Analyzing EV Charging Patterns: Towards Efficient Infrastructure Deployment

Yan Huang [1, a], Rui Jiang [2, b], Jincai Pei [1, c], Shifu Liang [2, d], Jiaming Song [3, e], Yang Ju [1, f], Jingchao Lian [4, g], and Cong Zhang [4, h, *]

[1] Xi'an Linchr New Energy Technology Co.,Ltd, Xi'an,710119, China;

[2] China FAW Group Corporation, Changchun 130013, China;

[3] Xi'an Zhi Dian Yun Lian Information Tech CO.,LTD, Xi'an, 710119, China;

[4] School of Automotive Engineer6ing, Harbin University of Technology, Weihai 264209, Shandong, China.

[a] huangyan@linkcharging.com, [b] jiangrui1@faw.com.cn, [c] peijc@linkcharging.com,

[d] liangshifu@faw.com.cn, [e] songjm@xazdyl.com, [f] juyang@linkcharging.com,

[g] 23S130292@stu.hit.edu.cn, [h, *] chinazc2022@126.com

Abstract. This paper analyzes real-world EV charging data, covering station distribution, volume, duration probability, and utilization efficiency. Future infrastructure developments and improvement recommendations are discussed. Based on diverse station data, including probability distributions and regression analysis, findings reveal disparities in infrastructure availability and charging patterns. Strategic planning and investment are emphasized to meet growing EV charging demands, along with exploring opportunities in renewable energy integration and smart charging technologies. Overall, this study provides insights for promoting widespread EV adoption and sustainable transportation.

Keywords: Charging infrastructure; characteristics; electric vehicles.

1. Introduction

The proliferation of electric vehicles (EVs) has led to an increased demand for efficient charging infrastructure, necessitating a thorough understanding of EV charging behavior and future requirements for sustainable transportation systems[1]. This study aims to analyze real-world EV charging data to gain insights into charging patterns and propose recommendations for future infrastructure development. With the rise in EV adoption, the need for comprehensive charging infrastructure planning becomes paramount to address the evolving needs of users and the transportation sector[2]. By examining the characteristics of EV charging behavior and anticipating future demands, policymakers and stakeholders can make informed decisions to ensure the effective deployment of charging infrastructure. Moreover, integrating renewable energy sources and smart charging technologies presents opportunities for enhancing the sustainability and efficiency of EV charging [3]. Thus, this study seeks to contribute to the ongoing discourse on the development of EV charging infrastructure and its implications for the transition to sustainable transportation systems[4].

The trend in charging infrastructure for electric vehicles (EVs) has witnessed significant growth and evolution in recent years, spurred by the increasing adoption of EVs globally[5]. This trend is characterized by a concerted effort among governments, private entities, and industry stakeholders to expand and enhance the charging network to meet the growing demand for electric mobility[6]. Initially, charging infrastructure deployment focused predominantly on urban centers and densely populated areas, catering to the needs of EV owners primarily within city limits[7-10]. However, as the popularity of EVs continues to rise, there is a discernible shift towards extending charging infrastructure into suburban and rural areas, thereby enhancing accessibility and addressing range anxiety concerns for EV users across diverse geographical regions [11]. This spatial distribution reflects an effort to maximize the convenience and usability of charging infrastructure, catering to the needs of both residential and commercial EV users while also supporting long-distance travel and intercity commuting[12]. Overall, the trend underscores a concerted effort to develop a comprehensive and inclusive charging infrastructure network that accommodates the evolving needs of the expanding EV market and facilitates the widespread adoption of electric vehicles as a sustainable transportation solution[13].

