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Innovative Application of the Public–Private Partnership Model to the Electric Vehicle Charging Infrastructure in China

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Abstract: The electric vehicle charging infrastructure is in the initial development period in China, where there is an imbalanced supply and demand structure, an increasingly mature institutional environment, and an imperfect support system. The infrastructure is important for supplying energy to electric vehicles, and it needs to be provided in a reasonable manner with a moderately advanced layout. Due to large-scale investment, unclear financing rights and responsibilities, a single participant, interlinked risks, and other factors, "absence" and "dislocation" of the charging infrastructure coexist. The public–private partnership (PPP) model is an effective supply path for the infrastructure. Thus, introducing the PPP model into the charging infrastructure can leverage social capital, eases the burden on local finance, enhances the level of project management and profitability, and reduces construction and operation risks. For the participant level of PPP projects in the charging infrastructure, the present study elucidates the support mechanisms required by the government, social capital, and intermediaries in order to construct an effective charging infrastructure in China.

Keywords: charging infrastructure; government; innovation; intermediary; public-private partnership (PPP)

1. Introduction

The construction and operation of a suitable electric vehicle charging infrastructure are prerequisites for the development and sustained operation of electric vehicles, as well as being important strategic measures for promoting a revolution in energy consumption and green development. The charging infrastructure mainly includes centralized charging stations and decentralized charging piles at public charging stations, as well as public charging piles and private charging piles in public transportation, sanitation, rental, engineering, logistics, and other areas. To promote the development of electric vehicles, it may be useful to offer these services to mobilize initiatives by the government and market, where the government may play a leading role in infrastructure construction according to the public–private partnership (PPP) model. The application of the PPP model has become a trend in energy, medical treatment, transportation, communication, water treatment, service fields, and other types of infrastructure worldwide [1–5]. The PPP model can share risks and achieve a win–win situation if the public and private sectors engage in clear communication and reach agreements about how social capital can be guided to participate actively in the provision of public goods and services. Since the Third Session of the Eighteenth Central Committee of the Party of China, there has been a focus on the overall development of the economy and society, as well as the issues of national governance and public administration. The central government has emphasized

that finance is the basis of national governance and that the market plays a decisive role in allocating resources. In particular, it has proposed the establishment of a marketing mechanism to introduce social capital into the charging infrastructure. The PPP model combines the advantages of public and social capital, thereby providing unique advantages due to macro- and micro-management features. The model is particularly active in the development of infrastructure with long-term, large-scale, and slow-return investment.

Current research into the charging infrastructure is focused on the innovation and improvement of key technologies, especially from the perspectives of physical and chemical principles [6], where improved battery production and use [7] can make the charging facilities serve electric cars more conveniently, safely, and faster [8]. Numerous studies of electric vehicle charging facilities have been performed as sub-units of research into electric vehicles [9] and their dependence is relatively strong [10]. Some studies have tested methods and operation models in advanced countries as well as comparing various models in order to suggest reasonable approaches to the development of vehicle charging facilities in their own countries [11]. Others have analyzed the relationship among stakeholders in electric vehicle charging facility construction and operation projects from the perspective of game theory, which showed that the level of support from the government as well as the charging prices may affect the provision of charging facilities [12–14]. In addition, the layout of charging facilities [15–17] and business operation models have been analyzed [7]. However, few studies have considered the application of the PPP model to electric vehicle charging infrastructure construction and thus there is an imperfect theoretical system. In an order released on 9 October 2015, the general office of the state council in China issued guidance to accelerate the construction of the electric vehicle charging infrastructure, which highlighted the urgent need for the state to engage in the construction and operation of the charging infrastructure for public services via the PPP model. Therefore, it is useful study the construction of a global theoretical framework for innovation in this field.

2. Status of Electric Vehicle Charging Infrastructure Construction

Due to the rapid development of the global electric vehicle industry, countries such as the USA, Japan, as well as those in Europe and other regions are actively developing charging infrastructure layouts [18]. For example, electric vehicle pilots in the USA have adopted a strategy based on a combination of "family charging" and "public charging" by providing a charging infrastructure with charging piles, although the current charging infrastructure in the USA cannot meet the daily charging requirements for electric vehicles, except in Pennsylvania. Japan has some advantages in terms of technology research and setting standards for electric vehicles. Thus, due to cooperation between the traditional automobile industry and electricity operators, Japan has accelerated the formation of a charging service network. European countries are also actively building charging infrastructure systems. By contrast, the construction of the electric vehicle charging infrastructure is still in its infancy in China, where "absence" and "dislocation" phenomena coexist. The production and sales of electric cars were booming in 2014 and 2015, but the construction of the charging infrastructure has the following characteristics.

2.1. Gaps between Supply and Demand Are Broadening Increasingly

There is potentially a huge demand for automobiles in China. Currently, it is vitally important to develop green transportation due to increased pollution and health issues in urban areas. In recent years, as mentioned by the National Bureau of Statistics (2015), the production and sales of electric automobiles are undergoing rapid growth in China because of stimulation to develop advanced technology, preferential policies, and pilot promotion [19]. Charging facilities are complementary to electric vehicles and a core part of the electric car industry chain. Thus, electric car manufacturers in China must expect the prior provision of charging piles to sell their products. However, excluding Tesla's provision of private charging outlets, the supplies for most electric vehicles

still require improvements and development of the charging infrastructure. In order to develop green transportation more effectively and promote the independent development of the electric vehicle industry in a market-driven context, the charging infrastructure industry must undergo explosive growth, and thus the investment demand window will be opened. According to the requirements in the Guidelines on Electric Vehicle Charging Infrastructure Development (2015–2020), the number of charging piles and stations should exceed 4.8 million and 12,000 by 2020, respectively, which are 154 times and 15 times the existing levels. According to the goals charging infrastructure sub-regional construction in China, the charging infrastructure will develop rapidly during the Thirteenth Five-Year Plan period in acceleration zones, demonstration zones, and active promotion zones, as shown in Figure 1.

