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Study on the Spatial Distribution and Utilization of Electric Vehicle Charging Stations in Guangzhou from the Perspective of Fairness

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Abstract. Driven by the global energy structure transformation and the “dual carbon” goals, the new energy vehicle industry and related industries have witnessed explosive growth. The charging station industry, as one of the cores supporting industries, holds significant research value. And Guangzhou, which has a rapidly growing market, has high representativeness and research significance. This research conducts a quantitative and qualitative study on spatial and usage equity of EV chargers in Guangzhou, employing spatial analysis methods such as Moran’s I for clustering detection to identify key influencing factors, evaluating usage fairness through Theil index decomposition. This study reveals that the current distribution of charging stations in Guangzhou exhibits significant spatial heterogeneity, and the matching between resources and population density is insufficient. These findings offer data-driven recommendations for optimizing EV infrastructure planning and promoting equitable urban mobility.

Keywords: EV charging station, fair, spatial distribution, usage

1. Introduction

In the context of deterioration of the environmental conditions in many cities, people's environmental awareness is gradually increasing. Scholars have proposed the concept of “green cities” in response to issues such as the greenhouse effect and energy consumption. This means that during the process of urban development, people should also attach importance to the city's ecology and sustainable development, construction should adopt environmentally friendly materials and renewable energy technologies [1], public transportation and pedestrian systems should be developed, exhaust emissions should be reduced, parks and green spaces should be increased, and ecological spaces should be created, fundamentally change people's environmental protection concepts and the way energy is used and consumed. Ultimately, the city's sustainable development can be achieved, and a harmonious coexistence between humans and nature can be realized [1-3],

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which precisely aligns with the characteristics of electric vehicles, with zero emissions and higher accessibility, combined with the big data and AI technologies [4].

The widespread adoption of electric vehicles (EVs) represents the direction and goal that society is striving for in order to achieve sustainable development [5]. In recent years, China's new energy vehicles and electric vehicles have developed rapidly. According to China Association of Automobile Manufacturers (CAAM), electric vehicles have a very broad and continuously growing market demand, with the monthly sales exceed 500,000 units, and even some reached 1,000,000 units this year [6]. This continuously increasing demand for electric vehicles makes rational layout of electric vehicle charging stations and the improvement of their utilization efficiency have become extremely important, since the uneven distribution of electric vehicles will lead to overloading or vacancy at some charging stations, and at the same time affect the usage situation of end-users [7].

When talked about the usage efficiency of EV charging stations, several studies have adopted charging data and experiments to explore the usage time of charging piles and people's charging behaviors. Scholars have found out that approximately 70% of the EVs are charged per day and a number of EVs are charged before and after working hours, while there's no significant differences between the start charging time between weekdays and weekends and also between different seasons [8]. Furthermore, the recent studies have included multiple charging events, the first EV charging may occur any time during the day, as the second is more likely to happen after midday [9]. Chen et al. made researches on four main types of charging point locations, workplace, domestic, pulic car park and on-street parking, where the usage time varies but usually all of them experience morning peak, suggesting a large number of charging piles are used by commuters [10].

Regarding the distribution of the charging stations, most of the existing studies focus on the economic reasons, market demand [5], power quality [11] and other factors' impact on the distribution of electric vehicle charging stations. However, there are few studies that analyze from the perspective of geographical location and geographical factors. Moreover, there is limited research on the contribution of the optimization and improvement of the distribution of electric vehicle charging stations to urban fairness. Therefore, our study aims to explore the spatial distribution and utilization of EV charging stations from a spatial equity perspective.

The research purpose of the paper is to explore whether the current allocation of electric vehicle charging stations in Guangzhou is fair, in terms of spatial distribution and utilization efficiency. Regarding spatial distribution fairness, there will be a comparison between the population density and the distribution of electric vehicle charging stations, in order to determine whether the location and quantity of the charging stations are appropriate. Also, the analysis of the characteristics of the current spatial distribution of charging stations based on the obtained data, as well as the influencing factors of the distribution will be discussed in this paper. When it comes to usage eficiency, there will be an evaluation on the usage time and whether there are any overloading or idle charging stations, using the results to assess their efficiency.

This paper is expected to uncover the spatial logic behind low utilization, expose the potential mismatch between "equitable construction" and "equitable usage," and provide theoretical support and practical recommendations for the optimized siting and allocation of EV charging infrastructure, as well as several suggestions for policy and industry development. Ultimately, the study aims to promote both maximum efficiency and fair access in the development of urban charging facilities, and effectively benefiting people's lives.

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2. Data collection

In this section, the paper will discuss the types of data that are have been required for the research, the techniques that are used to obtain the data, and the sources of the data, there will also be an explanation of why this type of data was obtained and why this particular method was chosen for data acquisition.

The required data, which are about the locations, quantities and usage times of electric vehicle charging stations among one week, in Guangzhou City. The data are sourced from popular domestic mapping and navigation softwares, which are Baidu Maps and Gaode Maps, through their data scraping processes.

The reason why this type of data is suitable for this research is to directly serve the research questions. In terms of exploring the fairness of spatial distribution, this essay aims to compare and match the data on the locations and quantities of charging stations with the data on population density. As part of urban infrastructure and public services, the electric vehicle charging network should follow the principle of inclusiveness. By comparing the distribution of charging stations with population density, it is possible to directly assess whether the public service resources are matched with the distribution of residents. Analyzing whether the residents live in the central urban area or remote areas, can relatively equally access the necessary charging services.

