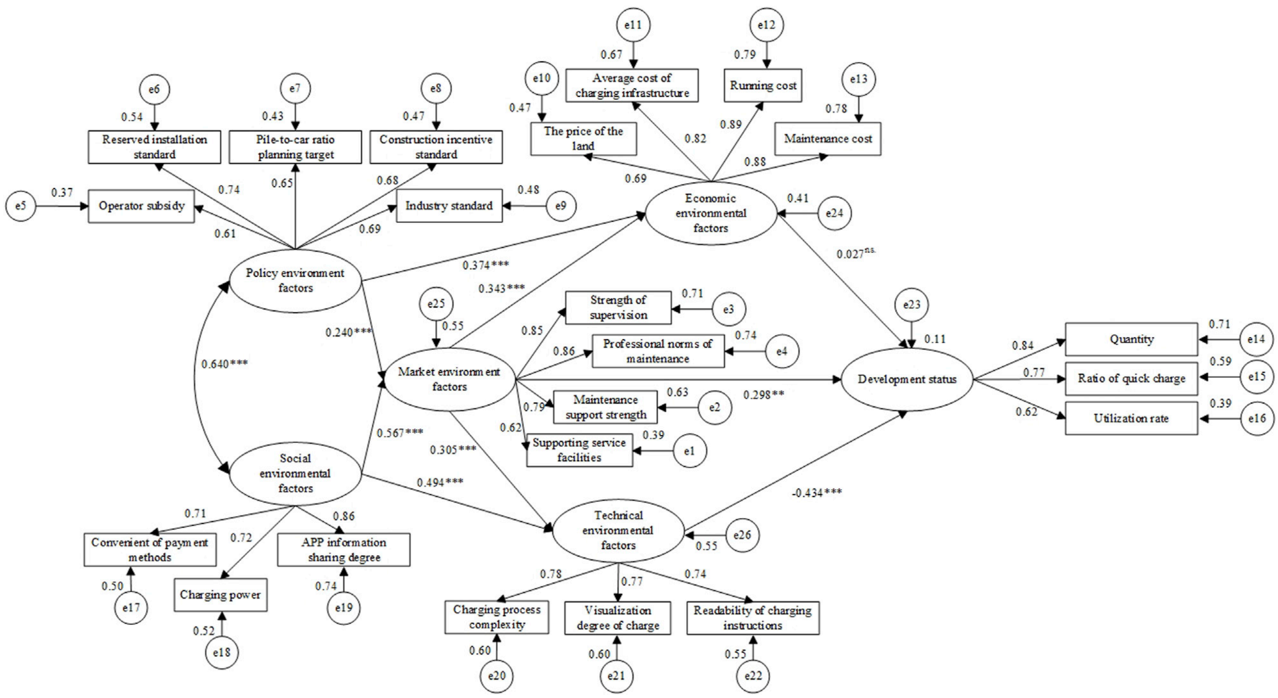

FIGURE 2
Path coefficient diagram of structural equation model.

(Brady et al., 2001). It would be better to increase the empirical sample size rather than remove a path that is not significant. This study believes that economic and environmental factors are the key factors affecting the development of PCI. Although the path of "economic environmental factors on development status" has not reached a significant level, this study does not intend to delete this path based on the basic principles of model design. To ensure more thorough verification, the sample size should be increased in subsequent research. Fuel prices *versus* time can also be added to improve perceptions.

The standardized path coefficients between the market, economic, and technological environment factors were 0.343 ($p < 0.001$) and 0.305 ($p < 0.001$), respectively. Therefore, H3b and H3c are supported. It also indicates that there is little difference in the

TABLE 10 Confirmatory factor analysis results.

Relational path	Normalized path coefficient	Standard error (S.E.)	C.R. (T-value)	p
Policy environment factors → Market environmental factors	0.240	0.096	3.388	***
Social environmental factors → Market environmental factors	0.567	0.082	7.595	***
Policy environmental factors → Economic environmental factors	0.374	0.096	5.044	***
Social environmental factors → Technical environment factors	0.494	0.108	5.500	***
Market environmental factors → Economic environmental factors	0.343	0.066	5.009	***
Market environmental factors → Technical environment factors	0.305	0.087	3.804	***
Policy environmental factors ↔ Social environmental factors	0.641	0.037	7.224	***
Economic environmental factors → Development status	0.027	0.070	0.353	n.s
Technical environment factors → Development status	−0.434	0.078	−4.519	***
Market environmental factors → Development status	0.298	0.084	3.148	**

Note: *** means $p < 0.001$, ** means $p < 0.01$, * means $p < 0.05$, n.s. Means $p > 0.05$.

level of influence that market environment factors have over technological and economic environment factors.

