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Monte Carlo-based Charging Demand Forecasting Model and Market Space Study

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Abstract: With the rapid development of China's new energy vehicle industry, charging infrastructure has gradually become a key factor affecting the further development of the new energy vehicle industry. Scientific and reasonable forecasts of the future development scale of the domestic charging infrastructure market have become an important element supporting the business planning of various related parties such as vehicle enterprises, charging pile enterprises, and the energy industry. Based on the distribution data of electric vehicle traveling and charging characteristics obtained from the industry research, this study proposes a set of charging infrastructure prediction model based on the principle of energy supply-demand balance, predicts the development scale of charging infrastructure in the country and key cities, and further analyzes the market competition and future market margin of the key cities, and evaluates the difficulty of future market entry in the key cities, which provides a basis for further development of the charging infrastructure industry. The difficulty of entering the future market in each key city is assessed, providing business decision support for industry participants. In the future, the charging infrastructure development scale prediction results proposed by this study can be used as the input parameters of the charging pile layout planning model to enhance the scientific nature of the charging infrastructure layout and help the industry to develop in a high-quality manner.

Keywords: Charging Infrastructure; Electric Vehicle; Charging Infrastructure Planning; Demand Forecasting.

1. Foreword

New energy automobile industry is one of the strategic industries in China. Under the background of "dual-carbon" target, new energy automobile industry has been growing explosively, with terminal retail sales of 5,578,000 units in 2022, and market penetration rate increased to 23.8%, which has completed the goal of "New Energy Automobile Industry Development Plan (2021~2035)" in advance. It has completed the goal of "the market penetration rate of new energy vehicles will reach 20% in 2025" in the "Development Plan for New Energy Vehicle Industry (2021~2035)", and has gradually entered a period of comprehensive market expansion, ushering in a new stage of development and growth. The unexpected development of new energy vehicle production, sales and ownership has brought challenges to the construction of China's energy supply network, and "energy supply anxiety" has always existed. Charging is currently the most mature way of energy supply, China's charging infrastructure market has a fast development speed, and regional development level differences, industry participants should be targeted to grasp the future of national and regional charging infrastructure industry development scale, to develop a reasonable energy supply business planning, and jointly help the construction of national high-quality charging system.

Charging infrastructure demand forecasting is an important fundamental research within the related field, and early statistical methods usually used static statistics for forecasting, such as population, car ownership, etc., such as Kou[1] , Barzani[2] Kou, Barzani, and Frade[3] However, charging infrastructure in China is still a fast-growing emerging industry, so it is difficult to reflect the real state of development of the industry using such methods due to the amount of historical data and other factors. As the industry matures, more methods are applied to charging infrastructure demand forecasting, such as: travel chain theory[4-7] Grey forecast model[8] , Cumulative Prospect Theory[9, 10] and simulation methods based on Monte Carlo, etc.[11-14] . Historical studies have shown that each method has its own unique advantages and applicability, however, current studies mainly focus on micro scenarios, such as a small or medium-sized area within a city, and lack of macro-view forecasting and research, which makes it difficult to provide direct support for the industry's high-quality development as well as for the business planning decisions of enterprises.

In order to support the enterprises of all parties in the industry to grasp the future development of the charging infrastructure market and help the charging infrastructure industry to develop with high quality, this study constructs a set of charging demand forecasting model based on Monte Carlo simulation, studies the scale of China's charging infrastructure development in the future up to 2035, and analyses the competition in the public charging infrastructure market of the first-tier and the new first-tier key cities and the space of the future market residuals, and It assesses the difficulty of market entry in each key city, providing strong support for industry participants' decision-making on energy supply business. In the future, we will also further carry out research on charging infrastructure planning and layout based on the forecast results of this study to support the high-quality development of the charging infrastructure industry.

2. China Charging Infrastructure Market Space Forecast

2.1. Logic of Charging Infrastructure Development Scale Forecast

The charging infrastructure demand forecast is based on the concept of energy demand supply and demand balance, and the logic of the forecast method is shown in the figure below, which is mainly divided into two execution steps: projecting

the energy demand of various types of electric vehicles, and calculating the quantity demand of charging infrastructure based on the results of energy demand. Since the power composition of the future charging infrastructure will have a direct impact on the forecast of the future charging infrastructure, it is also necessary to introduce charging decision rules to allocate the energy demand to various types of charging infrastructure with different power. The above two steps involve a total of six types of input parameters, and the forecast of energy demand needs to be calculated by three types of variables: the predicted value of vehicle ownership, vehicle behavioural characteristics, and vehicle technical parameters; furthermore, after allocating the energy to various types of charging piles through the charging decision rule, the technical parameters of charging piles as well as the utilization rate need to be taken to calculate the daily supply level of various types of charging infrastructures, and then finally, combined with the energy demand on each type of infrastructure, the energy demand is calculated for each type of charging infrastructure. energy demand on each type of infrastructure, and finally calculate the demand quantity of each charging infrastructure.