2. Methodology

The analysis is based on a dataset comprising real-time EV charging data collected from various charging stations, employing statistical methods such as probability distributions and regression analysis to derive meaningful insights. Data collection encompasses diverse geographical regions and charging scenarios to ensure a comprehensive representation of EV charging behavior, contains 300 thousand charging orders. Through the application of rigorous statistical techniques, patterns and trends in charging station utilization, charging volume, and duration distributions are identified. Additionally, regression analysis is utilized to model the relationship between charging behavior and external factors such as time of day, location, and EV model. By integrating multiple analytical approaches, a holistic understanding of EV charging dynamics is achieved, enabling informed recommendations for future infrastructure planning.

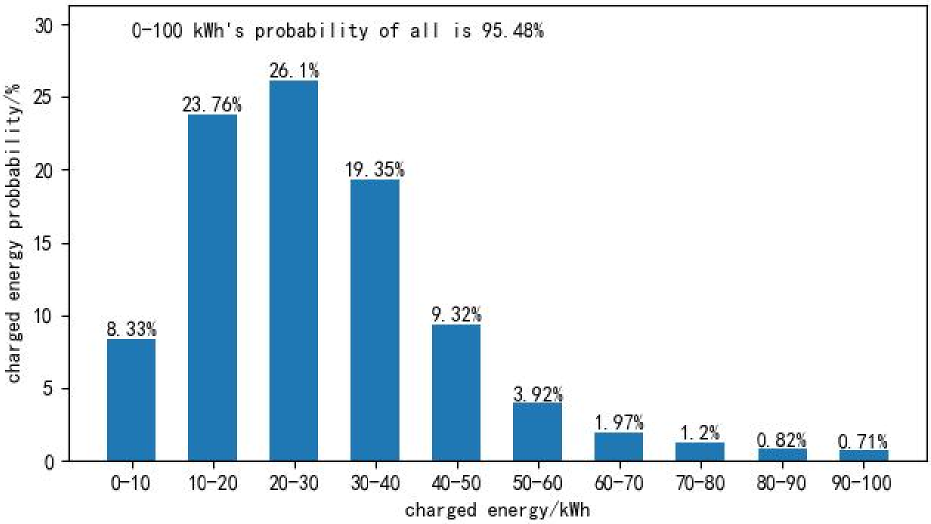

Figure 1. The distribution of the charged energy

The analysis of single charging orders reveals that a significant majority, accounting for 95.48%, of these orders involve charging amounts below 100 kWh. Within this distribution, specific proportions emerge: 8.33% of orders entail charging amounts within the 10 kWh range, while the range of 10-20 kWh constitutes 23.76% of the total orders. Additionally, orders within the 20-30 kWh range make up 26.1% of the total, and those within the 30-40 kWh range represent 19.35%. Notably, the cumulative percentage of orders below 40 kWh reaches 77.54%. These findings underscore a concentration of charging amounts within lower ranges, reflecting prevalent charging patterns among electric vehicle users.

