ISSN: 2710-0170

Investigation and optimization of public charging facilities layout in Chongqing

Chao Xu[1], Yuhan Liang[2], Xinyi Du[2], Yuxin Ran[2], Xiaoyue Wu[2], Guangcan Xu[1,*]

[1]School of Economic and Management， Chongqing Jiaotong University, Chongqing， 400074, China

[2] Chongqing Yangjiaping Middle School，400050, China

* Corresponding author: Guangcan Xu (Email: xgc@cqjtu.edu.cn)

Abstract

The strategic planning of charging facilities is crucial for fostering the adoption of new energy vehicles and ensuring the sustainable development of urban areas. This study comprehensively assessed the spatial distribution and accessibility of public charging facilities across the nine districts within the central metropolitan area of Chongqing, employing the kernel density estimation method and accessibility analysis. The findings reveal distinct accessibility patterns among the nine districts, characterized by higher concentration in central areas, lower coverage in peripheral regions, and non-uniform distribution within local areas. Moreover, significant variations in accessibility levels across different districts were observed. Building upon these findings, the study identifies prevailing issues in the current layout of charging stations and proposes measures to optimize and adjust the charging infrastructure in Chongqing. The aim is to offer practical recommendations for enhancing the overall configuration of charging stations in the city.

Keywords

Charging station; POI; kernel density; accessibility; layout optimization.

1. Introduction

With the state's heightened focus on "dual carbon" industries, the new energy automobile sector has experienced robust growth amid efforts toward energy conservation and emissions reduction. The issuance of the "New Energy Vehicle Industry Development Plan (2021-2035 Electric Vehicle Year)" has further bolstered the adoption of new energy vehicles. Fueled by both policy directives and market demand, the new energy vehicle market has sustained rapid expansion. By the close of 2023, national ownership of new energy vehicles had surged to 20.41 million. In Chongqing, the number of new energy vehicles escalated from 220,000 units at the beginning of 2023 to 500,000 units by year-end, with a market penetration rate of 48%, notably surpassing the national average of 35.7%. As the vital infrastructure for new energy vehicles, the planning and construction of charging stations play a pivotal role in driving their adoption and enhancing user experience (Ma et al, 2018). Nevertheless, existing EV charging station capacity falls short of meeting the escalating demand, underscoring the critical importance of rationalizing their layout (Li, Zhang, and Weng, 2021). Currently, research on the spatial layout of charging stations for new energy vehicles primarily centers on developing site selection models and optimization algorithms (Li, Liu, and Wang, 2021; Uslu and Kaya, 2021; Zhou, Zhu, and Luo, 2022). While these models and algorithms scientifically elucidate the planning of charging pile placement, there's a lack of comprehensive discussion regarding the spatial distribution and layout deficiencies of charging stations. Point of Interest (POI) data, as a form of geospatial big data, offers advantages such as high accuracy, ease of acquisition, and

ISSN: 2710-0170

comprehensive information coverage, and facilitates the study of urban spatial layouts (Wang et al, 2022). This study aims to utilize POI data to assess public charging infrastructure in Chongqing, employing ArcGIS EV kernel density analysis and accessibility analysis to delve into the equilibrium and accessibility of these stations. The objective is to uncover prevailing issues in charging station layout and offer targeted recommendations for future planning and deployment of EV charging infrastructure in Chongqing.

2. Research on the status quo of public charging facilities layout in Chongqing

2.1. Study Area

2.1.1. Overview of the study area

Located in southwest China, Chongqing Municipality serves not only as the economic, financial, scientific, and technological innovation hub, but also as the center for shipping, trade, and logistics in the upper reaches of the Yangtze River. Additionally, it holds significance as a vital hub for China's automobile industry. The municipality's diverse geographic features, coupled with a well-developed automotive industry base and government focus on the new energy vehicle sector, form a robust foundation with immense potential for the advancement of new energy vehicles in Chongqing. An in-depth examination of the spatial distribution of public charging stations for electric vehicles within the municipality reveals a predominantly centralized distribution across its nine main urban districts. Consequently, this research focuses on these nine districts (including Yuzhong, Dadukou, Jiangbei, Shapingba, Jiulongpo, Nanan, Beibei, Yubei, and Banan), aiming to analyze the layout characteristics of vehicle charging stations and propose relevant planning recommendations. The ultimate goal is to facilitate the systematic development of charging infrastructure for new energy vehicles in the city.