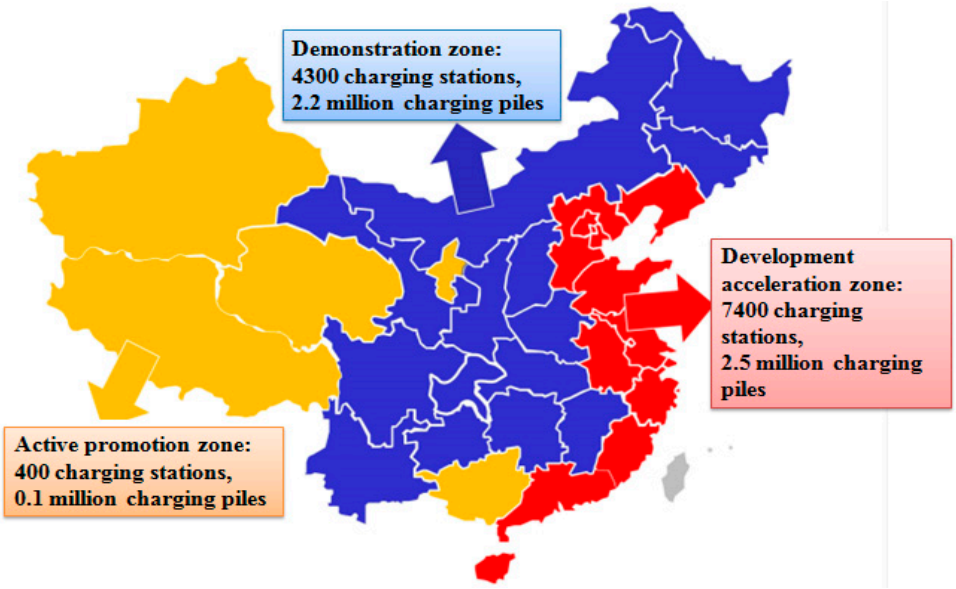

Figure 1. Goals for sub-regional charging infrastructure construction in China during 2015–2020 (data source: Guidelines on Electric Vehicle Charging Infrastructure Development (2015–2020)) [20].

The numbers of charging piles and stations have increased (as shown in Figures 2 and 3), but their growth has not matched that of electric vehicles (as shown in Figure 4) due to a lack of large-scale investment, unclear investors, immature technology, high construction risks, low utilization rates, and uncertain profit points for the charging infrastructure [21]. Beijing has vigorously promoted the development of electric vehicles with 35,800 pure electric cars and 21,000 charging piles at the end of 2015. However, there is still a huge deficiency of 10,000 charging piles. Furthermore, according to calculations by the Shanghai New Energy Automobile Promotion Office, at the end of 2015, the proportion of electric cars relative to charging piles in Shanghai was 1:0.32, i.e., three electric vehicles shared each charging pile. This is highly inconvenient for electric vehicle owners and the "many cars but few piles" dilemma needs to be solved. In addition, the charging spaces in the parking lots of many cities are occupied by non-electric vehicles so the charging piles are vacant, or there are even "zombie charging piles", which are difficult for vehicles to access. During the early development of the charging infrastructure, incompatible charging was prevalent, as well as many structural contradictions, and thus the supply and demand structure needs to be optimized.

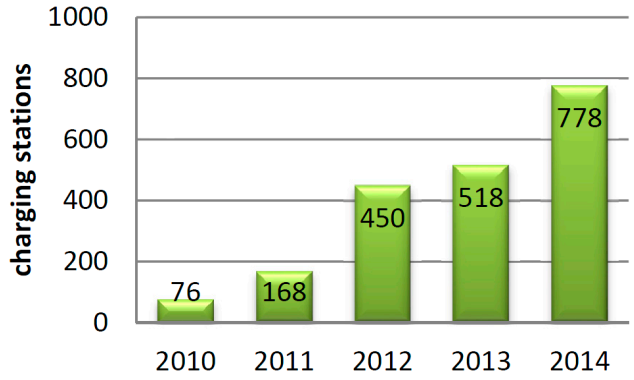

Figure 2. Annual numbers of domestic charging stations (cumulative) (data source: China's Industry Information) [22].

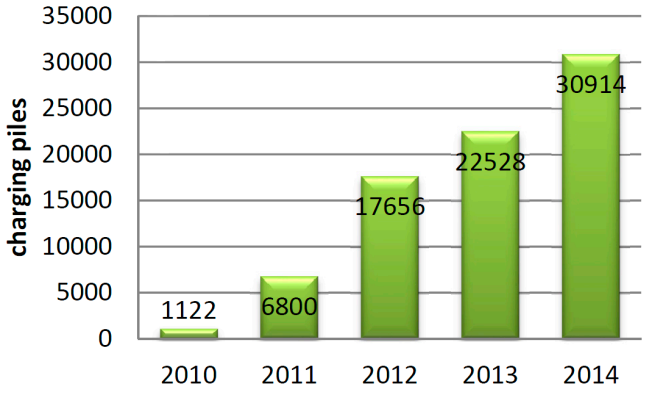

Figure 3. Annual numbers of domestic charging piles (cumulative) (data source: China's Industry Information) [22].

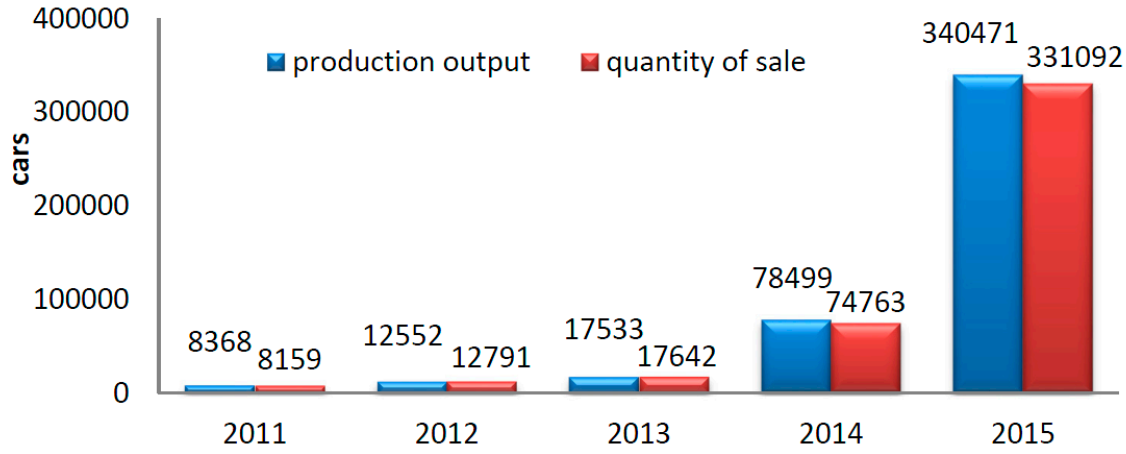

Figure 4. Annual production and sales of electric vehicles (data source: Automotive Industry Association) [22].

