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Charging Problems associated with Electric Vehicles (Evs): A Case Study

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Abstract

One of the challenges facing the mainstream adoption of EV is related to the infrastructure of electric vehicle charging, the pattern of demand for energy, and disparities in the availability of stations in different regions. This paper applies a secondary data analysis methodology through data on recorded EV charging data, world energy reports from Kaggle, and the IEA Global EV Outlook 2024 to examine major trends affecting the adoption of EVs. The results show major disparities in charging infrastructure, as urban areas have it well covered, but it lags for those in the rural and suburban areas, which further enhances range anxiety and constraint of EV penetration. The study's results on the demand pattern show a peak demand between 5 to 8 PM that would be responsible for some form of congestion and long waiting times at the charging stations. The trends of energy consumption show that the highest utilization rates are achieved through Level 2 and DC Fast Chargers, thus the emphasis on high-traffic location, while Level 1 chargers would most preferably be sited at overnight and workplace charging areas. Comparative insights from some global case studies have underlined the much effectiveness public-private partnerships get in scaling EV infrastructure particularly in those areas where there exists a very strong unified policy framework. The study proposes an upscaling of the rural charging network and the introduction of dynamic pricing strategies in the peak-hour congestion management with inspiration drawn from global best practices in the development of sustainable and scalable EV infrastructure; this would improve efficiency, ensure equity in access, and expedite the transition to sustainable mobility solutions.

Keywords: Electric vehicle infrastructure; Charging station reliability; Charging reliability; Urban-rural gap; Sustainability

1. Introduction

The transportation industry is experiencing a major shift with the rapid growth of electric vehicles (EVs), driven by global efforts to reduce greenhouse gas emissions and move away from fossil fuels. EVs are an important innovation in sustainable transportation, offering a cleaner and more energy-efficient alternative to traditional internal combustion engine (ICE) vehicles (Sanguesa et al., 2021). However, despite advancements in EV technology and supportive government policies, challenges in creating an adequate charging infrastructure continue to be a major obstacle to broader adoption (Deb et al., 2019).

A strong and accessible EV charging network is essential to easing concerns about limited driving range and supporting a smooth transition to sustainable mobility. However, many regions, especially in developing countries, face issues such as a shortage of public charging stations, long wait times, incompatible charging systems, and unreliable power supplies (Bhatti et al., 2015). These issues create significant barriers that prevent the widespread use of EVs .

In Nigeria, the adoption of EVs is still at an early stage, held back by high costs, limited charging stations, and an unstable power grid (Ahmad et al., 2022). Early users often face challenges like a lack of high-speed chargers and inconsistent government policies that fail to support network expansion (Wang et al., 2016). These issues make long-distance travel difficult, discouraging potential buyers. For EVs to be successfully integrated into Nigeria's transportation system, these challenges must be addressed with targeted and comprehensive solutions.

This study uses a case study approach to analyze key problems related to EV charging, focusing on the availability, reliability, and performance of current charging networks. The research aims to evaluate the state of charging infrastructure, identify the main challenges users face, and provide data-driven recommendations to improve coverage and system performance (Ahmad et al., 2022). This work also emphasizes the need for policies that address gaps in infrastructure and encourage partnerships between the public and private sectors to build a stronger EV ecosystem.

By tackling these challenges, this study aims to contribute to discussions on policy improvements and propose actionable solutions to strengthen sustainable transportation systems. A key goal is to close the knowledge gap on EV adoption in developing countries, where readiness and affordability are major concerns (Nour et al., 2020). Additionally, the research highlights the importance of building resilient, user-friendly charging networks that consider both urban and rural needs.

Research on EV adoption has identified various challenges and proposed potential solutions. Adhikari et al. (2020) developed an analytical hierarchical process (AHP) framework to rank 17 barriers to EV adoption in Nepal. These barriers were grouped into technical, policy, economic, infrastructure, and social categories. Their findings showed that a lack of public charging stations and the high purchase price of EVs were the most critical issues. However, the framework had limited adaptability to other countries and did not account for feedback from diverse user groups, which limits its broader application.

