Frontiers in Traffic and Transportation Engineering (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/ftte.2025.050106
ISSN 2616-2334 Vol. 5 Num. 1

Analysis of Charging Demand Characteristics for Electric Vehicles on Expressways: Evidence from Sichuan Province

Shifan Han[1,2], Fan Zhang[3], Zhan Shu[1], Dingding Li[2]

[1]*Sichuan Academy of Transportation Development Strategy and Planning Sciences, Chengdu, China*
[2]*Tianfu Yongxing Laboratory, Chengdu, China*
[3]*China Communications expressway Planning and Design Institute Co., Ltd, Chengdu, China*

Keywords: Expressway; Electric Vehicle; Charging Demand Characteristics; Sichuan Province

Abstract: The scientific layout of charging stations based on the charging demand of electric vehicles on expressways is great significance to reduce range anxiety of electric vehicles and promote the sustainable development of the electric vehicle industry. Taking the expressway in Sichuan Province as a case study, this study reveals the characteristics of charging demand during holidays and puts forward corresponding operation and management strategies by analyzing the infrastructure data and charging business data of charging stations in expressway service areas in Sichuan Province. The research results indicate that the uneven spatial and temporal distribution of expressway service areas in Sichuan Province is the core feature， and its main difficulties include the prominent contradiction between power supply and demand in electric vehicle, the unbalanced regional distribution and the overload operation of some stations in the peak season of tourism. In the future, when optimizing the layout and facility configuration of expressway charging stations, the actual charging demand characteristics of expressway electric vehicles should be further considered.

1. Introduction

The power of electric vehicles comes from the electrical energy stored in the on-board battery, and their charging demand is constrained by factors such as traffic conditions, charging facility layout, and weather[1]. Among them, the completeness of charging facility is the key to whether electric vehicles can receive energy supply. Therefore, in order to ensure the rapid development of the electric vehicle industry, China has has promulgated a number of policies to support the construction of charging infrastructure[2-4]. For the important scenario of intercity travel on expressways, if electric vehicles have a charging demand, they need to choose the nearest charging station on the expressway for recharging. Only when they are unable to get recharging or hoping for lower charging costs would one choose to go off the expressway to charge. The expressways usually have a high load characteristic of vehicles gathering and passing during holidays, in this situation, the supply capacity of charging service facilities on expressways will be greatly challenged. Exploring the temporal and

spatial differences of electric vehicles' charging demand on expressway can support the optimization of expressway charging infrastructure layout and capacity configuration adjustment, and assist expressway charging station operators in formulating appropriate strategies to improve the operational efficiency of charging stations.

Intercity travel during holidays is often closely related to long-distance travel. Studies by scholars such as Li Tao [5] revealed that the daily intercity travel volume during holidays such as the Labor day is significantly higher than on weekdays, but this study only focuses on the time heterogeneity in intercity travel. In order to predict the charging load of different types of electric vehicle, scholars such as Qin Jianhua and Pan Chongchao[6] mainly analyzed the charging distribution law of electric vehicle in time based on historical data, but lacked spatial analysis of different stations. Peng Geng and Haojie Yang[7] carried out the prediction research on the charging demand of electric vehicle based on spatio-temporal convolutional network, which fully captured the correlation of charging stations in time and space, but lacked the practical application on expressways. Scholars such as Liu Chaixin and Xi Qian[8-9] revealed that men are more inclined to choose electric vehicles to travel on holidays, but this mainly focused on individual behavioral choices towards electric vehicles. Scholars such as Haoxuan Kuang, Kezhou Chen[10] conducted a characteristic analysis of the demand for electric vehicle charging in holiday tourist destinations, but the research mainly focused on tourist destinations rather than charging stations on expressways. Although Li Zhi, Li Dongyu and others[11-12] carried out the research on location and capacity determination based on the expressway, they mainly established the model from the aspects of cost, service radius, queuing, and lacked an objective analysis of the space-time demand for charging electric vehicle on expressways.

