**Mechatronics and Intelligent Transportation Systems**
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# Optimizing Electric Vehicle Charging Infrastructure: A Site Selection Strategy for Ludhiana, India

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**Received:** 07-28-2024 **Revised:** 08-31-2024 **Accepted:** 09-19-2024

**Citation:** H. K. Channi, "Optimizing electric vehicle charging infrastructure: A site selection strategy for Ludhiana, India," *Mechatron. Intell Transp. Syst.*, vol. 3, no. 3, pp. 179–189, 2024. https://doi.org/10.56578/mits030304.

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**Abstract:** This study investigates the spatial distribution and potential expansion of electric vehicle (EV) charging infrastructure in Ludhiana, India, with a focus on optimizing site selection to accommodate increasing demand. A multi-criteria framework was employed, incorporating traffic volume, demographic data, and usage patterns of existing charging stations to identify high-priority locations. Central commercial zones, including Ghumar Mandi, Feroze Gandhi Market, ISBT Ludhiana, and Ludhiana Railway Station, were found to exhibit significant traffic density and high EV ownership rates, making them prime candidates for the establishment of new charging stations. Spatial analysis, including heat maps, bar graphs, and pie charts, was used to visualize these key areas, revealing critical patterns in demand and facilitating the strategic targeting of infrastructure expansion. Community engagement was emphasized as an essential component in ensuring that infrastructure development aligns with user needs and preferences. The study further highlighted the importance of accessibility, economic viability, and sustainability as pivotal criteria for site selection. The findings offer valuable insights for urban planners and policymakers, supporting the development of a robust EV charging network that contributes to the advancement of sustainable urban mobility and the reduction of carbon emissions in Ludhiana. These results provide a basis for informed decision-making in the design of EV infrastructure, guiding the city's efforts towards an eco-friendly, future-ready transportation system.

**Keywords:** Electric Vehicle (EV); Charging infrastructure; Site selection; Traffic volume; Demographics; Sustainability

## 1 Introduction

The global push towards electric vehicles (EVs) represents one of the most significant transformations in the transportation sector, driven by the need to mitigate climate change, reduce air pollution, and decrease dependence on fossil fuels. EVs are central to these efforts, as they offer a cleaner alternative to internal combustion engine vehicles. In recent years, the EV market has expanded rapidly, supported by policy initiatives, technological advancements, and a growing awareness of the environmental impact of traditional vehicles. According to the International Energy Agency (IEA), global EV sales have consistently risen by around 50% annually, with over 14 million EVs sold in 2023 alone and a forecasted 30 million annual sales by 2030. This growth is particularly pronounced in regions with robust policy support, such as Europe, North America, and parts of Asia, where governments are implementing ambitious carbon reduction targets [1].

India, too, is undergoing a significant shift toward electric mobility. Government initiatives such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme and various state incentives are accelerating EV adoption across the country. The Ministry of Heavy Industries recently announced a target to establish 22,000 EV charging stations by 2030 to support its goal of having 30% of all new vehicle sales be electric by that year. This rapid expansion is expected to reduce India's annual $CO_2$ emissions by approximately 30 million tons, helping the country meet its international climate commitments under the Paris Agreement.Despite the growth in EV adoption, charging infrastructure development has struggled to keep pace. The IEA reports that globally, there is an average of one public charger per ten EVs, though this ratio varies widely by region. In countries like Norway and the Netherlands, there are high-density charging networks, ensuring that users have ready access to charging points. However, countries with emerging EV markets, including India, face significant infrastructure challenges.

With around 2,000 public chargers across the entire country, India has one of the lowest charger-to-vehicle ratios globally. This scarcity underscores the importance of strategic site selection for charging stations in urban centers where EV adoption is accelerating [2].

In Ludhiana, Punjab, one of India's rapidly growing urban and industrial hubs, EV registration has surged by 70% in the last two years. The increasing adoption rate in the city, largely driven by high fuel prices, environmental awareness, and government incentives, calls for an efficient, user-centered charging network to support daily EV usage. As of 2023, however, Ludhiana's EV charging network remains limited, with several high-traffic commercial areas and key transit points underserved. Addressing these gaps is crucial to alleviating range anxiety among EV users and to making EV ownership more accessible and practical [3].

A well-planned charging infrastructure is essential for user convenience and for maximizing EV utilization. Studies have shown that proximity to charging stations is one of the top considerations for EV buyers, with accessible chargers reducing range anxiety and promoting wider adoption. Site selection for charging stations, therefore, involves analyzing multiple factors, including traffic density, EV ownership concentration, land availability, and grid accessibility. Successful EV infrastructure in cities like Ludhiana must balance user accessibility with economic feasibility, particularly by locating chargers in high-demand areas such as commercial centers, transit hubs, and residential neighborhoods [4].