2.1.2. Research Data

The primary data source for this study consists of Point of Interest POI data obtained from public charging stations located in the main urban areas of Chongqing Municipality. POI data, commonly known as point-of-interest data, comprises comprehensive attribute information for each charging station, including its type, geographical location, name, latitude, longitude, and other pertinent details (Xue et al, 2019). The POI data for public charging stations were sourced from the Gaode Data Open Platform, and data retrieval was conducted through a Python program. The dataset encompasses information on the number, name, geographic coordinates, and relevant attributes of charging stations within the main urban area of Chongqing Municipality. Data collection took place on March 9, 2024, and underwent rigorous filtering and deduplication processes, resulting in the identification of 1599 high-quality charging station records. We utilized ArcGIS 10.8 software to overlay and analyze the charging station datasets with the administrative division layer of Chongqing's primary urban area. This process resulted in the creation of a spatial distribution map illustrating the locations of charging stations, depicted in Figure 1.

ISSN: 2710-0170

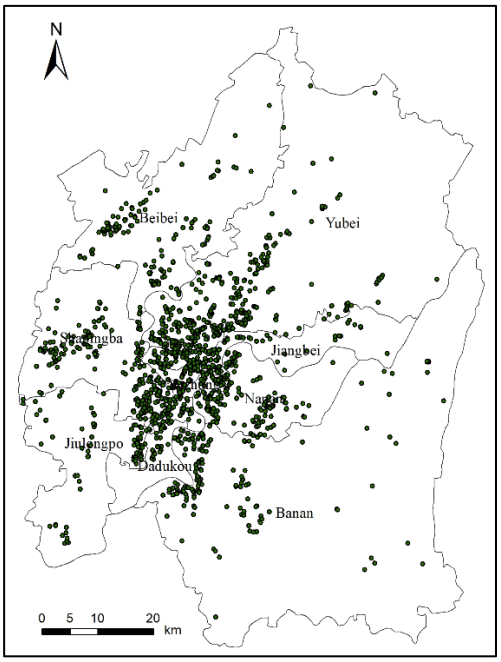

fig. 1 Charging Station Distribution in Chongqing Municipality's Main Urban Area

2.2. Research Methods

Initially, we conducted a systematic exploration of hotspot areas' spatial distribution patterns in Chongqing's main urban area using kernel density analysis. This analysis facilitates a comprehensive assessment of the correlation between existing charging station layouts and urban function distribution, as well as an evaluation of overall charging station equilibrium. Subsequently, the shortest distance method was employed to gauge accessibility across different areas, aiming to analyze the rationale and efficiency of public charging space layout.

Kernel density analysis is a robust spatial analysis technique that accurately reveals the clustering of various elements and reflects their spatial distribution characteristics by continuously simulating the distribution density of spatial point or line elements (Li, 2018). In kernel density analysis, density values gradually decrease with increasing distance from the center point; closer proximity to the center point corresponds to higher density values, whereas greater distance results in lower density values. At a distance equal to the bandwidth r, the density value becomes zero, a property facilitating precise assessment of charging station spatial distribution. The calculation formula for the kernel density analysis method can be expressed as:

$$O_i = \frac{1}{n\pi r^2} \sum_{j=1}^{n} K_j \left(1 - \frac{d_{ij}^2}{r^2}\right)^2 \quad (1)$$

In Eq.1, O_i denotes the kernel density of research point i, K_j denotes the weight value of research point j, d_{ij} denotes the distance between spatial point i and research object j, r is the value of the search radius, also known as the bandwidth, and n is the number of research objects j within the range of the bandwidth r. The study point j has the same weight value K_j within the bandwidth r.

Accessibility, which refers to the effective coverage of public charging facilities, stands as a crucial indicator for assessing the reasonability of charging station spatial layout. Accessibility is defined as the average travel distance from a charging facility to the remaining points within the study area over a specific period (Pan, and Cong, 2012). In this study, we employed the shortest distance method to evaluate accessibility. It offers a comprehensive and intuitive measure, under the assumption that individuals invariably opt for the nearest public service

ISSN: 2710-0170

facility. We evaluated the accessibility of various areas by computing the Euclidean distance from the centroid of each study unit to the nearest charging station. A shorter distance indicates a higher level of accessibility. A grid was generated as the analytical object using ArcGIS 10.8 software, and spatial accessibility within the grid was calculated using the grid centroid as the focal point for charging demand.