The standardized path coefficients between policy environment factors, market, and economic environmental factors were 0.240 ($p < 0.001$) and 0.374 ($p < 0.001$), respectively. Therefore, we assume that H4b and H4c are supported. This indicates that policy environment factors have a greater impact on economics than market environment factors.

We support H5b, H5c, and H5a because the standardized path coefficients between social environmental factors and market, technology, and policy environment factors were 0.567 ($p < 0.001$), 0.494 ($p < 0.001$), and 0.641 ($p < 0.001$), respectively. This shows that market and policy environmental factors are more affected by social environmental factors than by technology environmental factors.

5.4 Discussion about the perception of potential users

Potential users are not sufficiently sensitive to changes in the construction and operating costs of PCI because they have never used them. Therefore, from the perspective of potential users, economic and environmental factors have no significant impact on the development of PCI. In contrast, potential users believe that technological breakthroughs will have a significant impact on the development of PCI. A possible reason for this is that they have no actual charging experience; therefore, their views on PCI largely depend on external comments, and are easily misled by negative comments. These factors give potential users the impression that PCI development has advanced technologically to this point. Only by increasing the research and development of technology can the usage frequency of PCI be improved.

Potential users, as followers of PCI in the later stages, often hold skeptical attitudes toward innovative matters. Their lack of actual ownership of electric vehicles causes them to pay little attention to the charging market and legislative landscape. In contrast, potential users are more concerned about the introduction of relevant policies. Potential user concerns can be allayed with a reasonably comprehensive policy system and unambiguous charging guidelines. These results show that to realize the transformation from potential users to actual users, the government needs to increase the promotion of PCI, provide potential users with positive guidance, and enhance their understanding and confidence in PCI.

6 Conclusion

This study designed a more comprehensive framework to explore the key factors affecting the development of PCI, particularly from the perspective of potential users. It set a structural equation model with implicit variables for economic, technology, market, policy, and social environments. Research questionnaires were collected from Tianjin to inspect views on these factors. This contributes to data support and theoretical basis for the market development of PCI. The following conclusions were drawn from this study.

TABLE 11 Summary of hypothesis testing results.

Number	Research hypothesis	Result
H1a	Reducing the economic cost of PCI has a significant positive impact on promoting its development	No support
H2a	The advanced technology level has a significant positive impact on the development of PCI	No support
H3a	Good market environment has a significant positive impact on improving the efficiency of PCI	Support
H3b	Sound supporting infrastructure has a significant positive impact on improving the economic environment of PCI industry	Support
H3c	Strict market supervision and guarantees have significant positive influences on improving technical reliability	Support
H4a	Positive supporting policies have a significant positive impact on improving the market environment of PCI industry	Support
H4b	Scientific and reasonable incentive and subsidy policies and industry standards have a significant positive impact on reducing the economic cost of PCI and forming a good economic environment	Support
H5a	Good social and environmental benefits have a significant positive impact on improving the market environment of PCI industry	Support
H5b	The realization of interconnection and information sharing has a significant positive impact on improving the technical level of PCI	Support
H5c	A positive policy environment can improve social environmental benefits, while a good social environment can also promote the introduction of supporting policies, and they have a significant two-way positive correlation	Support

First, reducing economic costs will not significantly affect PCI. The empirical results show that the effects of economic and environmental factors on the current development situation are not significant. Second, the advanced technology levels of PCI development have a significant negative impact on the promotion of industry development. Technological reform attaches great importance to the mature stages of PCI development. Third, the current state of regional PCI development is directly reflected in market conditions. Market expansion is a key factor in future development. Fourth, policy and social environmental factors indirectly influence the development of PCI through intermediate variables such as economy, technology, and market environment. Fifth, low awareness of PCI and cognitive bias were the main obstacles to the conversion of potential users into actual users. Currently, most PCI operators advertise the development of PCI in network media for financial gain. However, potential users' lack of corresponding environmental consciousness, renders the publicity effect ineffective and further lowers their willingness to comprehend.