This article takes Sichuan as an example to analyze the temporal and spatial characteristics of the charging demand for electric vehicles on expressways. Leveraging the charging service data, charging infrastructure data from expressway charging stations, alongside information on the expressway network and service area stations, this study applies the K-S test to investigate whether significant disparities exist in the distribution of charging power demand for expressway electric vehicles across different date types. It also employs K-means clustering to categorize charging stations into distinct types. Based on these analyses, the temporal and spatial characteristics of expressway electric vehicle charging demand are explored and mined, with discussions extending to the underlying causes and relevant recommendations.

2. Research Data

Table 1 Introduction to Data Scale

Numble	Data Name	Quantity	Attribute	Data Size
1	Charging Business Data	1505630	15	120.4M
2	Charging Infrastructure Data	456	20	198KB
3	Road Network Data	1106	22	23.8M
4	Administrative Division Data	204	11	12.6M
5	Holiday Data	1/day	2	1KB/Day

The multi-source data utilized in this study encompass charging business data of 167 expressway service areas in Sichuan Province, charging infrastructure data of service areas, expressway network and service area location data, holiday data, etc. The types and scales of relevant data are shown in Table 1. The data were collected from April 28 to May 26, 2024, September 2 to October 13, 2024, and December 28, 2024 to February 28 of the following year. Due to certain differences in the structure and standard format of the collected raw data, as well as the existence of some data missing

and anomalies, data preprocessing work such as data cleaning, data integration and reduction, and data quality evaluation was carried out on the collected data to ensure that the basic data for subsequent research are reliable and consistent.

3. Research Method

To reveal the temporal differences in charging demand of electric vehicles on expressways, this study first employed the K-S test and found that, at the 0.05 significance level, there is a significant difference in the distribution of average charging power per station between non-holidays and holidays. Based on this, the overall impact of holidays and the three days before and after holidays on the charging demand of electric vehicles on Sichuan's expressways was analyzed.

To reveal the differences in electric vehicle charging demand among different service area charging stations on various expressway routes, this study adopted the K-means clustering method to classify the stations. The number of charging station types was determined using the elbow method, and based on this, the charging stations were classified. The types of charging stations are as follows(Table 2):

Table 2 Classification of charging stations

Numble	Station type	Daily average charging capacity
1	Super charging station	>3000 kw/h
2	Hot charging station	2000-3000 kw/h
3	Secondary hot charging station	1000-2000 kw/h
4	Low demand charging stations	500-1000 kw/h
5	Low demand charging station	<500kw/h

4. Results and Discussion

4.1 Temporal Characteristics of Charging Demand

Figure 1 shows the variation characteristics of weekly charging demand on non-holidays. The charging demand on non-holidays is mainly characterized by relative stability on Mondays and Tuesdays, a low point on Wednesdays, a gradual increase on Thursdays and Fridays, and a peak on weekends. Figures 2-6 show the distribution changes of charging demand during holidays and the three days before and after holidays, and there are differences in the impact of different holidays on the charging demand of Sichuan's expressways. Since the New Year's Day holiday in 2025 is only one day, this festival is not included in the study. The charging demand during the May Day and National Day holidays both presents the characteristics of "a surge before the holiday, a peak on the first day of the holiday-high-level, fluctuations during the holiday, a decline after the holiday". The charging demand during the Mid-Autumn Festival presents the characteristics of "steady growth before the holiday, high-level fluctuations during the holiday, a decline after the holiday". The charging demand during the Spring Festival holiday presents the characteristics of "fluctuating growth before the holiday, rising to a high level during the holiday, followed by a decline-rapid drop after the holiday". From the impact of different holidays, there is a significant "long tail effect" during the Spring Festival, and it is necessary to strengthen the guarantee of the service capacity of charging stations in expressway service areas. There is a "super high fluctuation" during the May Day holiday, and the demand for charging is concentrated. Operators need to take flexible measures such as mobile charging stations, battery swapping, and timely dispatch of electricity and energy.

