EV Infrastrucutre Exploration

Zixuan Zhao
ziz057@ucsd.edu

Phi Nguyen
pnguyen@sdge.com

Abstract

With rising environmental concerns and policy incentives, the electric vehicle (EV) market has grown rapidly. Despite this growth, current EV infrastructure lacks equitable accessibility across diverse communities. Prior studies often overlook the integration of demographic and vehicle type data in analyzing charging station distribution. This project addresses this gap by incorporating demographic and vehicle data. The goal of this research is to assess the alignment of current infrastructure within the San Diego area, providing insights that may guide the expansion of alternative fueling stations to support the increasing demand of sustainable transportation in the future. Methods include data fusion, time-series analysis, and graph theory to unearth insights using packages like OSMnx and datasets from the Alternative Fuels Data Center (AFDC), American Community Survey (ACS), and California Department of Motor Vehicle (DMV).

Code Repo: https://github.com/zzirving/CapstoneQ1/

1 Introduction

As environmental concerns and policy incentives drive the demand for cleaner transportation, Electric Vehicles continue to expand rapidly worldwide. In 2023, almost 14 million new electric cars were registered worldwide. This surge represents a 35% increase from 2022 and highlights the momentum within the EV market, which now comprises around 18% of all cars sold, compared to just 2% five years earlier in 2018. Within the San Diego Gas & Electric (SDG&E) territory, where California's adoption of EVs has consistently outpaced national averages, the need for robust and accessible EV infrastructure is critical. This report investigates the distribution of alternative fuel charging stations along with regional demographics and vehicle fuel types, with the aim of identifying gaps and inform future infrastructure development.

The main dataset used in this study is the Alternative Fuels Data Center (AFDC) dataset, which provides comprehensive information on alternative fuel charging stations across the United States. Each entry represents a unique charging station and includes key features such as the station's open date, fuel type, geographic coordinates (latitude and longitude), and zip code. This dataset is invaluable to the project because it offers detailed, location-specific data that allows for a spatial analysis of charging station accessibility within SDG&E territory.

Two complementary datasets are used. The first complementary dataset is 2022 American Community Survey 5-year data. This dataset, organized by zip code, offers demographic variables such as population density, median income, and education level. It can be merged with our main dataset via zip code. This data allows us to analyze the relationship between demographic characteristics and the availability of alternative fueling infrastructure. The second additional dataset is Vehicle Fuel Type Count by zip code. This dataset provides critical insights into the types of vehicles predominantly used in each area and enables us to assess whether the current infrastructure aligns with the local demand for specific fuel types.

Several studies have been conducted on the distribution of EV stations. The Pew Research Center's 2024 analysis on the state of EV charging infrastructure emphasizes the disparity in charging station accessibility across the U.S. This study underscores that while major urban areas often have robust charging networks, rural and lower-income communities are frequently underserved. The study also indicates that high-traffic corridors and intercity highways require more charging points to support long-distance EV travel effectively. These findings underscore the importance of strategically placed charging stations to encourage broader EV adoption and equitable access. SEPA Power's report on EV Charging Infrastructure provides a technical analysis of EV infrastructure needs, focusing on the operational requirements and challenges associated with integrating EV charging stations into the existing power grid. SEPA's study points out that the increase in EV demand places considerable pressure on local grids, particularly in areas with dense EV usage. This report highlights the importance of considering grid capacity and stability when expanding charging networks, as areas with insufficient grid resources may face challenges in meeting charging demand without upgrades.

2 Methods

2.1 AFDC Dataset

The AFDC dataset was collected using the public AFDC API with a personal access key. The EDA on this dataset consists of pre-processing, time-series analysis, and geographic analysis.

In the pre-processing phase, the dataset's structure and format were assessed. I dropped the irrelevant columns, queried the data to only filter for zip code within the SDG&E territory, and created a new column, `open_year`, from `open_date` to better facilitate time-series analysis.

The time-series analysis explored the growth of alternative fuel stations over time. Figure 1 uses the Race bar chart to effectively visualize the cumulative number of alternative fuel stations in notable cities in the SDG&E region over the years.

The spatial analysis makes use of folium library to create interactive map. It plots all alternative fuel stations in the SDG&E territory (green dots), 30 major shopping malls/plazas (red dots), and 30 key company/office locations (black dots) in the area, using longitude and latitude coordinates.