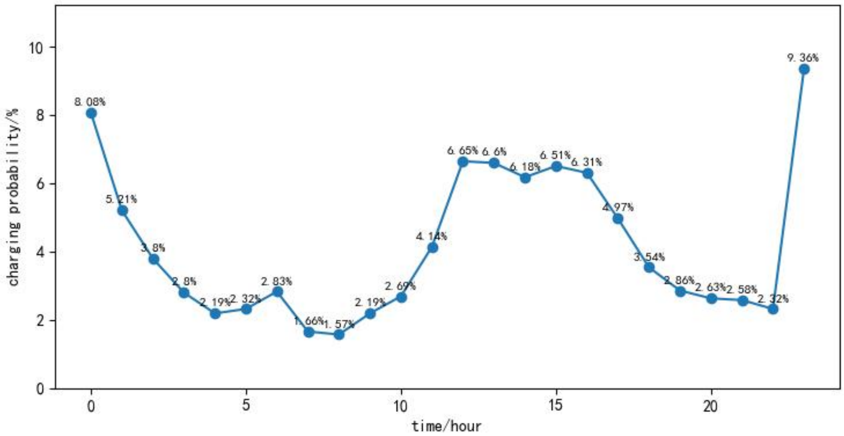

Figure 2. The charging activity distribution in a whole day

The analysis of charging activity distribution reveals a bimodal pattern characterized by two distinct peak periods. The first peak occurs during the late-night hours, typically between 10 pm and 1 am, indicating a notable surge in charging activity during this timeframe. This late-night peak may be attributed to EV owners opting to charge their vehicles at home after returning from daily activities or during off-peak electricity hours, thereby maximizing convenience and potentially benefiting from reduced electricity rates. Conversely, the second peak period is observed in the afternoon, spanning from 12 pm to 4 pm. This afternoon peak signifies a significant increase in charging activity during daytime hours, possibly reflecting the charging behaviors of individuals utilizing workplace or public charging facilities during their midday routines. The presence of these two distinct peak periods highlights the temporal variability in charging behavior and underscores the importance of accommodating diverse charging preferences when designing and managing charging infrastructure.

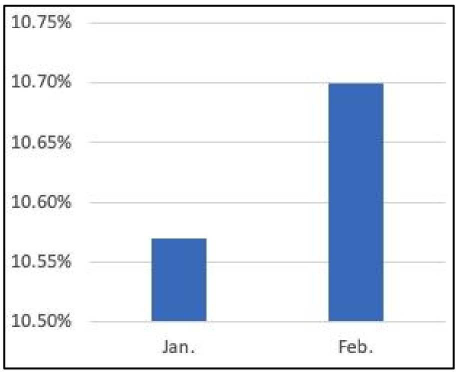

Figure 3. Time utilization efficiency of charging facilities

The analysis of time-of-use ratios reveals essential insights into the utilization efficiency of charging infrastructure. On average, the ratio of time-of-use stands at 10.57%, indicating that charging stations are operational and utilized for EV charging purposes approximately 10.57% of the total time considered. However, it is noteworthy that this average value is subject to significant variation across different charging stations and time periods. The maximum observed time-of-use ratio reaches 61%, indicating instances where charging stations are utilized intensively, potentially reflecting high-demand locations or specific time intervals characterized by increased EV charging activity. Understanding these variations in time-of-use ratios is crucial for optimizing the deployment and management of charging infrastructure to ensure efficient utilization and meet the evolving demands of EV users.

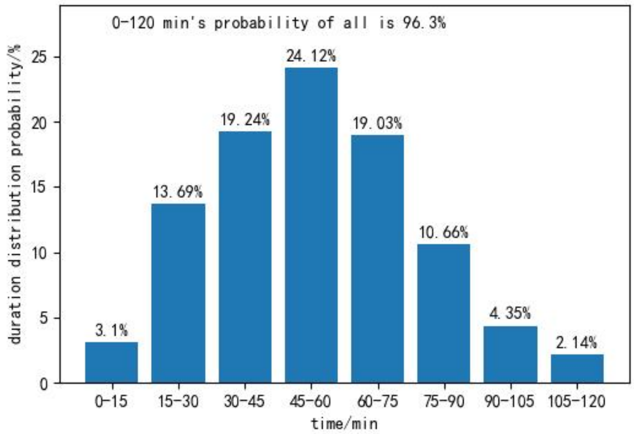

Figure 4. Charging duration distribution

The data from the graph illustrates the distribution of charging durations for each vehicle. Notably, a significant majority, accounting for 96.3% of the total charging sessions, fall within a timeframe of less than 2 hours. Among these sessions, three specific time ranges emerge as the most prevalent: 30-45 minutes, 45-60 minutes, and 60-75 minutes. Interestingly, the duration bracket of 45-60 minutes stands out as the most frequently occurring, constituting 24.12% of all charging sessions. Additionally, sessions lasting less than 1 hour collectively represent a substantial portion, amounting to 60.15% of the total. This distribution provides valuable insights into the charging behavior of vehicles, highlighting the prevalent charging patterns and durations within the observed dataset.

