DA353 Final Report

Electric Vehicle Charging Station Optimization

Minh Le and Yen Nguyen

Dr. Bonifonte

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1 Introduction

1.1 Background and Context

The adoption of electric vehicles (EVs) is increasing worldwide, mainly driven by growing awareness of environmental issues and technological advancements. These types of vehicles are now favored and recognized by the majority of consumers. With the increasing number of new energy-efficient vehicles, the demand for charging stations for these vehicles is also increasing. This makes the strategic placement of charging stations crucial, helping the government optimize infrastructure efficiency by minimizing the need for excessive stations. Finding the right locations for these stations is therefore important, ensuring they can provide convenient access for all EV users while contributing to a more sustainable future of transportation.

In King County, transportation accounts for nearly half of all greenhouse gas emissions, as stated in the *King County Sustainable Purchasing Guide for Vehicles*. In response to this environmental challenge, ambitious electric vehicle (EV) transition goals have been established. Despite initiatives aimed at enhancing public transportation, such as plans for zero-emission buses by 2035 as outlined in the *King County Metro Zero-Emission Fleet*, a significant infrastructure gap remains for private EV vehicles.

1.2 Objectives

Given the importance of strategic charging station placement and the existing gap in infrastructure for private EVs, our project aims to optimize the allocation of charging station locations in King County, Seattle. Our objective is to maximize the number of cars charged, effectively addressing the demand for EV charging. Leveraging data on registered electric vehicles, we will strategically design and implement charging station placements that cover all locations and efficiently meet the demand of registered cars. Through this project, we aim to contribute to the development of a more sustainable transportation ecosystem in King County.

2 Data Exploration

2.1 Datasets

Our primary dataset comprises registered Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) from the Washington State Department of Licensing (DOL) via data.gov. It is open to the public and gives us important information about how these vehicles are spread out and used. This dataset provides valuable insights into vehicle distribution and usage patterns, crucial for optimizing charging station locations. The data contains 17 columns and 177,867 rows. However, we only used the following columns for our model:

- *County*: Geographic region of a state that a vehicle's owner is listed to reside within
- *City*: City in which the registered owner resides.
- *Postal*: The 5 digit zip code in which the registered owner resides.
- *Vehicle Location*: The center of the ZIP Code for the registered vehicle.

	County	City	Postal Code	Vehicle Location
VIN (1-10)				
5YJYGDEE1L	King	Seattle	98122.0	POINT (-122.30839 47.610365)
5YJSA1E4XK	King	Seattle	98109.0	POINT (-122.34848 47.632405)
5YJYGDEEXL	King	Seattle	98144.0	POINT (-122.30823 47.581975)
1N4AZ0CP0F	King	Seattle	98119.0	POINT (-122.363815 47.63046)
1N4AZ0CP6D	King	Seattle	98107.0	POINT (-122.37815 47.66866)

Figure 1: Locations of Registered EVs in Seattle

In addition, we gathered data via energy.gov on the current locations of the charging stations in the area to compare our solution to existing stations. We obtained the data by requesting the API url with our own developer API key and the queried parameters related to electric vehicle stations. The following columns will be used for further analysis:

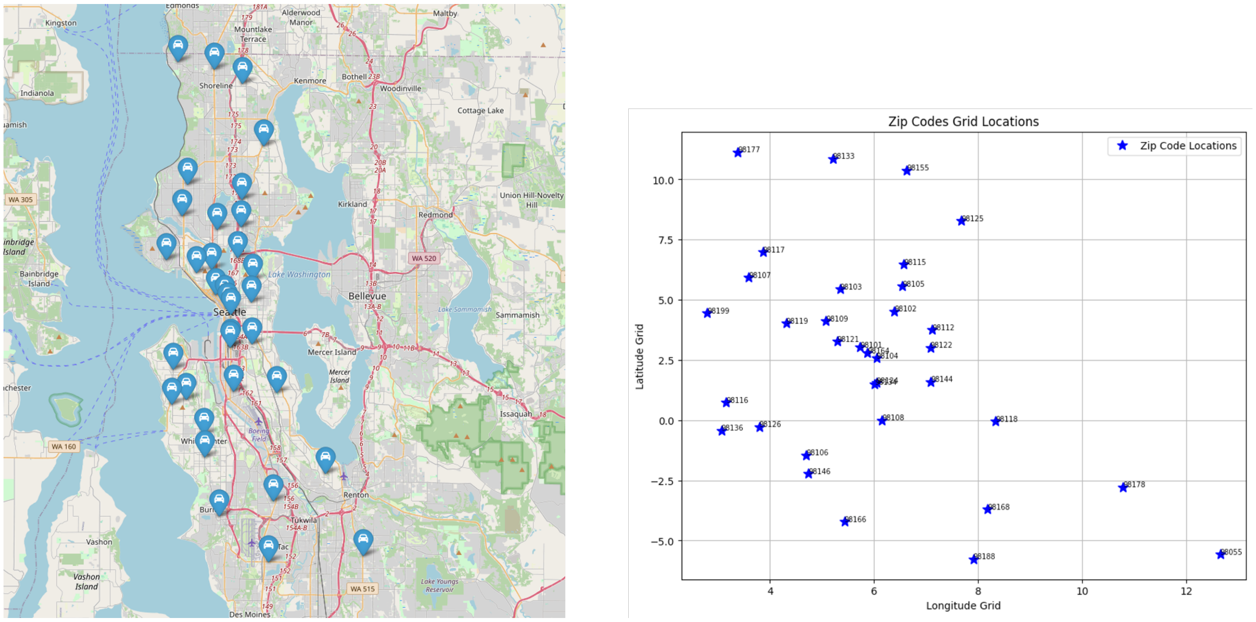
- *City*: City in which the station is placed
- *State*: State in which the station is placed
- *Latitude*: The latitude of the station
- *Longitude*: The longitude of the station

	Station Name	City	State	ZIP	Status Code	Expected Date	Owner Type Code	Geocode Status	Latitude	Longitude	Facility Type	Restricted Access
0	Seattle-Tacoma International Airport - General...	Seattle	WA	98188	E	NaN	P	200-8	47.443377	-122.296229	AIRPORT	False
1	Caplan's Rainbow Parking	Seattle	WA	98104	T	2022-12-31	P	200-8	47.604115	-122.332907	PARKING_GARAGE	False
2	City of Seattle - Central Library	Seattle	WA	98104	E	NaN	LG	200-9	47.606684	-122.332664	LIBRARY	False
3	City of Seattle - Seattle Center	Seattle	WA	98109	E	NaN	LG	200-8	47.622085	-122.347124	MUNI_GOV	False
4	KING COUNTY DES KSC STATION #1	Seattle	WA	98104	E	NaN	NaN	GPS	47.598663	-122.331009	NaN	NaN

Figure 2: Current Locations of Charging Stations in Seattle

2.2 Data Preprocessing

We use Postal Code to identify where the EVs are registered in Seattle (Figure 3(a)). Then we convert the location using latitude and longitude into grid location for further development and analysis (Figure 3 (b)).



(a) Real Map (b) Converted Grid Map

Figure 3: Real Map vs. Converted Grid Map

Based on the grid location, we established the ranges within which candidate locations should be selected: longitude [3, 13] and latitude [-6, 12] with a step size of 0.5. To reduce our computability time, we removed points that are either located in the sea when converted back to the map or located in an area that is outside the maximum distance threshold. We then obtained a total of 498 potential candidate locations represented by the red points in the grid map (Figure 4).