This study aims to optimize the siting of EV charging stations in Ludhiana by utilizing a data-driven, multi-criteria approach. By analyzing variables such as traffic volume, demographic patterns, and existing station utilization rates, this research identifies optimal high-demand locations for new charging infrastructure. Visualization tools, including heat maps and bar graphs, are used to highlight spatial demand patterns, enabling targeted infrastructure expansion that aligns with urban mobility goals and community needs. In doing so, the study not only addresses immediate infrastructure gaps but also contributes to a sustainable transportation framework that supports Ludhiana's transition toward a low-emission, electric mobility ecosystem. This research provides valuable insights for policymakers, urban planners, and stakeholders involved in developing EV infrastructure, establishing a framework that balances accessibility, sustainability, and economic viability. By prioritizing the needs of both current and potential EV users, Ludhiana can create an EV ecosystem that supports long-term environmental goals and enhances urban mobility for the future [5].

### 1.1 Background on Electric Vehicles

There is a technological revolution in the auto industry, especially in electric cars, facilitated by the improvements in technology in the manufacturing process of these cars, increasing environmental consciousness, and changing customer preferences. Unlike internal combustion vehicle engines, electric vehicles utilize electric motors powered by batteries. That means that their efficiency is much greener because they produce very few emissions of greenhouse gases as well as dependency on fossil fuels. The early electric vehicle—whether it was an invention or a discovery—dates back to the 19th century, with the first models demonstrating the potential of electrics as a means of propulsion. However, with the rise of gasoline-powered cars and advances in engine technology, EVs went out of favor for many decades in the 20th century. Increased awareness of climate change over recent decades and development in battery technology, mainly in lithium-ion batteries, have sparked renewed interest in electric mobility [6].

In addition, governments all over the world are introducing policies and offering incentives to promote the adoption of EVs through taxation benefits, rebates, and investments in charging infrastructure. More widely available models of EVs—from compact cars to SUVs—have also expanded consumer choices and made electric vehicles accessible to a bigger audience. Additionally, with the shift toward renewable sources of energy, electric mobility is geared toward building a more sustainable ecosystem for energy usage. This has no doubt led to progress: concerns over charging infrastructure, battery disposal, and price at purchase remain pressing issues. Yet the widespread adoption of smart technologies, including connected charging networks and vehicle-to-grid systems, is enough to make many of these problems melt away, making EVs both more appealing and more practical. In this context, the strategic development of charging infrastructure will be a critical factor. Widespread acceptance of EVs and consequently the accomplishment of environmental and economic objectives will require proper support for charging stations and all the essential infrastructural arrangements [7].

### 1.2 Importance of Charging Infrastructure

Charging infrastructure is considered a backbone of the electric vehicle ecosystem, especially regarding the transformation from gasoline-powered to electric mobility. Figure 1 illustrates why this has significant importance for several key factors: Accessible and well-distributed charging stations help overcome end-user range anxiety and encourage them to travel more miles without the fear of battery depletion. This directly affects consumer purchasing decisions on EVs since an increasingly dense set of charging stations remains to make the market even more attractive to the prospecting buyers. Further, a strong charging network ensures that both urban and rural areas enjoy fair access to electric mobility, as it would come to aid the various demographic sections. Of course, there is also a further opportunity for reducing the carbon footprint of EVs if renewable energy sources are also fed into the chargers in stations. The investment in charging in frastructure also stimulates local economies by attracting businesses and tourism as most stations act as commodity centers. Second, smart charging technologies also provide vehicle-to-grid (V2G) capabilities, improving peak demand times on the grid [8]. Finally, optimal charging infrastructure is needed to meet aggressive regulatory milestones aimed at the reduction of emissions and an increase in the adoption of EVs. In short, a well-designed charging infrastructure is quite fundamental in creating the optimum customer experience in line with environmental sustainability and economic growth, thus making it an indispensable part of the future of transportation [9].