The data of usage time will be used to analyze the efficiency of electric vehicle charging stations, assess whether there is a large-scale idle or overloaded situation of charging stations, and thereby analyze the fairness of the usage of EV charging stations. This shifts the discussion of fairness from “Do we provide facilities for everyone?” to “Are the facilities we offer truly and equally serving everyone?”, which is a more practical and policy-relevant research direction.

Furthermore, the collected data lasted a period of one week because this duration is a complete cycle of social activities, which naturally contains both the working days and weekends, two completely different behavioral patterns. During working days, by analyzing the charging patterns centered around "commuting", one can observe the charging demands during the morning rush hour (before going to work) and the evening rush hour (after work), as well as the relatively stable charging behaviors of commercial operation vehicles (such as ride-hailing services and taxis) during the day. On weekends, charging periods may be more scattered, the average charging time may be longer (combined with shopping and leisure activities), and there may be peak charging periods at high-speed service areas due to travel.

In addition, the data for a week is sufficient to support the research for statistical analysis, enabling the identification of peak and trough values, providing enough details to calculate relevant indicators. For a research, processing a week's worth of data is relatively feasible in terms of computing resources, data cleaning, and time costs. If one chooses data for a month or a year, the complexity of data processing will increase significantly, potentially exceeding the initial scope of the project.

Regarding why choosing to obtain data from map apps instead of applying to the government or relevant departments for data, the primary reason is the convenience of obtaining the data. Some data may take a long time to be approved. Secondly, with the advanced level of map software, it is capable of integrating data from multiple electric vehicle charging station operators. This means that the data is already integrated, handy to use, and the data on the map apps are updated very frequently. Based on the real-time data provided by the operators, this essay can learn about the usage of electric vehicle charging stations in the recent period, so that the data we applied will not have a significant lag.

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3. Data analysis methods

Overall, this research will adopt a combination of qualitative and quantitative methods. Quantitative research can conduct intuitive analysis of data and match charging stations with the population through GIS maps, objectively revealing the fairness of charging stations. However, this method cannot identify the underlying reasons, whether due to costs or limitations of the power grid, etc. The inclusion of qualitative research can supplement the reasons behind the research results. Through on-site investigations, one can more realistically perceive the advantages and disadvantages of the charging station layout, and add context to the data, thereby revealing the social and economic factors behind the data at a deeper level.

3.1. Spatial distribution characteristics and fairness

In this section, the essay will discuss the spatial distribution characteristics and fairness of electric vehicle charging stations in Guangzhou, making an analysis of the characteristics of the current spatial distribution of charging stations based on the obtained data, as well as the influencing factors of the distribution.

3.1.1. Spatial distribution pattern

The first step is to analyze the distribution pattern of electric vehicle charging stations in Guangzhou based on the obtained data, using GIS to create a distribution map and explore whether there are any clustering characteristics. GIS visualization can directly present the abstract charging station locations on the map in an intuitive manner, facilitating the overlay with maps of factors such as population density and road networks in the later stage. However, merely observing the distribution map with the naked eye cannot determine its significant situation, nor can it determine whether it is randomly formed or shows a clustered distribution.

In order to further analyze the patterns of spatial distribution, the study will conduct spatial autocorrelation analysis and kernel density analysis, calculate the Moran's I index, and identify the spatial distribution pattern. Spatial autocorrelation analysis and the calculation of Moran's index provide the basis for judgment, quantifying the distribution of charging stations in Guangzhou as being aggregated, dispersed, or randomly distributed. At the same time, it can also calculate the p-value to prove its significance, providing an objective answer for the distribution pattern [12] . Thirdly, combined with density analysis, it can visualize the concentrated areas, intuitively showing the core areas with high density of charging station distribution, and also presenting the influence range of each hotspot. Through the combined application of these methods, they can mutually confirm, scientifically revealing the spatial distribution pattern of charging stations, laying a good foundation for exploring the reasons for their distribution.

3.1.2. Spatial distribution influencing factors

Based on the existing research, this article has identified several factors that have a significant impact on the distribution of electric vehicle charging stations, which are population density, accessibility, land use, road network density, GDP and POI. On the demand side, the population density and POI factors are selected to reflect the users' demands. On the supply side, GDP represents the investment and consumption capacity of the region. In terms of infrastructure conditions, the road network density and accessibility can reflect the convenience of using charging stations. The selection of these factors makes this research more scientific.

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Next, the research will use the Geographically Weighted Regression (GWR) method to study the impact of these variables on the spatial distribution of charging piles. This method can calculate the regression coefficients for each geographical location (such as each street or grid), rather than a global average result, revealing the imbalance of space and plays an important role in precise decision-making and improvement [13] .

In this part it will also be a multiple collinearity tests on the variables to avoid collinearity, this step can eliminate the mutual influence among variables. By examining the relevant values such as VIF, it is possible to identify and eliminate the variables that have significant mutual influence, thereby enhancing the credibility of the results.

Finally, the essay will test the values of standardized residuals (StdResidual), evaluating the degree of fit and avoid omitting any important variable, thereby summarizing the main distribution pattern and the influencing factors hidden behind it.

3.2. Usage and fairness

In this section, there will be the analysis of changing characteristics of the usage rate of charging stations, and will analyze their distribution patterns based on key time points. Through grouping and regional classification, there will be analysis of the main reasons that affecting their usage.