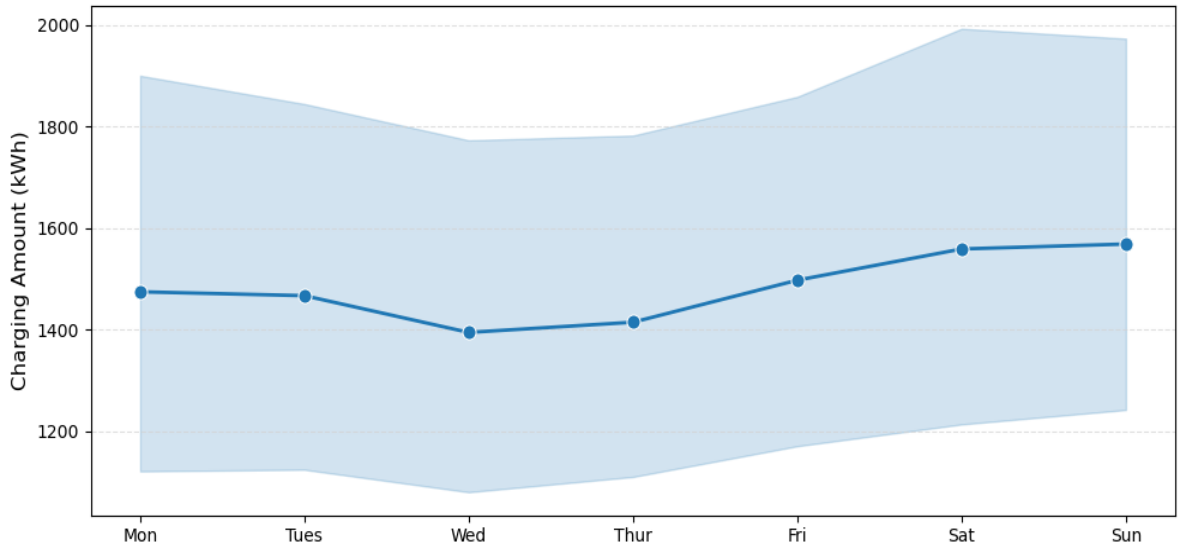

Fig.1 Charging Capacity Tend

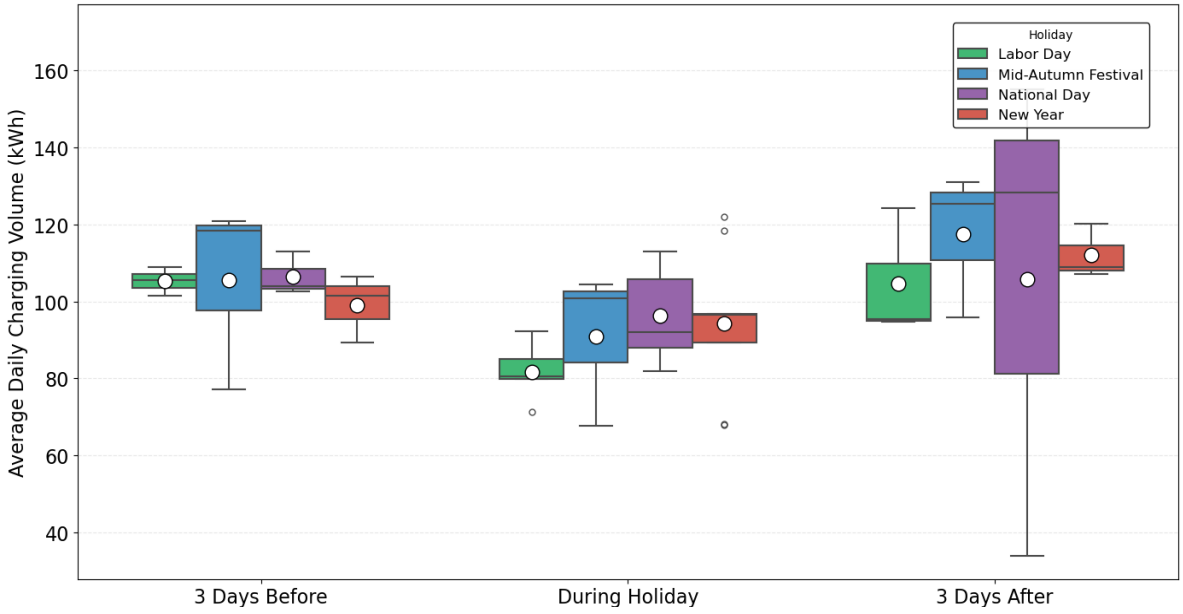

Fig.2 Charing Volume Distribution Around Holidays

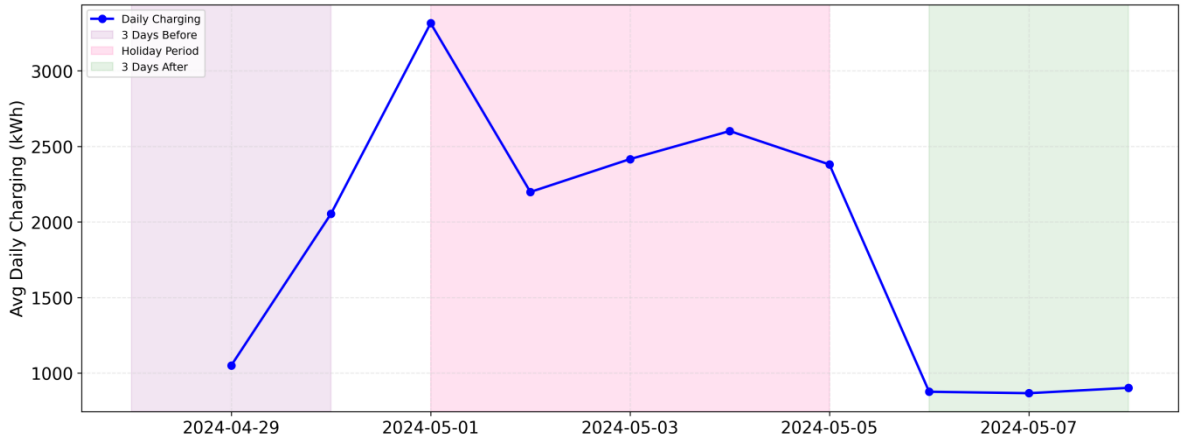

Fig.3 The Labor Day Charging Tend

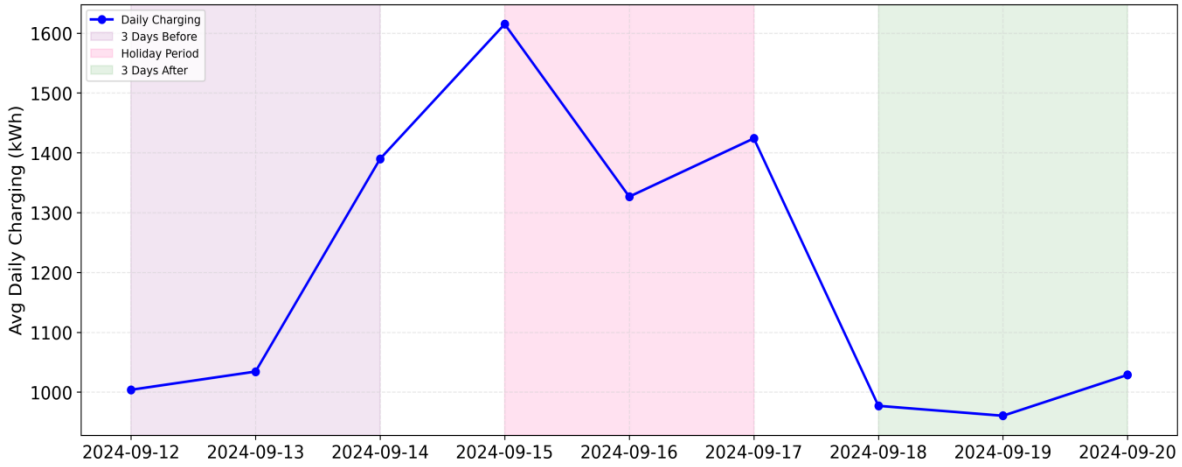

Fig.4 The Mid-Autumn Festival Charging Tend

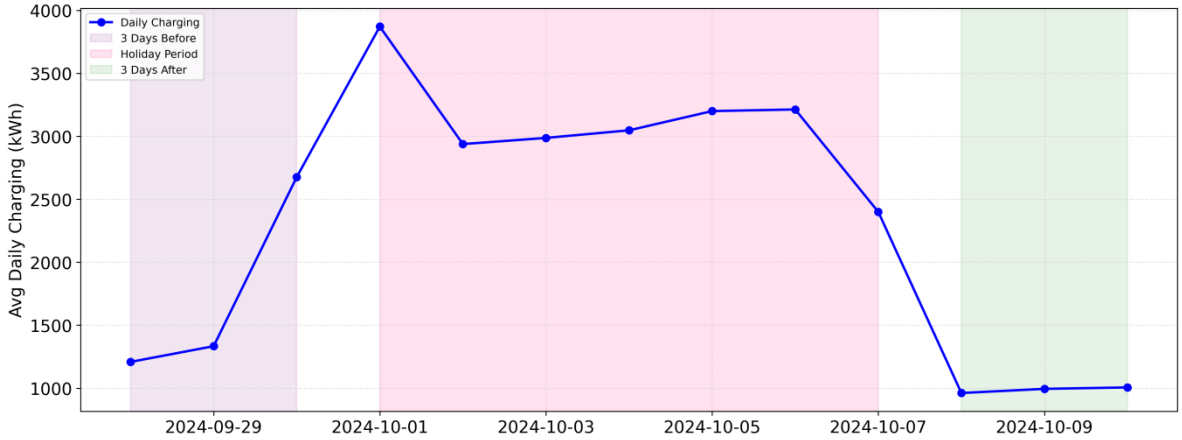

Fig.5 The National Day Charging Tend

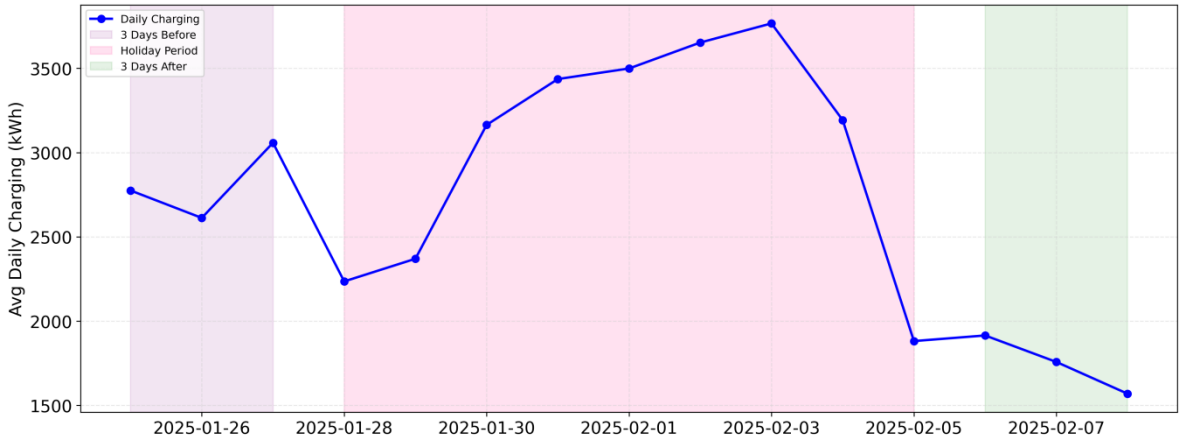

Fig.6 The Spring Festival Charging Tend

4.2 Spatial Characteristics of Charging Demand

4.2.1 Overall spatial characteristics

Overall, the spatial imbalance of charging demand on the expressway in Sichuan province is prominent (figure 7), which is specifically manifested as follows: (1) Core agglomeration and

gradient decline. With the Chengdu Plain Economic Zone as the core, the density of charging stations and charging demand show a gradient distribution characterized by "high in the core and low in the periphery". (2)The significance of the Northeast Sichuan Economic Zone is prominent. Although the economic vitality of the Northeast Sichuan Economic Zone is lower than that of the Chengdu Plain, it bears important transit and regional travel needs due to its advantageous transportation location connecting Sichuan, Chongqing, and Shaanxi. (3) There is a significant development gap between the Southern Sichuan Economic Zone and the Panxi Economic Zone. Benefiting from the development of the Yangtze River Economic Belt and regional industrial linkage, the Southern Sichuan Economic Zone has outstanding performance in the distribution of hot-spot and sub-hot-spot charging stations. Restricted by terrain, population density and economic scale, the Panxi Economic Zone has charging stations concentrated in Panzhihua City and Liangshan Yi Autonomous Prefecture, with a relatively high proportion of low-demand stations.