Krishna (2021) explored consumer perceptions and emotional factors influencing EV adoption by analyzing social media discussions and online forums. This study emphasized that negative emotions, such as range anxiety and concerns about maintenance, contribute to hesitancy among potential buyers. Although this research provided valuable qualitative insights, it lacked quantitative data and policy recommendations to support effective infrastructure planning.

Xiong et al. (2020) proposed a behavioral model called the "k-Level Quantal Response Equilibrium" (QRE) to examine how EV drivers make decisions when selecting charging stations. The model considered factors such as queue length, pricing, and accessibility. However, the study assumed uniform decision-making patterns across all users, which may not reflect the diversity in real-world behavior.

Goel et al. (2021) reviewed the barriers to EV adoption in India and highlighted the potential of vehicle-to-grid (V2G) technology for grid optimization. The study identified insufficient government incentives and low public awareness as significant obstacles. Despite its comprehensive approach, the research did not provide detailed cost-benefit analyses for implementing V2G solutions.

Adhikari et al. (2020) also pointed out that policy inconsistencies and stakeholder conflicts frequently impede the development of EV infrastructure. Similarly, Xiong et al. (2021) argued that effective collaboration among stakeholders is crucial for optimizing charging station placement. However, both studies overlooked the role of public-private partnerships in fostering infrastructure development.

While previous studies have explored various aspects of EV adoption, significant gaps remain, particularly in addressing disparities in charging infrastructure accessibility between urban and rural areas. Many studies overlook real-world user charging behaviors and the impact of infrastructure availability on EV adoption. Additionally, few integrate a combined analysis of infrastructure distribution, policy frameworks, and user demand patterns to provide comprehensive solutions.This study seeks to bridge these gaps by analyzing secondary data on charging station locations, user charging patterns, and policy measures. By evaluating infrastructure disparities and peak demand trends, the research aims to propose strategic interventions that enhance charging accessibility and promote a more sustainable and inclusive EV ecosystem.

2. Materials and Methods

This study employs a secondary data analysis approach, utilizing a dataset obtained from Kaggle and validated against insights from the Global EV Outlook 2024 (IEA, 2024). The dataset provides a comprehensive overview of electric vehicle (EV) charging behavior, infrastructure distribution, and user demand trends across multiple regions, including urban and rural locations in India and the United States. By analyzing these data points, this study seeks to identify key challenges in EV charging accessibility, peak demand periods, and infrastructure gaps.

2.1 Data Sources

The study integrates data on EV charging behavior and charging station locations to analyze charging patterns and infrastructure distribution. The EV charging behavior dataset contains records of charging sessions, vehicle models, battery capacities, charging start and end times, energy consumption, station locations, and user behavior patterns. This dataset covers charging station usage primarily in the United States, including key metropolitan areas such as Houston, Los Angeles, and San Francisco. The charging station location dataset provides geographic data, vendor details, power capacities, operating hours, and supported vehicle types, primarily covering charging infrastructure in India, including cities like Delhi, Mumbai, and Bangalore. By examining these datasets together, this study evaluates the spatial distribution of charging infrastructure, identifies areas with inadequate accessibility, and highlights disparities in charging availability between high-density and underserved regions.

2.2 Data Processing and Visualization

Data was structured and analyzed using Python where Pandas was for data processing and Matplotlib/Seaborn for visualization. Instantiated charging session timestamps in date time format to hourly trends of the demand, and peak charging periods mainly identified based on grouping charging sessions by the hour of the day. The charging sites were classified into urban and rural using the names of the cities to bring out the differences in comparisons across charger type while aggregating energy consumption trends to bring out differences in efficiencies among different vehicle models. The author created graphical illustrations of all key findings, which include patterns on charging demand patterns, disparities in regional disparities of charging station availability, differentials in power usage, and differences in infrastructure deployment in urban and rural areas.Additionally, comparative analysis between Indian and U.S. datasets was conducted to highlight infrastructure challenges across different geographical contexts and assess the impact of uneven distribution on EV adoption.