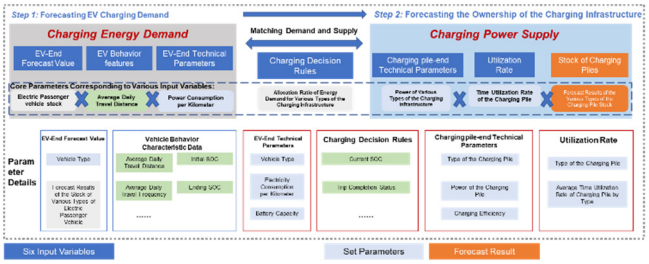


Figure 1. Charging infrastructure demand forecast logic

2.2. Model Input Parameters

The charging infrastructure forecasting model includes a total of six types of input parameters, of which the predicted value of vehicle end of ownership will be expanded in the forecasting results section, and the details of the remaining five parts of the parameter settings are as follows:

(1) Vehicle-end forecasts

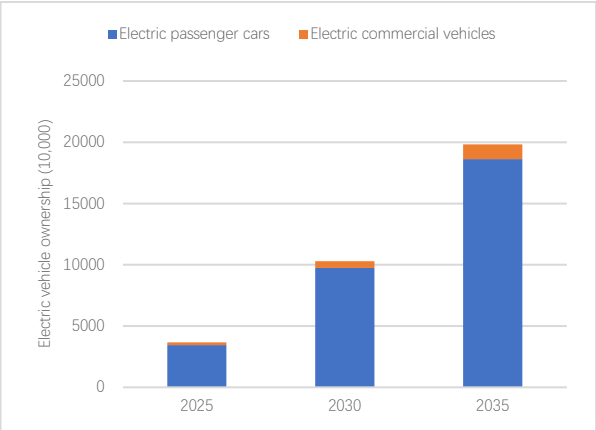


Figure 2. Results of Electric Vehicle Ownership Scale Forecast

This model proposes to study the level of charging infrastructure development in the country, therefore the forecast of vehicle end-use ownership is for electric vehicles and includes passenger cars and commercial vehicles. Due to the differences in behavioural parameters behind different vehicle groups, this study further classifies vehicle types, with passenger cars divided into operational and non-operational passenger cars, and commercial vehicles divided into: light goods vehicles, medium and heavy goods vehicles, and city buses. Combined with the projections of this research team, is expected to reach nearly 200 million EVs by 2035 for future development in China.

(2) Vehicle behavioural characteristics

Behavioural distribution data includes travel behaviour distribution and charging behaviour distribution. The travel behaviour distribution is based on the average daily mileage distribution of vehicles, and this parameter is the key to energy demand forecast, while the charging behaviour data is based on the user's starting charging SOC, and the charging decision rule of the model is also based on the user's starting charging SOC situation.

(3) Technical parameters of car ends

Vehicle technical parameters in the model mainly refer to the total power of battery and kilometre power consumption levels of vehicles, the model involves a total of five types of vehicles, of which the same technical parameters are used for passenger cars, and the three types of commercial vehicles are set for their own technical parameters. The technical parameters are set based on the average parameters of high sales models, and research by industry experts, taking into account the progress of vehicle technology, and setting different levels of total power and kilometre power consumption levels for each type of vehicle in 2025, 2030 and 2035 respectively.

(4) Utilization rate

According to the economic calculation of the charging station, as shown in the figure below, when the time utilization rate of the charging station reaches more than 13%, the charging station will achieve profitability, fully considering the profitability of the operator, the future improvement of the operation service level and the current level of public charging pile charging time utilization rate (less than 20%), the model sets the future level of time utilization of public charging piles at 25%, and the utilization rate of private piles at 4% based on the industry research data. The utilization rate of private piles is set at 4% based on industry research data.

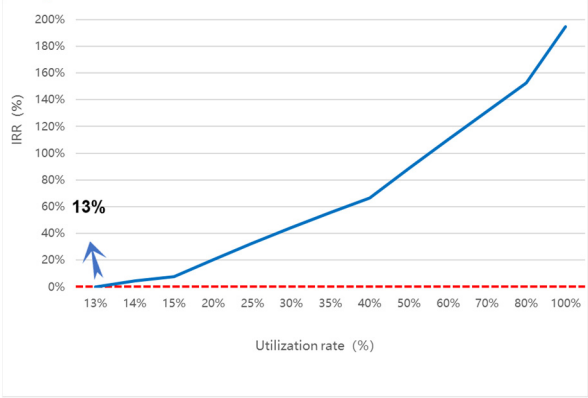


Figure 3. Charging station economics study

(5) Technical parameters of pile end

The technical parameters at the pile end are mainly charging power and charging efficiency, the setting of which needs to consider the application of advanced technology and the replacement of existing piles. In terms of power setting, AC charging piles are mainly 7kW, and the current average power level of DC charging piles is around 120kW, which will be used as the first type of standard piles in the model. In addition, super charging piles are gradually emerging, and Guangzhou and other places have put forward the

