EV Charging Station Optimization for WA

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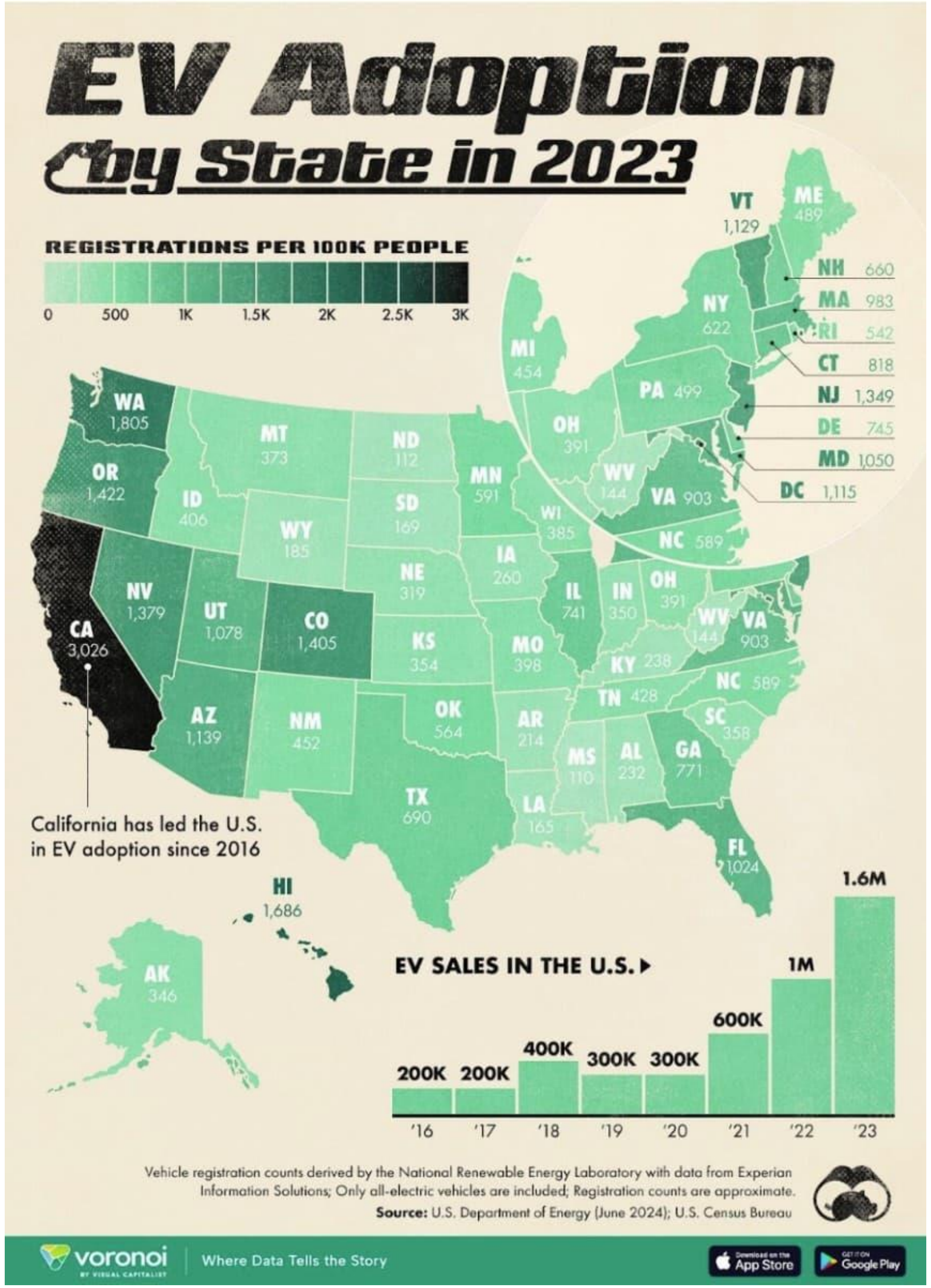
Problem Introduction

- Washington State is a leader in EV market, 2nd in the US for EV market share
- EVs accounted for 10% of WA's vehicle market share ~> growing demand for supporting infrastructure.
- On track to comply with its legal mandates to transition to zero-emission vehicles:
  - By 2030, 68% of new cars must be pollution-free
  - By 2035, all new cars must be pollution free

=> An optimized charging infrastructure is critical to streamline WA's EV adoption.