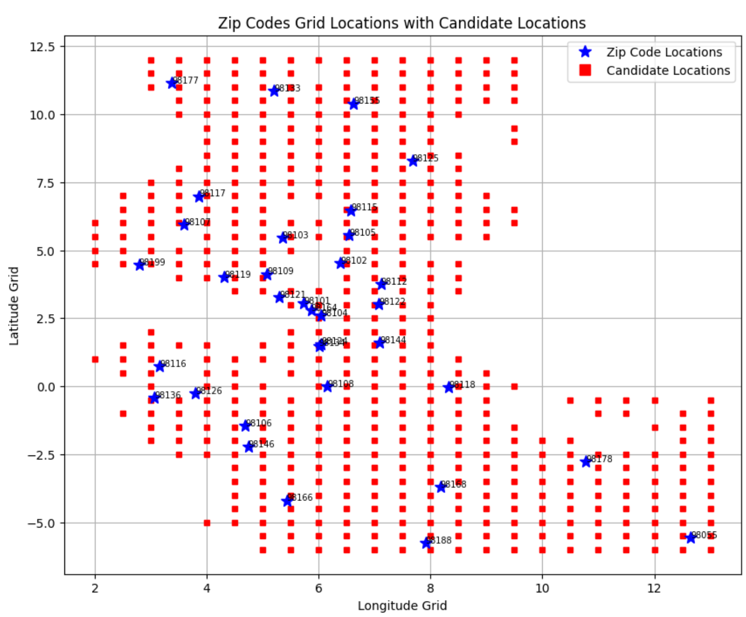


Figure 4: Zip Codes Grid Locations with Potential Candidate Locations

3 Model

3.1 Assumptions

To streamline our project, we operate under the following assumptions:

- We assume a uniform power consumption demand for each vehicle, approximating it based on the average power consumption of electric cars.
- The construction cost and power capacity of a new station are considered consistent across all locations, irrespective of demand variations.
- Vehicle locations are specified by "Postal Code," indicating that each car is located within the designated area represented by its postal code.
- Each charger is capable of providing power to a single car.

3.2 Model Formulation

We want to develop a mixed integer programming (MIP) model to solve the problem. The structure of the model is:

1. **Set:**
    - Let Z represent the set of postal codes obtained from the dataset.
    - Let S denote the set of candidate charging locations.
2. **Data:**
    - D: the maximum distance threshold between a vehicle and its assigned charging station.
    - ST: the maximum number of stations that can be installed.
    - C_{min} and C_{max}: the minimum and maximum number of chargers we can have at a charging station j.
    - d_{ij}: the distance between vehicles in postal code i ($i \in Z$) and station j ($j \in S$).
    - n_i: the number of cars requiring charging in postal code i ($i \in Z$).

3. **Decision Variables:**

   - C_j: Binary variable indicating whether to open charging station j, $j \in S$.
   - X_{ij}: Continuous variable representing the proportion of vehicles in postal code i ($i \in Z$) choosing station j ($j \in S$) for charging service.
   - N_j: Integer variable representing the number of chargers installed at charging station j, $j \in S$.

4. **Objective Function:** Maximize the number of vehicles can be charged by the opened stations (vehicle coverage)

$$\max \sum_{i \in Z} n_i X_{ij}$$

5. **Constraints:**

   - Only charge at the stations that have been selected: $X_{ij} \leq C_j \quad \forall i \in Z, j \in S$.
   - The total coverage percentage of each postal code must not exceed 1: $\sum_{j \in S} X_{ij} \leq 1 \quad \forall i \in Z$.
   - Limit the distance between each postal code and its assigned charging station to a maximum threshold of D units: $d_{ij} C_j \leq D \quad \forall i \in Z, j \in S$.
   - Ensure that the total demand supplied by each charging station equals the total demand of each station: $\sum_{i \in Z} n_i X_{ij} = N_j \quad \forall j \in S$.
   - The number of chargers installed at each chosen station must meet the required minimum and maximum threshold: $C_{\min} C_j \leq N_j \leq C_{\max} C_j \quad \forall j \in S$
   - Ensure that only a limited number of stations are opened: $\sum_{j \in S} C_j \leq ST$.