3.2.1. Usage rate change characteristics

Firstly, this article will study the temporal variation characteristics of charging station usage rates, exploring the charging frequency during weekdays and weekends, and roughly analyze the influencing factors of the unevenness in usage rates over time. Next, based on the obtained charging changes, this research will select some typical time points and typical charging station cases, such as peak charging periods and low charging periods for further study.

3.2.2. Evaluate the degree of imbalance usage

In this part, the initial plan of this study was to use the Gini coefficient to analyze the imbalance rates of the entire Guangzhou city and each district, which provides an intuitive and comparable macroscopic criterion. This conclusion is easy to understand and convenient for comparison between cities or among different streets. However, the Gini coefficient can tell people “how severe the imbalance is”, but it cannot answer “where this imbalance comes from” [14] . This is why in this stage, the Theil index will be introduced to precisely decompose the overall imbalance into “inter-regional imbalance” and “intra-regional imbalance”.

When introducing the Theil Index, this essay will firstly group the various charging piles according to the corresponding streets, and calculate the Theil Index within each group as well as the Theil Index within each region. This can assess whether the imbalance mainly comes from within the regions or between the regions, and determine the impact of the internal structure of the city on the fairness of charging pile usage [15] . If the imbalance mainly comes from the regions themselves, it indicates that the problem is of a macro strategic nature, and the root cause lies in the uneven resource allocation across regions, development policy bias, or economic disparity. If the imbalance mainly comes from within each region (for example, the differences between the core streets and the peripheral streets within each region are significant), this suggests that the problem is of a micro layout nature, and the root cause lies in the implementation of planning within each

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region, the selection of sites, or community-level management issues, which can provide important basis for subsequent distribution and operation adjustments of charging piles.

3.3. Comprehensive evaluation

After separately analyzing the distribution fairness and usage fairness of electric vehicle charging stations, this study will conduct a comprehensive construction of an evaluation model. It will take into account all the influencing factors and fairness characteristics that affect the spatial distribution and usage of charging stations, and verify the significance of fairness variables in explaining the usage rate.

There will be a comprehensive evaluation model, using SPSS to provide preliminary, global average estimates of the influencing factors, but it may be biased due to the neglect of spatial effects. The use of charging stations is essentially a spatial behavior, which inevitably involves spatial dependence and heterogeneity. Revealing how the strength of each influencing factor changes with geographical location will also make the conclusion more scientific.

In the selection of independent variables and dependent variables, this study incorporated spatial characteristics, usage conditions, and fairness variables together to construct a complete explanatory framework of “supply-demand-fairness”. The specific variables are shown in Table 1. Finally, this essay will verify the significance of fairness variables in usage rates, eventually ranking the facors according to the model.

Table 1. Independent variable and dependent variable

Variable	Type of Variable	Specific Name of Variable		
Independent Variable	Spatial Characteristics	Charging Station Density	Land Use	Road Network
	Usage Conditions	Population Density	Income	Price
	Equity Variables	Accessibility Index		
Dependent Variable		Average Utilization Rate		

3.4. Qualitative method

Apart from the quantitative research proposed before, this research will also integrate qualitative research methods to investigate the usage characteristics of charging stations in four typical scenarios, including residential area, work area, commercial area and transportation hub, conducting a detailed analysis of their usage situations.

This qualitative analysis can explain the results of the previous quantitative analysis and provide vivid contextual explanations for spatial models and statistical outcomes. The residential area is the primary parking location for vehicles. After a day's work, charging at night is a necessary requirement for people, and it can most directly reflect the current situation of charging and people's needs. The work area is where vehicles stay for a long time during the day. Daytime charging is the key to optimizing energy replenishment. For the commercial area, charging is more like an additional component of the consumption experience. The demand is characterized by its variability and elasticity, which can reveal the role and limitations of the market in driving the development of the charging network. Finally, transportation hubs are important locations for long-distance travel, where charging is highly uncertain. By combining these four scenarios, it is possible to cover the most important charging locations in life and provide precise and comprehensive solutions based on the characteristics of each location.

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4. Test results and analysis

In this chapter, the analysis will be conducted based on the data analysis methods mentioned earlier. The results of the analysis will be clarified and presented in the form of charts and tables. Additionally, the analysis results will be interpreted, examining the spatial distribution fairness and usage fairness of electric vehicle charging stations in Guangzhou.

4.1. Spatial distribution characteristics and fairness

4.1.1. Spatial distribution pattern

Based on the analysis method mentioned earlier, in this section, the research will firstly analyze the distribution characteristics by creating a distribution map, using GIS. The total number of charging stations in Guangzhou is 5144, and the total number of charging ports for new energy vehicles is 47,500. Among them, 1,891 (38%) stations have no charging data. This research will only analyze the charging stations that have charging data. The amount and spatial distribution of charging stations in Guangzhou are shown in Figure 1. As can be seen from the graph, the charging stations are mainly located in the core area of Guangzhou.