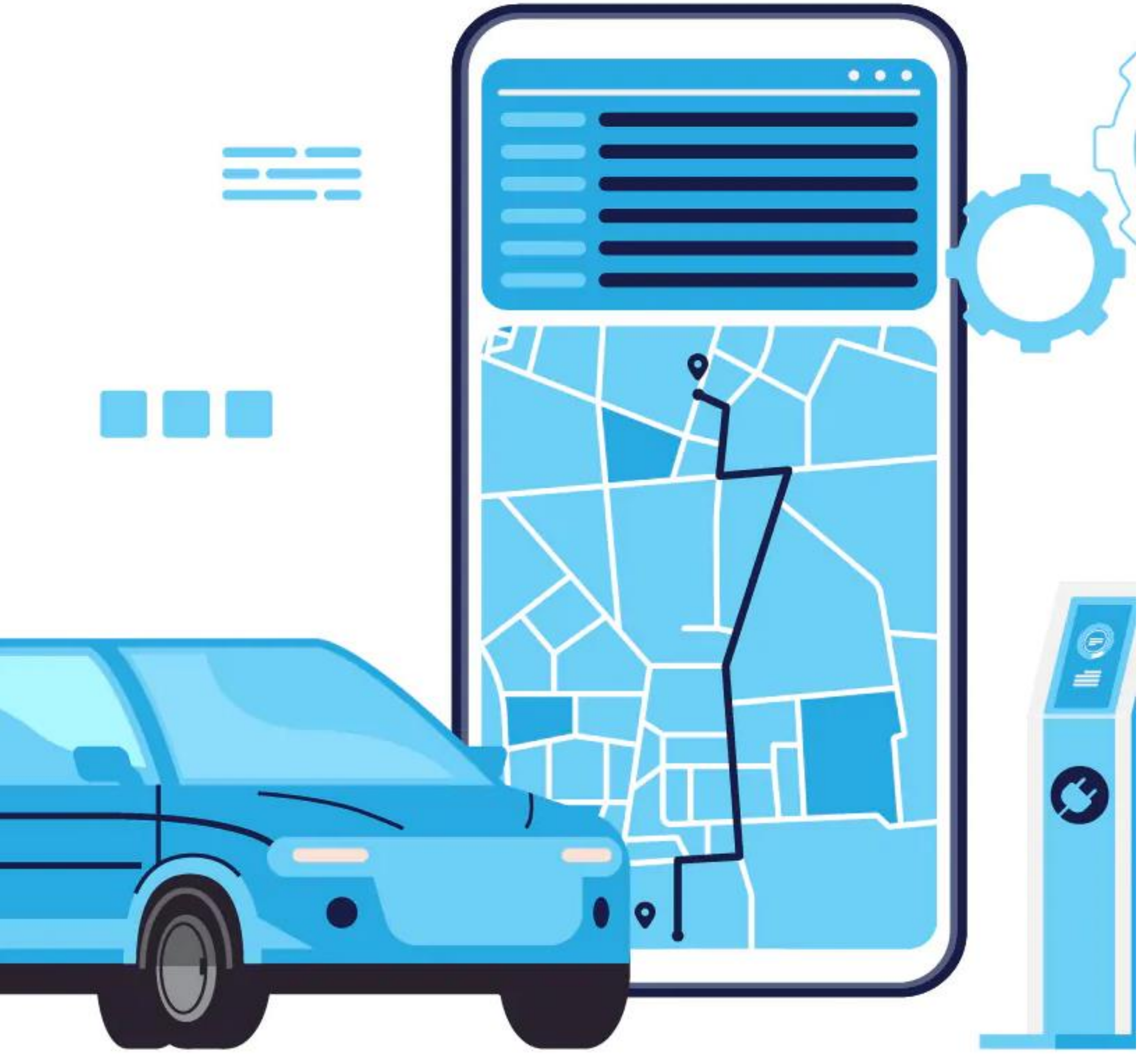
Challenge Overview

Currently, Washington State has over 2,000 charging locations and more than 5,800 charging ports[4]. However, reports highlight a shortage of chargers, and the existing network faces several challenges:

- **Unknown efficiency in resource allocation**: it is unclear if the current distribution of chargers is effectively meeting demand or minimizing underutilization.
- **Potential inefficient location strategy**: Poorly located charging stations may not serve high-demand areas, key routes, leading to inefficiencies
- **Environmental consideration:** Excessive deployment of hardware can increase carbon footprint and material waste

To address the shortage, the state plans to nearly double its capacity by 2035[4]. Rather than focusing solely on adding more chargers, our team aims to address the supply inefficiency by optimizing the allocation of stations and chargers.

*Target: Determining the **optimal locations** for EV charging stations and the **optimal number of each type of chargers** by solving an optimization problem. This will serve as a benchmark to **evaluate the efficiency of WA's current charging infrastructure.***



Problem Formulation

Data Used/Derived

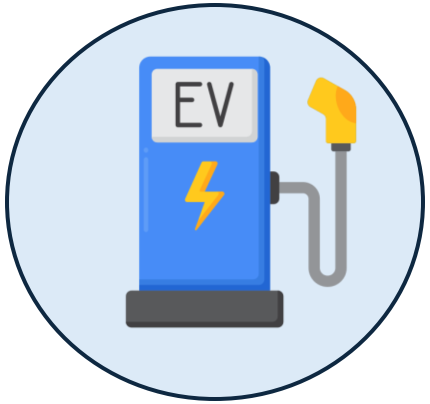
- **Electric Vehicle Population Data 2024 (Kaggle):**
    - DOL Vehicle ID: unique identifier assigned by the Washington State DOL for each registered vehicle
    - Electric range (miles): the distance the vehicle can travel on electric power alone.
    - Postal Code: Registration address for the vehicle