Based on the above conclusions, this study proposes the following policy recommendations: It is crucial to improve the policy system and dynamically strengthen the construction of industrial security mechanisms. First, prior to implementing any incentives or subsidy policies, local governments should conduct a thorough investigation into the expansion, distribution, and charging requirements of regional electric vehicles, and plan a reasonable development pace and scope for PCI. Second, priority should be given to improving the allocation rate of PCI in public places, such as public parking lots and transportation hubs. This will help reduce the use anxiety in potential users. Third, accelerating the construction of a standard PCI system could be beneficial. These strategies include establishing a nationwide intelligent supervision platform and a big data abnormality early warning mechanism. Finally, regulators should publicize the concept of green environmental protection at the government, society, enterprises, schools, and other levels. These strategies can raise the publicity and introduction of electric vehicle development incentive policies, improve the public, especially potential users' awareness of PCI, and improve cognitive bias.

Regulators must effectively enhance the charging parties' economic benefits and encourage technological R&D. To guarantee the sustainable and healthy development of PCI, regulators should first pay attention to the hiring and training of scientific researchers and actively support critical technology R&D procedures. Second, enhancing the level of industry intelligence and charging speed could simplify the PCI construction and operation processes. Third, various measures should be taken to reduce the economic costs of PCI construction. This can reduce potential users' barriers to entry and help effectively turn potential users into actual users. In addition, regulators should innovate their business models. It is helpful to strengthen supervision to reduce users' taking up of parking spaces when charging, thereby improving the facility's environment. Enhancing PCI usage efficiency and allowing for more flexible parking fee adjustments are also beneficial. Expediting the peak-valley price policy and designing a dynamic pricing mechanism are useful. These steps can balance power use time and achieve user charge cost minimization from the standpoint of drawing in new users. Through intelligent recharging, new technologies, such as the private recharging infrastructure sharing mode, regulators can simplify charging process and improve the user convenience.

This study has several limitations. This study examined the factors that influence the development of PCI from the perspective of potential users. However, the data for this study was limited to prospective PCI users in Tianjin. The behavioral traits and perceived preferences of potential users vary depending on the region, as local industrial development, policy support, seasonal climate, geographical environment, and other factors influence potential users in different ways. Future research samples should be further enriched to increase the research data from other provinces and cities in China. In addition, it can be compared and analyzed among different provinces to ascertain the features of each province's development. This aids in adapting to local conditions, formulating targeted development strategies for PCI, and proposing developmental suggestions. Secondly, while this study innovatively identifies the influencing factors of PCI development from the perspective of potential users, the comparison between the theoretical and real-world user experiences is still theoretical and unsupported by evidence. Finally, we mainly examine PCI development from the consumer perspective. Future research can focus on the perspective of operators, proposing policy implications for PCI development including construction and operation, to ensure the high-quality development of the charging infrastructure industry.

Data availability statement

The datasets presented in this article are not readily available because the data are not publicly available due to privacy. Requests to access the datasets should be directed to PH, phao@tju.edu.cn.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

X-PC: Conceptualization, Writing–review and editing. XJ: Conceptualization, Data curation, Methodology, Writing–original draft. X-CY: Data curation, Writing–original draft, Formal Analysis. PH: Writing–original draft, Funding acquisition, Investigation. B-CX: Writing–review and editing, Funding acquisition.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by the General Project of the Humanities and Social Science Fund of the Chinese Ministry of Education "A study on optimization mechanism and policy coordination of power system grid source towards carbon neutral goal" under Grant No. 21YJA630023. We also appreciate the Major Project of the National Social Science Fund "Research on the Transformation Path and Collaborative Mechanism of Energy Structure under the "Two-Carbon" Goal under Grant No. 22\&ZD104; National Natural Science Foundation of China National Dual Carbon Strategy Special Policy Modeling and Strategic Research Key Project "Smart Grid Collaborative Development Optimization Mechanism, Scheduling Strategy and Policy Research for Carbon Neutrality" under Grant No. 72243009; National Natural Science Foundation of China under Grant Nos 72171165, 72174141, and 71874121.

Acknowledgments

We thank the reviewers for their comments, which have improved the quality of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2024.1257121/full#supplementary-material

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