2.2 ACS Dataset

The American Community Survey data was obtained through the Cenpy package. It is broken down by zip code, each entries provides information on a zip code's demographic, such as median household income, total population, and population with advanced degrees.

To understand the spread and central tendencies of these variables, I used box plots to visualize the distribution of the median household income. And used scatter plots to investigate potential correlations between these socio-economic variables and the number of chargers in each zip code, the results were surprising:

2.3 DMV Dataset

This dataset is available via the ca.data.gov public API. There are 6 individual datasets for the years of 2023, 2022, 2021, 2020, 2019, 2018. This study chooses the latest 2023 version to best represent the current situation. Each row represents a specific combination of vehicle attributes aggregated within a given ZIP Code, which captures the total count of vehicles meeting the specified criteria within a particular geographic region.

Pie chart are used to show the distribution of fuel types across all registered vehicles. Intrigued by how fuel type varies between vehicle weight categories, we created a stacked bar chart to show the distribution of fuel types within each weight class. Additionally, we generated a time series plot that showcase the relationship between installation of EV chargers and adoption of EV vehicle using data merged with the AFDC dataset

2.4 OSMnx

OSMnx is a Python package designed for working with OpenStreetMap (OSM) data to model, analyze, and visualize street networks and related geospatial data. It is especially useful in urban planning, transportation analysis, and geographic data visualization.

Building on the capabilities of OSMnx, we developed a method that finds the closest charger to a given location. The method takes a geographic coordinate (latitude and longitude) as input and returns: The closest charger's location, the distance in kilometers to the charger, and a plot of the driving route between the two points.

3 Results

https://zzirving.github.io/CapstoneQ1/bar_race.html

Figure 1: Dynamic Race bar chart of cumulative EV charger counts between cities

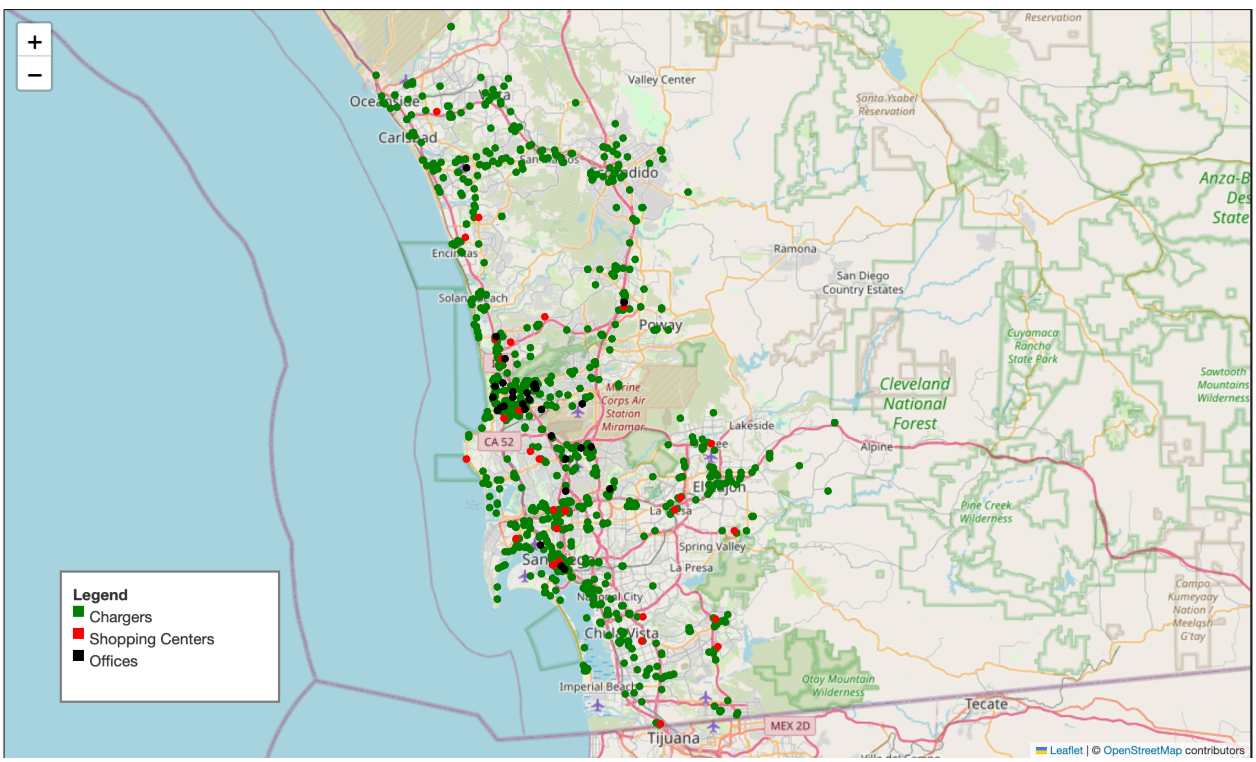

Figure 2: All alternative Fuel stations, plotted with 30 shopping centers and 30 major company offices