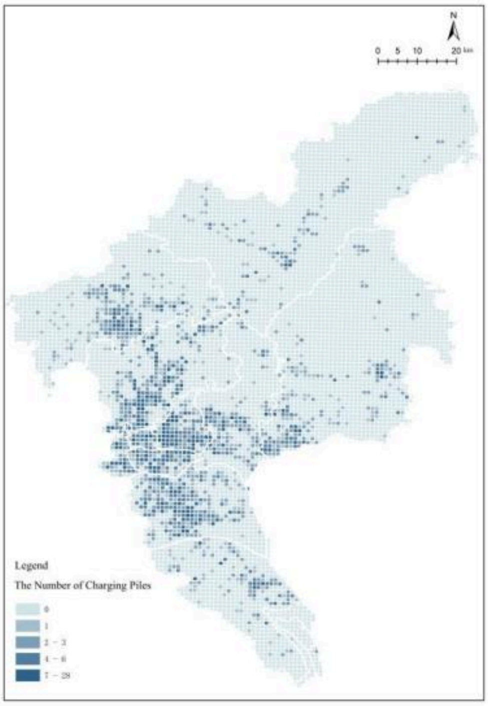

Figure 1. Charging station spatial distribution map

In the spatial autocorrelation analysis and kernel density analysis, Figure 2 shows the spatial distribution clustering map of charging stations in Guangzhou, calculated using the Anselin Local Moran's I algorithm. The meanings of each cluster are shown in Table 1. As it can be seen from the graph, the distribution of charging stations in Guangzhou exhibits significant spatial heterogeneity, and the central urban area of Guangzhou and the core areas of each district are high-density zones, while there are scattered low-density clusters in the northern parts of Zengcheng, Conghua, and Huadu, with the remaining areas lack charging resources.

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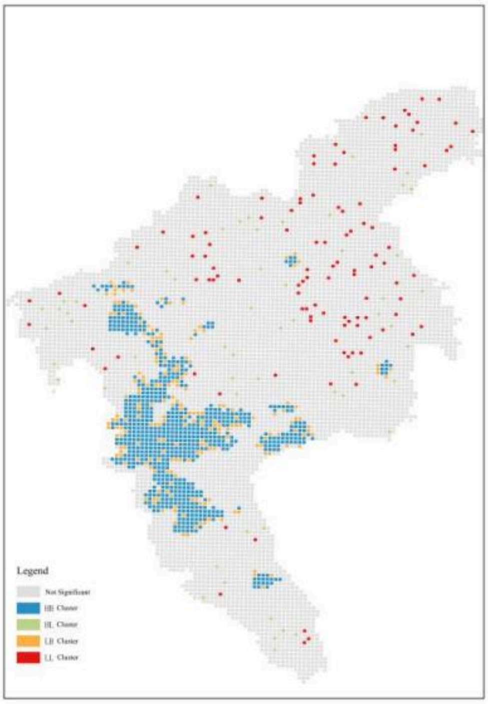

Figure 2. Cluster map of charging station spatial distribution

Table 2. Legend explanation

Type	Meaning
HH	This position is a high value, and the surrounding area is also a high value, that is, high-high clustering
HL	This position is a high value, but the surrounding area is a low value, that is, high-low clustering
LH	This position is a low value, but the surrounding area is a high value, that is, low-high clustering
LL	This position is a low value, and the surrounding areas are also low values, that is, low-low clustering
non- significant	no significant features

4.1.2. Spatial distribution influencing factors

When analyzing the reasons for the distribution of electric vehicle charging stations, this part took the following factors into account, which are population density, accessibility, land use, road network density, GDP and POI, as these factors can reflect the users' demands, investment and consumption capacity and others that play an important role in distribution.

In the multiple collinearity tests on the variables (Table 3), the VIF results are smaller than 7.5, means that there's no collinearity between these variables and can be included in the model simultaneously. What's more, the significance values are all greater than or equal to 75%, indicating that the variables have a relatively significant impact on the distribution of charging stations. This proves that the selection of influencing factors is correct, and the next step of analysis can be carried out.

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Table 3. Variable significance and conflict detection

Variable	VIF	Conflict	Significance	Negative	Positive
Population	1.44	0	100%	0%	100%
Accessibility	1.45	0	100%	100%	0%
Construction Land	1.81	0	75%	50%	50%
GDP	1.39	0	100%	0%	100%
POI	1.79	0	100%	0%	100%
Road Network Density	1.65	0	75%	50%	50%

In the Geographically Weighted Regression (GWR) method, according to table 3 and table 4, population density, POI density, GDP, and road network density show positive driving effects. Population density and POI density have a highly significant positive correlation with the distribution of charging stations, revealing the importance of demand orientation in the distribution of charging stations. GDP, as an important economic factor, proves the significance of market and investment capabilities in the allocation of charging station resources. This also matches the distribution characteristics, where most charging stations are located in core areas, and economically developed regions have stronger investment capabilities and payment capabilities. The positive correlation of road network density can help users reach charging stations more conveniently and also reduces the difficulty of maintenance. Therefore, these four factors have a very strong positive driving ability.

In addition to the positive influencing factors, this study also found that accessibility and the density of construction land showed a negative correlation in the distribution of electric vehicle charging stations. This might indicate that the distribution of charging stations shows a relatively concentrated pattern: After the charging stations in the central areas are well-established, the charging resources in the less accessible areas will increase. Regarding the density of construction land, in the core areas of the city, it may be constrained by high land prices and intense competition, which hinders the construction of large-scale charging stations, resulting in a negative correlation.

Next, in the analysis of the model's steady state, the adjusted R-squared of all models ranged from 0.47 to 0.62, the Koenker's p-value of all models were all 0, and the VIF values of all variables were all much lower than the recommended threshold of 7.5, indicating that the models have a good degree of fit, there is almost no multicollinearity problem among the variables, and they have strong stability and reliability.

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Table 4. Exploratory regression indicators

AdjR²	K(BP)	VIF	Model
0.50	0	1	+POI***
0.55	0	1	+Population***
0.54	0	1	+GDP***
0.47	0	1	+road network density***
0.62	0	1.81	+Population*** -Accessibility*** -Construction Land** +GDP*** +POI*** +Road Network Density**

Notes: This table takes each indicator as the independent variable and the distribution of charging station locations as the dependent variable. It studies the model fitting degree and steady state under the conditions of each indicator being considered individually and in combination, ensuring the rationality of indicator selection.