2.2. Technological Advances Never Stop

Technological advances also affect the construction of the charging infrastructure. Thus, battery production technology and the electricity storage model are updated constantly, although there have been no breakthroughs in cell production promotion. Therefore, it is still necessary to construct a suitable charging infrastructure. Wireless charging technology will soon enter into the common market [23], where a special coil is installed in the vehicle chassis to allow wireless charging of

electric vehicles. In China, Shougang Group (City) and ZTE Corporation (City) are building a stereo garage with wireless charging capabilities in 2016, which will provide 40 "big spaces" and a charging service for electric buses. "Wireless charging" technology will gradually be extended to private cars. Furthermore, a portable electric vehicle charging "pile" built by a mechanical packaging enterprise in Hefei will enter the market, which weighs only 3 kg and can be placed in a car, thereby allowing electric vehicles to be charged wherever a power supply can be accessed. Low carbon technology, wireless networks, new materials, and other technologies are also affecting the construction of charging stations. In particular, the first super photovoltaic charging station was built in Shijingshan, Beijing on 20 October 2015, which is a greener method for providing the charging power supply, and it allows the use of green energy throughout the full lifecycle.

2.3. Intensive Release of Policies

China made a commitment to reduce the proportion of carbon dioxide emissions and the ratio of non-fossil fuels in primary energy consumption at the Climate Change Conference in Paris in 2015. The construction and operation of the electric vehicle charging infrastructure will help to fulfill this commitment. In recent years, policies have been implemented to support the development of electric vehicles. Many of these policies aim to stimulate electric vehicle production and sales, which include financial subsidies, tax preferences, concessionary credit, and prior license registration. Thus, these polices have allowed the government to accelerate investment and the construction of the charging infrastructure, where the relevant policies are shown in Table 1, including the overall PPP and charging infrastructure policy documents based on laws and regulations issued by the State Council, the Development and Reform Commission, the Ministry of Finance, and all general government offices, as well as jointly by various ministries.

Table 1. Summary of relevant policies to support the construction of the electric vehicle charging infrastructure since 2015.

Issuing Time	File Name	Issuing Body
30 January 2015	Regulation on the Implementation of the Government Procurement Law of the People's Republic of China [24]	No. 658 Decree by the State Council of the People's Republic of China
18 March 2015	Opinions on Accelerating the Promotion of the Application of New Energy Vehicles in the Transportation Industry [25]	The Ministry of Transport
26 March 2015	Automobile Storage Battery Industry Standard Conditions [26]	The Ministry of Industry and Information Technology
7 April 2015	Guidelines on Demonstration of Financial Capacity of the Government and Social Capital Cooperation Projects [27]	The Ministry of Finance
22 April 2015	Notice on the Promotion of Financial Support Policies by New Energy Vehicles in 2016–2020 [28]	The Ministry of Finance, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Development and Reform Commission
7 May 2015	Notice on Vehicle and Vessel Tax Incentive Policies on Energy-saving or New Energy Vehicles and Vessels [29]	The Ministry of Finance, the Ministry of Industry and Information Technology, National Tax Bureau
8 May 2015	Made in China, 2025 [30]	The State Council
11 May 2015	Notice on Improving Oil Price Subsidy Policies of Urban Buses and Speeding up Application of New Energy Vehicles [31]	The Ministry of Finance, the Ministry of Industry and Information Technology, the Ministry of Transport
25 June 2015	Notice on Further Improving Demonstration Work of the Government and Social Capital Cooperation Projects [32]	The Ministry of Finance
9 October 2015	Guiding Opinions on Accelerating the Electric Vehicle Charging Infrastructure Construction [33]	The General Office of the State Council

Table 1. *Cont.*

Issuing Time	File Name	Issuing Body
17 November 2015	Guidelines on Development of the Electric Vehicle Charging Infrastructure (2015–2020) [34]	National Development and Reform Commission, National Energy Administration, the Ministry of Industry and Information Technology, the Ministry of Housing and Urban-rural Development
23 December 2015	Management Approaches on Investment and Construction of Public Charging Facilities for New Energy Minibuses in Beijing City [35]	Development and Reform Commission of Beijing
11 January 2016	Notice on Incentive Policies on New Energy Vehicle Charging Infrastructure and Strengthening the Application of New Energy Vehicles during the Thirteenth-Five Year Plan Period [36]	The Ministry of Finance, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, Development and Reform Commission, National Energy Administration
11 January 2016	Implementation Plan for Speeding up the Construction of Electric Car Charging Infrastructure in Chongqing City [37]	Municipal Government Office of Chongqing
12 January 2016	Government Office of Anhui Province's Opinions on Accelerating the Construction of Electric Vehicle Charging Infrastructure [38]	Government Office of Anhui Province
19 January 2016	Opinions on Accelerating the Construction of Provincial Electric Vehicle Charging Infrastructure [39]	Government Office of Hebei Province
25 January 2016	Special Plan for New Energy Vehicle Charging Facilities in Luzhou City (2015–2030) [40]	Municipal Urban-rural Planning Administration of Luzhou

Several regions have noted the importance of supporting charging facilities. For example, since 2015, Shanghai municipality has stated that a license will only be issued to a new energy vehicle after proving that a charge pile has been installed. Beijing encourages social capital to participate in the construction of the charging infrastructure in various ways such as PPP. Depending on the relevant standards required by the country and the city where they are located, investment and construction enterprises can apply for municipal subsidies on fixed assets of less than 30% of the total investment in projects and they have access to the platform for public service management. These policies include many regulations and consumption stimulation policies, but few that support research and development.

