Analysis of Electric Vehicle Charging Stations in Washington State

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***Abstract*—Electric vehicles (EVs) offer a promising solution to reduce emissions and address fossil fuel depletion. Successfully transitioning from traditional vehicles to EVs requires comprehensive efforts in technological innovation, infrastructure expansion, and policy adaptation. Understanding the progress of EV adoption and the establishment of electric charging stations is crucial for informed policymaking. In this project, we analyzed datasets on EV adoption and the opening of electric charging stations in Washington (WA) State. The datasets were initially examined separately and later merged to generate a combined map. Our exploration revealed a significant surge in EV adoption in WA since 2010, while the opening of electric charging stations lagged behind. Spatial distribution analysis highlighted a notable imbalance, with more EVs than available charging stations, and their distribution was uneven. Through this project, we aim to gain insights into the evolution of the EV market by examining both EV adoptions and the development of electric charging stations.**

I. Introduction

In the nascent stage of market penetration, electric vehicles (EVs) emerge as an environmental boon, characterized by zero emissions during operation, a notable distinction from their combustion engine counterparts. This promising trajectory positions EVs as pivotal contributors to mitigating the imminent shortage of fossil fuels. However, this transition is not without challenges, requiring a holistic approach encompassing technological advancements, infrastructure development, and policy adaptations.

The primary environmental advantage of EVs lies in their emission-free operation, contingent on the energy mix of their primary source. Though the electricity needed for charging may originate from power stations with emissions, the net environmental impact remains considerably lower compared to traditional vehicles. The global push towards sustainable practices and climate consciousness propels the EV market into a crucial role in the broader context of environmental conservation.

As the EV landscape evolves, critical considerations extend beyond individual vehicles to encompass comprehensive ecosystem adjustments. To fully support the burgeoning fleet of EVs, crucial enhancements are imperative. Among these, the expansion of driving ranges assumes paramount significance. Proactive measures must be undertaken to boost the range of EVs, addressing consumer concerns related to limited travel distances. Simultaneously, a pivotal shift in electricity supply mechanisms is essential, demanding the redesign of power grids to accommodate new charging stations seamlessly.

The success of EVs is intricately tied to the reliability and accessibility of charging infrastructure. In this regard, electricity suppliers face the arduous task of restructuring power grids and optimizing the scheduling of charging stations. These adaptations are critical for offering a high-quality service characterized by usability, minimal delays, and enhanced security. Governments and private entities alike must collaborate to facilitate the transition towards a more EV-friendly infrastructure, aligning with the global drive towards sustainability.

Vehicle manufacturers are already proactively integrating advanced features into new EV models, incorporating navigation and infotainment systems. These technological enhancements, coupled with wireless connectivity, lay the groundwork for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication. Leveraging technologies such as 3G and anticipated 4G cellular networks or IEEE 802.11p, manufacturers aim to create a seamless network where EVs share real-time information about their locations, charging station availability, and other pertinent details. This interconnectedness holds the potential to revolutionize the EV experience, providing users with up-to-date information for dynamic travel optimization.

Looking ahead, the vision for EVs extends beyond individual optimization to a collective, cooperative network. In this envisioned future, EVs collaborate to maximize the efficient utilization of charging infrastructure. This collaboration is made possible through networked communication, where EVs cruising on the roads receive advertisements for nearby charging stations as they detect a low battery charge. The integration of vehicular adhoc or cellular networks facilitates this seamless communication, offering users dynamic information about charging station locations, availability, and average waiting times.

As technology continues to advance, the concept of on-demand charging emerges as a potential paradigm shift in EV charging dynamics. While current charging systems may be time-consuming, ongoing developments aim to reduce charging times significantly. In the envisioned future, on-demand charging becomes one of many charging systems, potentially situated at diverse locations such as parking lots, shopping malls, residential areas, and educational campuses.