2.3. Data Analysis

2.3.1. Kernel Density Analysis

Utilizing the POI data of public charging stations, we conducted kernel density analysis using ArcGIS 10.8 software to generate a kernel density estimation map of charging stations across the nine districts of Chongqing's main city (Figure 2). The figure illustrates a clear central aggregation pattern in the spatial distribution of charging stations. Significant variations in station numbers exist across regions, with higher densities observed in the central area of the main city and lower densities in remote regions, resulting in an uneven distribution. Specifically, charging stations are predominantly clustered in Yuzhong District, the western part of Jiangbei District, the southern section of Yubei District, the northeastern area of Jiulongpo District, and the northwestern portion of Nanan District, forming a centralized aggregation pattern. Additionally, scattered charging stations are found in Beibei and Shapingba districts, displaying a pattern of discrete distribution.

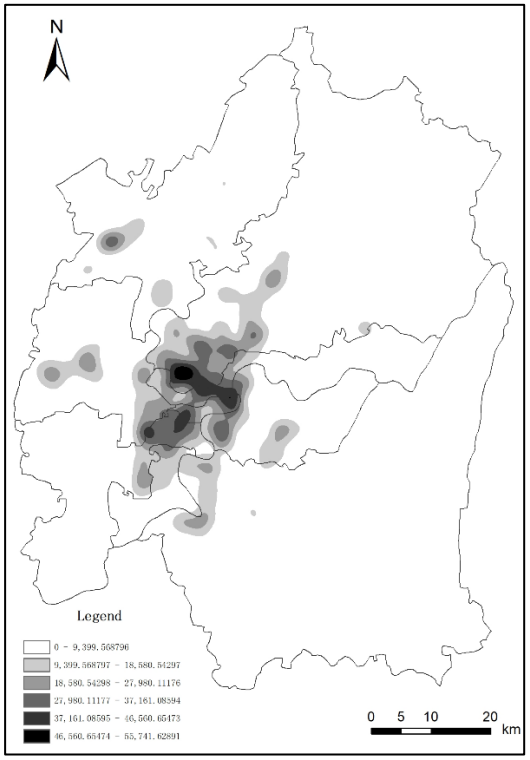

fig. 2 Kernel density analysis of charging stations in the main urban area of Chongqing Municipality

The spatial distribution density of charging stations across the nine districts of Chongqing's main city exhibits a consistent trend of decline as distance from the city center increases. Figure 3 provides detailed insights into the varying numbers and densities of charging stations among different regions.

ISSN: 2710-0170

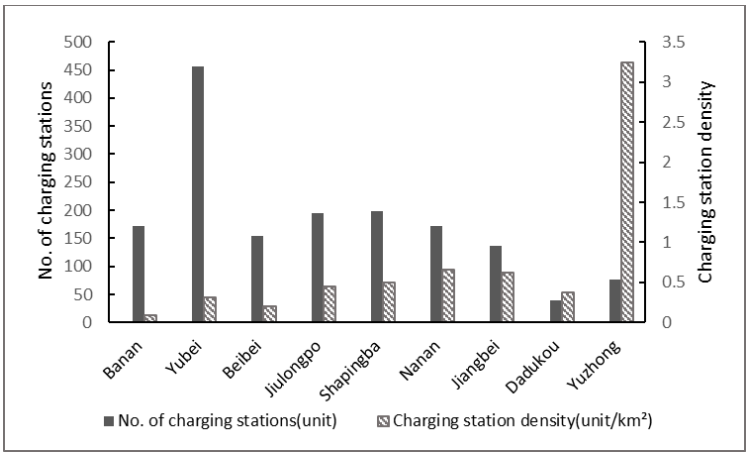

fig. 3 Number and density of charging stations in each district of Chongqing's main urban area

2.3.2. Reachability Analysis

In this study, analysis was conducted using 51·67 grids as the units, with the center of each grid serving as the point of charging demand. The proximity table between the center point of each grid unit and charging stations was generated using the neighborhood analysis tool in ArcGIS 10.8 software. Grid accessibility was analyzed to mitigate the impact of administrative boundaries on accessibility calculations. The assessment of charging station accessibility, based on the spatial shortest distance method, is illustrated in Fig. 4. The results of the accessibility assessment were visualized using a gradient color scale, ranging from red to blue, with blue indicating ample charging station resources and red indicating scarce availability. This color gradient helps to visualize the extent of charging station coverage across different grid areas.