    ~> Washington has **85,684 registered EVs** (with non-zero electric range) distributed across **519 zip codes**
- **Distance Matrix API (Google Maps):**
    - Compile a driving distance matrix for each pair of zip codes

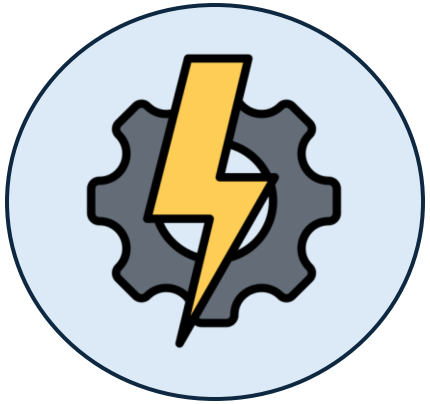
Problem Formulation

Considerations

The locations (zip codes) to install charging stations



The number of level 2 and level 3 chargers installed at each location



Whether to upgrade existing electrical infrastructure

Parameters

Demand (EV Range)

Parameter		Description
Demand of each zip code		Average electric range of vehicles in each zip code
Coverage	C[i, j]	C[i, j] = 1 if location j is covered by station i, 0 o.w.
	Coverage threshold (theta)	Assume **location j is covered by station i** if the distance between them are **less than 20% (theta) of location j's average electric range**
Public charger demand percentage		Approximately **30%** of households with electric vehicles **do not** have a charger installed at home
Average percentage charged		Most people tend to charge their EVs when the battery range drops below 20% and typically charge it up to 80% (7). Therefore, we assume average percentage charged = 60%
Daily active charging hours		10h per day