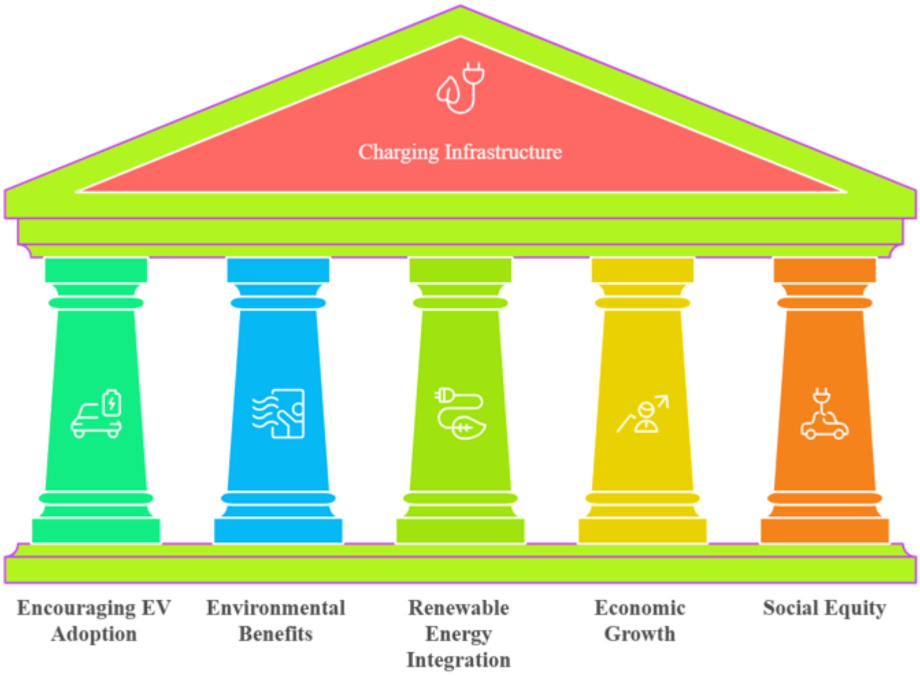


**Figure 1.** Importance of charging infrastructure

### 1.3 Literature Survey

The literature on optimal site selection strategies for EV infrastructure includes various studies that focus on different aspects of energy management and planning. Al Wahedi and Bicer [10] conducted a case study in Qatar to assess the optimal sizing of renewable energy and storage systems for an autonomous electric vehicle fast charging station. The study aimed to fulfill the daily EV demand in an uninterruptable manner by incorporating hybrid wind, solar, and biofuel systems along with ammonia, hydrogen, and battery storage units. Li et al. [11] proposed a data-driven planning approach for electric vehicle charging infrastructure in Sydney, Australia. The study introduced a market-based mechanism and a competitive resource allocation strategy for EV charger planning using a predict-then-optimize diagram and a Cournot competition game model. Janjić et al. [12] developed a multi-criteria P-median methodology to optimize the number and locations of electric vehicle charging stations, with a case study in the city of Niš, Serbia. Duan et al. [13] investigated the planning strategy for an electric vehicle fast charging service provider in a competitive environment, considering queuing impacts on EV users. The study integrated a user equilibrium traffic assignment model with queuing theory and an adaptive route selection algorithm to optimize the planning scheme of a CSP. ElGhanam et al. [14] proposed an online, mobility-aware, spatial EV allocation algorithm within a dynamic wireless charging coordination strategy, evaluated using a hypothetical case study in Dubai and Sharjah, UAE. Overall, these studies highlight the importance of considering renewable energy sources, competitive environments, queuing impacts, and spatial allocation algorithms in the optimal site selection strategies for EV infrastructure. Future research could further explore the integration of renewable power generation systems, multi-criteria decision-making methodologies, and dynamic infrastructure allocation strategies to enhance the efficiency and sustainability of EV charging stations.

### 1.4 Problem Formulation

The problem of optimal site selection for EV infrastructure involves identifying strategic locations to maximize accessibility, efficiency, and sustainability. For this case study, the goal is to develop a framework that evaluates potential sites based on criteria like proximity to high-demand zones, grid connectivity, renewable energy integration, and socio-economic impact. The problem also considers minimizing costs, travel times, and environmental impact while ensuring scalability for future expansion. The challenge is to balance these factors in a model that uses geographic, economic, and demand data to recommend optimal charging station locations, particularly suited for rural or underserved regions [15]. The primary goals for analyzing the EV charging infrastructure of Ludhiana are discussed below:

-Assess the charging stations available, and study traffic and demographical data to understand which regions need the most additional charging stations based on peak demand.

-Determine ideal location selection criteria for new EV charging stations, based on accessibility and key factors such as traffic, supply, and demand patterns, proximity of existing key destinations, infrastructure, and other target users or business opportunities.

-Engage residents and businesses in the planning process to ensure, while the charging infrastructure is fulfilling the needs of the community, that it is promoting the adoption of EVs.

## 2 Methodology

The decision on the most appropriate location for electric vehicle charging stations shall be based on key evaluation areas that shall be considered in ensuring that the infrastructure puts more emphasis on user needs, maximization of utilization, and relevance to community goals [16]. Access to the location of charging stations should be conveniently sited, preferably near access roads and highway intersections as well as busy traveling zones, near public transport stations, as depicted in Figure 2. Traffic nature and volume analysis is important to identify high-potential usage areas, especially in busy commercial districts or travel corridors, which are going to have more demand for charging services. In addition, strategic location in places visited regularly, such as shopping centers, restaurants, workstations, and recreational places, is convenient for EV owners and encourages prolonged dwell times for efficient charging. Utility infrastructure and the capacity to be found at potential sites must also be evaluated to ensure they can support the needed power by charging stations, with proximity to the substations making the installation faster and cheaper. Understanding land use regulations and zoning laws is a good factor for compliance and feasibility; one should check out the zoning compatibility of sites and necessary permits and talk to a local planning department to ensure smooth compliance with these regulations. Sites must be secure and safe, too; charging stations need to be placed in well-lit and highly visible areas to enhance user safety. Assess vandalism risks and deploy enough security measures, such as cameras, etc. [17]. Finally, engagement with local communities offers precious insight into how users think in terms of their preferences and concerns and would help build support for the project and, hopefully, collaborative partnerships with local businesses and government. By considering site selection criteria, stakeholders will improve the effectiveness and accessibility of EV charging infrastructure and work towards improved user experiences while attaining goals related to sustainability by the community.