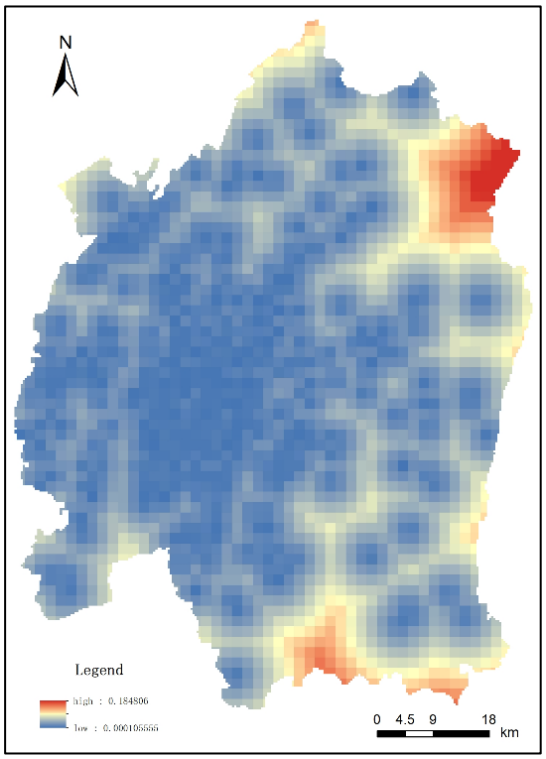

fig. 4 Accessibility Analysis of Chongqing Main City

Based on the findings depicted in Figure 4, the accessibility of charging stations in the nine districts of Chongqing Main City exhibits a pattern of high accessibility in the central city, lower accessibility in the outer ring, and an uneven distribution of local accessibility. This suggests that the central city of Chongqing possesses more abundant charging station resources compared to its surrounding areas. Specifically, areas such as Yuzhong District, Nanan District,

ISSN: 2710-0170

southern Yubei District, and southern Beibei District, among others, demonstrate a high density of charging station distribution and relatively abundant charging station resources. Conversely, peripheral areas like southern Banan District and northern Yubei District face greater challenges in charging due to limitations in the number of charging stations and charging distance.

3. Analysis of the status quo of public charging facilities layout in Chongqing

With the rapid development of the electric vehicle industry, electric vehicles have become an essential mode of transportation for future urban residents. The growing concern for residents' electric vehicles has further propelled the continuous enhancement of public charging station construction and development. A well-planned public charging station layout can effectively cater to residents' daily charging needs. However, the current situation of charging station layout in Chongqing presents several noteworthy challenges that require attention and resolution.

3.1. Insufficient Total quantity

According to the "Special Planning for Charging and Switching Infrastructure in Chongqing's Central City (2023-2025)" released by the Chongqing Municipal Bureau of Planning and Natural Resources in July 2023, the number of electric vehicles in the nine districts of Chongqing's main city reached 171,000 as of December 2022. Despite the construction of 90,000 charging piles, the vehicle-to-pile ratio stands at 1.9:1. While the overall ratio of charging facilities to vehicles in the main urban areas of Chongqing City is relatively high, there remain challenges such as insufficient total charging infrastructure, low density, and inadequate coverage. The current number of public charging stations falls short of meeting the escalating demand for electric vehicles, resulting in difficulties for users to locate available charging facilities promptly. In densely populated areas, the surge in electric vehicle numbers outpaces the development of charging facilities, particularly evident during peak charging hours. This imbalance leads to a situation where the supply of charging stations fails to meet demand, causing inconvenience in daily life and business activities.