Parameters

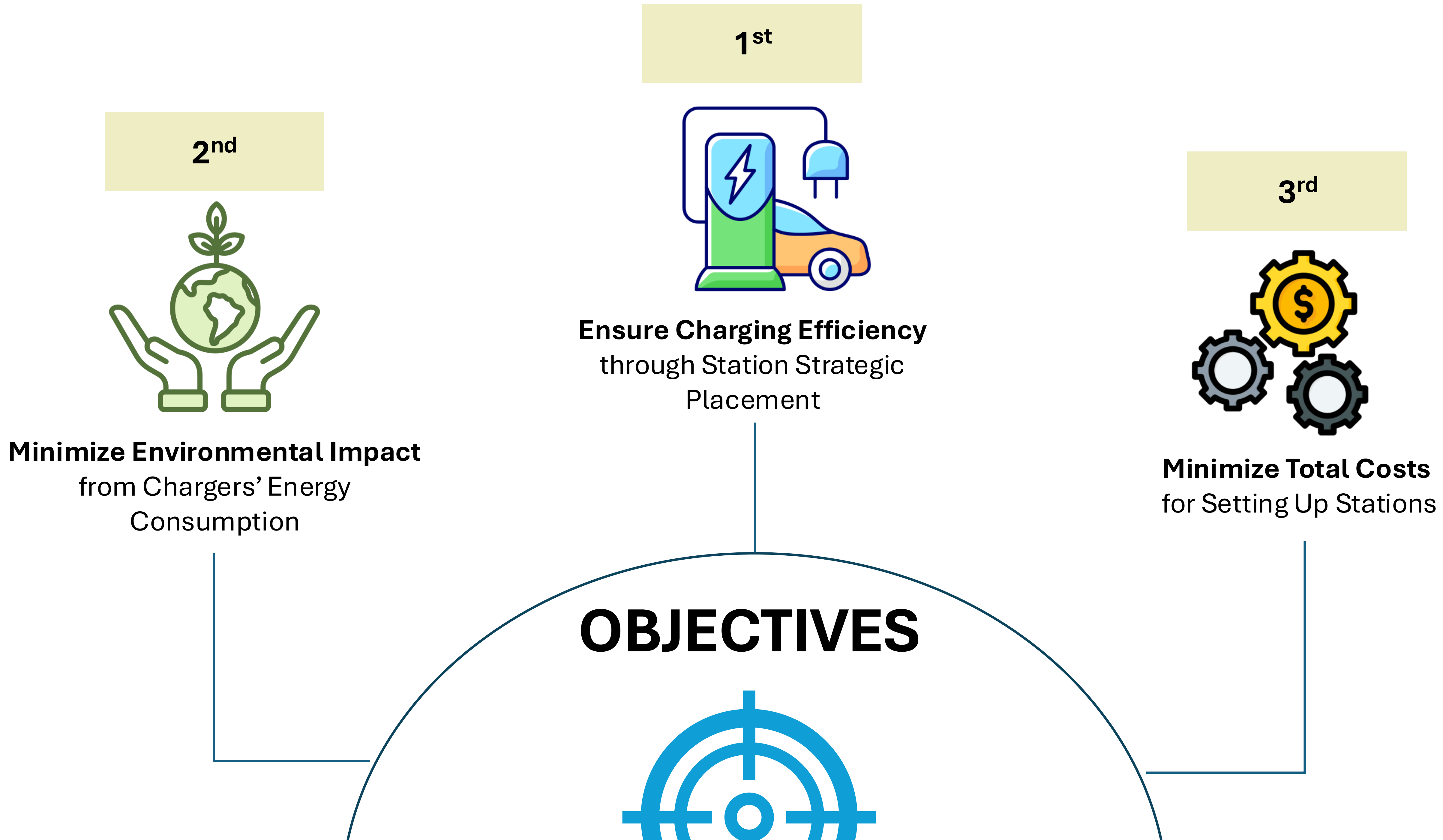
Environmental Impact

Parameter	Description
Power Consumption	Level 2 charger: 13 kW Level 3 charger: 200 kW
Charging Speed	Level 2 charger: 15 miles/hour Level 3 charger: 210 miles/hour
Power Consumption per Mile	Level 2 charger: 13kW/15 miles/hour = 0.87 kWh/mile Level 3 charger: 200kW/210 miles/hour = 0.95 kWh/mile
Total Consumption (kWh)	C2 = 0.87kWh/mile x (Demand met by L2 in miles) C3 = 0.95 kWh/mile x (Demand met by L3 in miles)
Environmental Factor	EF2 (Level 2 charger(Solar)) = 3.1 × 10−4 gha/kWh EF3 (Level 3 charger(Fossils)) = 3.15×10−5 gha/kWh
Total Environmental Impact (gha)	E = EF2 x C2 + EF3 x C3 = (3.1 × 10−4 gha/kWh) x C2 + (3.15×10−5 gha/kWh) x C3 Global Hectare or gha quantifies the biologically productive area required to provide resources consumed by the station (such as energy) and to absorb associated wastes, including CO_2 emissions.

Parameters

Set Up Costs

Parameter	Description
Cost per charger	Include hardware and installation cost: - Level 2: $ 8,250 - Level 3: $ 65,000
Station Cost (base)	Fixed costs related to site preparation, getting permit, and others (station design, lighting, security systems, etc.). Total to $ 50,000
Electrical Upgrade Cost (3 tiers)	Upgrade costs will vary from $0 to $100k based on the electrical load (number of chargers and type of chargers)
Usable capacity	The electrical capacity (amps) that is available for use to operate all chargers at each location.


1st
Ensure Charging Efficiency
through Station Strategic
Placement
2nd
Minimize Environmental Impact
from Chargers' Energy
Consumption
3rd
Minimize Total Costs
for Setting Up Stations
OBJECTIVES

Objective 1: Maximize Total Charging Capacity per Hour

By maximizing the total charging capacity, we can meet demand efficiently, minimize wait times, and optimize resource utilization.

$$\boxed{\text{Total Charging Capacity per Hour} \quad = \quad \underbrace{\text{Total Miles Added by Type 2 and Type 3 Chargers per Hour}}_{\displaystyle \sum_{i=2,3} \left[\text{Number of chargers of type (i) x Charging speed of type (i)} \right]}}$$

Objective 2: Minimize Environmental Impact

Environmental Impact	**=**	**Total of Ecological Footprint based on total miles of range (gha)**

$$\underbrace{\text{Total of Ecological Footprint based on total miles of range (gha)}} = \sum_{i=2,3}\left[\text{Total consumption from demand (range) fulfilled by charger level (i) (kWh)} \times \text{Environmental factor for charger level (i) (gha/kWh)}\right]$$

Objective 3: Minimize Total Costs

Minimize total costs associated with setting up chargers and charging stations at all chosen locations

Total Costs = Charger Setup Cost + Station Setup Cost

Charger Setup Cost:
- Total costs for buying, installing, and setting up chargers (Level 2 and Level 3) at all locations

Station Setup Cost:
- Station costs (base)
- Electrical Upgrade Costs (if applicable)

Problem Constraints

Coverage: Every EV is within range of at least one charging station
~> No demand is left unserved

Demand Fulfillment: Charging capacity is sufficient to meet demand at each location
~> Every zip code has enough chargers nearby to meet its total charging needs

Capture extra demand while avoiding oversupply: The total demand fulfilled by both Level 2 and 3 chargers must not exceed 120% of total demand from all EVs.

Electrical Upgrade: Ensures that the electrical infrastructure at each site can handle the charging station. If the electrical load exceeds the available capacity, upgrade to the appropriate tier

Avoid Overbuilding: Ensures that up to 20 chargers can be installed at each location

Number of Chargers: using the current number of EV chargers (level 2 and level 3) in WA to mimic current state in the optimization problem.