development vision of building a "super charging capital". In order to reflect the impact of cutting-edge technological products on the future scale of demand for charging infrastructure in the short term, a representative 480kW super charging pile is selected as the second category of standard piles. Finally, considering the charging technologies that will be promoted and applied in the medium and long term in the future, and combining with the national standard 2015+, a megawatt-class pile of 1,000kW is set as the third type of standard pile in the model.

Charging efficiency refers to the actual power depreciation of the charging pile. The charging efficiency of a single charging pile is calculated as follows:

$$\alpha = \frac{W_T}{P \times T}$$

Style:

α--Charging efficiency;

W_T- - the actual amount of charging in the time period T;

P- - Charging pile power;

T--Duration of the analysis;

Based on the measured dynamic data of 591 charging piles at 50 charging stations for 14 consecutive days to analyse the charging efficiency, the calculation results are shown below, and combined with the results of industry experts' research, different charging efficiencies are set for each charging pile, and combined with the utilization rate setting, the daily energy supply level of each charging pile can be calculated, as shown in Table 1 below.

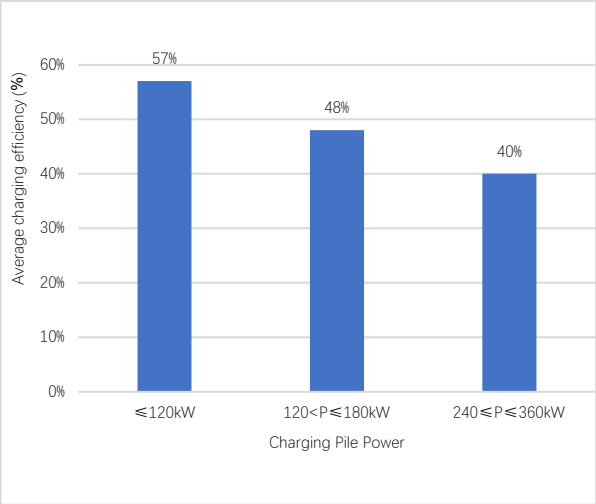


Figure 4. Charging efficiency

Table 1. Charging pile technical parameter setting

Charging pile power/kW	Charging efficiency/%	charging pile causality	Daily energy supply level/kWh
7	85 per cent	Private, public	7.7
120	75 per cent	Public	540
480	65 per cent	Public	1872
1000	45 per cent	Public	2700

(6) Charging decision rules

In this study, based on a large sample of vehicle owners of different models, the probability selection matrix of different vehicle groups for the four types of charging infrastructures under different trip completion conditions and different vehicle SOC levels is set up, and each simulated vehicle in the model will apply this probability matrix to make probabilistic choices of charging piles based on the SOC conditions calculated in the simulation process as well as the trip completion conditions.