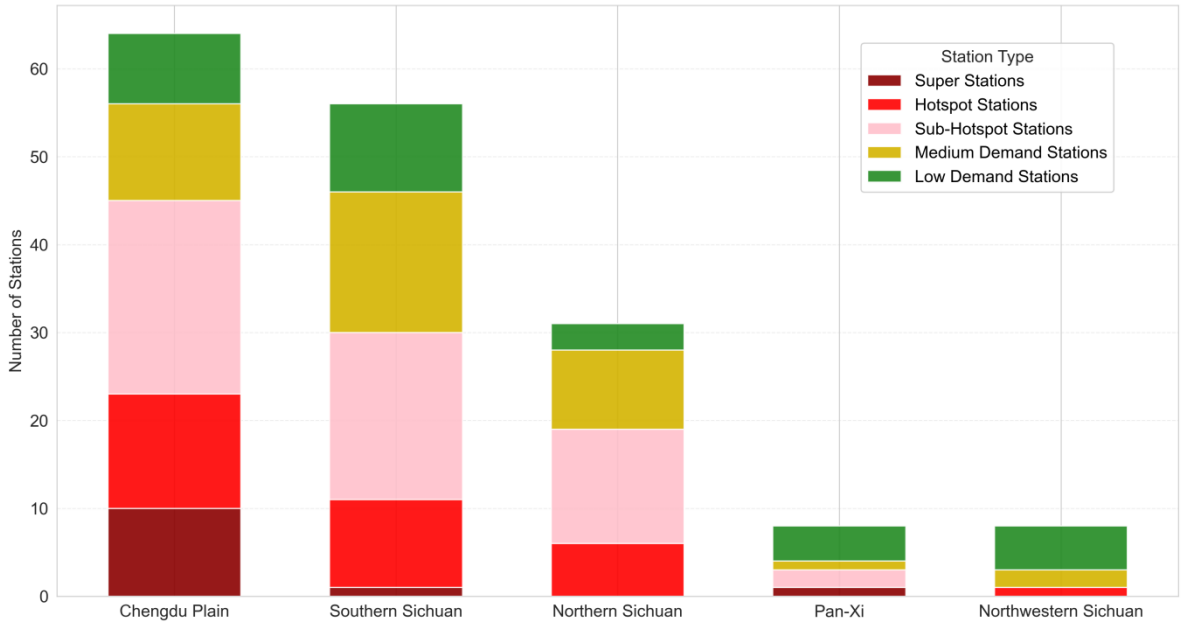

Fig.7 Distribution of Charging Stations in Various Economic Zones

4.2.2 Channel spatial characteristics

From the perspective of expressway corridors, the spatial characteristics of the corridors are mainly manifested in the following three aspects: (1) Polarization of charging demand in the corridors. At the channel level, a clear distribution pattern of "high load on core channels and low demand on remote lines" has been formed. (2) The spatial differences in the corridor aggregation effects. The Chengdu Plain Economic Zone and the Southern Sichuan Economic Zone have formed high-value charging clusters based on high-speed channels such as Beijing-Kunming Expressway and Xiamen-Chengdu Expressway, while the Northwest Sichuan Ecological Demonstration Zone has shown a phenomenon of low value charging clusters. (3) Holidays have different impacts on the demand for corridor charging. During holidays, the demand for charging on multiple expressways shows a exponential growth (figure 8), especially the popular tourist or return routes are most affected by holidays.