3. Results and Discussion

This section presents findings from the analyzed dataset, focusing on charging demand patterns, infrastructure distribution, energy consumption trends, and accessibility disparities.

3.1 Charging Demand Patterns

Analysis of charging session data shown in Figure 1 revealed that peak charging hours occur between 5 PM and 8 PM, aligning with the evening commuting period. The demand for charging stations surges sharply during these hours, reaching its highest point at approximately 7 PM. This spike is primarily driven by individuals returning home from work and immediately plugging in their EVs for recharging. The rapid increase in demand results in congestion at charging stations, leading to longer wait times and potential energy distribution challenges. The demand pattern throughout the day follows a gradual increase starting in the late morning, intensifying in the afternoon, and peaking in the evening before declining after 9 PM. This behavior indicates that work-related commutes significantly influence charging station usage. Notably, the demand remains relatively low during the early morning hours, suggesting that overnight charging is not as prevalent, possibly due to home-charging accessibility.

To mitigate congestion and improve station efficiency, dynamic pricing models could be introduced to incentivize off-peak charging. Higher costs during peak hours would encourage some users to adjust their charging schedules, thereby balancing demand more effectively. Additionally, implementing scheduled charging slots would help evenly distribute usage across non-peak hours, reducing the risk of long queues and inefficient station utilization.

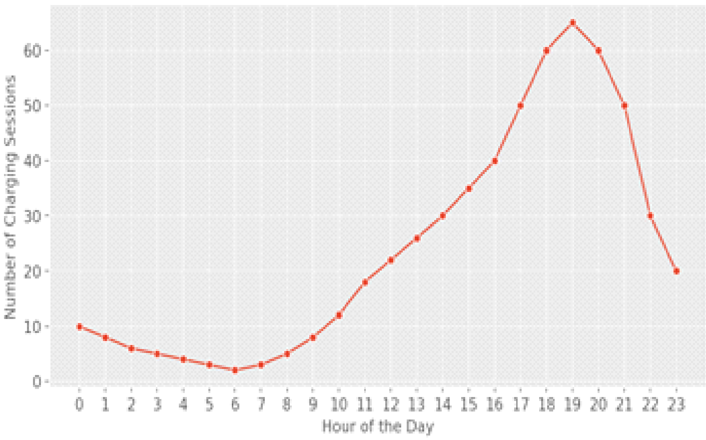

Figure 1: Charging demand patterns throughout the day

3.2 Infrastructure Distribution

Charging station availability shown in Figures 2 and 3 varies significantly across different regions, revealing a stark contrast in charging infrastructure between major metropolitan areas and smaller cities. Urban centers such as New Delhi, Delhi, and Nagpur in India have the highest number of charging stations, reflecting their advanced infrastructure and stronger policy support for electric vehicle (EV) adoption. Similarly, in the United States, cities like Los Angeles, San Francisco, and Houston exhibit high charging station usage, indicating better-developed EV ecosystems.However, this distribution is highly uneven, with many suburban and rural areas facing a severe shortage of public charging stations. This disparity presents a major challenge for EV adoption, as potential users in less-developed regions may struggle with range anxiety due to limited access to charging points. The steep drop-off in station availability beyond top-ranking cities suggests that infrastructure expansion has been concentrated in a few high-density locations, leaving other areas underserved.This imbalance in infrastructure development underscores the pressing need for targeted policies and strategic interventions to promote equitable EV accessibility. Without deliberate efforts to extend charging networks to smaller cities and rural communities, the widespread adoption of EVs could be constrained, reinforcing regional disparities in sustainable mobility. Government incentives, public-private partnerships, and strategic investments in charging corridors along highways and intercity routes could play a pivotal role in mitigating these challenges. Expanding charging stations beyond metropolitan areas would not only enhance convenience for EV users but also foster confidence in electric mobility, supporting the transition toward a more sustainable transportation system. Addressing infrastructure gaps is critical to overcoming one of the most significant barriers to EV adoption—charging accessibility in diverse geographic locations.