3.2. Unbalanced spatial distribution

The spatial distribution of public charging facilities in Chongqing exhibits distinct characteristics across administrative districts and within streets within those districts. Kernel density analysis reveals a concentration of charging facilities primarily in Yuzhong District, the western section of Jiangbei District, the southern area of Yubei District, the northeastern region of Jiulongpo District, and the northwestern part of Nanan District. These areas, particularly the central urban zone centered around Yubei District, boast a well-established charging infrastructure. Conversely, regions like the northern sector of Yubei District and the southern portion of Banan District experienced later development and are less integrated with the core area due to various factors. These areas exhibit lower levels of service industry development and weaker population attraction, resulting in less coverage by charging facilities. Statistical analysis reveals that the majority of public charging stations in Chongqing's nine main districts are spontaneously established by charging operators. In some areas, there is an overlap in coverage or an insufficient number of charging stations, indicating a lack of systematic consideration for the city's overall layout.

3.3. Unbalanced supply and demand

The distribution of charging stations in the nine districts of Chongqing's main city predominantly centers around the urban core, particularly Yubei District. This concentration

ISSN: 2710-0170

results in overlapping coverage, leading to an oversupply of charging facilities and resource wastage in certain core areas. Conversely, charging stations in peripheral areas have overly large service radii, posing challenges for EV users who must travel long distances to access charging points, thereby increasing inconvenience and costs. Consequently, there is a discrepancy between the daily charging requirements of residents across the nine districts of Chongqing's main city and the availability of public charging infrastructure, resulting in an imbalance between supply and demand.

4. Optimization and adjustment of public charging facilities layout in Chongqing

Public charging facilities, as vital infrastructure supporting the proliferation of electric vehicles, are garnering increased attention. The arrangement and design of electric vehicle charging stations are not solely linked to enhancing energy utilization efficiency but also directly impact urban transportation planning and environmental air quality enhancement. Hence, executing the layout and planning of public charging stations for electric vehicles in a scientifically sound and rational manner is of paramount importance.

4.1. Layout optimization strategy

(1) The government should coordinate the planning of charging station layout and implement preferential policies to encourage enterprises to participate in construction. The rapid development and popularization of electric vehicles make the construction of charging facilities crucial. In Chongqing, major public charging station brand dealers hold a dominant position. The government can collaborate with enterprises to jointly invest in charging station construction and incentivize their participation through preferential policies. Concurrently, the government can coordinate charging station layout to ensure it is more reasonable and efficient from a citywide perspective.

(2) The layout of public charging stations must consider urban traffic demand comprehensively. The layout plan should stem from an in-depth analysis of urban traffic flow, vehicle utilization rate, and charging demand. In densely trafficked urban areas, charging station density should be increased appropriately to meet demand during peak traffic hours. Conversely, in suburban or fringe urban areas, charging station density can be moderately reduced to conserve resources and minimize environmental impact. When formulating the charging station layout plan, urban traffic characteristics should be fully considered to ensure it meets the needs of different regions.

(3) The planning of public charging stations should prioritize resource-intensive utilization. Given the city's limited land resources, it is crucial to strategically plan charging station construction. One approach is to integrate charging stations with parking lots, gas stations, and other facilities to maximize resource utilization. Additionally, adopting a multi-level and three-dimensional charging station design can optimize space usage and increase facility capacity. Through judicious planning of charging station construction, not only can land resources be effectively conserved, but the efficiency of charging facilities can also be enhanced, further advancing electric vehicle development.

4.2. Existing layout optimization and adjustment balance

The planning and construction of urban public charging facilities at this stage emphasize rationality and fairness, aiming to align roughly with the distribution of the urban population. Exploring the rationality of facility layout involves integrating time factors, spatial factors, land use factors, personal preferences, and usage patterns. Therefore, in the layout of public charging facilities in Chongqing Municipality, it is essential not only to meet the criteria of the vehicle-to-pile allocation ratio but also to ensure the service level of public charging stations

ISSN: 2710-0170

supported by these indicators. This entails considering the distribution of public charging stations, the correlation between the number of stations and the population distribution, the setting of service radii, and alignment with areas of charging demand. Consequently, the current layout of public charging stations needs to be adjusted rationally to meet the demands of residents. To address the imbalance in the layout of public charging stations and the challenge of charging station coverage in some areas, the government needs to provide reasonable guidance and coordinate the layout of public charging stations in line with the surrounding construction development trend and charging facility construction.