Table 5. Interpretation of exploratory regression indicators

Abbreviation	Full Name	Recommended Value	Meanings
AdjR²	Adjusted R-squared	>0.5	Fitting Degree
K(BP)	Koenker's p-value	<0.05	Model Steady State
VIF	Maximum Variance Factor	<7.5	Variable Collinearity
Model	Variable Symbol(+/-)	\	Positive and Negative Effects
Model	Variable Significance(*)	\	Variable Significance

4.2. Usage and fairness

4.2.1. Usage rate change characteristics

This study investigated the usage rates of five types of charging stations. The usage rate of charging piles shows periodic changes within 24 hours, and the overall usage trends on weekdays and weekends are similar. The peak usage times are 00:30, 08:00, and 12:30, while the low points mainly occur during the time periods of 10:00-11:00 and 14:30-18:00.

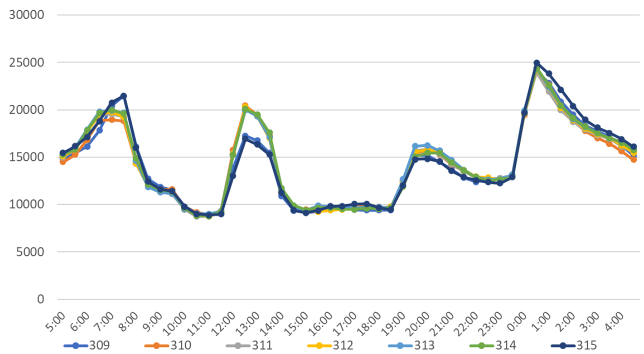

Figure 3. Usage rate characteristics

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4.2.2. Degree of imbalance usage

In the study of fairness, this research employs the Theil index and its decomposition method, combining both demographic and economic perspectives to quantitatively evaluate the fairness of charging pile distribution across 12 administrative districts of Guangzhou. Based on the number of charging piles, permanent population, and GDP data covering 112 sub-districts, the study identifies the sources of unfairness in charging pile allocation.

Using the number of charging piles, population, and GDP data at the street level (covering 112 sub-districts of Guangzhou), a weighted Theil index model was applied to quantify distributional fairness:

$$T = \sum_{i=1}^{n} s_i \bullet \ln \frac{s_i}{q_i}$$

where s_i is the share of charging piles in the region, and q_i is the share of population or GDP. By decomposing the total index into inter-group differences (between districts) and intra-group differences (within districts), the main sources of unfairness are identified. The total index can be expressed as:

$$T = T_{between} + T_{within}$$

Here, $T_{between}$ reflects inter-district differences, while T_{within} represents intra-district balance. The contribution rate of each component indicates the primary drivers of unfairness.

$$C_{between} = \frac{T_{between}}{T} \times 100\%$$

The analysis results are presented in the following three tables.

Table 6. Comprehensive theil index and contribution rate

Weight Type	Total Theil Index	Inter-group Theil Index	Intra-group Theil Index	Inter-group Contribution (%)	Intra-group Contribution (%)
Population	1.77	0.051	1.72	2.88	97.12
GDP	0.522	0.289	0.231	55.36	44.12

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Table 7. Theil index and contribution rates (population weighting)

District	Charging Pile Share (%)	Population Share (%)	Between-group Contrib.	Within-group Contrib.	Total Contrib.	Contribution Rate (%)
Conghua	2.45	3.84	-0.011	0.077	0.066	3.75
Nansha	2.59	2.53	0.00063	0.003	0.004	0.21
Zengcheng	7.44	7.85	-0.004	0.010	0.006	0.33
Tianhe	13.12	12.00	0.012	0.374	0.386	21.81
Haizhu	6.81	9.36	-0.022	0.434	0.412	23.30
Panyu	19.53	16.24	0.036	0.515	0.551	31.12
Baiyun	26.82	20.04	0.078	0.058	0.136	7.67
Huadu	8.43	8.79	-0.004	0.017	0.013	0.76
Liwan	4.63	6.63	-0.017	0.035	0.018	1.01
Luogang	3.57	2.77	0.009	0.087	0.096	5.40
Yuexiu	1.43	5.94	-0.020	0.030	0.010	0.55
Huangpu	3.19	4.00	-0.007	0.080	0.073	4.10

Table 8. Theil index and contribution rates (GDP weighting)

District	Charging Pile Share (%)	GDP Share (%)	Between-group Contrib.	Within-group Contrib.	Total Contrib.	Contribution Rate (%)
Conghua	2.45	1.51	0.012	0.004	0.016	3.09
Nansha	2.59	4.35	-0.013	0.006	-0.007	-1.43
Zengcheng	7.44	4.41	0.039	0.009	0.048	9.10
Tianhe	13.12	21.90	-0.067	0.074	0.006	1.24
Haizhu	6.81	8.06	-0.011	-0.017	-0.029	-5.48
Panyu	19.53	11.36	0.106	0.037	0.143	27.42
Baiyun	26.82	9.15	0.288	0.071	0.359	68.73
Huadu	8.43	6.67	0.020	0.003	0.023	4.39
Liwan	4.63	4.70	-0.00068	0.034	0.034	6.44
Luogang	3.57	8.49	-0.031	0.008	-0.022	-4.30
Yuexiu	1.43	13.53	-0.032	-0.005	-0.037	-7.02
Huangpu	3.19	5.87	-0.019	0.005	-0.014	-2.68

The study found that the total Theil index for the population dimension reached as high as 1.77, indicating severe inequity, with 97.12% of the inequality originating from intra-district disparities. This imbalance is especially pronounced at the street level: for instance, in Yuexiu District, Guangwei Sub-district has only 0.09 charging piles per 10,000 residents, whereas Dengfeng Sub-district has 1.02 per 10,000 residents. In Baiyun District, the gap between Jingxi Sub-district (0.02 piles/10,000 residents) and Junhe Sub-district (7.08 piles/10,000 residents) is a staggering 354-fold difference, reflecting extreme fragmentation of resource allocation in emerging districts.