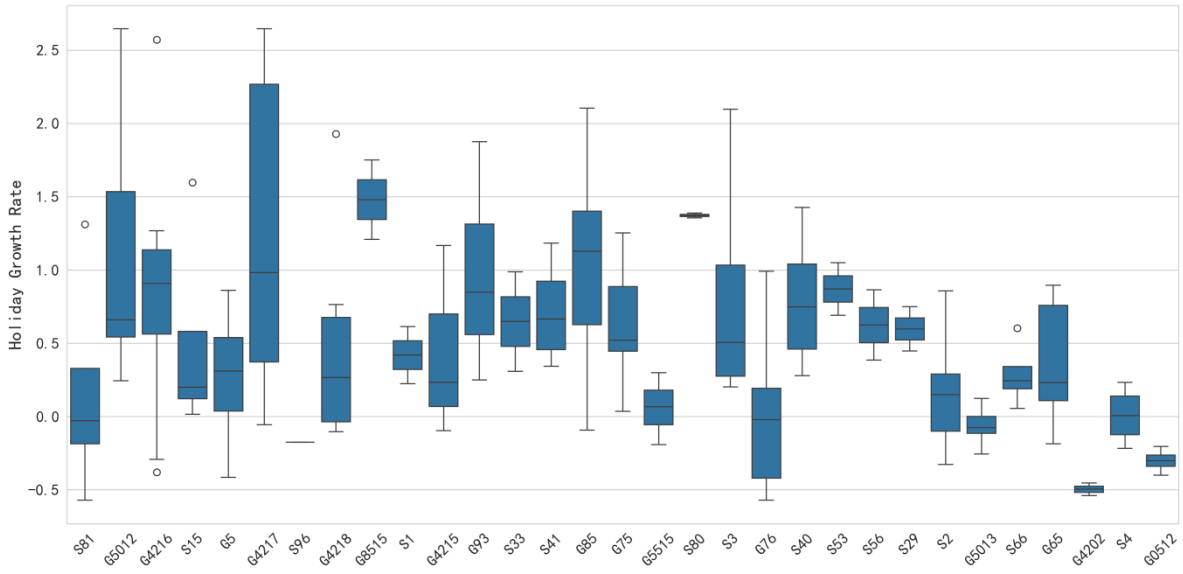

Fig. 8 Top 10 expressways with average daily charging during holidays

4.2.3 Issues and Suggestions

Comprehensive analysis shows that the uneven spatial and temporal distribution of expressway charging stations in Sichuan Province is the most core feature, and its main difficulties include the prominent contradiction between power supply and demand in electric vehicle, the unbalanced regional distribution and the overload operation of some stations during peak tourist seasons. In order to alleviate the above difficulties and promote the development of energy integration, it is recommended to: (1) Add mobile charging piles during peak holidays, promote "tidal" charging parking space management, and dynamically adjust service capacity according to demand forecast. (2) Expand the capacity of fast charging piles and increase the power in high demand areas, and lay out slow charging piles or integrate optical storage and charging facilities in low demand areas to reduce operation and maintenance costs. (3) Introduce photovoltaic/energy storage systems to smooth out power grid peaks and valleys, and prioritize the dispatch of renewable energy electricity.
(4) Through the time-of-use electricity price, users are guided to off-peak charging，then enhance the utilization of clean energy and reduce the intensity of carbon emissions. (5) Strengthening publicity to guide users in adopting electric vehicles for travel and promoting low-carbon development in the transportation sector.

5. Conclusion

To alleviate the pressure of centralized charging services in terms of time and space on expressways, and to support the formulation of strategies such as the layout of charging stations and the optimization of facility configuration on expressways, this study investigated and analyzed the temporal and spatial characteristics of charging demand at 167 charging stations on expressway service area in Sichuan Province. The conclusion indicates that, both in time and space, the charging demand for electric vehicles on expressways presents strong imbalance and contradictions between charging supply and demand. To this end, the research time span should be extended, the granularity of research data should be refined, the analysis of charging operation data should be deepened, and suggestions for facility supply layout and configuration that meet the charging needs of expressways should be further explored.