In conclusion, the trajectory of electric vehicles represents a multifaceted evolution encompassing technological innovation, infrastructure development, and policy adaptations. The environmental promise of zero emissions positions EVs as integral components in the quest for sustainable transportation. As the world navigates towards a future marked by the electrification of transportation, stakeholders must collaborate to overcome challenges and embrace opportunities, ensuring a seamless transition to a cleaner and more sustainable mobility ecosystem.

1. Charging Station Map for USA: - Created a comprehensive map detailing all electric vehicle charging stations across the United States. - The map provides a visual representation of the geographic distribution of charging infrastructure, aiding EV users in planning cross-country journeys.

2. Electric Vehicles in Washington State: - Compiled a detailed description of all electric vehicles currently in use within Washington State. - The information includes various attributes of each electric vehicle, such as make, model, range, and charging capabilities, offering a comprehensive overview of the EV landscape in the region.

3. Distance Between Any Two Points and Corresponding Charging Stations: - Calculated the distances between any two specified points in Washington State to assist electric vehicle users in trip planning. - Provided a list of charging stations along the route between these points, enabling users to strategically plan stops based on their electric vehicle's range and the availability of charging infrastructure.

II. Related Research

The charging station location problem is to seek the proper plan of settling charging stations under some practical constraints, which belongs to the category of facility location problem that has been widely studied in literature. [1] Although it has been asserted as an NP-Complete problem, many efforts have been made to optimize the location of charging stations. There are many practical restraints of locating a charge station, and many of them have been investigated. For example, Fu's [2] research fully considered the influence of the distance from the charging user to the charging station, Zavvos et al. [3] modeled competing station investors who aim to maximize expected profit, Kłos et al [4] took the distance between charging stations into account, Hisoglu et al. [5] even considered the geographical information of solar farm site because they were interested in solar-supplied electric vehicle charging station, just name a few.

There are also many algorithms that have been applied to optimize the location of charging stations. A popular type of model to solve the charging station location problem is the flow-based model.

The idea behind this kind of model is the fact that EVs need to be recharged while on the way from the origin to the destination when the travel distance is larger than the EV's driving range. Thus, the recharging demand could be modeled as a set of origin-destination trips where charging stations must be placed to make sure the distance between two consecutive stations does not exceed the driving range. Many flow-based models have been developed to have various characteristics (bi-level, station capacity, path deviation, etc.) and objective functions (minimization of cost, time, power, etc., and/or maximization of cover, service, profit, etc.). [1] For example, He et al. developed a bi-level mathematical model to optimize the location of charging stations for EVs with the consideration of driving range. The upper-level of the model is to maximize the flows served by charging stations, and the lower-level depicts the route choice behavior given the location of charging station. [6] In addition to flow-based models, there are also other approaches to solve the charging station location problem. For instance, this problem could be treated in classical facility location modeling approaches. In this approach, the recharging demand mainly arises at the nodes of a road network instead of EV trips. The node-based demand usually originates from a cluster of EV drivers who prefer to recharge their vehicles in stations located close to their home, workplace, etc. A location–allocation approach is usually used to minimize total system costs and satisfy all customer demands. [7] Some other efforts also have been made to solve the charge station location problem without using the flow-based and node-based demand representations. Jung et al developed a method based on the vehicle trajectory. The trajectory of each vehicle can be determined by a stochastic itinerary-interception model according to the occurring passenger demand and the recharging needs of the vehicle, which also allows the model to optimize the location of charging stations. [8]

III. Approach

Our approach to comprehensively analyze electric charging stations and electric vehicles (EVs) in the state of Washington involved a combination of spatial analysis and network graph methodologies.

Spatial Analysis: We leveraged spatial analysis techniques to visualize and interpret the geographical distribution of both electric charging stations and EVs. Using tools such as Geopandas, we created maps highlighting the locations of charging stations and EV adoption across the state. This spatial representation enabled us to identify patterns, density variations, and potential gaps in infrastructure coverage. For instance, we discerned areas with high concentrations of EVs but limited charging stations, signaling potential challenges for users.