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From the economic perspective, the total Theil index decreased to 0.52, but the contribution of inter-district differences rose to 55.36%, revealing a strong correlation between resource allocation and economic activity. Notably, Baiyun District's share of charging piles (26.82%) is nearly twice its GDP share (9.15%). In Renhe Town of Baiyun District, there are 8.81 charging piles per 100 million RMB of GDP, far exceeding Yunpu Sub-district in Huangpu District (0.5 piles/100 million RMB GDP). This "low economy–high resources" characteristic accounts for 68.73% of total inequality.

In contrast, Yuexiu District accounts for 13.53% of GDP but only 1.43% of charging piles; remarkably, Beijing Sub-district, a core business area, has no charging piles at all. Panyu District provides a positive case: in Nancun Town, there are 5.04 charging piles per 100 million RMB GDP, achieving a relatively good match between infrastructure and economic vitality.

The findings demonstrate that current charging pile allocation shows significant spatial heterogeneity. Inequity at the population dimension far exceeds that at the economic dimension, reflecting insufficient alignment of resources with population density. At the economic dimension, inter-district disparities contribute 55.36%, highlighting the strong influence of regional economic development levels on charging infrastructure deployment.

4.3. Comprehensive evaluation

The above study has calculated the distribution and usage efficiency of electric vehicle charging stations in various areas of Guangzhou from the perspective of geographic element distribution. The next step of the research will involve inputting the collected charging station pricing data and average market prices into SPSS for descriptive statistics and comparative analysis, in order to conduct a comprehensive evaluation.

Table 9. SPSS analysis result

Statistic	Value
N	246,864
Range	3.00
Minimum	0.00
Maximum	3.00
Mean	0.6154
Std. Error of Mean	0.00091
Std. Deviation	0.45460
Variance	0.207
Skewness	0.465
Std. Error of Skewness	0.005
Kurtosis	0.309
Std. Error of Kurtosis	0.010
Valid N (listwise)	246,864

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Table 10. One-way anova

Statistic	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9016.874	0.801	11.257	225.378	.000
Within Groups	12290.156	246,062	.050	/	/
Total	21307.030	246,863	/	/	/

From the analysis results, it can be seen that the specific current prices of each charging pile conform to a normal distribution pattern (with skewness close to 0 and kurtosis close to 3), indicating that most charging piles in Guangzhou are priced at a median level, with fewer low-priced and high-priced charging piles. Next, we will conduct a variance analysis between the current price and the market price, and the results are as follows. From the analysis results, we can see that there are significant differences between the actual price of each charging pile and the market guidance price at that time, so the price setting of some charging piles may be unfair.

In summary, after obtaining the impact weights of the seven major influencing factors—per capita GDP, number of charging stations, POIs, accessibility, charging station density, road network density, and construction land area (ranked in descending order from high to low)—and the conclusion that there is heterogeneity in the efficiency and fairness of electric vehicle charging station usage in Guangzhou, the total relationship among charging station utilization rate can be summarized as: the Land Constraints indirectly influence the Demand-Side Regulation and direct constraint the Supply-Side Dominance, while the Demand-Side Regulation gives a feedback regulation to the Supply-Side Dominance.

What's more, this study only collected data on the usage and distribution of electric vehicle charging stations in Guangzhou, and whether the research results have general guiding significance remains to be discussed.

5. Qualitative method

This section focuses on four typical scenarios of charging station usage: residential areas, working areas, commercial areas, and transportation hubs. Through on-site investigations and data collection, the study examines the user groups, usage characteristics, and usage patterns during different time periods.

5.1. Residential areas

Among the several residential areas surveyed in the field, the charging stations in these areas are often located together with parking lots, electric bike charging cabinets, etc., and are integrated with the retail commercial layout in the surrounding areas. Also, the electricity price and service fee for charging stations reach their lowest point during the night, while the charging volume peaks.

This might be the reason why many people say that charging at night is more convenient. Because it won't interfere with daytime travel or commuting, and it also allows for nearby consumption, bringing a steady stream of night-time customers to the nearby stores. At the same time, coordinating with the retail business for layout can also facilitate the charging of vehicles for the lower-level merchants, thereby driving the demand for goods purchases and other activities.

In addition, the charging stations in old residential areas are mainly slow-charging stations, and the facilities are relatively insufficient, resulting in queues. In such situations, the owners of electric vehicles have different charging requirements [16] , so private charging stations have emerged, and

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they gain a high popularity, which make them compete with the public charging stations located near the residential areas.

5.2. Work areas

In this section, this study investigated the situation of charging stations near the company. The charging stations in the work areas are facing regional supply-demand imbalances. In some high-density office areas, there is a queueing phenomenon at the charging stations. Meanwhile, some newly-built parks have a relatively high idle rate. This is because the initial planning of the newly-built parks was overly advanced, but the formation of industries and the cultivation of popularity take time, resulting in a lag in demand.