2.4. Social Capital Is Relatively Abundant

During the 30 years since the "Reform and Opening Up" of China, an abundance of social capital has been accumulated, such as deposits in the financial institutions shown in Figure 5. This huge amount of social capital is actively seeking more favorable investment directions. Due to the rapid development of electric vehicles, the construction and operation of the charging infrastructure is becoming an emerging industry, which has attracted the attention of many investment bodies, including power grid enterprises, petrochemical enterprises, and equipment manufacturers. At present, power grid enterprises are still the main body involved, particularly the State Grid Corporation of China, which is positively distributing large charging stations due to its advantages in terms of the transmission and distribution of power. Most of the social capital is still waiting to see the layout, but the concept of cooperation among the government, electric vehicle manufacturers, and consumers is gradually emerging. It is possible to attract various social bodies to participate in the construction and operation of the charging infrastructure according to the various types of charging needed in different places.

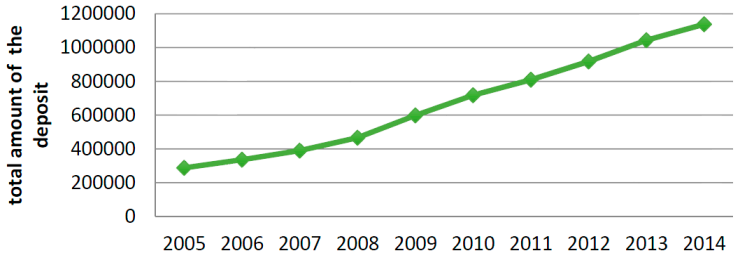

Figure 5. Deposits in financial institutions during 2005–2014 (unit: 100 million RMB) (data source: National Bureau of Statistics of China) [41].

3. Analysis of the Reasons for Backward Charging Infrastructure Construction

The charging infrastructure is a production sector that lies "upstream" and its investment is a form of "prior social capital", which has a high sensitivity coefficient. A specific ratio of investment in the charging infrastructure relative to investment in the electric vehicle industry is preferred, where the ratio can increase by a certain percentage, as shown in Figure 6. However, the imperfect charging infrastructure constrains the development of electric vehicles, which then affects the construction of the former. This vicious circle makes it difficult to achieve the development goal of green transportation. At present, the main reasons for hysteretic charging infrastructure construction are described in the following.

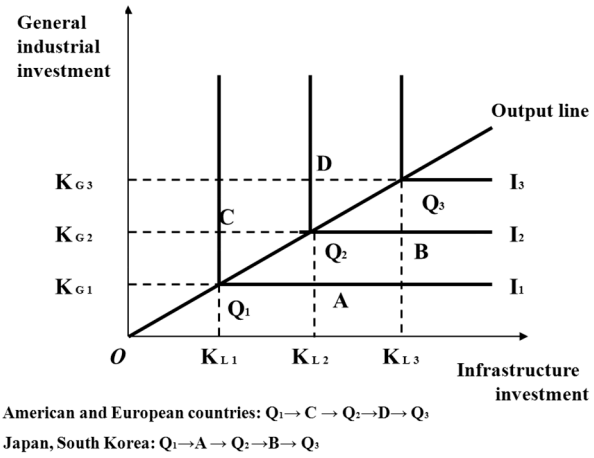

Figure 6. Illustration of the output model.

3.1. Large-Scale Investment and Unclear Rights and Liabilities

The electric vehicle charging infrastructure is a form of quasi-public goods, where the initial investment is large but not sufficient. The infrastructure requires a long-term use and maintenance process, which demands steady capital inflows. If the government is the only investment body, its burden is high and the setting of the budget in advance lacks flexibility. At present, normal charging pile construction costs 10,000–30,000 RMB and rapid charging pile construction costs 0.1–0.2 million RMB [42]. Without considering the land use fee, a charging station comprising 10 battery chargers costs about 5 million RMB. Due to economic weakness and the limited financial resources of the new normal economy, if the nation encourages the construction of charging facilities via financial subsidies and tax preferences, then the provision of supporting subsidies by the provincial and municipal financial ministries will place a high pressure on local finances and possibly lead to a local debt crisis. Thus, a strong inflow of social capital is required, which is profit driven. In addition, due to the diversity of investment structures, there are differences in the form of project assets, cash flow control, and rights and liabilities. If there is high pressure for charging infrastructure construction

and an urgent demand, we should coordinate how the investment space is converted into projects to facilitate their orderly construction and operation.

Currently, the rights and liabilities of investment bodies are unclear in the field related to the supply of the charging infrastructure. First, we must consider the rights and liabilities of the government and the market. In the context of the market-oriented reform of public utilities, the design has been developed in an entirely top-level manner. Thus, there has been an excessive emphasis on the government's dominant position in infrastructure construction in the past, but it is necessary to understand the nature and risks of market mechanisms in a comprehensive manner, and we should not exaggerate the role of the market. Second, the characteristics of the charging infrastructure's external benefits are obvious, so the allocation of rights and liabilities among the central and local levels of the governments in charge of infrastructure construction must be defined. Access, licenses, and the full cost of the infrastructure needs to be standardized and supervised vigorously. Furthermore, the construction of the charging infrastructure involves many departments such as the Ministry of Finance, which may affect continuity. Multiple management bodies or a lack of management may occur, which could lead to poor management and further discontinuity in some systems. In addition, social capital is more concerned with investment income and the interests of investors rather than social benefits when it participates in the construction of the charging infrastructure. Finally, public participation in construction is not sufficient because although electric cars have many positive effects, only some electric car owners and potential customers are concerned with the operation of charging infrastructure projects.