Network Graphs: To delve deeper into the connectivity and accessibility of charging stations, we employed network graph analysis. By representing charging stations as nodes and establishing edges based on spatial proximity, we constructed a network graph. This approach allowed us to identify optimal routes and connections between charging stations, offering insights into the efficiency of travel routes for EV users. Additionally, the network graph facilitated the identification of key charging hubs and potential areas for infrastructure expansion.

Integration: The synergy between spatial analysis and network graphs provided a holistic understanding of the electric mobility landscape in Washington. Spatial analysis illuminated the geographical disparities, while network graphs contributed to the identification of strategic charging station connections. This integrated approach facilitated a comprehensive evaluation of the current state of EV infrastructure, enabling stakeholders to make informed decisions for future planning, expansion, and optimization.

By combining spatial analysis and network graph methodologies, our approach offered a nuanced and actionable perspective on the spatial and connectivity dynamics between electric charging stations and vehicles in Washington, providing valuable insights for sustainable and efficient electric mobility planning.

IV. Experiments

A. Data

Two datasets were used in this project. The first dataset is about EVs that are registered through the Washington State Department of Licensing from 1997 to 2024. There are 134474 items in this dataset, which contains 17 features of EVs, such as location (longitude and latitude, county, city, postal code), year, manufacturer, EV type, electric range, etc. Another dataset is about electric and alternative fuel charging stations in the United States and Canada. There are 70406 items in this dataset which has as many as 65 features. Some important features related to this project include location information (longitude and latitude, state, city, zip, street address, intersection directions, etc.), access information (access code, access day time, open date, etc.), fuel type code, and so on.

B. Experimental Setup

In the experimental configuration for our professional paper, we conducted a thorough investigation into the spatial dynamics of electric charging stations and electric vehicles (EVs) within the state of Washington. Leveraging the capabilities of Geopandas, we meticulously curated and visualized a dataset encompassing the geographical coordinates of both electric cars and charging stations, providing a comprehensive map of their distribution across the state.

Utilizing Geopandas tools, we applied advanced spatial analysis techniques, including Kernel Density Estimation (KDE), to gain insights into the coverage and accessibility of the electric mobility infrastructure. The KDE plot served as a valuable visual representation, highlighting areas with dense concentrations of EVs and charging stations. This spatial analysis facilitated a quantitative evaluation of the extent to which different regions in Washington benefit from the existing electric mobility ecosystem.

Furthermore, our spatial analysis delved into the strategic placement of charging stations in relation to major travel routes. By examining the geographical distribution along key corridors, we aimed to identify optimal locations that enhance the convenience and efficiency of EV travel. This aspect of the analysis provides valuable information for understanding the accessibility and usability of the charging station network, offering insights for both EV users and infrastructure planners.

In our comprehensive study on electric vehicle (EV) infrastructure in Washington, we extended our analysis beyond spatial visualization and incorporated network graph methodologies to identify optimal charging station routes. Leveraging network graphs, we aimed to determine the necessary charging stations for a seamless journey from one point to another within the state.

By applying network graph algorithms to our dataset, we generated a network representation of the charging stations, considering their spatial connectivity and accessibility. This approach allowed us to establish a clear understanding of the relationships between charging stations and identify the most efficient routes for EV users traversing specific routes.

Our findings include a detailed list of charging stations required for a smooth journey from one point to another, providing practical information for EV users planning their routes across Washington. The network graph analysis not only highlighted the essential charging stations but also considered factors such as proximity, charging capacity, and strategic placement, contributing to an optimized and user-friendly electric mobility experience.

This integration of network graph analysis into our study enhances its practical relevance by offering actionable insights for both EV users and infrastructure planners. The detailed list of required charging stations serves as a valuable guide for planning efficient travel routes, promoting the seamless integration of electric vehicles into Washington's transportation network.