The commuting distance of employees is a key factor determining the charging demand [17] , and this demand varies significantly over time, mainly concentrated during lunch breaks and after work hours, which poses extremely high requirements for charging power and operational strategies. Therefore, the work area is mainly equipped with fast charging stations to meet the demand for efficient energy replenishment.

5.3. Commercial areas

For commercial areas, there is a high demand for electric vehicle charging. During consumers' shopping and other stay periods, they have the need for charging. The research data confirm that the idle time during charging periods in commercial establishments is less than 5 minutes in most cases [18] , demonstrating the significant demand for charging. However, the average duration of their stays is relatively short, so super charging stations and fast charging stations are more widely adopted in commercial areas, and the competition is quite intense, resulting in a higher variety of charging station brands compared to other scenarios.

In addition, during the research, it was also discovered that since the charging vehicle owners stay in the shopping mall during charging, apart from the charging service, the charging stations have also developed related services such as parking fees, car rental, and car washing, which have increased the value per customer and brought more profits to the shopping mall.

5.4. Transportation hubs

During the research conducted at transportation hubs such as railway stations and passenger terminals, it was found that the demand for charging stations has a distinct seasonal pattern and is relatively high. Most of the charging stations at transportation hubs are equipped with both fast-charging and slow-charging stations, and there are also a large number of charging stations yet to be put into use, ensuring an adequate supply. Quick charging can be carried out even during the intervals between flights at airports. Existing studies have even proposed the idea of dynamic wireless charging in response to this phenomenon [19].

However, there are also some problems. Some charging stations lack signs, making it difficult to guide, which has led to some charging piles being idle. Additionally, the charging pile business model is monotonous, and there are no facilities such as lounges or convenience stores nearby, this may affect people’s overall experience, especially passengers who have to wait for a long time.

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6. Discussion

This study aims to explore the fairness of the distribution and usage of electric vehicle charging stations in Guangzhou. In terms of distribution, the research focuses on the matching degree between the distribution of charging stations and the demand, and also explores the main influencing factors behind the distribution. The analysis results show that charging stations are mainly concentrated in areas with high population density and economic development level. In terms of usage fairness, this study focuses on identifying the usage characteristics and whether there is any imbalance between or within different regions, in order to verify whether the usage is fair.

In the research journey, it has undergone a rigorous stage of data acquisition and data analysis, it still has flaws and shortcomings, especially the data and the analytical methods that will be used in the experiment and the explanation of the results.

First of all, in terms of data, the total number of charging stations in Guangzhou is 5144, and the total number of charging ports for new energy vehicles is 47,500. Among them, 1,891 (38%) stations have no charging data. This research only analyzed the charging stations that have charging data, so the results are inevitable to differ from the actual data of the charging stations.

When it comes to the data length, this study selected a one-week dataset for analysis, there will inevitably be some accidental factors that cannot investigate, such as weather conditions and factors related to holidays. Therefore, obtaining long-term data on the usage of EV charging stations and drawing conclusions based on it will be more reliable, but this will require a significant amount of time for analysis and summary.

In addition, there are also limitations in data acquisition. The specific charging capacity, charging prices, and vehicle models of electric vehicles are not provided by the map apps. This also stops the research from conducting in-depth user behavior analysis, such as changes in charging behavior due to specific price factors.

Since the data of the map apps is provided by the operators of EV charging stations, this research cannot determine if there are any omissions. The map apps may also lack information on the distribution and usage of private charging stations, as they are seldom open to the public. Besides, the specific situation of the charging stations cannot be learnt from the apps, such as whether they are damaged or unusable. This also has an impact on the analysis to some extent.

Finally, this research integrates a variety of complex analytical methods. Although it allows for a relatively detailed description of the distribution and usage of existing data, the complexity of the results also increases the difficulty of applying these findings to guide the government in formulating policies for adjusting the supply of charging stations. The research is also limited in explaining the causal relationship between the current distribution and usage of charging stations and the manufacturers' considerations of overall benefits.

7. Conclusion

7.1. Research results

In the first stage of this study, regarding the analysis of distribution characteristics and causes, it was found that the electric vehicle charging stations in Guangzhou exhibited a significant clustering effect, and most of them were located in the core areas, which means that the areas have developed economies and large populations. When analyzing the reasons for their distribution, according to Table 3 and Table 4, population density, POI density, GDP, and road network density all showed positive driving effects, while accessibility and construction land density showed a negative

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correlation in the distribution of electric vehicle charging stations, which might be due to the reasons of Guangzhou's economic development and high land prices.

When exploring the issue of usage fairness, the results revealed a serious inequality in the use of charging stations. 97.12% of this inequality originated from differences between different regions, and this imbalance was particularly evident at the street level. This reflects the extreme imbalance in the allocation of resources in emerging areas. Meanwhile, the research has found that there is a close connection between the distribution of charging station resources in Guangzhou and economic activities. The characteristic of “low economic level and high resource input” is particularly prominent.

Overall, the current distribution of charging stations shows significant spatial heterogeneity. The degree of inequality in terms of population is far greater than that in terms of economic factors, which reflects the insufficient matching between resources and population density. Therefore, it can be concluded from the research results that there is an unfair distribution and usage of electric vehicle charging stations in Guangzhou.