3.2. A Single Body for Charging Infrastructure Construction and Operation

There is a trend toward the diversification of participants in charging infrastructure construction, but in reality, there is only a single body and poor interaction among potential players. The government can raise funds through taxes, fees, by issuing bonds, establishing project funds, and in other ways to support the supply of the infrastructure. However, these methods can only raise funds and they are not sufficient to transform advanced project management concepts and technology into infrastructure projects. If the government leads construction, this increases financial pressure and it cannot ensure the operational efficiency of charging stations because the government is not specialized in this role, which is not conducive to large-scale intensive construction and the operation of electric vehicle charging stations. If we consider the charging stations at the Beijing Olympic Games, where large-scale investment was dominated by the government, the actual operation of 50 pure electric buses was only 60% possible, which is an insufficient utilization rate for vehicles. The battery performance was poor and the charging stations were operated at a loss. The construction of the charging infrastructure under leadership by companies can increase the sales of electric vehicles from their own brands, but it can also result in the unordered development of charging stations due to a lack of coordination among bodies, which constrains the development of the electric vehicle industry. For example, the poor compatibility of Tesla special charging piles results in a waste of resources. Furthermore, some electric car users can afford their own charging stations, which leads to low utilization rates and a lack of safety. However, the costs of construction and operation are too high for most consumers.

3.3. Various Risks Coexist

The construction and operation of the charging infrastructure is a long-term process, which may take over one decade and the project might encounter various risks. From the viewpoint of static participants, the risks for the government mainly include policy, law, business default, rent-seeking, and force majeure risks. These risks will directly prevent the plan from proceeding as scheduled. Investment and operation merchants may have concerns about the government's credibility and unpredictable promotion policies, and thus risks may emerge, including technical, security, market uncertainty, default, unstable charging fees, and price adjustment risks. Price adjustments may occur due to changes in the price levels and labor costs. Consumers will also encounter uncertainties such as

mileage anxiety, security risks, price risks, and technical risks. In addition, there are construction risks and profitability risks from the perspective of a dynamic investment process. Urban land resource shortage risks occur because the construction of the charging infrastructure depends on the availability of land, and urban land resources may be insufficient to meet the needs of the urbanization process. Building new public charging stations or transforming existing parking lots cannot solve the problems of insufficient parking spaces, the high costs of power grid transformation, and uncoordinated property management companies. The cost of electric vehicles is lower compared with that of conventional cars, but there are insufficient consumers. The greater investment required in pre-construction and the higher labor costs for post-construction operations will lead to low efficiency, thereby making it difficult to earn profits. At present, the Beijing Olympic Games charging piles and Shanghai World Expo charging stations are operated at a loss. Finally, there are also exit risks because the charging infrastructure may lose its value in the future and waste resources due to continuous advances in electric vehicle technology. Furthermore, clearing up work will require further inputs in the case of an exit.

3.4. Support Systems Need Strong Coordination

The construction and operation of the charging infrastructure requires smart city planning, intelligent grid building, and an intelligent transportation layout, which involves multiple stakeholders, high complexity, and difficulties with promotion. First, the infrastructure cannot exist independently of the power grid. The charging infrastructure will have a significant impact on the safe operation of the grid and power quality, but it is also constrained by the operation and control of the electricity distribution network. Second, in the context of vigorous urbanization, smart city construction and open community planning will affect the layout of the charging infrastructure network. Furthermore, the construction and distribution of the transportation infrastructure network are connected closely to the charging infrastructure. Therefore, we must coordinate and systematize the planning of the charging infrastructure, power grids, transportation, and urban planning.

4. Innovative Application of the PPP Model to Charging Infrastructure Construction

The charging infrastructure is important for the supply of energy to electric vehicles and it demands the effective provision or a planned layout to meet the operational needs of electric vehicles in key regions or between cities. The application of the PPP model has gradually become popular in various fields since the Fifth Session of the Eighteenth Central Committee of the Party of China due to the advances in mixed ownership, the continuing development of supply-side reforms, the establishment of market-based mechanisms for social capital investment in ecological environmental protection, and the operation of the PPP project management platform and project library by the National Development and Reform Commission, the Ministry of Finance, and other departments. In June 2016, 8644 PPP projects were included in the information platform project library, which accounted for 9.885657 trillion yuan (RMB) [43]. However, only seven PPP projects were related to charging infrastructure construction. Table 2 shows all the projects launched by the government according to the traditional Build–Operate–Transfer model, where these projects are still at the basic stage of recognition and preparation for PPP project operation, so the relevant implementation has not occurred and the targets are unclear. The relevant regulations are not suitable at present, so in order to generalize the innovative application of this model and ensure the effective supply of the charging infrastructure, it will be necessary to provide policy suggestions regarding the roles of the government, social capital, and intermediary cooperation.

Table 2. Summary of PPP projects related to the construction of the charging infrastructure.

Project Name	Launch Date	Proposed Cooperation Term	Investment Amount (yuan) (RMB)	Target
Public charging infrastructure for a new energy vehicles network project in Tianjin	28 October 2014	20 years	516 million	Charging piles: 2000 Bus charging stations: 40
Pure electric bus charging station project in Xuzhou	1 March 2015	15 years	138 million	Bus charging stations: 27
Charging infrastructure for a new energy electric vehicle project in Anqing	18 January 2016	13 years	818 million	Charging piles: 1700 Bus charging stations: 4 (no less than 99 dc charging piles)
Combination of parking and maintenance, as well as charging for a new energy school bus project in Zunyi, Guizhou Province	1 October 2015	15 years	50 million	Replace or add 20 new energy buses, build three parking lots in Jiutianmen, Pearl, Yingbin avenue, as well as constructing a comprehensive maintenance field, charging pile, and ancillary facilities
Electric vehicle charging station construction project in Xining, Qinghai province	1 January 2016	30 years	50 million	Build charging station in Xining City and Qinghai Lake scenic spot
Pure electronic bus charging station/pile construction project in Kuerle, Xinjiang province	17 November 2015	30 years	300 million	Charging piles: 170 Charging stations: 3 (no less than 90 charging piles)
Motor vehicle charging infrastructure construction project in Hetian	21 September 2015	30 years	55 million	Proposed construction of five large urban public charging infrastructure systems