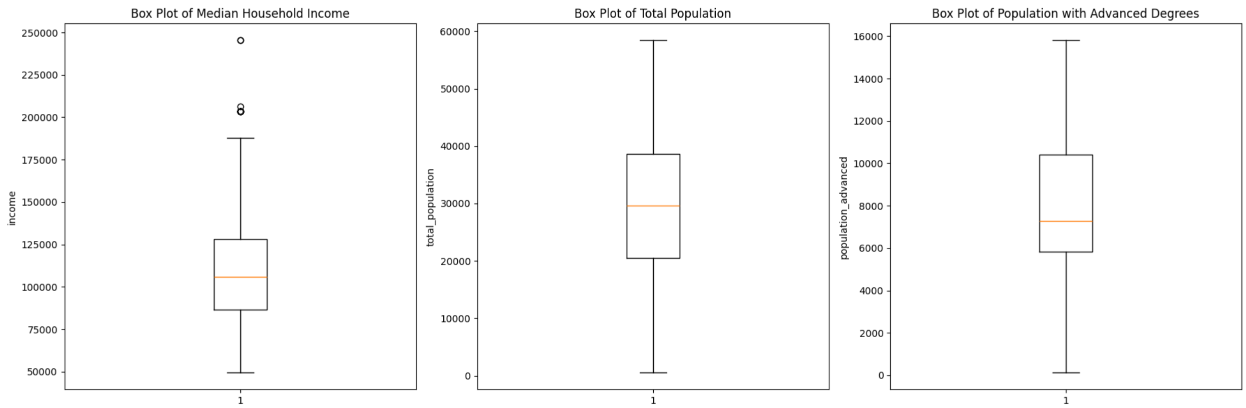

Figure 3: distribution of Median Household Income, Total Population, and Population with advanced Degree

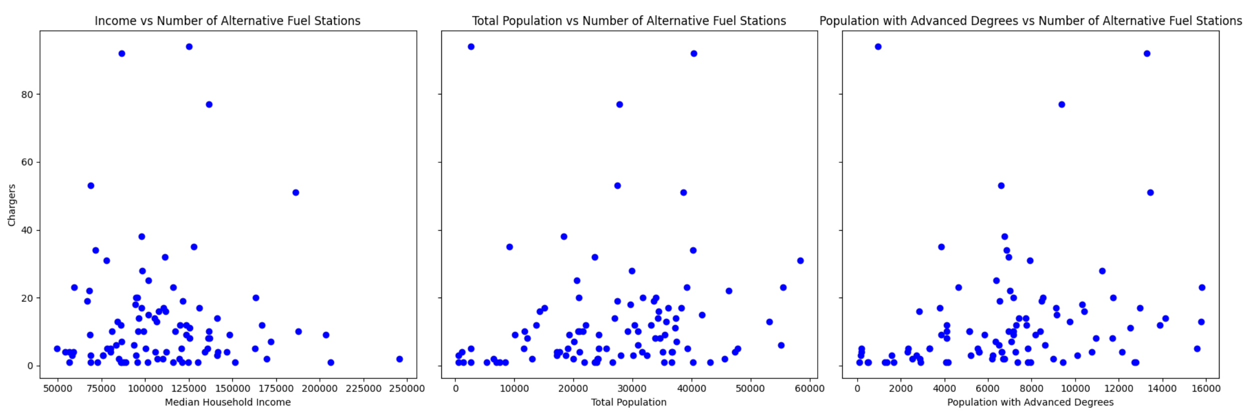

Figure 4: Correlation between the Number of Alternative Fuel Stations and Median Household Income, Total Population, and Population with Advanced Degrees