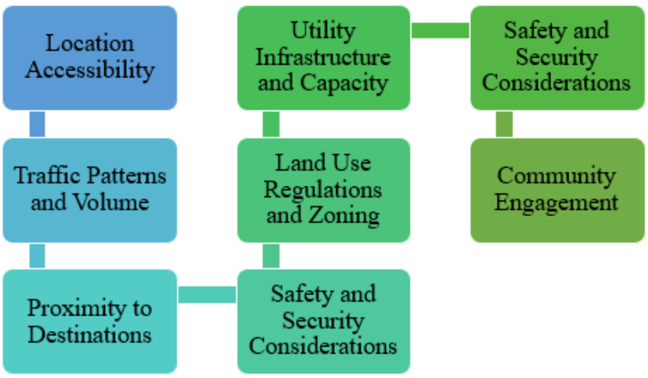


**Figure 2.** Site selection criteria

## 3 Case Study of Ludhiana

The northern Indian state of Punjab's Ludhiana city has been aggressively uplifting electric vehicle charging infrastructure to counter rising environmental issues, along with the mass adoption of electric vehicles. The city officials have launched several initiatives in partnership with private players focused on setting up a comprehensive network of charging stations across the city. Identification of places with high traffic and strategic locations nearer to commercial centers and transport stations to ensure easy access for the users. For these analyses, MATLAB software was used for analysis when determining possible sites of charging stations based on these factors: traffic patterns, demographic data, and proximity to already extant electrical infrastructure. It involves the use of geospatial data to create heat maps where areas of high EV ownership are located and where expected charging demand would be high [18]. The model is very rich by integrating different types of data sets to help find appropriate optimal charging station placement to maximize utilization in support of the city's sustainability goals. The case study of Ludhiana epitomizes data-driven decisions in the development of effective EV infrastructure and positions the city as a model for other cities in India that aspire to transition to electric mobility. The methodology for the analysis of EV charging infrastructure in Ludhiana involves the following key steps as shown in Figure 3. Traffic patterns, demographics, and charging stations already exist, and geospatial information is gathered, cleaned, and integrated into the data set. The analysis is finalized by incorporating the generation of heat maps that can define where demand is most likely to be located and by assessing charging demand using regression models. Sites are then selected based on several developed criteria. Also, there are engagements with the community through surveys and stakeholders' meetings for input. Finally, phased implementation is developed, and usage rate and user feedback are monitored so that the infrastructure meets the needs of the community.

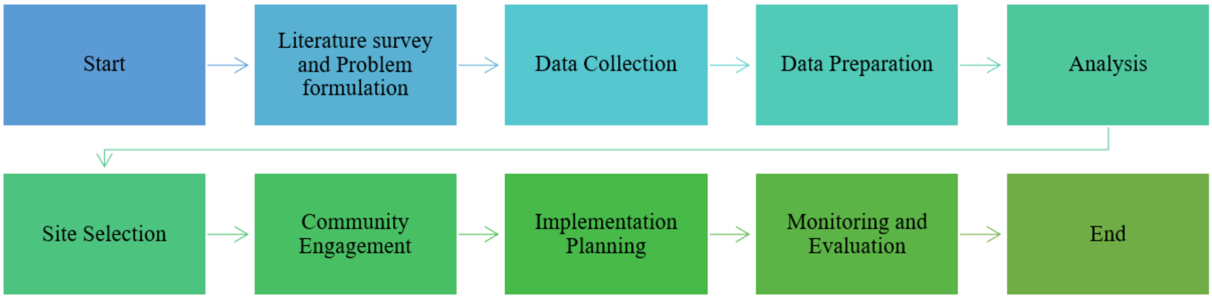


**Figure 3.** Methodology flow chart

**Table 1.** Traffic data

| Location ID | Latitude | Longitude | Traffic Volume (Vehicles/Day) | Peak Hour Volume (Vehicles) |
|---|---|---|---|---|
| 1 | 30.9009 | 75.8573 | 12000 | 1500 |
| 2 | 30.9076 | 75.8523 | 8000 | 1000 |
| 3 | 30.9142 | 75.8432 | 15000 | 2000 |
| 4 | 30.9015 | 75.8586 | 9500 | 1200 |

**Table 2.** Demographic data

| Location ID | Population | Average Income (INR) | EV Ownership Rate (%) | Area Type (Urban/Rural) |
|---|---|---|---|---|
| 1 | 25000 | 30000 | 5 | Urban |
| 2 | 15000 | 25000 | 4 | Urban |
| 3 | 20000 | 20000 | 3 | Rural |
| 4 | 10000 | 15000 | 2 | Rural |