4.1. Government Mechanisms for Encouraging the Application of the PPP Model to Charging Infrastructure Construction

Market failures are unavoidable but effective intervention by the government may promote the Pareto optimal allocation of resources to enhance the overall level of social welfare. The government encourages the application of the PPP model to charging facilities because it can provide high-quality electric vehicle charging services at low costs to the whole community. The government should actively accept the PPP model to build sustainable partnerships among the charging infrastructure construction bodies and continuously improve awareness of this service. The innovative application of the PPP model could clarify the rights and liabilities of governments and enterprises, as well as elucidating the division of power and the property rights of investors. Central government should consider the top-level design and develop national standards urgently, as well as standardizing the charging technology, specifications, and interface standards for electric vehicle batteries to improve compatibility. According to the demand for and beneficiaries of charging facilities, central government should fund scientific and technological R & D investment, as well as training funds for personnel involved with the charging infrastructure, and take the main responsibility for designing the charging facility layout and the construction of an inter-provincial electronic highway. Local governments have the main responsibilities for the facilities within regions. Thus, based on the results obtained by data mining, they can determine the daily residential travel behavior, travel demand, traffic density, charging service radius, road network planning, urban layout, and power grid development, thereby ensuring the rational distribution of the charging infrastructure, as well as preventing blind development and redundant construction. According to the "Value for Money Assessment method on the Guidelines on Value for Money Assessment of PPP (Trial)" (finance and economics (2015) No. 167) issued by the Ministry of Finance on 18 December 2015 [44], it is possible to determine whether the PPP model can substitute for the traditional method for investment by the government when providing public service projects. For each project, the government can develop operation mechanisms according to the PPP model for the charging infrastructure based on the Chinese government's five-factor perspective, i.e., economy, politics, culture, society, and ecological civilization.

The participation of the government during the initial construction of the charging infrastructure will be beneficial for reducing costs, achieving economy of scale, and guiding the market demand to allow enterprises to overcome the problem of undirected construction, as well as promoting technological innovation for charging stations to reduce investment and operational risks. Governments may adopt economic means at all levels, particularly financial tools to promote the application of the PPP model in the field of infrastructure charging, as shown in Figure 7. In terms of financial expenditure, governments may define their responsibilities in terms of all aspects of the investment share, operation and maintenance, risk decomposition, and support facilities according to all the links during the construction and operation of a PPP project. They should build a high-quality government procurement platform, improve the public bidding and tendering system for PPP projects, and maintain public welfare by providing financial subsidies to projects. In addition, they should reduce the risks of social capital, and solve or mitigate the issue of instability and inadequate initial profits. In terms of revenue, particularly taxes, there should be different tax privileges in the development acceleration zone, demonstration zone, and active promotion zone based on the planning of the infrastructure in specific regions. In terms of budget management, the PPP projects need sufficient financial capacity after evaluating the value for money and carefully controlling the size of new PPP projects to manage financial risks. The new normal economy is affected by slower economic growth and declining land prices, thus the financial situation in China is in a difficult stage and local government debt risks have increased. Employing the PPP model can moderately reduce the burden on the government and achieve inflows in terms of social capital via financial leverage. When governments prepare budgets, they should define the expenditure responsibilities, including fiscal revenues and the expenditure on PPP projects during budget management, as well as normalizing budget approval and strengthening legal constraints.

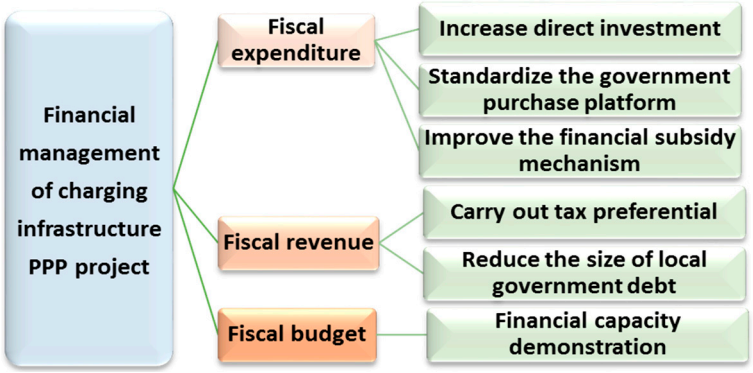

Figure 7. Financial management of PPP projects for charging infrastructure construction.

In terms of politics, governments should continuously improve national governance, strengthen democracy, allow many parties to provide the charging infrastructure, optimize the market and legal environment, and improve the information disclosure system. Furthermore, they should actively promote the construction and operation of the infrastructure to spur the development of the new energy automotive industry, as well as ensuring energy security and the orderly development of the automobile industry. According to the requirements for "streamlining administration, instituting decentralization, and optimizing service", it will be necessary to simplify the approval process for the construction of new charging facilities by only examining and approving centralized charging facility construction projects with independent land. The charging piles and small movable charging facilities constructed in the original parking lots should be registered with the local Development and Reform Commission. In terms of culture, the government should guide the PPP model for the charging infrastructure. The concept of contract compliance is the core of the PPP model, where regulation ensures that the model is operated and democracy is the basis. In the social sphere, governments

at all levels can provide high-quality public services for electric vehicle charging, strengthen public awareness of charging piles in the public domain, and create an atmosphere that promotes green development. In terms of the construction of an ecological civilization during the Thirteenth-Five Year Plan period by implementing green traffic and urbanization, the government can continuously change the energy structure, improve energy efficiency, promote the production and use of electric vehicles, and encourage the development of the charging infrastructure. Thus, the government should transform its traditional concept and formulate an overall plan by focusing on the returns for social capital and creating a good social environment, which encourages, supports, and guides the development of mixed economies. It should also provide an omnibearing service, develop a comprehensive information platform, and an indicator evaluation system, which can be examined, regulated, and operated to prevent corporations from pursuing high profits and ignoring public interests, thereby carefully controlling the size of new PPP projects for the charging infrastructure.