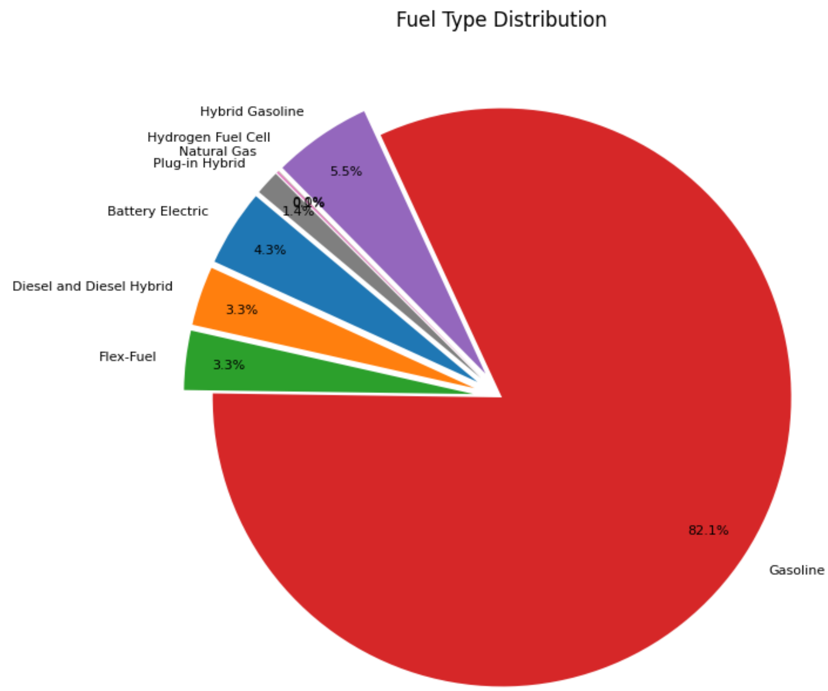

Figure 5: fuel type distribution of all registered vehicles

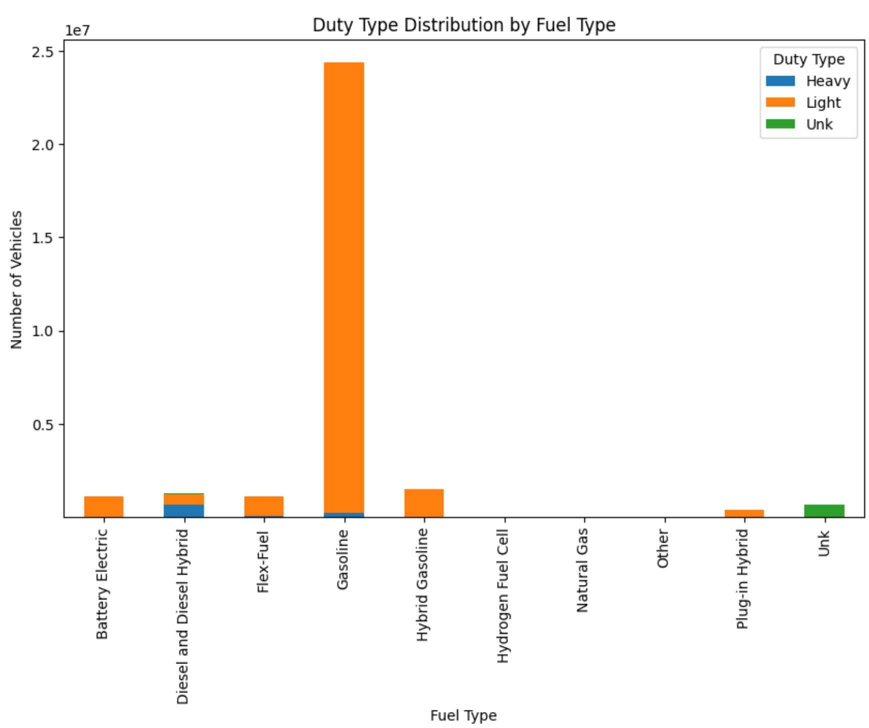

Figure 6: Duty type distribution within each fuel type

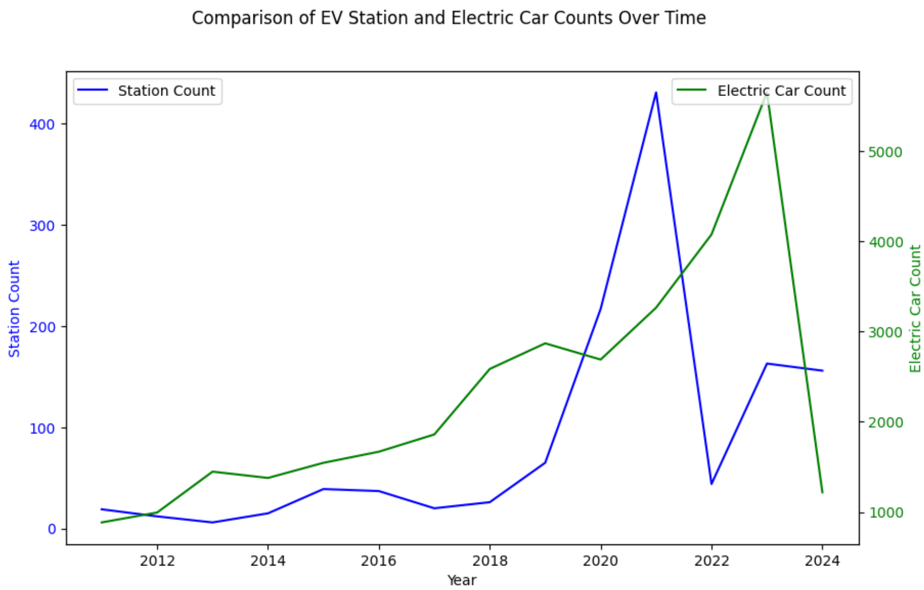

Figure 7: Comparison of EV station counts and electric car counts over time, showing trends in infrastructure growth and vehicle adoption

Figure 8: Finds the closest charger given an arbitrary point(UCSD in this example)

4 Discussion

4.1 AFDC EDA

Figure 1 illustrates the evolution of electric vehicle (EV) charger adoption across cities. Initially, around 2010, most cities had only a minimal number of chargers. However, starting in approximately 2013, San Diego experienced a rapid expansion in EV infrastructure, significantly outpacing other cities. Around the same time, some cities that previously have no chargers began establishing their initial EV charging stations. This period marks the first notable boom in EV infrastructure development, likely due to California's strong policy incentives for clean energy, such as tax credits and grants. Another contributing factor could have been the growing popularity of early EV models, such as the Tesla Model S, which increased the necessity for public charging infrastructure., likely driven by increased awareness of climate action and regional competition to attract environmentally conscious residents.

A second surge in growth is observed around 2020, during which the number of chargers in each city increased exponentially. This growth could be explained by the inclusion of green energy investments in post-COVID-19 recovery packages, which allocated significant resources to EV infrastructure development. Moreover, the exponential growth of EV sales due to falling battery costs and the availability of affordable EV models likely drove the urgent need for more chargers. In many cases, more chargers were installed within a single year than in the entire preceding decade, reflecting both policy-driven mandates and increased private investments in EV networks by companies such as Tesla and ChargePoint.