Please refer to Appendix 1 for details regarding Electrical Upgrade Costs and Requirement

Solutions Discussion

Total Charging Capacity per Hour
225,270 miles/hr

Environmental Impact
481.3 gha

Total Costs
~ $ 119.9 M

Stations Count: 265

Level 2 Charger
Total number: 4,546 units
Total demand covered: 681,900 miles

Level 3 Charger
Total number: 748 units
Total demand covered: 1,570,800 miles

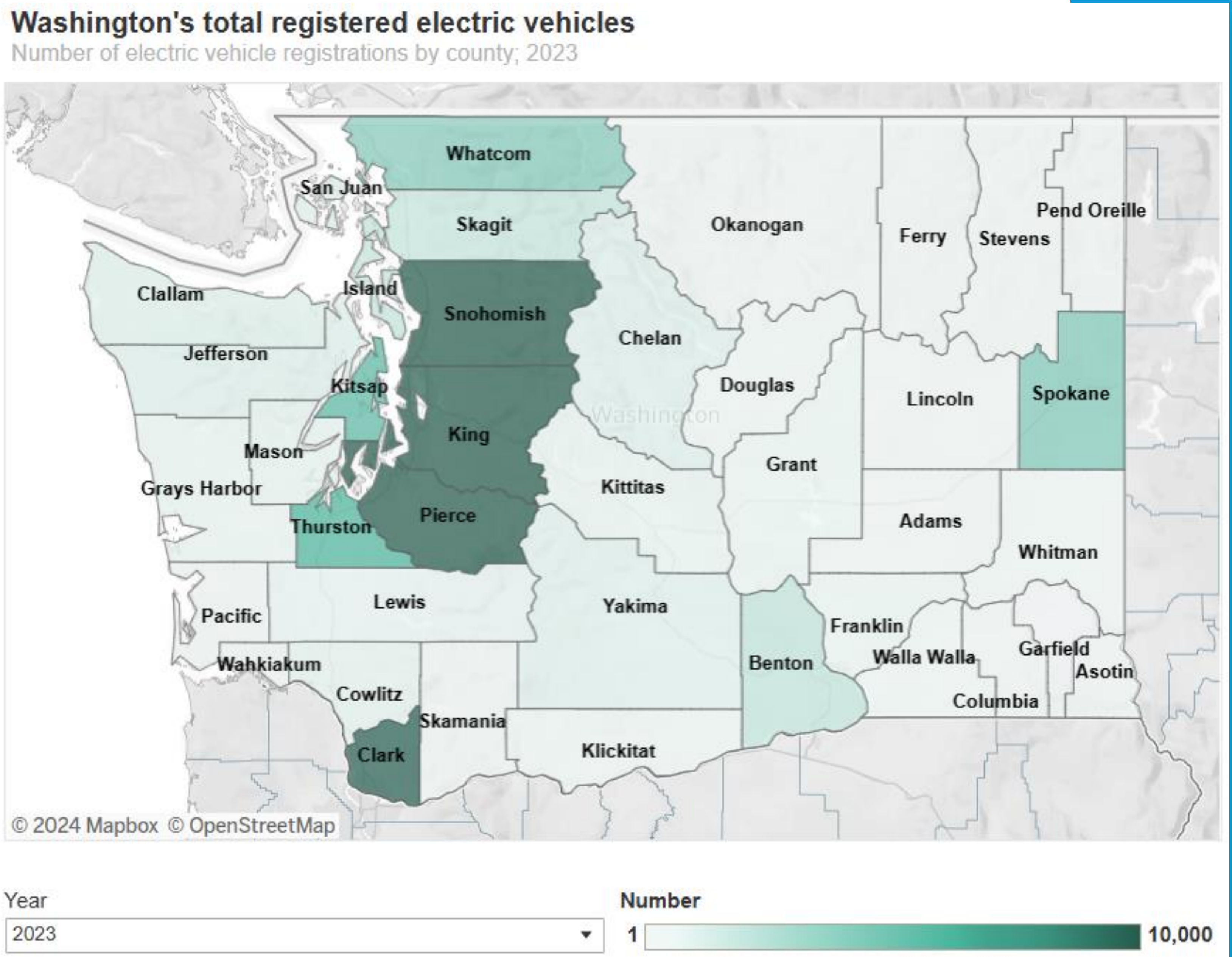
Solutions Discussion

	Level 2 Chargers	Level 3 Chargers
CURRENT	**4,546 units**	**1,295 units**
OPTIMAL	**4,546 units**	**748 units**

- Level 2 charger allocation is well balanced to meet current demand.
- Level 3 charger allocation may be excessive, particularly in low-demand and underutilized areas.