4.2. Mechanisms for Operating Social Capital to Apply the PPP Model to Charging Infrastructure Construction

More social capital can be obtained from the charging infrastructure for electric vehicles if incentive policies are issued by the government. In China, social capital can be obtained from state-owned enterprises, collective enterprises, and private enterprises, where the specific types of participants are shown in Figure 8. The charging infrastructure can generate electricity and service fees. Irrespective of who pays the fees, the pricing and charging forms of the infrastructure operators can be regulated using the PPP model to ensure reasonable returns for social capital and to stimulate the supply for the infrastructure. Social capital can employ the PPP model to participate in the construction and operation of the charging infrastructure, the design of a suitable cycle by feasibility analysis, project approval, bidding for construction and operation, and using risk-sharing mechanisms to avoid market, technology, and government risks, thereby improving the efficiency of project management.

Figure 8. Major participants in social capital for PPP projects related to the charging infrastructure.

Currently, public companies and state-owned enterprises with close connections to the government and relatively well defined superstructures have obvious advantages in PPP projects. The inflow of state-owned assets can avoid information asymmetry as well as unclear profits and losses during the independent operation of social capital. The coordinated development of the PPP model and state-owned enterprises according to "the economic reform of mixed ownership" model can break policy restrictions and allow the government to obtain shares and dividends, while state-owned enterprises can follow the PPP model and non-public enterprises may be integrated into the construction of charging infrastructure projects. The government and the party with social capital can sign contracts and set up project operation companies, which are generally held by the latter, to combine the advantages of public and social capital.

At present, power grid companies are the main providers of the charging infrastructure. In addition to the smart grid, the State Grid Corporation and Southern Power Grid Company are competing to arrange and optimize their charging networks to promote the use of new energy. They can transform wind energy and solar power into electricity, and supply power to the charging infrastructure for electric vehicles. For example, the Yunnan Power Grid vigorously promotes the "Internet + charging infrastructure" to enhance the charging service level, promote the operational efficiency and user experience, as well as increasing the interaction between energy sources and information for electric vehicles and smart nets. Furthermore, participants with social capital can strengthen the cooperation with government, rearrange public parking lots for buses, taxis, shopping malls, supermarkets, gymnasiums, and industrial zones, and build charging stations. Petroleum and petrochemical companies can participate in the construction process by taking advantage of the existing good layout. These companies can build charging piles to provide services around public roads such as intercity highway toll stations. Future charging for electric vehicles mainly comprises the infrastructure in residential and working zones. All types of enterprises can cooperate, especially with property management companies to develop charging facilities in residential garages. The electricity charges for the ports can be reduced as well as the user fees, and installation fees can be removed by considering the initial installation modes for cable TVs and phones. Due to advances in technology, the charging and discharging system can even be supplied for free to promote the recycling of products and peak load shifting, as well as improving the participation mechanism for users of electric cars.

4.3. Intermediary Support Mechanisms for Social Capital to Encourage the Application of the PPP Model to Charging Infrastructure Construction

Cooperation is the core feature of PPP projects for the charging infrastructure. The cooperation among intermediaries can solve the problem of asymmetric information, reduce risks, and improve the efficiency of cooperation. First, PPP is an effective method for financing and it must depend on financial intermediaries. According to the principles of sustainable business, financial institutions should enhance the lines of credit and credit ratings for PPP projects, provide innovative financial and insurance products, such as green banks, securities, funds, insurances, bonds, and other hybrid products, as well as applying risk compensation policies to improve the financial service systems. Financial institutions should also promote stock equity, protect usufruct, franchise rights, and other ways of pledge financing, establish special fund investment companies for PPP projects with finance, construction, and operation capacities, and break the traditional noninvolvement of funds in the construction and operation of projects. In addition, financial institutions should build a multi-level guarantee system, actively promote the establishment of financing and guarantee funds, broaden financing approaches, and achieve closed-loop risk.

Second, legal intermediaries have significant role in charging infrastructure construction. Since November 2014, the Ministry of Finance has vigorously promoted the application of PPP and the government has issued a series of laws and regulations, as well as policies, to advance the development of PPP. On 19 January 2015, the Ministry of Finance issued the "Guidelines on PPP Project Contracts (Trial)" [45], which clarify the details of contract signing. Thus, the rights and liabilities of parties can be appointed by referring to existing contract models in a fully standardized manner in demonstration projects. Legal professionals are also required during the bidding process for government procurement. If disputes occur during projects, they should rely on the law to obtain a solution. Arbitration institutions such as a third party should be introduced if necessary. When confronted with the "One Belt, One Road" strategy, foreign capital should obey the relevant laws and regulations when they are involved in PPP projects. Mutual trust should be enhanced and international projects should operate in accordance with the law.

Furthermore, asset evaluation agencies can evaluate PPP projects during the asset transfer process, and thus it is necessary to establish professional asset evaluation and advisory bodies. Given their extensive industrial experience and abilities, asset agencies can improve the efficiency of project

promotion and offer technical support in terms of institution building, program planning, and negotiation projects. In particular, they can evaluate the infrastructure investment by the government using a cost method, market approach, and income approach to avoid the loss of state-owned assets during the transfer of follow-up projects.

In addition, it would be useful to set up cloud platforms for the charging infrastructure and build an "Internet + charging infrastructure" industrial ecology model based on sustainable development to promote diversification and cooperation by networking. This model could make full use of the available information resources, thereby allowing the government, social capital, and consumers to understand the supply and demand characteristics of the charging infrastructure without delay. In order to facilitate the implementation of a future "energy Internet", the charging infrastructure can allow data sharing and deliver information to car owners. The charging facilities for electric vehicles will need to be connected to mobile devices such as cell phones, where the APP (application) client can be utilized to view the distribution, occupancy, and charging situations for these facilities in real time, as well as reserving parking spaces online for charging. The establishment of dynamic adjustment mechanisms can resolve the mileage anxiety among consumers and allow mobile payment for charging fees. On 18 January 2016, Beijing launched the "E Charging Net" as a public service platform for charging facilities to achieve interconnection among public charging piles. Internet-based crowd-funding was also obtained to develop this new model. Thus, on 24 November 2015, "Circle Funding Net" was formally launched on a network platform for crowd-funding. This "Net" can attract private investors to ensure the control of project construction and operation, as well as reducing risk to protect the interests of all parties.