C. Results

At first, we analyzed these two datasets separately before merging them. Figure 1 shows EV adoption in the top 30 cities of WA. The top 10 cities are Seatle, Bellevue, Redmond, Vancouver, Kirkland, Botshell, Sammamish, Renton, Olympia, and Tacoma. As a comparison, Figure 2 is the number of electric charging stations in the top 30 cities of WA. The top 10 cities are Seattle, Bellevue, Tacoma, Spokane, Vancouver, Richland, Renton, Olympia, Kirkland, and Redmond. We can see that these two lists are almost identical but the order is different. It indicates that more EVs need more charging stations, or more charging stations can support more EVs. However, the distribution of EV stations are not even so that not each city has the same number of stations to support the adoption of EVs. Next, we analyzed how the adoption of EV and the opening of

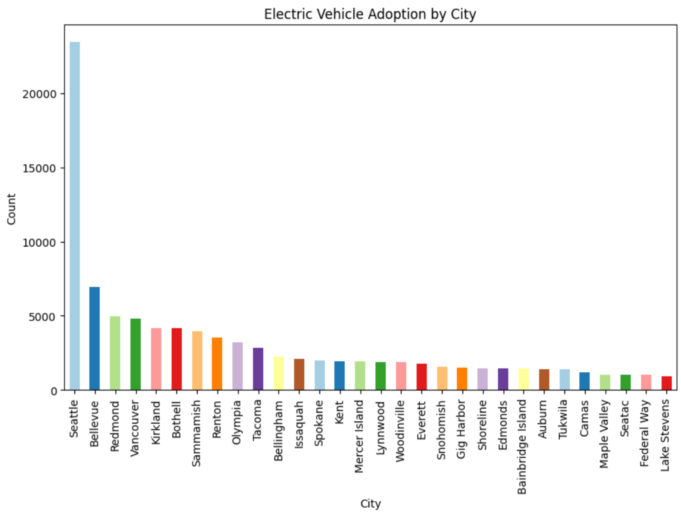

Fig. 1. Distribution of EV by city in WA

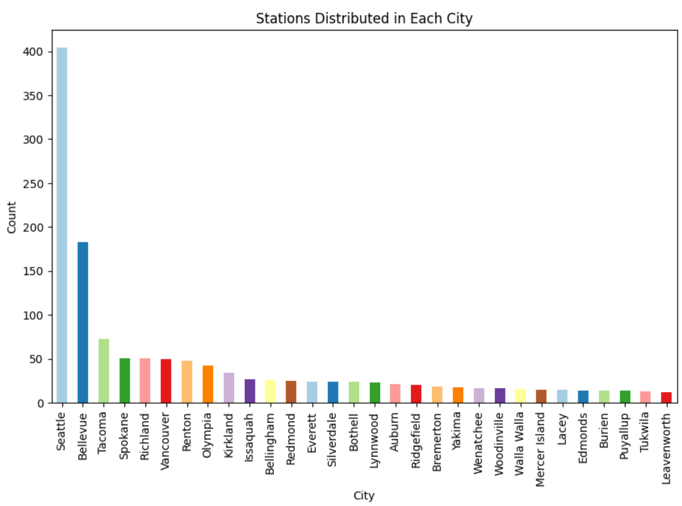

Fig. 2. Distribution of fuel stations by city in WA

electric charging stations change with time. Figure 3 clearly shows the adoption of EV in WA increases quickly. We can see that the number of EVs in WA surged in 2010. There were 23 adoptions in that year but it jumped to 815 the next year. The increase has been very strong since 2010 and it reached the peak of 27919 in 2022. In contrast, Figure 4 shows a quite different scenario of opening electric charging stations. The number of newly opened charging stations remained low before the beginning of 2021, which significantly lagged behind the adoption of EVs. More than 200 stations were opened at the beginning of 2021, which reached a peak of the building of electric charging stations. However, the trend didn't last long and the opening slowed down again after 2021. From these two figures we can see that the adoption of EV and the opening of electric charging stations are not in the same pattern, and it becomes important how to reduce the gap.