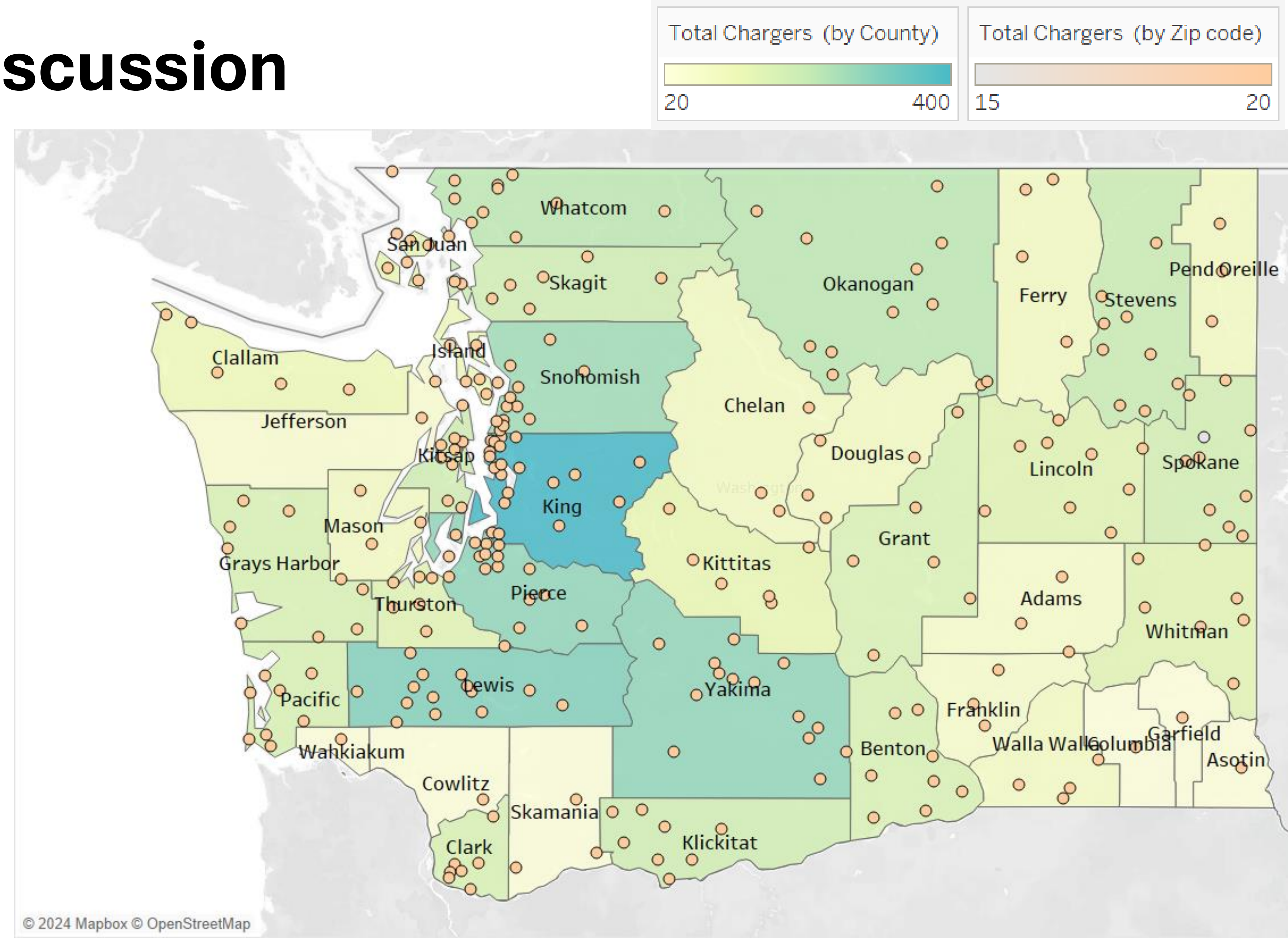
=> *The optimal solution minimizes overinvestment in infrastructure and freeing up resources for future expansion*