3.3 Model Parameters

We have to make further decisions on the model parameters. Firstly, we set the maximum distance threshold between the charging location and the vehicle to be within 2.0 ($D = 2.0$) unit in grid locations. After converting from grid back to real-life distance, 2 units in the grid would cover approximately 3.8 miles in longitude and 3.6 miles in latitude. Thus, the 2 units distance threshold we choose is equal to 5.23 miles in real-life. Since these are Euclidean distances, real distances considering road path will be somewhat larger, so we estimate the real-life distance to be around $10-12$ miles. Besides distance threshold, we also assume the minimum and maximum chargers of each station to be 20 and 80 chargers ,respectively ($C_{min} = 20$ and $C_{max} = 80$). Lastly, we set the allowable number of stations to be constructed is 450 ($ST = 450$), mirroring real-world data with approximately 500 stations in Seattle.

4 Results

After using Gurobi to solve our model, 282 stations were chosen to installed from the given set of candidate locations (Figure 5). The size of the red points corresponds to the supply capacity of each candidate location. The number of cars can be covered by the stations are 22236, which are about 75.51% of the total demand. This percentage also accounts for a significant portion of individuals who can conveniently charge their vehicles at home. Our decision process also factored in real-world road distances and the actual capacity of charging stations, ensuring that our choices closely reflect real-world conditions. Candidate locations are strategically placed in densely populated central areas to maximize coverage across multiple postal codes. This clustering around central areas ensures efficient service to a wide geographic area while allowing each station to effectively manage its capacity limitations.

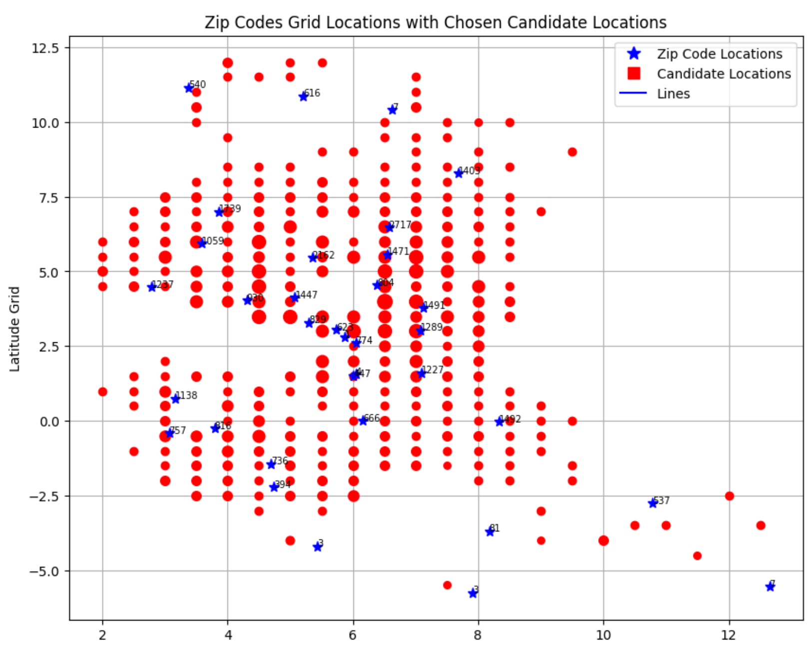


Figure 5: Zip Codes Grid Locations with Chosen Candidate Locations

The distribution of chargers in each stations is illustrated in the summary table (20 first rows), as below:

Postal Code	Station	Coverage Percentage	Number of cars assigned	Number of chargers	Distances
98116	14	7.03	80	80.0	1.188833
98199	21	6.47	80	80.0	0.791774
98107	22	3.78	39	80.0	1.845683
98199	22	3.23	40	80.0	0.957682
98107	23	7.55	80	80.0	1.650317
98107	24	7.55	80	80.0	1.593909
98116	47	7.03	80	80.0	1.863015
98116	50	7.03	80	80.0	0.703437
98116	51	7.03	80	80.0	0.709101
98116	52	7.03	79	80.0	1.005398
98119	58	4.30	40	80.0	1.871073
98199	58	3.23	40	80.0	0.293523
98107	59	7.55	80	80.0	1.436679
98107	60	7.55	80	80.0	1.175179
98107	61	3.78	40	80.0	1.094553
98117	61	2.30	40	80.0	1.680673
98117	62	4.60	80	80.0	1.445912
98117	63	4.60	80	80.0	1.362594
98126	82	4.90	40	80.0	1.907455
98146	82	10.15	40	80.0	1.756239

Figure 6: Summary Table

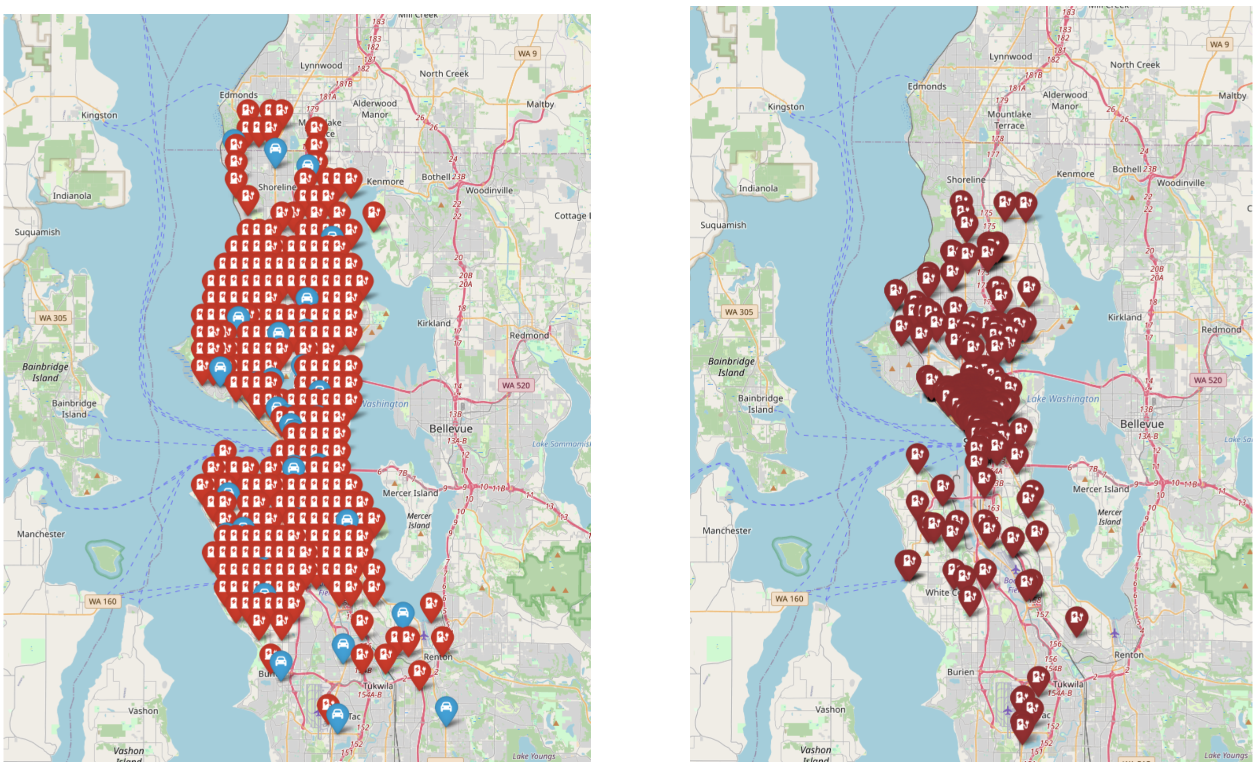
The table displays the number of cars in each postal code that can be charged by each station ("Number of cars assigned"), as well as the coverage percentage for fulfilling the demand of the respective postal code. Additionally, it presents the supply capacity of each station, represented by column "Number of chargers," along with the distances between the vehicles in a postal code and their designated station. It's worth noting that due to the nature of solving the problem using Gurobi for Mixed Integer Programming (MIP), some stations may exhibit a slight excess supply (where supply is less than capacity) due to rounding during optimization.