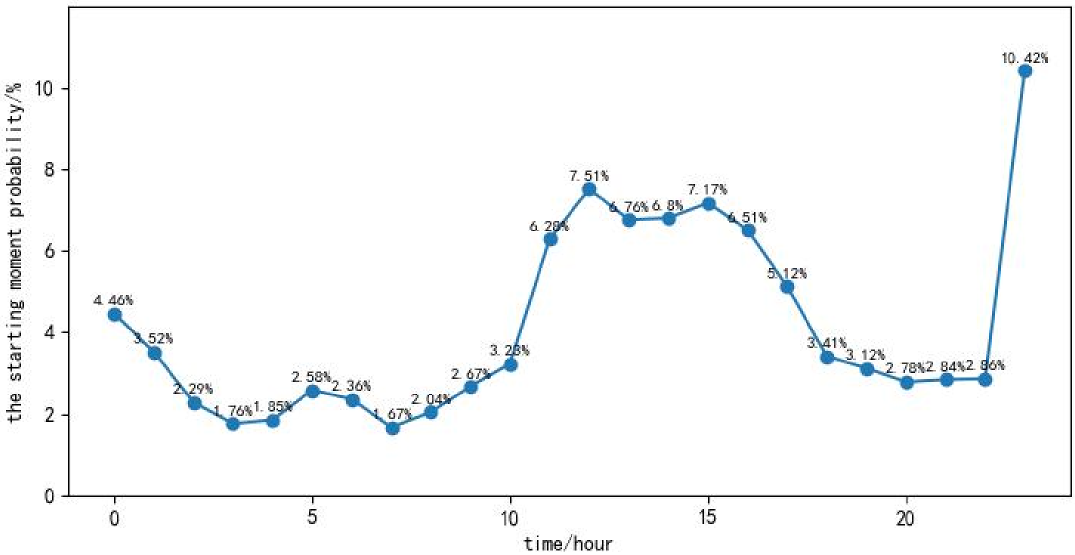

Figure 5. The start time distribution of all charging activities

The statistical analysis of the starting times for charging behavior reveals several noteworthy trends. The peak charging time is observed to be at midnight, constituting 10.42% of all charging sessions. This high percentage suggests a preference among many users for organized charging during off-peak hours. From the early hours of the morning until 7 a.m., there is a gradual decline in the initiation of charging sessions, reaching its lowest point at 7 a.m. with only 1.67% of sessions starting at this time. This decline coincides with users' departure for work in the morning, indicating a pattern that aligns with the demand for charging before commuting. Another notable peak charging period occurs between 11 a.m. and 4 p.m., spanning the midday and afternoon hours. At 8 p.m. in the evening, there is a notable dip in charging activity, with the fewest number of users initiating charging sessions at this time. These patterns provide valuable insights into users' charging behaviors and their preferences for specific times of the day, reflecting considerations such as convenience and routine.

3. Results

The comprehensive analysis of real-world electric vehicle (EV) charging data yielded valuable insights into various aspects of charging behavior and infrastructure utilization. The study revealed that a significant proportion, accounting for 95.5%, of single charging orders involved quantities below 100 kWh, indicating a prevalent preference for lower charging amounts among EV users. Further examination of charging patterns unveiled a bimodal distribution, with distinct peak periods observed during late-night hours, typically between 10 pm and 1 am, and in the afternoon, spanning from 12 pm to 4 pm. These findings highlight temporal variability in charging behavior and underscore the need for flexible infrastructure planning to accommodate diverse charging preferences. Additionally, analysis of time-of-use ratios demonstrated an average utilization efficiency of 10.5%, with observed peaks reaching up to 61%, indicating opportunities for optimizing infrastructure deployment and management to meet evolving demands.