An interesting observation is that Poway established the first electric station in 1991, but as of 2024, it has the least number of chargers in the SDG&E territory.

Figure 2 reveals that EV chargers are located where the population gathers (shopping mall, workplace) and where the traffic is the heaviest (crowded highways). These findings align with our expectations, as these locations maximize the accessibility and convenience for EV users. Shopping malls and workplaces are destinations where people spend significant amounts of time, making them ideal for charging vehicles while parked. Additionally, placing chargers along crowded highways supports long-distance travel by ensuring drivers can recharge during road trips, alleviating range anxiety.

However, certain clusters of chargers appeared in areas without these features, suggesting the influence of additional, unexamined factors. Utility infrastructure may play a role, as areas with robust electrical grids are more suited for charger installation. Moreover, these locations might be strategically chosen to create a connected network, enabling long-distance travel for EV users.

4.2 ACS EDA

To understand the spread and central tendencies of these variables, Figure 3 visualizes the distribution across different zip codes. Notably, median household income showed some high-end outliers, suggesting that certain zip codes have significantly higher values compared to others. This observation may be indicative of wealthier neighborhoods or areas.

The primary objective of incorporating census data was to evaluate the hypothesis that EV charger adoption is correlated with specific demographic characteristics. Specifically, the analysis aimed to determine whether wealthier zip codes, those with larger populations, or those with a higher percentage of residents holding advanced degrees, would exhibit a greater density of EV chargers. To test this hypothesis, Figure 4 investigate potential correlations between these socio-economic variables and the number of chargers within each zip code.