**Table 3.** Charging station data

| Station ID | Location ID | Charging Type (Level 2/DC Fast) | Number of Ports | Installed Date | Usage Rate (Charges/Month) |
|---|---|---|---|---|---|
| 1 | 1 | DC Fast | 4 | 2023-01-15 | 150 |
| 2 | 2 | Level 2 | 2 | 2023-03-10 | 80 |
| 3 | 3 | DC Fast | 6 | 2023-02-20 | 200 |
| 4 | 4 | Level 2 | 3 | 2023-05-05 | 50 |

The methodology involved collecting and preprocessing traffic, demographic, and EV usage data for Ludhiana, followed by multi-criteria analysis and geospatial modeling in Google Colab. Machine learning models were used to predict future EV demand, and site selection simulations were run to identify optimal charging station locations.

Google Colab provided an efficient, cloud-based platform for analyzing and visualizing data on traffic, demographics, and EV station usage in Ludhiana, supporting the optimization of EV charging station site selection. Its integration with libraries like Pandas, NumPy, and machine learning tools, along with free GPU/TPU resources, enabled collaborative, data-driven decision-making and predictive modeling for future demand patterns. Ghumar Mandi, Feroze Gandhi Market, ISBT Ludhiana, and Ludhiana Railway Station were selected based on their high traffic volumes, proximity to key commercial and transportation hubs, and significant EV ownership rates. These locations are central to Ludhiana's urban fabric, making them ideal candidates for the installation of new EV charging stations to cater to growing demand. Traffic data contains critical information on vehicle flow, and each row specifies a unique location identified by latitude and longitude as shown in Table 1; it captures daily traffic volume and peak hour volumes and identifies which places are high-demand areas that can be considered for potential charging stations. Demographic data provides population characteristics for each location, indicating statistics for population count, mean income, and percentage of EV in the population as indicated in Table 2. This allows for evaluating demand for charging infrastructure with distinctions between urban and rural settings. Charging station data lists all the available facilities for EV charging, indicating the type of charge, accessible number of charging ports, installation date, and usage rates expressed by monthly charges. Table 3 is a comprehensive dataset that acts as a starting point for understanding the current infrastructure, predicting the demand, and thereby planning strategically for future requirements in Ludhiana [19, 20].

Figure 4 shows a bar graph of the volume of traffic by location and depicts graphically the daily vehicle counts at various sites in the city of Ludhiana. Each bar illustrates a specific location and, in its vertical magnitude, the volume of traffic. There is hence an easy comparison of traffic levels by which locations have the highest flow of vehicles. The analyzed data may be utilized by the stakeholders to identify which areas have potential demand for a charging station for electric vehicles to provide infrastructure in such areas. The traffic volume data collected from four locations reveals varying levels of vehicle activity, essential for determining optimal sites for EV infrastructure. Location 3 has the highest traffic volume, with 15,000 vehicles per day, suggesting it might be a prime candidate for EV charging stations due to the high potential user base. Location 1 follows closely with 12,000 vehicles per day, also indicating significant demand potential. Location 4, with 9,500 vehicles per day, and Location 2, with 7,500 vehicles per day, have lower but still substantial traffic flows. This data implies that Locations 1 and 3 would likely yield the highest utilization rates, whereas Locations 2 and 4, though less trafficked, could be secondary options that still contribute to overall network efficiency by serving additional traffic clusters.