4. Conclusion

In conclusion, the analysis of real-world EV charging data provides valuable insights for policymakers, stakeholders, and infrastructure planners. The prevalence of lower charging amounts suggests a need for infrastructure designs that cater to varying user preferences. The identification of distinct peak periods underscores the importance of temporal considerations in infrastructure planning to ensure efficient resource allocation. Moreover, the variability in time-of-use ratios highlights opportunities for optimizing infrastructure deployment and management to enhance overall efficiency. These findings contribute to ongoing discussions on the development of EV charging infrastructure and underscore the significance of accommodating diverse charging behaviors to facilitate the widespread adoption of electric vehicles and foster sustainable transportation systems.

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References

[1] Ahmad, Fareed, and Mohd Bilal. "A Comprehensive Analysis of Electric Vehicle Charging Infrastructure, Standards, Policies, Aggregators and Challenges for the Indian Market." Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 45, no. 3 (2023): 8601-8622.

[2] Saldarini, Alessandro, Seyed Mahdi Miraftabzadeh, Morris Brenna, and Michela Longo. "Strategic approach for electric vehicle charging infrastructure for efficient mobility along highways: a real case study in Spain." Vehicles 5, no. 3 (2023): 761-779.

[3] Bommana, Babji, J. S. V. Kumar, Ramakrishna SS Nuvvula, Polamarasetty P. Kumar, Baseem Khan, Suresh Muthusamy, and Ravikiran Inapakurthi. "A comprehensive examination of the protocols, technologies, and safety requirements for electric vehicle charging infrastructure." Journal of Advanced Transportation 2023 (2023).

[4] Tamay, Pablo, and Esteban Inga. "Charging Infrastructure for Electric Vehicles Considering Their Integration into the Smart Grid." Sustainability 14, no. 14 (2022): 8248.

[5] Nath, Angshu, Zakir Rather, Indradip Mitra, and L. Sahana. "Multi-criteria Approach for Identification and Ranking of Key Interventions for Seamless Adoption of Electric Vehicle Charging Infrastructure." IEEE Transactions on Vehicular Technology (2023).

[6] Hu, Dandan, Shuxuan Cai, and Zhi-Wei Liu. "Electric Vehicle Charging Infrastructure Location Optimization with Mixed and Forecasted Charging Requirements." Complexity 2023 (2023).

[7] Pandžić, Hrvoje, Bojan Franc, Stjepan Stipetić, Franko Pandžić, Matko Mesar, Marija Miletić, and Sara Jovanović. "Electric vehicle charging infrastructure in Croatia–First-hand experiences and recommendations for future development." Journal of Energy: Energija 71, no. 3. (2022): 16-23.

[8] Hager, K., & Graf, A. (2023). The Impact of Charging Infrastructure on Local Emissions of Nitrogen Oxides. World Electric Vehicle Journal, 14(4), 90.

[9] Powar, Vishwas, and Rajendra Singh. "End-to-End direct-current-based extreme fast electric vehicle charging infrastructure using lithium-ion battery storage." Batteries 9, no. 3 (2023): 169.

[10] Chen, Tianjin, Xiao-Ping Zhang, Jianji Wang, Jianing Li, Cong Wu, Mingzhu Hu, and Huiping Bian. "A review on electric vehicle charging infrastructure development in the UK." Journal of Modern Power Systems and Clean Energy 8, no. 2 (2020): 193-205.

[11] Hu, Dandan, Shuxuan Cai, and Zhi-Wei Liu. "Electric Vehicle Charging Infrastructure Location Optimization with Mixed and Forecasted Charging Requirements." Complexity 2023 (2023).

[12] Mulrow, John, and Emily Grubert. "Greenhouse gas emissions embodied in electric vehicle charging infrastructure: a method and case study of Georgia, US 2021–2050." Environmental Research: Infrastructure and Sustainability 3, no. 1 (2023): 015013.

[13] Powar, Vishwas, and Rajendra Singh. "End-to-End direct-current-based extreme fast electric vehicle charging infrastructure using lithium-ion battery storage." Batteries 9, no. 3 (2023): 169.