Contrary to expectations, the results revealed no significant correlation between income levels and the number of chargers, defying the original assumption. For instance, one of the wealthiest zip codes within the SDG&E territory had nearly no EV chargers. Similarly, population size and educational attainment did not show a meaningful relationship with charger density. Several potential explanations could account for the lack of observable correlations. First, the adoption of EV chargers in wealthier areas may be lower if residents predominantly charge their vehicles at home, reducing the demand for public chargers. Furthermore, infrastructure development may be driven more by logistical considerations, such as available parking spaces, rather than the amount of Electric Vehicle in the area. These factors highlight the complexity of EV charger distribution.

4.3 DMV EDA

Figure 5 shows the distribution of all fuel types across all vehicles in the SDG&E area. The results revealed that gasoline-powered vehicles dominate the landscape, making up over 80% of all vehicles. On the other hand, Battery Electric Vehicles (BEVs) represent just 4.3%, which was surprising given the apparent prevalence of EVs on the road. Nonetheless,

The low representation of BEVs at 4.3% underscores the early stage of transition to electrification, despite increasing incentives and awareness. Figure 6 offers valuable insights. Heavy vehicles are overwhelmingly powered by diesel, with some use of gasoline. Alternative fuels are almost non-existent among heavy vehicles. This finding underscores the significant gap in electrification and alternative fuel adoption among heavy-duty vehicles. Factors such as the high energy density requirements for long-distance hauling, limited charging infrastructure for commercial use, and the slower turnover rate of commercial fleets contribute to this disparity.

Lastly, Figure 7 tracked the number of EV charging stations opening over time and the number of EV cars built each year. The plot revealed some interesting trends: The peak in EV charging station openings occurred in 2021, but the production of EVs did not peak until 2023. This offset is logical. It underscores the importance of infrastructure readiness in driving consumer adoption since robust charging networks play a critical role in fostering consumer confidence, ultimately boosting EV sales. It also indicates that policies and investments aimed at building infrastructure can serve as a catalyst for accelerating EV adoption.

5 Conclusion

This report highlights critical insights into the distribution and accessibility of EV charging stations within the SDG&E territory, offering a multifaceted understanding of the region's charging infrastructure. By integrating datasets from the AFDC, U.S. Census Bureau, and California DMV, the study explores the interplay between socio-economic factors, vehicle types, and charging station availability.

The findings challenge traditional assumptions, revealing no clear correlation between charger density and factors such as income, population size, or educational attainment. Wealthier areas, surprisingly, were not always better served, with some affluent zip codes having few or no chargers. Spatial analysis showed that chargers are often clustered near population-dense areas like shopping centers and workplaces, though some appeared in unexpected locations, hinting at other influential factors. Additionally, the dominance of gasoline vehicles, limited adoption of battery electric vehicles (BEVs), and the near-absence of alternative fuels among heavy vehicles highlight gaps in electrification. The temporal analysis revealed an offset between peaks in charging station installations (2021) and EV production (2023), suggesting that infrastructure development precedes consumer adoption to build confidence in EV accessibility.

These insights provide a foundation for more targeted and effective strategies to expand EV infrastructure. A focus on equitable access and sustainability will be crucial in meeting the increasing demand for clean transportation solutions while ensuring that all communities can benefit from the transition to electric mobility.

6 Future Directions

6.1 Addressing Limitations

One limitation of this study is the granularity of the demographic data. The data, derived from the U.S. Census Bureau, is aggregated at the zip code level. While this provides a useful overview, a finer resolution could offer a more detailed understanding of how EV infrastructure aligns with socio-economic factors. Future efforts to access and integrate higher-resolution demographic data could uncover patterns that remain obscured at the zip code level and improve the precision of the analysis.

Another limitation is the lack of charger usage data. This study focuses on the spatial placement of EV chargers but does not consider utilization rates or charging patterns. Including data on the frequency and duration of charging sessions would enable a more nuanced understanding of demand, helping to identify both underutilized and overburdened stations. Such insights could inform strategies for optimizing the placement and operation of chargers.

6.2 Potential Extensions

A promising direction for future work is the modeling of EV adoption trends. Building on the time-series analysis, predictive models could be developed to estimate future demand for charging stations. These models could incorporate external factors such as policy changes, technological advancements, and fluctuations in fuel prices, providing valuable insights to guide long-term planning and investment in EV infrastructure.

Another area for further investigation is the influence of non-traditional factors on charger placement. This study found that some chargers are located in areas without obvious population or commercial density. Future research could explore factors such as proximity to tourist attractions, transit hubs, or local government incentives, which may play a significant role in determining optimal charger locations.

7 References

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