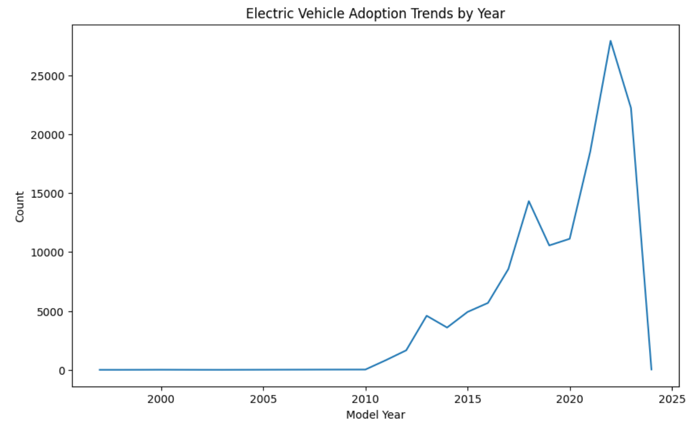

Fig. 3. The adoption of EV in WA by year

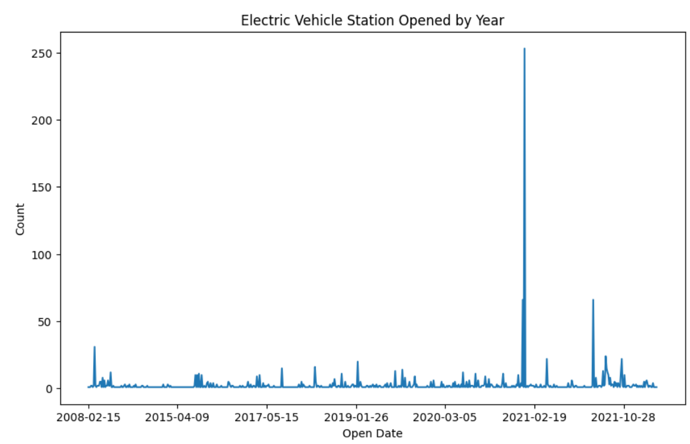

Fig. 4. Newly opened fuel stations in WA by year

An important factor of determining the relationship between EVs and electric charging stations is the electric range of EVs. Here we analyzed the range of EVs in WA, and the results were shown in Figure 5. The maximum range of EVs in WA is 337 miles, the first quantile is 150 miles, and the median is 21 miles. The analysis shows that many items of the dataset didn't record the electric range because the median range is so small that it doesn't make sense. Despite the incompleteness of the dataset, the analysis still gives us a general idea of the electric range of EVs which would help us in later analysis.