Solutions Discussion

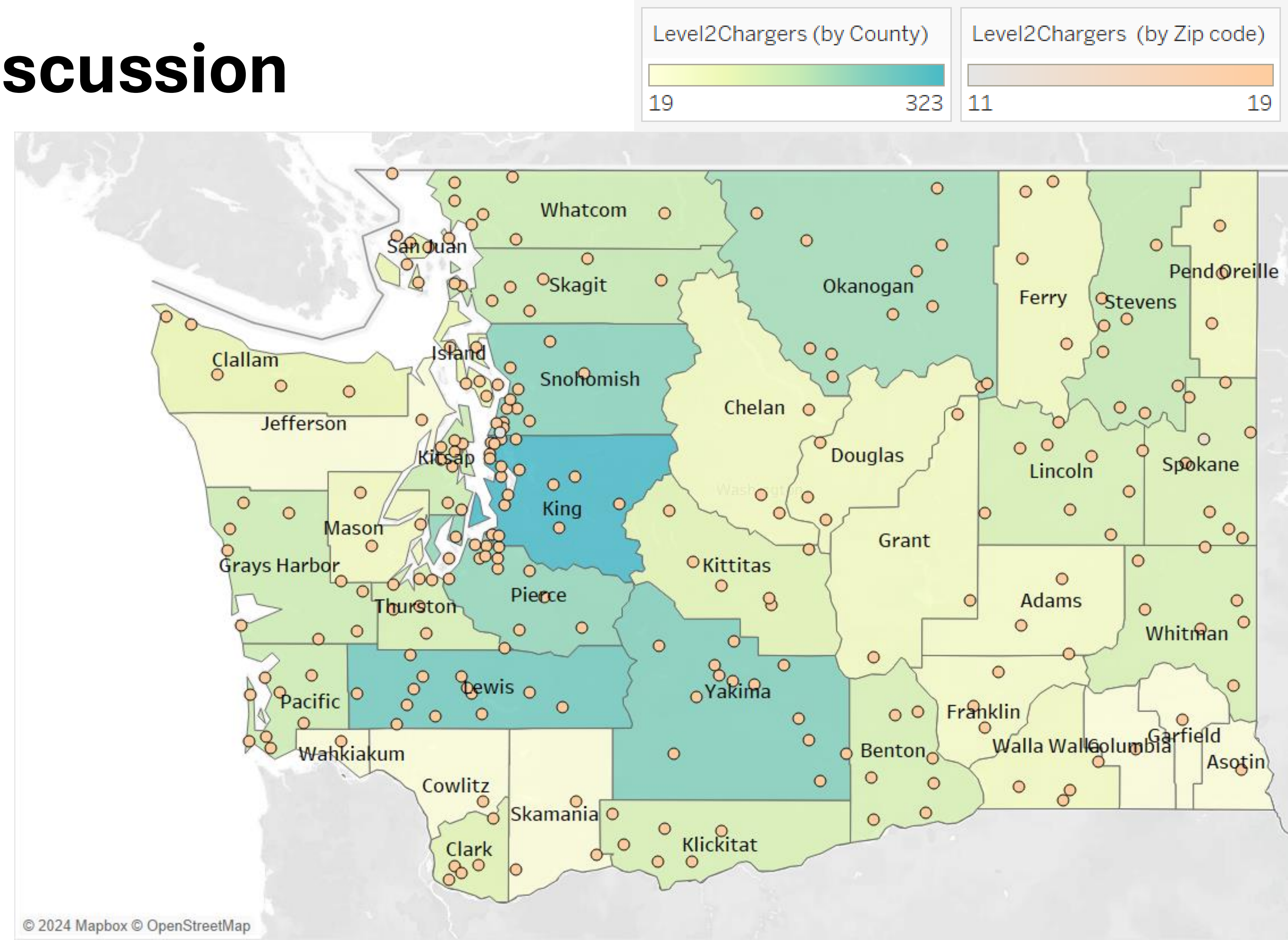


Solutions Discussion

Charging station distribution & Total charger count at each region



Solutions Discussion

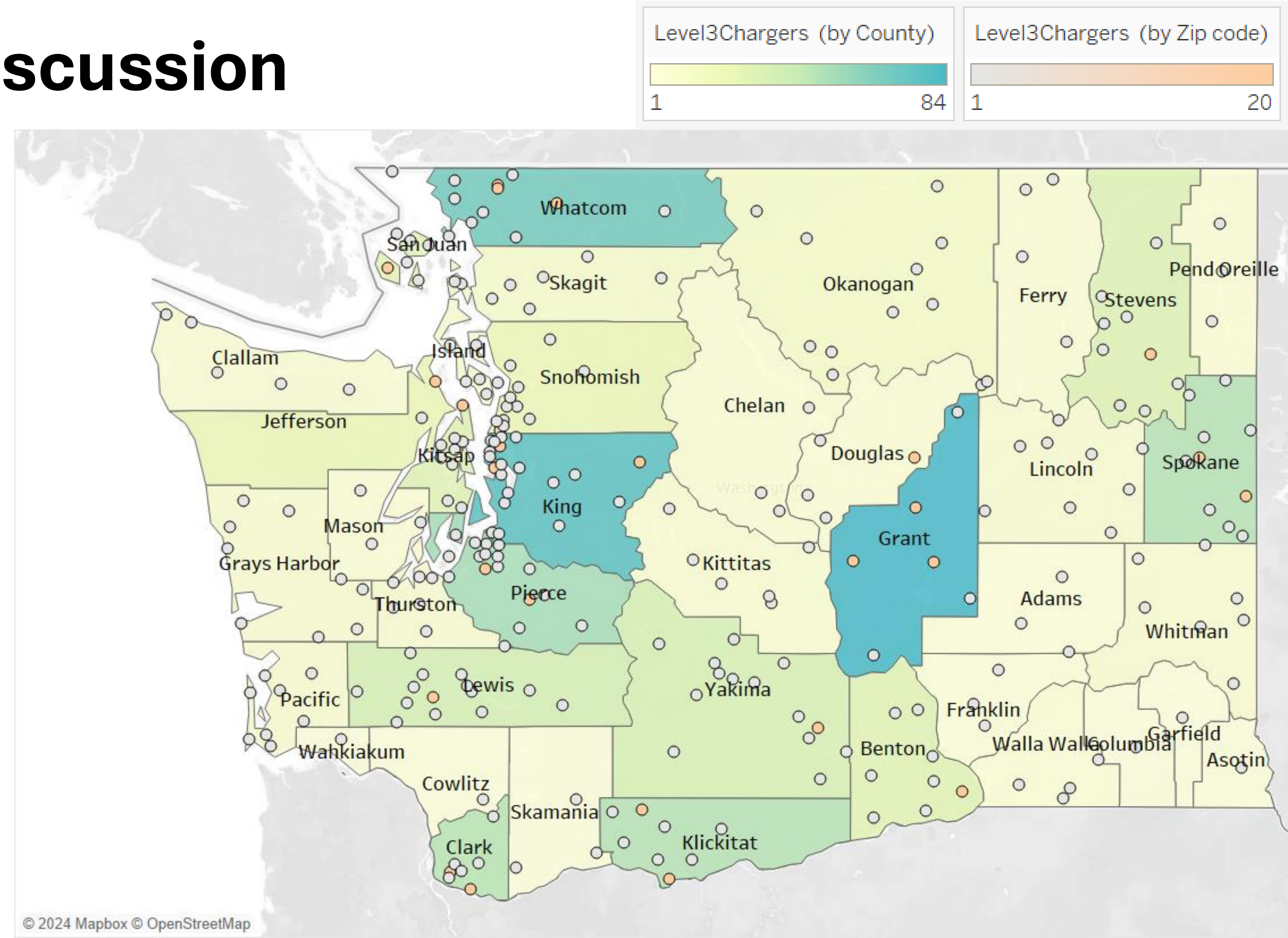


Total Type 2 charger count

at each region

Solutions Discussion

Total Type 3 charger count at each region



Extension 1: Parameter Sensitivity

Vary coverage threshold (0.1 to 0.5): This parameter determines how large the service area is for each station, balancing **coverage vs. network density**.

Total Charging Capacity per Hour (miles/hour)	Total Environment Impact (gha)	Total Cost	Total Range fulfilled by Type 2 Chargers (miles)	Total Range fulfilled by Type 3 Chargers (miles)	Total number of Type 2 Chargers	Total number of Type 3 Chargers
225,270	481.3	$ 119.9 M	681,900	1,570,800	4,546	748

Implications:

- The number of chargers and their placement are sufficient to meet the demand coverage requirements even under stricter thresholds, **OR**
- Constraints related to demand fulfillment, charger capacities, or coverage radius might already ensure that all areas are adequately covered, making the parameter irrelevant.

==> May need to reexamine the current coverage threshold (0.2)

Extension 1: Parameter Sensitivity

Vary average percentage charged (previously assumed 60%)