3.3 Energy Consumption Trends

The study found that Level 2 chargers, as visualized in Figure 4, exhibit the highest average energy consumption per charging session, indicating their effectiveness for users requiring moderate to fast charging. DC Fast Chargers also consume a substantial amount of energy, making them suitable for rapid charging in high-demand areas such as highways and urban fast-charging hubs. In contrast, Level 1 chargers consume the least energy, making them ideal for overnight charging at residential locations or workplace environments where vehicles remain parked for extended periods. These findings suggest that a strategic deployment of charging infrastructure is crucial for optimizing energy efficiency and meeting user demands. High-power Level 2 and DC Fast Chargers should be prioritized in commercial and transit-heavy locations, whereas Level 1 chargers can be expanded in residential and workplace settings. Proper planning of charger placement based on usage patterns can enhance the accessibility and practicality of EV charging networks, ultimately supporting wider EV adoption and minimizing charging-related constraints.

3.4 Comparative Analysis

From the findings in Figure 5, Urban residents have a significantly higher probability of finding a charging station nearby compared to rural residents. City locations were used to categorize charging stations under an envisioned future city by distinguishing them from rural centers. The results indicate a striking imbalance in station availability, concentrating more charging points towards urban locales. The finding emphasizes the immediate need for policy-driven rural charging infrastructure development to ensure equity in EV adoption. Skillful improvement of EV infrastructures in the rural writs could extend the use of EVs and reduce the anxiety of those who would like to use them. In the absence of any interventions aimed at improving the level of access, EV adoption may be concentrated within cities, thus leaving the rural driver at a disadvantage. Therefore, targeted investments, incentives, and public-private partnerships are required to bridge the infrastructure gap and to promote general access to EVs.

3.5 Global vs. Local Practices

Best practices from leading EV adoption regions, such as Norway, emphasize public-private partnerships to scale infrastructure efficiently. In regions lacking policy cohesion, slow infrastructure deployment hampers EV adoption, limiting the effectiveness of EV policies. Countries with well-established government incentives and funding mechanisms tend to experience faster EV infrastructure growth, whereas those without such policies lag behind. Adopting successful global strategies and adapting them to local contexts could help accelerate EV infrastructure development in underdeveloped regions.

3.6 Implications and Recommendations

To address the identified challenges, this study highlights the importance of expanding rural charging infrastructure to support equitable EV adoption. Implementing dynamic pricing strategies can help manage peak-hour congestion and prevent station overload. Furthermore, adopting global best practices for sustainable and scalable EV infrastructure development can enhance accessibility and improve the efficiency of charging networks. Policymakers and stakeholders must collaborate to address these gaps and create a well-integrated EV charging ecosystem that supports the growth of electric mobility.