5 Model Validation and Evaluation

To further evaluate the effectiveness of our model, we will compare our result to existing stations using the dataset we obtained from energy.gov. From Figure 6, after comparing our result with the current map of charging stations in Seattle, we found some similarities between the two maps, especially the placement of stations in the central areas. However, our result suggests that more charging station should be opened and expanded in the following locations: Shoreline, Mountlake Terrace, Magnolia, Burien, White Center, and Fairwood.

Our recommendation includes expanding existing stations in central areas (as our optimal solution has stations with larger capacity placed in the center) to optimize resource allocation, while reducing the number of stations in these densely populated regions to avoid over-saturation. Additionally, we propose establishing more compact stations in less populated areas to mitigate traffic congestion and reduce travel distances for users.

Overall, if we consider the supply of each location from our solution and from the existing charging stations, we have reduced half of the existing stations in Seattle while efficiently meeting the majority of the charging service demands.



(a) Proposed Solution (b) Existing Charging Stations

Figure 7: Proposed Solution vs. Existing Charging Stations

6 Sensitivity Analysis

We will make a sensitivity test to figure out the key factor that shape our model. For this part, we will explore how our result change for a different range of maximum supply capacity for each station (from 20 to 300).

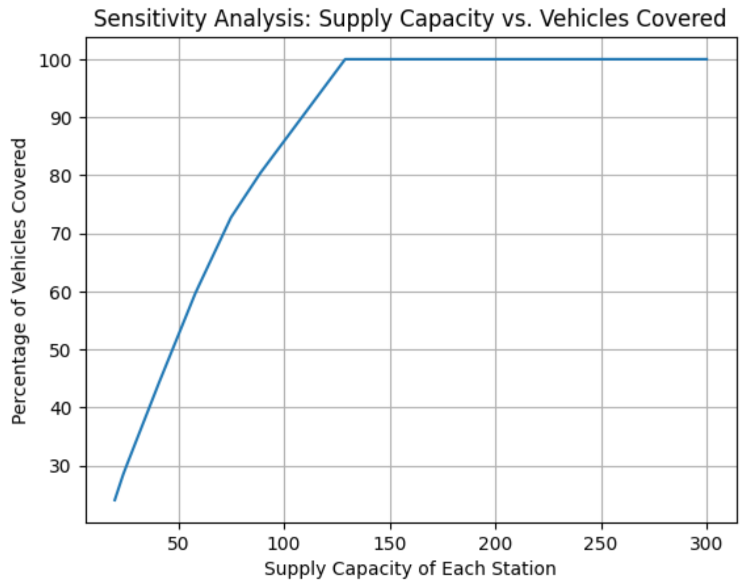


Figure 8: Supply Capacity vs. Vehicles Coverage

As a result, increasing the supply capacity of each station leads to a higher percentage of cars covered (Figure 8). The coverage percentage rises notably until it reaches 75 cars can be supplied per station. After that, the coverage still increases but at a slower rate. It then stabilizes at 100% coverage when the supply reaches around 130 chargers per station.

We then explore how our result change based on a different range of distance threshold between vehicles in a zip code and their assigned station.