2.3. Monte Carlo-based Demand Forecasting Process for Charging Infrastructure

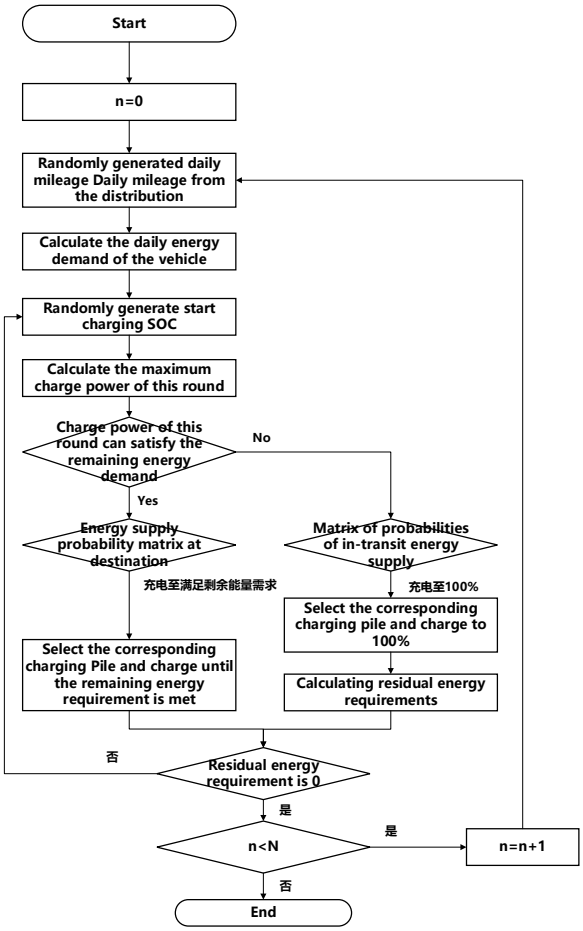


Figure 5. Energy demand forecast and allocation process for N simulated vehicles

The energy demand forecast and allocation process of the model applied in this study mainly applies Monte Carlo simulation, and the energy demand forecast and allocation process for N vehicles is shown in the figure below. The model carries out energy demand forecast and allocation vehicle by vehicle, based on the average daily mileage distribution of each type of vehicle, extracts the total mileage of the vehicle for one day, and combines the kilometre power consumption data of each type of vehicle to calculate the power demand of the vehicle for that day, and then carries out the allocation of the energy demand, and determines the state of the vehicle's charging power when it is charging by extracting the charging start SOC one by one, and then, based on the state of the power and the completion of the trip, invokes the corresponding user probability selection matrix for the of the charging pile selection, and the charging energy will be allocated to the corresponding charging pile, and continue to cycle this process until the energy demand of the day to meet all the energy demand, so that a simulation of the energy demand forecast and allocation process of the vehicle is completed, and continue to cycle the above process until the completion of all the vehicle simulation, you can get the energy demand level of various types of charging infrastructure in the future, By the application of the foregoing calculations and applying the daily energy supply

level of each charging pile, we can get the demand quantity of each type of charging pile, and can complete the charging infrastructure demand forecast for the whole country as well as key cities.

3. Analysis of China's Charging Infrastructure Development Market Size and Competition in Key Cities

3.1. National Charging Infrastructure Market Size Analysis

The charging infrastructure demand forecasting model proposed in this study is applied to forecast the level of development of the domestic charging infrastructure market. The national charging infrastructure market maintains a growth trend in the future, with total charging infrastructure ownership expected to be approximately 14,824,000 units in 2025, 43,079,000 units in 2030, and 82,439,000 units in 2035. From the point of view of the vehicle-to-pile ratio, the future of the domestic vehicle-to-pile ratio shows a slight decline followed by a stable trend, and it is expected that the vehicle-to-pile ratio is expected to reach 2.4 in 2035.

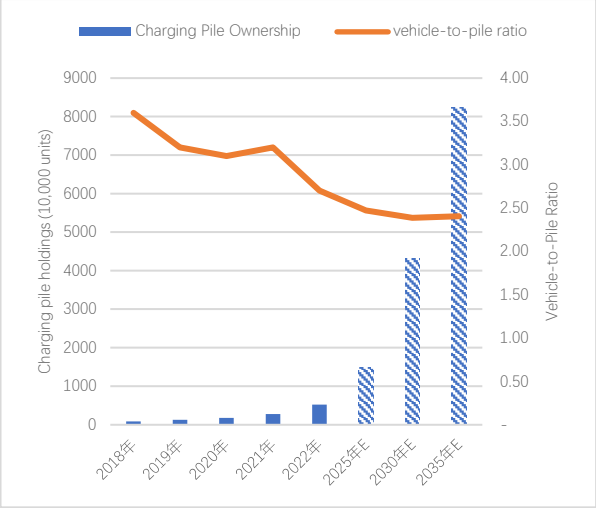


Figure 6. National charging infrastructure forecast results

Compared to the historical development trend, the next ten years or so, the degree of change in the national vehicle to pile ratio is small, but this does not mean that the charging infrastructure market has been developed to mature, the market space still exists, the trend is mainly related to the following reasons:

(1) China's early charging infrastructure construction is dominated by AC piles, its service capacity is relatively weak, the massive construction of AC piles also makes the early vehicle-to-pile ratio declined faster, however, with the maturity of DC charging technology and the pursuit of charging efficiency of users, the future part of the stock of public AC charging piles will be replaced by DC facilities, so the future of the charging infrastructure market will go through the structural upgrading and the full expansion of the market. The market space is reflected in the upgrading of stock facilities and the construction of new facilities.

(2) The charging infrastructure market has gone through the "horse race" stage of various operators, and the domestic charging infrastructure has been rapidly expanding, making the current vehicle-to-pile ratio reach a relatively low level, but the utilization rate of some of the stations is low, and there are difficulties in profitability. Charging operators are slowing down the pace of expansion, such as the State Grid of charging infrastructure construction assessment indicators will be changed from the number of facilities construction facilities charging volume, from the " quantity aimed" to "operation quality aimed" mode change. However, as operators pay more attention to the scientific layout of facilities and the quality of operations, the utilization of stations will gradually improve, and profitability will also improve at the same time. (3) The distribution and use of charging piles will be more scientific and reasonable with the future development of the industry. With the further clarification of the national policy, the construction of China's charging infrastructure network will gradually move towards high-quality development, and the charging infrastructure market will gradually mature and the level of the vehicle-to-pile ratio will be relatively stable in the period of 2030-2035.