The innovative application of the PPP model depends on international cooperation. On 12 December 2015, the "Conference of the Parties of the United Nations Framework Convention on Climate Change" was concluded in Paris, France, where 195 countries approved the Paris Agreement as the first global agreement on climate change. This agreement stresses: "the urgent need to enhance the provision of finance, technology and capacity-building support by developed country parties, in a predictable manner." In the context of globalization, the electric car is being promoted as a green transport model with low carbon usage and reduced emissions. The electric vehicles in China are faced by the same challenges encountered in the USA, Japan, and Europe. Thus, China should take the initiative and participate in the establishment of international standards, as well as learning from the advanced technology, management experience, and capital inflow methods for charging infrastructure construction in developed countries. The Global Infrastructure Facility Partnership Program provides a global open platform for mobilizing and connecting institutions so that they can invest in the preparation, planning, and risk sharing for single infrastructure projects. These institutions can support the infrastructure of emerging markets and developing economies.

5. Conclusions and Future Research

5.1. Conclusions

The PPP model harnesses internal driving forces to implement concepts, technology, and institutional innovation. The electric vehicle charging infrastructure requires the introduction of the PPP model to encourage the development of operating mechanisms among participants. In the present study, we defined the charging infrastructure and the PPP modes based on the provision of the charging infrastructure via long-term cooperation between the public sector and market departments in order to achieve a win–win situation. We analyzed the main reasons for constructing a suitable charging infrastructure based on the differences between supply and demand, technological advances, policy dividends, and the relative abundance of social capital. These reasons include issues related to large-scale investment, unclear rights and liabilities, a single body for construction and operation, mixed risks, and imperfect support systems. Based on fundamental economic theories, we clarified the suitability of constructing and operating the charging infrastructure according to the PPP model,

as well as identifying the important factors that would help to promote the PPP model in this field, particularly the enthusiasm for social capital participation, the ability of businesses to participate in project management and operation, and a variety of innovative management approaches to solve the "absence" and "dislocation" problems in the charging infrastructure. We stressed the decisive role of the market in resource allocation and how the government can stimulate the vitality of the market. We analyzed the bodies involved in the construction of the PPP model for the charging infrastructure from a macroscopic viewpoint, and we proposed a mechanism for stimulating the application of the model, as shown in Figure 9. The government should provide legitimate support and adopt relevant policies from the five-factor perspective of economy, politics, culture, society, and ecological civilization, particularly in the fiscal area. The responsibility for expenditure is determined according to the service scope, so the government should develop standards for the charging infrastructure as soon as possible, as well as providing specific suggestions in terms of direct investment, government procurement, subsidies, various tax-related privileges, and budgetary arrangements for fiscal expenditure, such as increasing financial support for scientific research into the charging infrastructure. The public pricing of electricity is also very important because the interests of social capital are mainly determined by differences in price. It is also necessary to summarize project experience to create a favorable policy environment for the future rapid development of the charging infrastructure. From the perspective of social capital bodies, different types of enterprises should adjust their methods to the local conditions, as well as increasing technology research and development, preparing for project financing, planning, construction, and operation, thereby playing a key role in infrastructure development. Related industries should also be developed at an appropriate scale. From the perspective of intermediaries, there are facilitative roles for finance, law, asset valuation, an Internet cloud platform, and international cooperation, which could achieve mutual benefits and a win–win situation, while professional personnel training is also very important. The PPP model also needs to be optimized in terms of the energy, environment, medical treatment, transportation, communication, water treatment, and service fields, as well as other infrastructure worldwide.

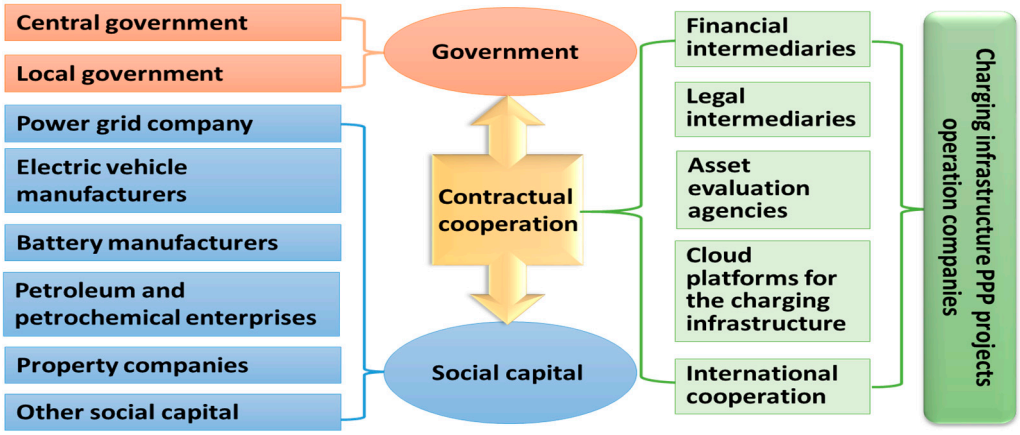

Figure 9. Static framework showing the relationships in the PPP model of the charging infrastructure.

5.2. Future Research

The PPP model is still being promoted vigorously so that all levels of government have high enthusiasm and there is increasing engagement with social capital. However, the standardization of project implementation needs to be improved, where it is necessary to consider the top-level design, complex management, and interconnections. In this study, we analyzed the static framework of the PPP model of the operation of the charging infrastructure, particularly the distribution of power and responsibility during the construction of the charging infrastructure. However, the dynamic operation of the whole project life cycle needs to be enhanced greatly by considering project revenue sources,

supervision, rent seeking, and the exit mechanism for the PPP model. In particular, further research is needed regarding the deep game relationship between the government and the market, the pricing rules for charging fees, risk transfer management, and contract model construction. Systematic studies are also needed of the information age "Internet +", dynamic adjustment mechanisms for the intelligent power grid, and the construction and operation of an Internet crowd-funding platform, while a comparative study of the infrastructure charging supply models implemented throughout the world would be useful.

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