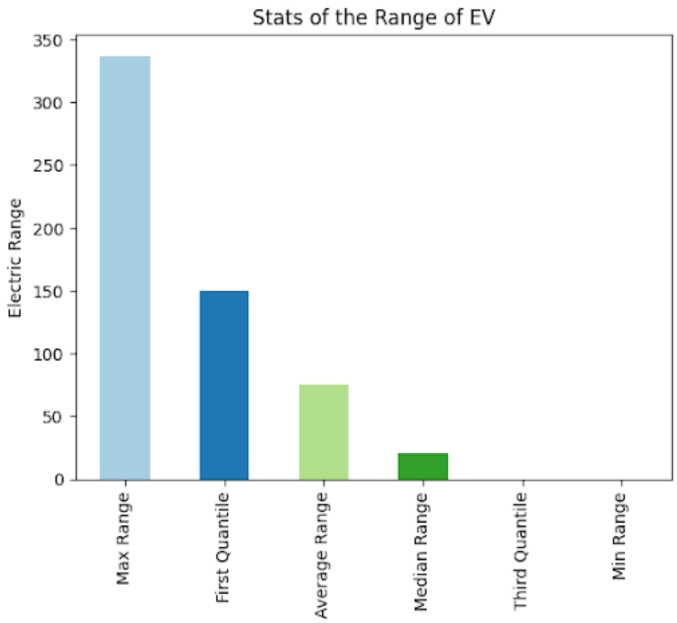

Fig. 5. The driving range of EV in WA

We also analyzed some other interesting information about EVs and electric charging stations. Figure 6 shows the main type of EVs in WA. We can see that 76.9% of EVs in WA are battery electric vehicles, and the rest 22.1% are plug-in hybrid electric vehicles. As for the electric charging stations, we find that 89.6% are public stations and only 10.4% are private (Figure 7). In addition, we also analyzed the manufacturers of EVs although the data was not shown here. The most popular EV company is Tesla, which is in a dominant position. Some other manufacturers are Nissan, Chevrolet, Ford, BMW.

The spatial distribution analysis underscores a notable asymmetry, revealing a prevalence of electric vehicles (EVs) over available charging stations in Washington. This incongruity highlights a potential challenge for EV users, indicating that the existing charging infrastructure may not be proportionate to the growing population of electric vehicles. Such disparities emphasize the critical need for strategic expansion and optimization of charging stations to accommodate the increasing demand for electric mobility, ensuring a harmonious and sustainable integration of EVs into the transportation network.

There are 134,474 electric vehicles in Washington state. According to our calculations, 134,014

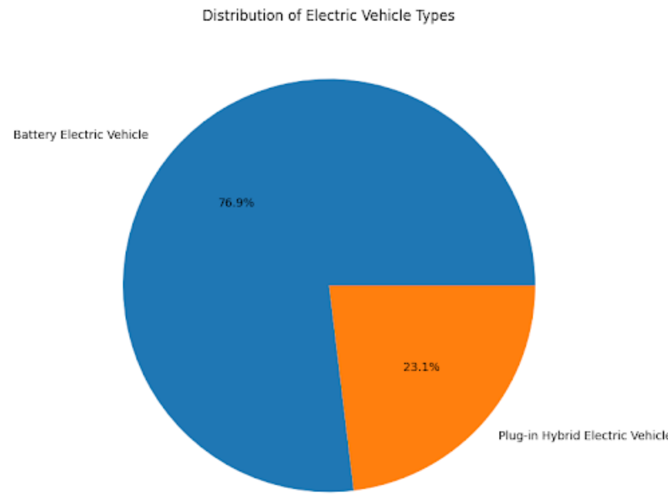

Fig. 6. The type of access to fuel stations in WA by type

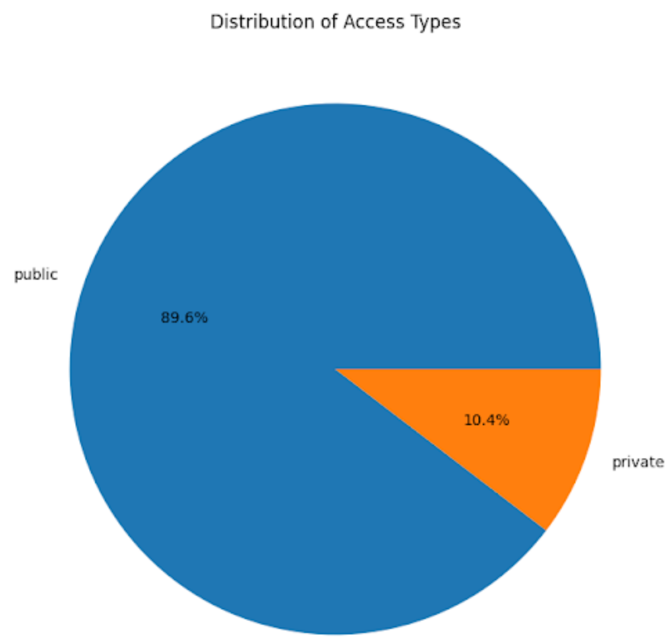

Fig. 7. The type of EV in WA by type

electric cars can find a suitable charging station within 30 miles, and only 460 electric cars cannot find a suitable charging station. This suggests that charging stations can be easily found for most electric vehicles. At the same time, we draw the diagram. The red area is the 30-mile range of the charging station, and the gray area is the location of