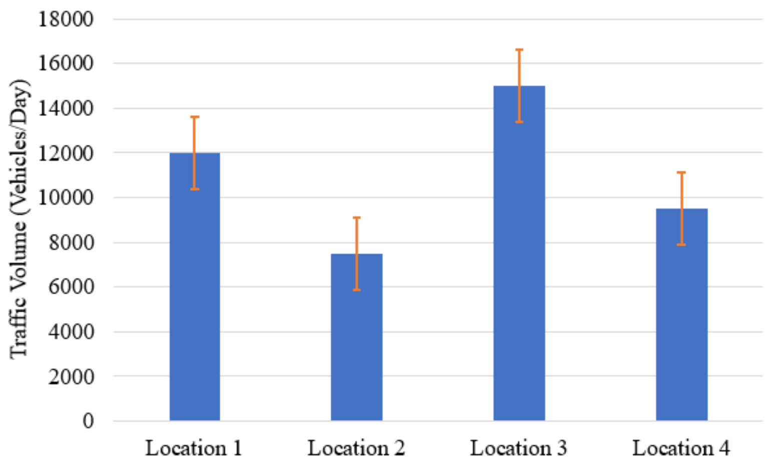


**Figure 4.** Traffic volume by location

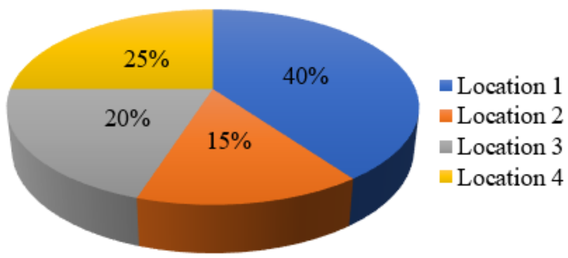


**Figure 5.** EV ownership rate by location (%)

Figure 5 shows a pie chart of EV ownership rates by place. It describes the percentage of electric vehicle ownership across various regions of Ludhiana. Each segment in the pie symbolizes a particular place, and the size of the segment illustrates the proportion of EV owners to the overall population in that place. This visualization would help understand ownership distribution of EVs among stakeholders, especially areas with higher adoption rates, so they can precisely identify where there should be investment in charging infrastructure to promote further electric vehicle adoption and improve the overall ecosystem of EVs in the region. The pie chart shows the EV ownership rate across four locations, totaling 100 units. Location 1 has the highest EV ownership rate at 40%, suggesting a higher demand for EV infrastructure, given the larger concentration of EV users. Location 4 follows with 25%, and Locations 3 and 2 have ownership rates of 20% and 15%, respectively. This distribution highlights Location 1 as a priority site for EV infrastructure development, with significant user demand. However, Locations 4 and 3 also show moderate demand, which could justify secondary infrastructure to create a well-distributed network.

Figure 6 provides population (in thousands) and traffic volume (in thousands of vehicles per day) for four locations, helping to assess the potential demand for EV infrastructure. Location 1 has the highest population of 2.5 thousand and a significant traffic volume of 1.2 thousand vehicles, indicating a substantial base of potential users for EV charging stations. Location 3, with a population of 2 thousand and the highest traffic volume of 1.5 thousand vehicles per day, also shows strong potential, especially for high-traffic areas. Location 2, with a population of 1.5 thousand and traffic volume of 0.8 thousand, and Location 4, with a population of 1 thousand and traffic volume of 0.99 thousand, reflect moderate demand. These insights suggest that Locations 1 and 3 are priority areas for EV infrastructure due to their higher population density and traffic, while Locations 2 and 4 may support additional, strategically placed charging facilities to optimize network coverage.

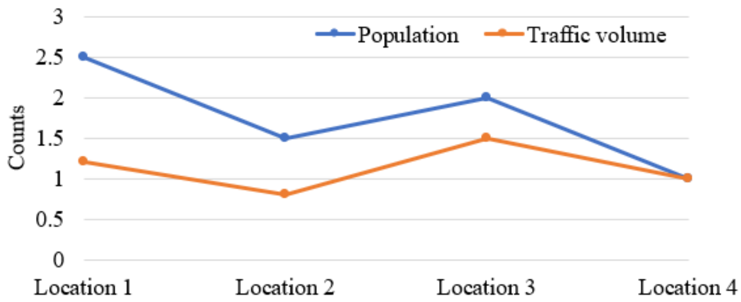


**Figure 6.** Population vs. traffic volume

The monthly usage rates measured in the number of charges per month for a given charging station are presented in Figure 7, which represents the line graph of charging station usage over time. Each point on the graph corresponds to a month and marks how the usage varies in the chosen period. The upward trend reveals increasing adoption of electric vehicles and greater reliance on the charging infrastructure. This visualization helps stakeholders understand the patterns of user behavior and demand and then make better decisions about future investments, positions of stations, or expansions of charging facilities to meet increasing demands.

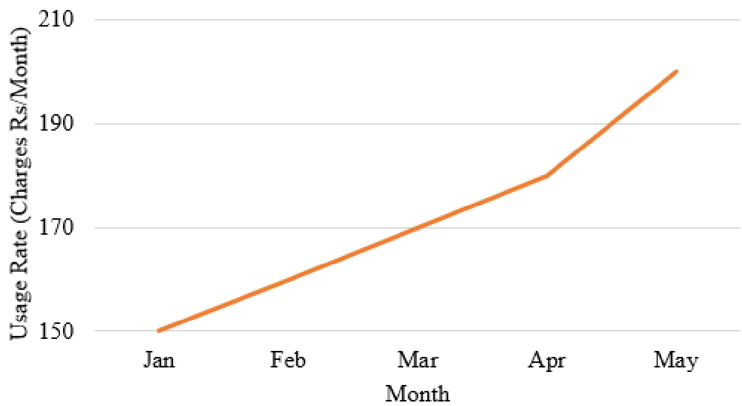


**Figure 7.** Charging station usage over time

The line plot of population versus traffic volume demonstrates the relationship between the number of residents and the number of daily vehicle counts at different locations in Ludhiana as depicted in Figure 8. Every line is a representation of population or traffic volume that can easily allow cross-comparison across the defined locations.

The trend across the plot includes whether areas with high populations are related to increased traffic volumes. This analysis is important to urban planners as it will alert them of the possible placement of EV charging stations, allowing them to develop a probably aligned infrastructure in areas with high demands and population density.