4.3. New layout optimization balance

Currently, the main city of Chongqing's nine districts encounters challenges with insufficient charging stations and a disparity between supply and demand. Thus, there's an urgent necessity to expand the coverage of public charging facilities by establishing new stations to meet public charging requirements. The execution of the new public charging facility planning program necessitates the establishment of comprehensive mechanisms and procedures. Firstly, charging station providers must engage in thorough communication and consultation with relevant government and urban planning departments to ensure alignment with urban and land use planning. Secondly, it is paramount to carefully select suitable sites for charging station construction. Prioritizing accessibility, charging stations should be strategically located near major traffic arteries to facilitate convenient access for electric vehicle (EV) users. These sites should offer adequate space for both charging infrastructure and parking, while also considering potential future expansion requirements. Lastly, charging station providers should enhance communication and interaction with vehicle owners and users, promptly addressing their concerns and needs to enhance overall satisfaction and user experience.

5. Conclusion

The layout and establishment of charging stations play a pivotal role in advancing the adoption and utilization of electric vehicles. This study assesses the spatial arrangement of public charging stations across nine districts in Chongqing's main city through kernel density analysis and accessibility evaluation. Findings reveal a centralized aggregation pattern of charging stations within these districts, with higher accessibility observed in the central areas compared to the periphery, indicating the non-uniform distribution of accessibility locally. The spatial distribution of charging infrastructure to some extent reflects the allocation of urban resources. The paper suggests enhancing the spatial arrangement of charging stations by augmenting scientific and technological investments and enhancing the efficiency of current charging facilities to address the charging requirements across varied topographical regions. Furthermore, urban charging station layout optimization should consider district-specific characteristics such as terrain, economic factors, and travel demand.

Acknowledgments

This work was supported in part by the Chongqing primary and secondary school innovative talent training project (Grant no. CY230711), the Humanity and Social Sciences Research Project of Chongqing Education Commission (Grant no. 22SKGH174), and the Research Foundation of Chongqing Jiaotong University (Grant no. F1220061).

ISSN: 2710-0170

References

[1] Ma, J., Liu, X. D., Chen, Y. S., Wang, G. P., Zhao, X., He, Y. L., ... & Zhang, Y. X. (2018). Status quo and countermeasures of China's new energy vehicle industry and technology development. China Journal of Highway and Transport, (08), 1-19.

[2] Li, Y. M., Zhang, X. Z., & Weng, Z. M. (2021). Research on the development strategy of charging facilities for new energy vehicles under demand-side management. Enterprise Science and Technology Development, (08), 22-24.

[3] Li, J., Liu, Z., & Wang, X. (2021). Public charging station location determination for electric ride-hailing vehicles based on an improved genetic algorithm. Sustainable Cities and Society, 74, 103181.

[4] Uslu, T., & Kaya, O. (2021). Location and capacity decisions for electric bus charging stations considering waiting times. Transportation Research Part D: Transport and Environment, 90, 102645.

[5] Zhou, G., Zhu, Z., & Luo, S. (2022). Location optimization of electric vehicle charging stations: Based on cost model and genetic algorithm. Energy, 247, 123437.

[6] Wang, R. Z., Zhou, P., Pan, Y., Lin, Y. C., & Xiang, X. (2022). Study on spatiotemporal aggregation and dispersion patterns of urban functional areas based on big data. Geography and Geo-Information Science, (01), 45-50.

[7] Xue, B., Li, J. Z., Xiao, X., Xie, X., Lu, C. P., Ren, W. X., & Jiang, L. (2019). A review of research on human-land relationship based on Point of Interest (POI) big data: theory, method, and application. Geography and Geo-Information Science, (06), 51-60.

[8] Li, X. (2020). Identification of the multi-center structure of cities based on spatial clustering characteristics of POI elements: a case study of Zhengzhou. Acta Scientiarum Naturalium Universitatis Pekinensis, (04), 692-702.

[9] Pan, J. H., & Cong, Y. B. (2012). Measurement of spatial accessibility of 4A and above tourist attractions in China. Scientia Geographica Sinica, (11), 1321-1327.