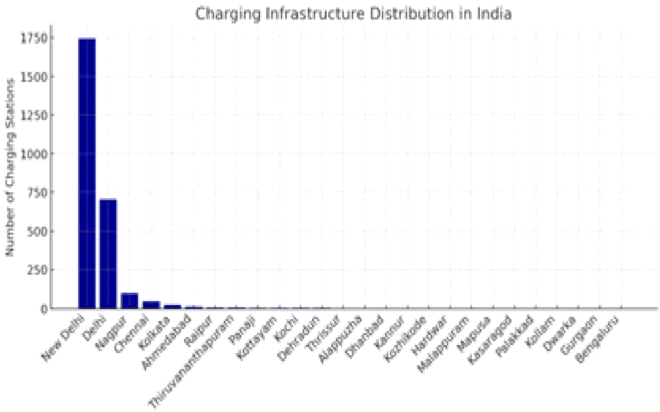

Figure 2: Charging Usage Distribution in India

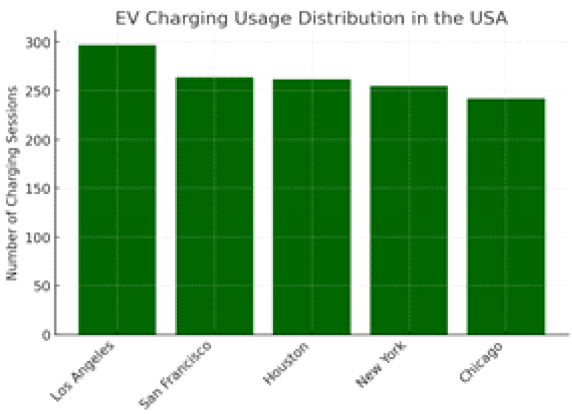

Figure 3: Charging usage distribution in USA

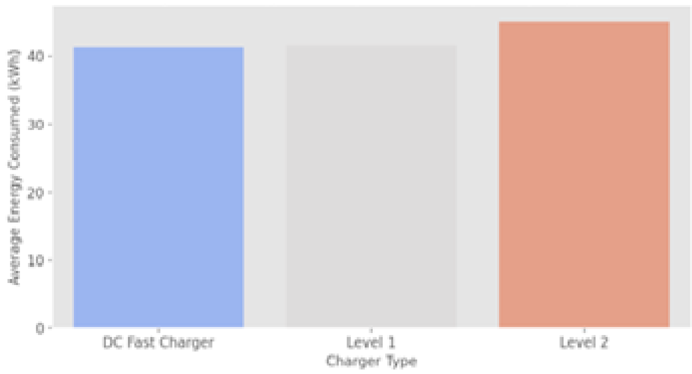

Figure 4: Energy consumption trends by Charger type

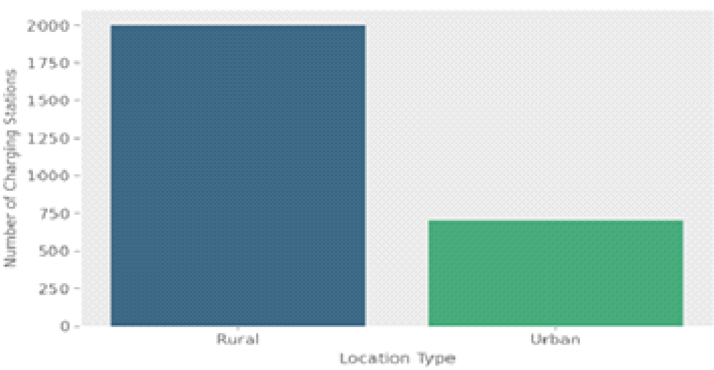

Figure 5: Urban vs. Rural Charging Accessibility

4. Conclusion

The study brings to light the major charging infrastructure pitfalls that the electric vehicle market has. When all stations are well distributed within cities, the rural and suburban areas remain very underserved thus creating disparities in the accessibility of EV. The uneven distribution directly affected charging behavior since urban-users had relatively more charging options while their rural counterparts had production and transportation logistics coupled with potential range anxiety. Second, the charger type was a more significant variable in infrastructure efficiency than seen before based on the analysis of the energy consumption evolving trends. Level 2 and DC Fast Chargers are built mainly for populous areas, thus allowing quick charging which contrasts with Level 1, mostly used in low-demand residential or workplace applications. Probably, well-coordinated using these charging practices may not only type congestion at areas of high demand but also elongates purely potential users.To address these issues, policymakers and industry stakeholders must focus on equitable infrastructure expansion. Targeted investments in rural charging stations, coupled with financial incentives such as tax credits and subsidies, can encourage private and public sector participation. Additionally, integrating renewable energy solutions into charging infrastructure can enhance energy resilience while promoting sustainability.

This underscores the importance of strategic planning in EV infrastructure deployment. By implementing data-driven policies and ensuring a balanced distribution of charging stations, stakeholders can bridge the infrastructure gap, alleviate range anxiety, and create a more accessible and efficient EV ecosystem. A well-integrated charging network is essential for fostering widespread EV adoption and achieving long-term sustainability in transportation.

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