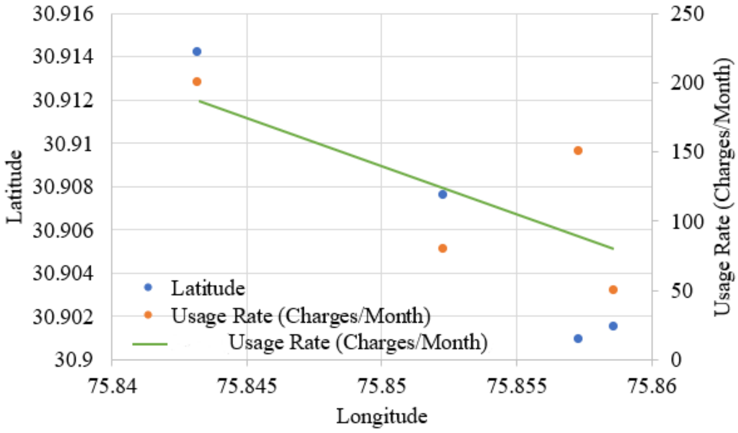


**Figure 8.** Heat map of charging station locations

The monthly usage rate data for EV charging shows a steady increase in demand from January to May. In January, the usage rate is Rs150 charges per month, which rises slightly to Rs160 in February and continues to increase each month. By March, the rate reaches Rs170 charges per month, indicating growing interest and demand for EV charging. In April, usage increases further to Rs180 charges, and by May, it peaks at Rs 200 charges per month. This upward trend suggests that demand for EV charging infrastructure may be seasonal or influenced by other factors, such as favorable weather or higher travel activity in spring. Planning for EV infrastructure should account for these variations in demand to ensure that charging capacity meets peak usage.

Figure 8 shows a heatmap that provides insights into the usage rate, daily traffic volume, and peak hour volume at four specific locations, identified by their latitude and longitude coordinates. Location at (75.8432, 30.9142) exhibits the highest values across all metrics, with a usage rate of 200 charges per month, a daily traffic volume of 15,000 vehicles, and a peak hour volume of 2,000 vehicles. This indicates a high demand for EV charging infrastructure, likely due to substantial traffic and user concentration. The location at (75.8573, 30.9009) follows with a usage rate of 150 charges per month and a daily traffic volume of 12,000 vehicles, suggesting moderate demand. Meanwhile, the location at (75.8523, 30.9076) has a lower usage rate of 80 charges per month and an 8,000 daily traffic volume, and (75.8586, 30.9015) shows the lowest demand with only 50 charges per month despite having a traffic volume of 9,500 vehicles per day. This heatmap indicates that demand for EV charging aligns closely with both high traffic volumes and peak hour usage, highlighting locations (75.8432, 30.9142) and (75.8573, 30.9009) as primary candidates for EV infrastructure expansion.

## 4 Results and Discussion

The analysis of optimal site selection for EV charging infrastructure, based on traffic volume, EV ownership rate, population density, and usage rate, provides a comprehensive understanding of demand across four different locations. Each data set—traffic volume, EV ownership rate, population, and monthly usage rate—reveals unique insights about the suitability of each location for EV infrastructure expansion. Traffic volume and peak hour data indicate potential demand based on vehicle flow. Location 3, with the highest daily traffic volume of 15,000 vehicles and a peak hour volume of 2,000 vehicles, stands out as a prime candidate for EV infrastructure due to its high traffic density, which increases the likelihood of EV users in need of charging. Location 1, with 12,000 vehicles per day and a peak hour volume of 1,500, also demonstrates significant potential. Locations 2 and 4 have lower traffic volumes, at 8,000 and 9,500 vehicles, respectively, with lower peak hour volumes, making them secondary options. EV ownership rates further highlight where EV infrastructure may be most beneficial. Location 1 has the highest EV ownership rate at 40%, followed by Location 4 at 25%, Location 3 at 20%, and Location 2 at 15%. The high ownership rate at Location 1 aligns well with its substantial traffic volume, indicating that this location could see high utilization of EV charging stations. Location 4, despite lower traffic volume, has a moderate ownership rate, suggesting localized demand even with lower vehicle flow. Population density correlates with traffic volume, providing another layer of insight. Location 1 has the highest population of 2.5 thousand with significant traffic flow (1.2 thousand vehicles), suggesting a concentrated demand area for EV infrastructure. Location 3, with a population of 2 thousand and the highest traffic volume (1.5 thousand vehicles), further supports its selection as a priority site due to both traffic and population. In contrast, Location 2, with a population of 1.5 thousand and lower traffic volume, may not require immediate infrastructure expansion, while Location 4's smaller population (1 thousand) aligns with its moderate traffic volume.