3.2. Analysis of Charging Market Competition in Key Cities

Based on the model proposed in this study, we analyze the future development space of the public charging infrastructure market in China's first-tier and major new first-tier cities, and analyze the market competition of public charging infrastructure in each city, guide industry participants to understand the future market competition, and measure the market space. These analyses will provide reference for new players in the industry.

3.2.1. Beijing

Firstly, we analyze the current competition status of Beijing's public charging market. In recent years, fierce competition in Beijing makes the leading operating companies dominate the market. Although Telaidian and Xingxing Charging are still expanding their businesses at a high growth rate, but the market share of the top two operators continues to shrink. By 2022, the market share of the top two operators is less than 50%. Historical data shows that the growth rate of surplus charging market in Beijing is synchronized with the overall market development trend in Beijing, and the market surplus is expanding year by year.

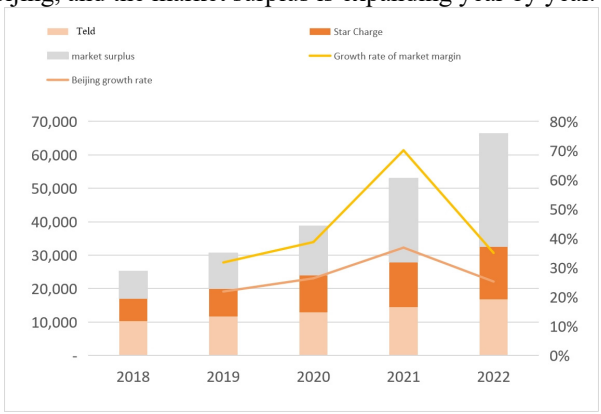


Figure 7. Competitive in Beijing's Public Charging Market

Based on the results of the prediction model proposed in this study, Beijing's public charging infrastructure will shift from high-speed to medium-low speed development in the future, and will continue to expand to reach 1.133 million units in 2025 and 2.308 million units in 2030, 3.25 million units in 2035. It is expected that the market space of leading companies will be squeezed out, and the development potential of Beijing's public charging infrastructure market is still huge. Assuming that the growth rate of the head space keeps pace with the total market size, the market margin of the Beijing market will be close to 80% in the future, with

huge development potential.

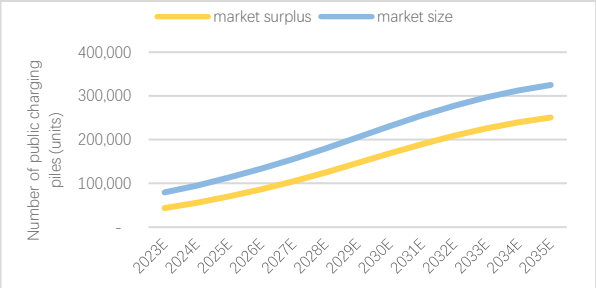


Figure 8. Beijing Public Charging Market Residual Forecast

3.2.2. Shanghai

Analysing the status quo of competition in Shanghai's public charging pile market, Shanghai presents a three-part pattern, with Teld, Star Charge and local operator SAIC Anyue occupying more than 60% of the market space, and each of the three operators basically occupying 20% of the market space in 2022. As a one-stop integrated service provider engaged in the investment, construction and operation of charging facilities for new energy vehicles under SAIC Group, SAIC Anyue has nearly 90% of its business concentrated in the Shanghai area, but its expansion speed is much slower than the future growth of demand in Shanghai, and even less than that of Teld and Star Charge, which provides market space for new competitors in the industry, such as Xiaoju Charge, CloudFastCharge and so on in recent years to quickly seize part of the space.

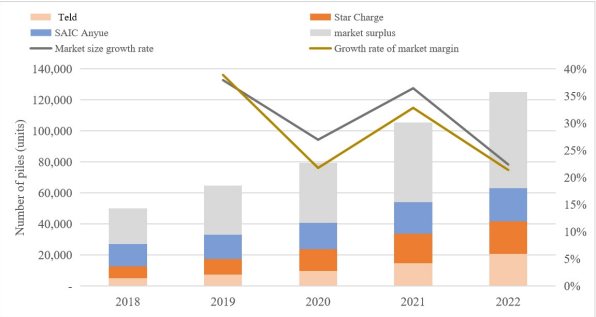


Figure 9. Competition in Shanghai's public charging market

From the forecast data, it can be seen that the current total supply of public piles in Shanghai is slightly oversupplied, which is strongly correlated with the competition of the head operators. The future market space in Shanghai is slowly expanding, and the CR3 is expected to shrink to about 40% by 2035, which means the market still has a large competitive space.