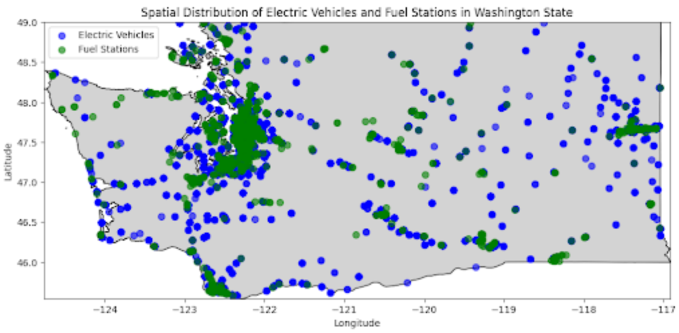

Fig. 8. Spatial distribution of EV and fuel stations in WA

the electric vehicle. As can be seen from the figure, most EVs without EV charging stations are located in remote areas of Washington state. We color each state according to the number of fuel stations. It can be clearly seen that California and Texas have a very large number of fuel stations.

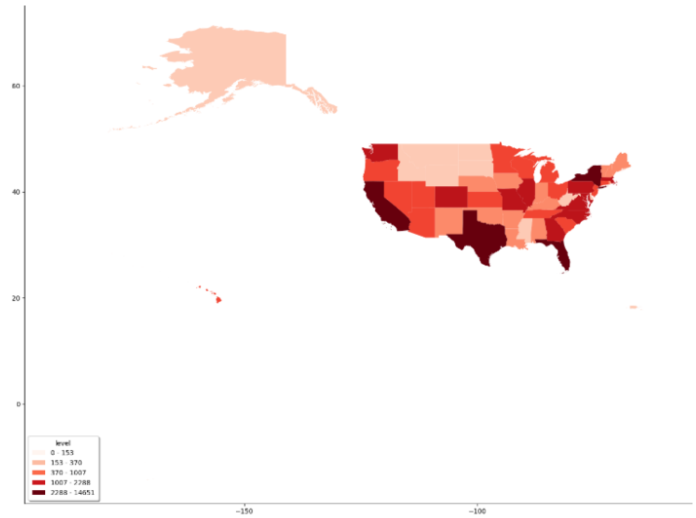

Fig. 10. Color the status based on fuel stations amount

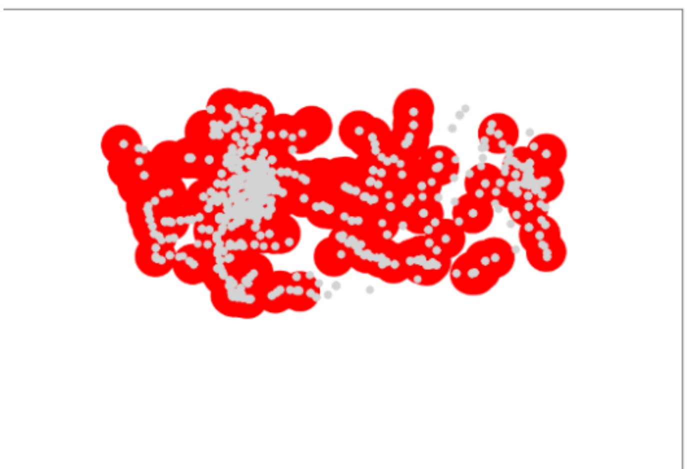

Fig. 9. Distribution of EV and fuel stations within 30 miles

V. Discussions

The datasets of EVs and electric charging stations were separately analyzed before merging. We find that the distribution of EVs and charging stations in cities are in the same pattern. Generally, cities owning more EVs have more electric charging stations. However, the distribution is not even. Some cities have more EVs while other cities have more electric charging stations. It implies that in some cities the growth of electric charging stations can't catch up with the growth of EV adoptions. This is also confirmed by the time series data. The EV adoption in WA surged in 2010 and kept a strong trend of increasing since then. In contrast, the opening of electric charging stations remained low most of the time except a sudden surge at the beginning of 2021. It demonstrates that the building of electric charging stations significantly lagged behind the adoption of EV.

Overall, the map shows that the adoption of electric vehicles is highest in the more populated areas of the state, such as King County (Seattle), Snohomish County (Everett), and Pierce County (Tacoma). This is likely due to a number of factors, including higher income levels, more charging infrastructure, and greater awareness of the environmental benefits of electric vehicles.However, the map also shows that the adoption of electric vehicles is increasing in all counties in Washington state. This is likely due to a number of factors, including falling prices of electric vehicles, improved performance and range of electric vehicles, government incentives, and increased availability of charging infrastructure.The largest cluster of electric vehicles is in the Seattle metropolitan area. This is not surprising, as Seattle is a major metropolitan area with a large population of environmentally conscious residents.There are also significant clusters of electric vehicles in other major metropolitan areas, such as Everett, Tacoma, and Spokane.There is a growing cluster of electric vehicles in the Tri-Cities