Acknowledgment

This research was funded by the Sichuan Provincial Transportation Technology Project: Planning and Low-Carbon Technologies for Expressway Charging Stations (2023-D-07).

References

[1] Chen Lidan, Zhang Yao, Antonio FIGUEIREDO. Overview of Charing and Discharing Load Forcasting for Electeic Vehicles. Automation of Electric Power System, 2019, 43 (10): 177-191.
[2] The General Office of the State Council. Guiding Opinions of the General Office of the State Council on Further Building a High Quality Charging Infrastructure System. Central People's Government of the People's Republic of China, 2023.
[3] The National Development and Reform Commission and other departments. Implementation Opinions of the National Development and Reform Commission and Other Departments on Further Enhancing the Service Guarantee Capability of Electric Vehicle Charging Infrastructure. Development and Reform Commission website, 2022.
[4] Action Plan for Accelerating the Construction of Charging Infrastructure Along expressways. Website of the Ministry of Transport, 2022.
[5] Li T, Wang J, Huang J, et al. Exploring temporal heterogeneity in an intercity travel network: A comparative study between weekdays and holidays in China. Journal of Geographical Sciences, 2020, 30:1943-1962.
[6] Qin Jianhua, Pan Chongchao, Zhang Xuan, et al. Electric Vehicle Charging Load Prediction Based on Charging Behavior Analysis. Electrical Measurement & Instrumentation, 2023, 60 (4): 19-26.
[7] Geng Peng, Yang Haojie, Shizong Xia, et al. Electric Vehicle Charing Demand Forecasting Based on Spationtemporal Graph Convolutional Networks. Transportation Engineering, 2024, 24 (11): 37-45.
[8] Chai Xinxi. Study on Travel Mode Choice Behavior in Consideration of New Energy Vehicles. Xi'an: Chang'an University, 2023.
[9] Liu Qian. Research on Residents' Travel Intention and Travel Mode Choice under the New Energy Vehicle Policy. Xi'an: Chang'an University, 2023.
[10] Kuang Haoxuan, Chen Kezhou, Li Jun. Analysis of Holiday Electric Vehicle Charging Demand in Tourist Locations. Proceedings of the 2025 World Transport Conference (WTC2025) (Volume 2), 2025.
[11] Li Zhi. Research on Location and Capacity Determination of Charging Stations for Electric Vehicles on Freeways. Dalian: Dalian Maritime University, 2023.
[12] Li Dongyu. Research on Site Selection and Volume Decision of Electric Vehicle Charging Stations on Expressway. Dalian: Dalian Maritime University, 2021.