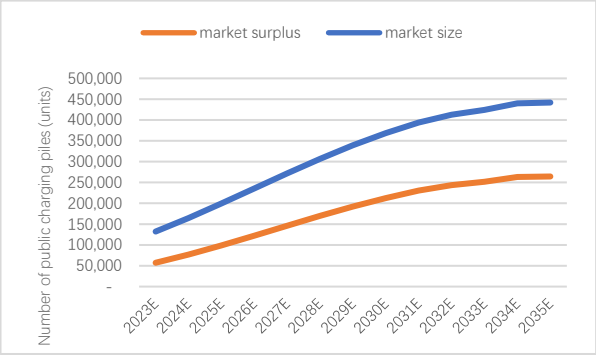


Figure 10. Shanghai Public Charging Market Residual Forecast

3.2.3. Guangzhou

From the current public charging market competition pattern, competition of public charging market in Guangzhou is more intense. Weijingyun, as a typical operator of the platform model, continued to keep in the top two. Although Star charging, and Teld are in the expansion, their market space is gradually squeezed. The Southern Power Grid, which is the national team in charging market, maintains a relatively stable market share. Xiaoju charge and the local operator WanchengWan Charge seem to catch up later, which achieved a breakthrough from zero to the top of the market.

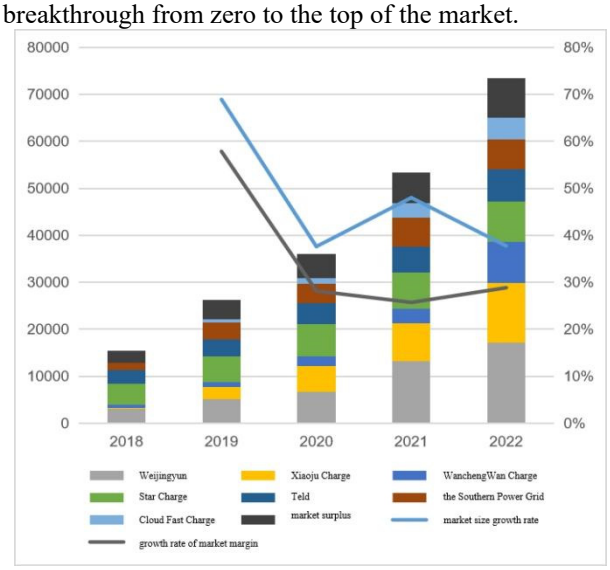


Figure 11. Status of competition in the public charging pile market in Guangzhou

From the forecast results, the fierce competition of the public charging market in Guangzhou has led to an oversupply of the market, which will put enormous pressure on new entrants, with the remaining market size expected to be less than 15%. New entrants must consider the operating effectiveness of the existing operators within the local market, and formulate their own strategies to enter this market with caution.

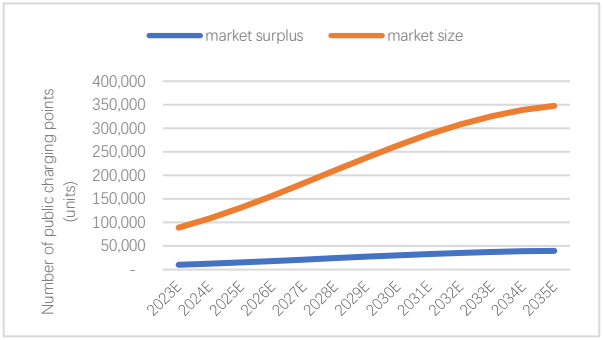


Figure 12. Forecast of Public Charging Market Residual Capacity in Guangzhou

3.2.4. Shenzhen

Similar to Guangzhou, the head competition in Shenzhen's public charging market is also very intense, local operators Hui Charge, Shenzhen Chedianwang and Weilan Fast Charge have been holding the leading position in the industry in the last 5 years, Teld has fluctuated its market share from 7% to 10% after its layout in recent years, and the market space of the Southern Power Grid has gradually shrunk from 26% (the first position in market share) in 2018 to less than 8% in2022, indicating that the competition among the head operators in Shenzhen has been very fierce in the past five years.

From the forecast results, Shenzhen's current market is oversupplied, which is inextricably linked to the fierce competition among the head operators. But from a structural point of view, the market is in urgent need of renewal in Shenzhen, where public DC piles account for less than 20% due to the early layout of the city. Going forward, with the

expansion of demand at the pile end, competition among head operators will continue, with little market headroom for new entrants, which is expected to reach more than 90% of the head market space by 2035. This puts tremendous pressure on new industry competitors, and new entrants will have to invest more resources to enter this local market.