region (Kennewick, Pasco, and Richland). This is likely due to the fact that the Tri-Cities region is home to a number of high-tech companies, which tend to attract employees who are more likely to adopt new technologies.There are also a number of electric vehicles in rural areas of Washington state. This is likely due to the fact that the state offers a number of incentives for electric vehicle owners, including rebates and tax credits.

VI. Conclusion

In summary, our analysis focused on EV adoption and charging station distribution in Washington's top 30 cities. The close alignment between cities with high EV adoption and the presence of charging stations underscores the interconnectedness of EVs and charging infrastructure. However, the uneven distribution of charging stations reveals a potential gap in widespread EV support. Temporal analysis highlights a substantial surge in EV adoption since 2010, peaking in 2022, contrasting with slower charging station openings, especially before 2021. This misalignment emphasizes the need for synchronized growth between EVs and charging infrastructure. Examining EV electric ranges exposed challenges due to incomplete data but laid a foundation for future analyses. Insights into predominant EV types and public charging stations underscore key considerations for infrastructure planning. Spatial distribution analysis reveals a significant imbalance, with more EVs than charging stations, signaling a potential hurdle. Addressing this incongruity requires strategic investments in charging infrastructure to support the growing electric vehicle population, fostering a sustainable and integrated electric mobility ecosystem in Washington's transportation network.

Acknowledgement

The authors thank the contributors who provide the datasets in Kaggle.

VII. Author Contributions

Yang Liu

- Analyzed the datasets before merging

Gautham Gali

- Merged the dataset of EV and the dataset of fuel station and mapped the merged dataset

Kaiyi Chen

- Analyzed the merged dataset

All authors contributed equally to the writing of the final report.

URLs

A. *Electric Vehicle Data (1997-2024)*

https://www.kaggle.com/datasets/iottech/electric-vehicle-data-1997-2024-update-version/data

B. *Electric & Alternative Fuel Charging Stations 2023*

https://www.kaggle.com/datasets/saketpradhan/electric-and-alternative-fuel-charging-stations?select=Electric+and+Alternative+Fuel+Charging+Stations.csv

C. *Colab*

https://colab.research.google.com/drive/1up4vSs0dwjzWW8cUAoLtDZH3qf5IfoWS?usp=sharing

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