The monthly usage rate for EV charges shows a seasonal or steady increase in demand from January to May, peaking at 200 charges in May. Location-specific data reveal that Location 3 has the highest monthly usage rate of 200 charges, followed by Location 1 with 150 charges. This trend confirms that these two locations not only experience high traffic but also have an active EV user base. Locations 2 and 4, with lower usage rates of 80 and 50 charges, respectively, may serve as supplementary sites but do not exhibit the same level of demand as Locations 1 and 3. The combined analysis suggests that Locations 1 and 3 are the optimal sites for EV infrastructure due to their high traffic volumes, peak hour intensity, substantial population, and higher monthly usage rates. These factors indicate a robust demand for charging facilities, making them ideal candidates for prioritizing infrastructure investment. The high EV ownership rate in Location 1 further supports its suitability as a key site. Locations 2 and 4, while still relevant, exhibit lower demand across these metrics, suggesting they may be better suited for secondary or supplementary charging stations that can serve overflow or meet regional needs without extensive investment. The seasonal variation in charging demand, as seen in the increasing usage rates from January to May, suggests that EV charging needs fluctuate with changes in weather, travel patterns, or specific seasonal activities. This trend highlights the need for adaptable, smart charging strategies that can optimize power distribution and reduce peak load stress during high-demand periods. Smart charging systems, using data-driven predictions, can balance grid loads by scheduling charging during off-peak hours, prioritizing high-demand locations, and integrating renewable energy sources to improve efficiency and sustainability year-round. This approach demonstrates the importance of integrating traffic, population, and usage data in EV infrastructure planning. By focusing on high-demand areas, urban planners and policymakers can enhance accessibility, improve utilization rates, and support the growing transition to electric vehicles, all while ensuring an efficient allocation of resources.

## 5 Future Trends and Innovations

Emerging technologies, changing policies, and dynamic market predictions offer a very bright future for electric vehicle charging. New developments in electric vehicle charging systems are going to change the user experience and the efficiency of infrastructure. Such developments include ultra-fast charging stations, with which a car can gain 100 percent charge within 15 minutes. Waiting time for cars will become much less with such charging stations. Another technology being developed is wireless charging technology; its development makes charging even easier for vehicles that do not need a physical connection. Another innovative technology with the ability to draw energy from the grid and provide surplus energy back into the grid to stabilize energy usage within the grid is referred to as V2G, or vehicle-to-grid.

Simultaneously, policy changes are expected to play an important role in shaping the future landscape of EV charging. Charging stations will begin receiving mandatory installations in new developments and incentives to retrofit existing infrastructure globally as governments continue to introduce regulations. It is an aggressive step not only to expand the charging network but also to encourage the use of renewable energy in powering these stations. Tighter emission controls will likely speed up what is already an accelerating rate of adoption for EVs, making comprehensive charging infrastructure doubly necessary.

Since rising demands from consumers for electric vehicles, combined with favorable governmental frameworks, have increased, predictions for the EV charging market have shown marked above-average growth for these coming years. Analysts predict exponential growth in the global EV charging market, characterized by immense investment in public and private charging networks. Continued advancements in battery technology will keep adding to long ranges and shorter charge times and boost the confidence of consumers in electric vehicles. In general, a combination of emerging technologies, favorable policy, and increasing consumer acceptance is sure to result in a transformative future for the EV charging market that will lay the ground for a more sustainable transportation ecosystem.

## 6 Conclusion

This study highlights that developing an effective EV charging infrastructure in Ludhiana requires a multi-faceted strategy focused on accessibility, sustainability, and community engagement. Key insights from traffic volume, EV ownership rates, population density, and seasonal usage patterns indicate that a data-driven, multi-criteria approach can optimize the placement and utilization of charging stations. Locations 1 and 3 emerge as high-priority sites due to their high traffic flow and substantial usage rates, making them ideal for maximizing charging infrastructure efficiency. Strategically selecting high-demand locations, informed by market and community analysis, ensures that charging stations are readily accessible and fully utilized. Collaboration with local businesses and government agencies can further strengthen the network, promoting community ownership and supporting adoption. Looking forward, adopting ultra-fast, wireless charging, and renewable energy sources will be critical to future-proofing the network. Moreover, incentives and supportive regulations, combined with interoperable payment systems, can ease friction in EV adoption. Stakeholder engagement during planning and implementation, along with continued investment in public education and awareness, will help align the infrastructure with community needs and expectations. Ultimately, this comprehensive approach to EV infrastructure development not only facilitates the shift to electric mobility but also advances broader environmental goals by improving air quality, reducing carbon emissions, and enhancing urban resilience. Ludhiana's commitment to such sustainable practices positions it as a forward-thinking city at the forefront of the EV movement, ready to meet the transportation needs of today and the future.

**Data Availability**

The data supporting our research results are included within the article or supplementary material.

**Acknowledgments**

The author would like to express his sincere gratitude to the Department of Electrical Engineering, Guru Nanak Dev Engineering College, Ludhiana, Punjab, for their invaluable support and guidance throughout this research. Their resources and expertise greatly contributed to the successful completion of this study.

**Conflicts of Interest**

The author declares no conflict of interest.

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