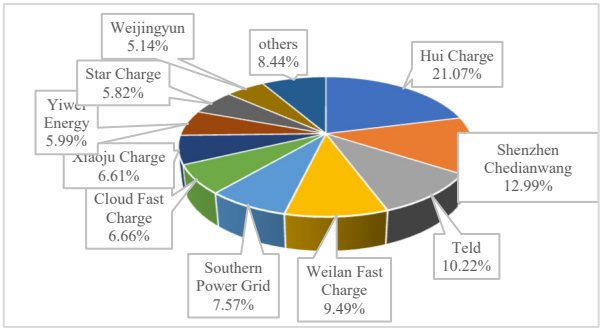


Figure 13. Competitive status of public charging pile market in Shenzhen

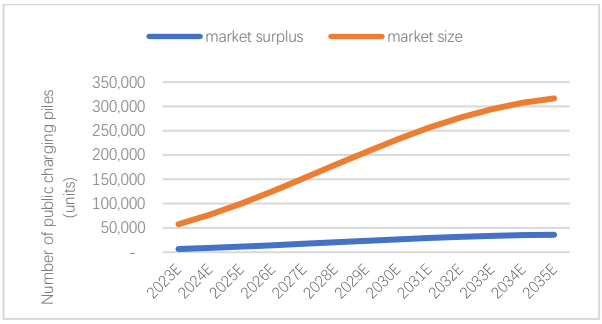


Figure 14. Forecast of Public Charging Market Residual Capacity in Shenzhen

3.2.5. Hangzhou

From the status of competition in the Hangzhou public charging market, Hangzhou's current market competition pattern is also focused on the head, Teld's market share has shrunk from close to 40% in 2018 to about 20% nowadays, whose expansion speed is not as fast as Star Charge, Xiaoju Charge and Cloud Fast Charge. Star Charge has achieved a 20-fold expansion of the market scale. Fierce competition among head has led to frequent changes in the industry landscape.

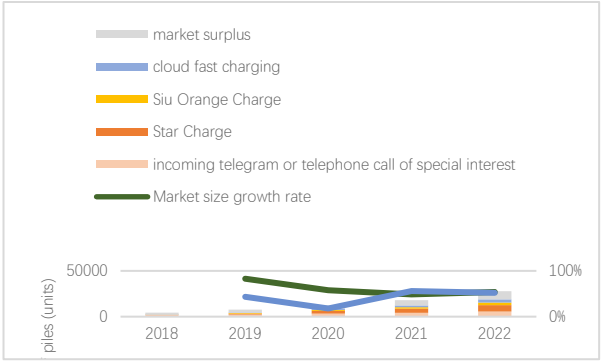


Figure 15. Current status of competition in the public charging pile market in Hangzhou

The forecast results show that the current market supply in Hangzhou is insufficient, which is one reason why the market landscape is still unstable. The head CPOs are accelerating their deployment, but still not as much as the growth in demand. In the future, competition among head CPOs will continue, with new entrants expanding along with the market margin, which is expected to be 45% by 2035.

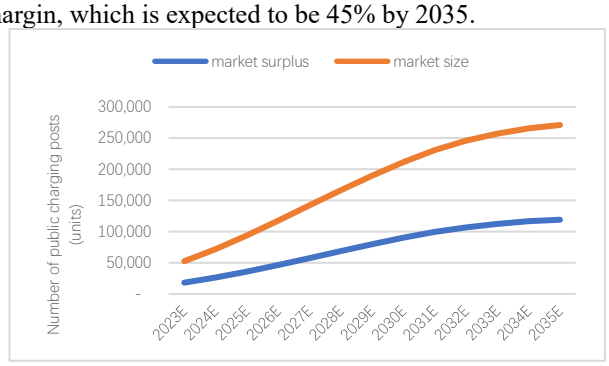


Figure 16. Forecast of Public Charging Market Residual Capacity in Hangzhou

3.2.6. Tianjin

The public charging market in Tianjin has a more obvious head effect, with the market share of Teld and Star Charge shrinking from over 90% to 70%, indicating that new competitors entering the industry have seized a portion of the market space, such as Xiaoju Charge and Cloud Fast Charge, etc., and the remaining market volume is showing an expansion trend.