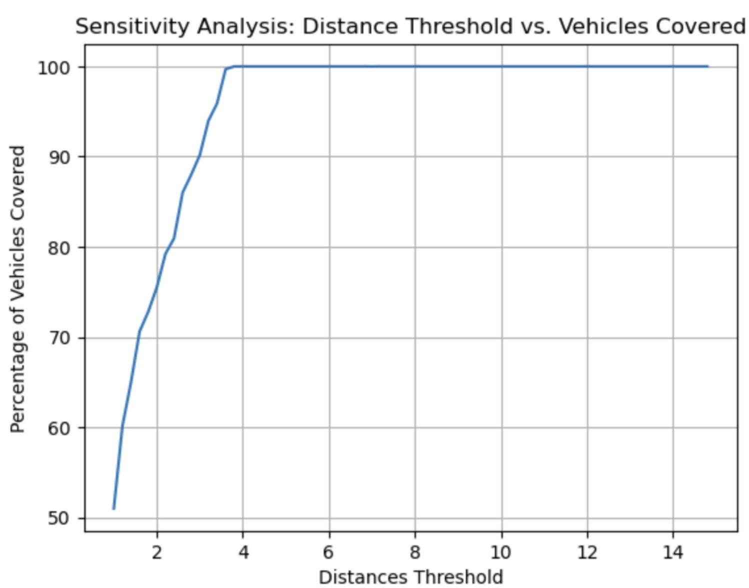


Figure 9: Distance Threshold vs. Vehicles Covered

As we increase the distance thresholds in our model, we observe a corresponding increase in demand coverage(Figure 9). Notably, the coverage percentage rises significantly to 70% until the distance threshold reaches approximately 1.8 grid units. Beyond this point, the coverage continues to increase, but at a slower rate, eventually reaching 100% at around 3.8 units. From there, the coverage stabilizes at around 100%.

The sensitivity analysis underscores the importance of slight adjustments in supply capacity and distance thresholds, as they can significantly influence the model's objective. Opting for a distance threshold of 2 and a maximum capacity of 80 for charging stations results in less sensitive parameters, where changes in the objective occur at a slower rate.

7 Conclusion

7.1 Limitations

While this project aims to identify potential locations for charging stations based on ZIP code data, it has several limitations that should be acknowledged. Firstly, since we use ZIP codes to represent the location of the EVs' users, the selection of candidate charging stations will not be fully optimized. Additionally, this approach may overlook important considerations, such as land ownership, existing infrastructure, or consumer behaviors. Indeed, there may be locations that are not allowed for station construction or lack of electricity supply. Moreover, our model is based on the assumption that there is a specific supply for each charging station and the regulations in the number of stations can be constructed. In real-world scenarios, the supply of each station could vary and the limitations of station installation are different. Lastly, we have not considered factors such as construction or environmental costs that could potentially influence the selection of the charging station locations.

7.2 Future Studies

For future studies, there are several avenues for further exploration and refinement of the methodology used in this project to identify charging station locations. Firstly, we want to incorporate data sources related to land ownership, charging station construction costs, and real-time traffic data to get a more comprehensive understanding of charging demand and selections within different geographic areas. In addition, instead of minimizing the total charging stations or maximizing coverage, we want to see how our result changes when the objective is to minimize the total cost (which includes construction and environmental costs). By addressing these considerations and leveraging advanced analytical approaches, future studies have the potential to inform more effective and equitable strategies for expanding electric vehicle charging infrastructure to support the transition to sustainable transportation systems.

7.3 Conclusions

In summary, our model's effectiveness is underscored by its alignment with current station locations. Our analysis has identified potential adjustments to existing stations and promising areas for new ones, extending both north and south of Seattle. We have also conducted sensitivity analysis to enhance the model's precision and usefulness. Our aim is that this research aids in fostering a greener transportation network in King County. By promoting the strategic placement of charging stations, we anticipate a tangible reduction in carbon emissions and a smoother transition towards electric vehicle adoption. This endeavor aligns with broader sustainability goals, fostering cleaner air and a healthier environment for communities in King County. Ultimately, our collective efforts aim to pave the way for a more eco-friendly and resilient transportation ecosystem, benefiting both present and future generations.

8 References

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