7.2. Suggestions on the distribution and efficiency of electric vehicles

The current distribution of charging stations is unfair, and the configuration of charging stations tends to be based on the GDP scale of each street rather than the population scale. It is recommended to adopt a hierarchical optimization strategy: first, prioritize filling the population service gap in old urban areas such as Yuexiu and Haizhu; Secondly, reconstruct the layout of resource mismatch areas such as Baiyun District; Finally, a "population economy" dual factor dynamic monitoring model can be established to evaluate the rationality and fairness of charging pile configuration in real time, promoting the coordinated evolution of facility planning and urban development.

7.3. Future work

In this research, there are still many deficiencies in data acquisition and data analysis. In the future, more analytical elements should be incorporated, such as the usage price of charging piles, by analyzing the factors of the price, people can infer the layout concept of charging pile operators, and the users’ responses to different prices. Secondly, qualitative research can be enhanced through methods such as interviews and questionnaires. By interviewing users of charging stations, researchers can depict the profiles and usage preferences of users from different industries and with different backgrounds, thus further analysis can be conducted. It is also possible to conduct interviews with operators, exploring the underlying reasons for the layout of charging stations from the supply perspective, and conduct in-depth research on the internal mechanisms and influencing factors of the economic development of each county.

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References

[1] Brilhante, O., & Klaas, J. (2018). Green City Concept and a Method to Measure Green City Performance over Time Applied to Fifty Cities Globally: Influence of GDP, Population Size and Energy Efficiency. Sustainability, 10(6), 2031. https: //doi.org/10.3390/su10062031

DOI: 10.54254/2754-1169/2025.BL30540

[2] Lehmann, S. (2011). What is green urbanism? Holistic principles to transform cities for sustainability. In Climate change-Research and technology for adaptation and mitigation. IntechOpen.
[3] Jabareen, Y. R. (2006). Sustainable urban forms: Their typologies, models, and concepts. Journal of planning education and research, 26(1), 38-52.
[4] Sanguesa, J. A., Torres-Sanz, V., Garrido, P., Martinez, F. J., & Marquez-Barja, J. M. (2021). A Review on Electric Vehicles: Technologies and Challenges. Smart Cities, 4(1), 372-404. https: //doi.org/10.3390/smartcities4010022
[5] Chen, L., Huang, X., Zhang, H., & Luo, Y. (2018). A Study on Coordinated Optimization of Electric Vehicle Charging and Charging Pile Selection. Energies, 11(6), 1350. https: //doi.org/10.3390/en11061350
[6] The Industry Information Department of China Association of Automobile Manufacturers. (2025, June 20) Analysis of New Energy Vehicle Production and Sales in May 2025. http: //www.caam.org.cn/chn/4/cate_30/con_5236777.html
[7] Chen, L., Huang, X., Chen, Z., & Jin, L. (2016). Study of a New Quick-Charging Strategy for Electric Vehicles in Highway Charging Stations. Energies, 9(9), 744. https: //doi.org/10.3390/en9090744
[8] Quirós-Tortós, J., Navarro-Espinosa, A., Ochoa, L. F., & Butler, T. (2018, June). Statistical representation of EV charging: Real data analysis and applications. In 2018 Power Systems Computation Conference (PSCC) (pp. 1-7). IEEE.
[9] Quirós-Tortós, J., Ochoa, L. F., & Lees, B. (2015, October). A statistical analysis of EV charging behavior in the UK. In 2015 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT LATAM) (pp. 445-449). IEEE.
[10] Chen, T., Zhang, X. P., Wang, J., Li, J., Wu, C., Hu, M., & Bian, H. (2020). A review on electric vehicle charging infrastructure development in the UK. Journal of Modern Power Systems and Clean Energy, 8(2), 193-205.
[11] Yong, J. Y., Ramachandaramurthy, V. K., Tan, K. M., & Mithulananthan, N. (2015). A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. Renewable and sustainable energy reviews, 49, 365-385.
[12] Chen, Y. (2023). Spatial autocorrelation equation based on Moran’s index. Scientific reports, 13(1), 19296.
[13] Sulekan, A., & Jamaludin, S. S. S. (2020). Review on Geographically Weighted Regression (GWR) approach in spatial analysis. Malays J Fundam Appl Sci, 16(2), 173-7.
[14] Catalano, M. T., Leise, T. L., & Pfaff, T. J. (2009). Measuring resource inequality: The Gini coefficient. Numeracy, 2(2), 4.
[15] Cao, P., & Tao, H. (2024). Sustainable development in Gansu Province: Theil index and cluster analysis. Sustainability, 16(11), 4518.
[16] Sastry, K. V., Fuller, T. F., Grijalva, S., Taylor, D. G., & Leamy, M. J. (2021, October). Electric vehicle smart charging to maximize renewable energy usage in a single residence. In IECON 2021–47th Annual Conference of the IEEE Industrial Electronics Society (pp. 1-6). IEEE.
[17] Huang, Y., & Zhou, Y. (2015). An optimization framework for workplace charging strategies. Transportation Research Part C: Emerging Technologies, 52, 144-155.
[18] Simolin, T., Rauma, K., Viri, R., Mäkinen, J., Rautiainen, A., & Järventausta, P. (2021). Charging powers of the electric vehicle fleet: Evolution and implications at commercial charging sites. Applied energy, 303, 117651.
[19] Tan, Z., Liu, F., Chan, H. K., & Gao, H. O. (2022). Transportation systems management considering dynamic wireless charging electric vehicles: Review and prospects. Transportation Research Part E: Logistics and Transportation Review, 163, 102761.