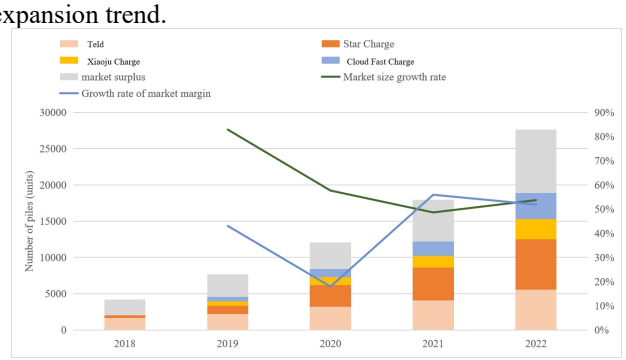


Figure 17. Status of competition in the public charging pile market in Tianjin

From the forecast results, the current supply of public charging market in Tianjin still fails to meet the demand. With the expanding charging demand in Tianjin, the head CPOs expand steadily. The market margin is gradually expanding, by 2035, CR2 is expected to shrink to 50%, new entrants in the industry still have the opportunity and space to take up the position.

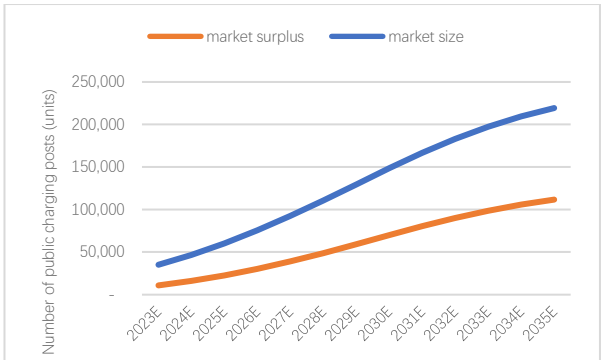


Figure 18. Tianjin Public Charging Pile Market Residual Forecast

In summary, key cities are divided into three categories based on their market entry difficulty, and their entry difficulty decreases in order (the more stars, the greater the difficulty). Results are shown in the table below. Overall, the future public charging market in key cities still has huge market potential, and new entrants should not only consider the external competitive environment, but also carefully formulate competitive strategies based on their own resource

advantages. For example, in Shenzhen, Guangzhou and other cities where competition is fierce, they can adopt differentiated strategies to cut into the market and seize market space based on a group company's resource advantages.

Table 2. Analysis of Difficulty of Market Entry for Public Charging Piles in Key Cities

Difficulty of market entry	Cities covered	Market characteristics
☆☆☆☆	Shenzhen, Guangzhou	Oversupply and Fierce Competition.
☆☆☆	Beijing, Shanghai	Slightly Oversupplied, Headline Congregation and Small and Medium-sized Operators Dispersed.
☆	Tianjin, Hangzhou	Unformed Pattern and Potential Market.

4. Summary

China's charging infrastructure industry has been developing rapidly in recent years, the market is changing fast and there are certain differences in various regions. In order to further respond to the State Council's policy requirements for high-quality development, industry participants need to grasp the development trend in the future, to identify regional differences effectively in the market among different business models, and to formulate a reasonable business development planning. At present, the industry's forecast for the scale of charging infrastructure is mainly micro-level, lacking the overall development scale of the country's prediction and inter-regional comparative analysis. We analyse the current situation of the domestic development and propose a charging infrastructure forecasting model, and forecast the scale of public charging infrastructure development in the country as well as the first-tier and the new first-tier key cities. In addition, we also analyse in-depth the current status of the competitive landscape in each key city as well as the future market margin space, providing business decision-making references for new players in the industry. The key findings of this study are as follows:

(1) China's charging infrastructure will continue to grow in the future, it is expected that the total amount of charging infrastructure will reach more than 80 million units in 2035. The vehicle-to-pile ratio will reach about 2.4, which will first decline and then gradually stabilise. These indicate that China's charging infrastructure market will be transformed from the past barbaric growth to high-quality, high-level development.

(2) At present, there are differences in the competition in the public charging infrastructure market among first-tier and new first-tier cities, which can be divided into three categories. a) The market competition in high-level development cities represented by Guangzhou and Shenzhen is extremely fierce, with the head CPOs basically occupying the market, and there is very little market space; b) Beijing and Shanghai show a slightly oversupplied state, with the head CPOs gathering and the small and medium-sized CPOs dispersing, and the market competition is relatively fierce; c) Tianjin and Hangzhou, represented by new first-tier cities, have relatively little competitive pressure. The market will still be in the stage of rapid development, the remaining space is optimistic.

The prediction model in this paper can effectively support city-level charging infrastructure demand forecasts. In the future, with the further construction of the high-quality development charging network, local government will also pay more attention to scientific and effective layout of the charging infrastructure. The results of this research can be used to assess the market margin space for the charging industry participants, as well as be used as the input data for the charging infrastructure planning and layout model to help the future high-quality development of urban charging infrastructure industry.

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