Average % Charged	Total Charging Capacity per Hour (miles/hour)	Total Environment Impact (gha)	Total Cost	Total Range fulfilled by Type 2 Chargers (miles)	Total Range fulfilled by Type 3 Chargers (miles)	Total number of Type 2 Chargers	Total number of Type 3 Chargers
0.30	112,635	149.8	$ 80,993,250	681,150	445,200	4,541	212
0.48	180,225	348.9	$ 104,271,750	680,850	1,121,400.	4,539	534
0.60	225,270	481.3	$ 119,899,500	681,900	1,570,800	4,546	748
0.72	270,330	614.8	$ 135,254,500	678,900	2,024,400	4,526	964
0.90	337,920	813.9	$ 158,623,000	678,600	2,700,600	4,524	1286

Extension 2: Weighted Multi-Objective Function

To counterbalance the differences in scales (miles/hour, gha, $), we assign these weights to make sure the model still prioritizes total range first, followed by environmental impact and total costs.

Objective	Minimize Total Costs	Minimize Environmental Impact	Maximize Total Range per Hour
Weights	150,000	10,000	0.000001

	Total Charging Capacity per Hour (miles/ hour)	Total Environment Impact (gha)	Total Cost	Total number of Stations	Total Range fulfilled by Type 2 Chargers (miles)	Total Range fulfilled by Type 3 Chargers (miles)	Total number of Type 2 Chargers	Total number of Type 3 Chargers
Weighted	225,495	486.4	$ 123.3 M	392	665,250	1,589,700	4,435	757
Hierarchical	225,270	481.3	$ 119.9 M	265	681,900	1,570,800	4,546	748

Extension 3: Charger Breakdown

Introduce the charger reliability factor to account for instances where chargers do not work. Our model originally assumes that chargers work 100% of the time (100% reliability factor).

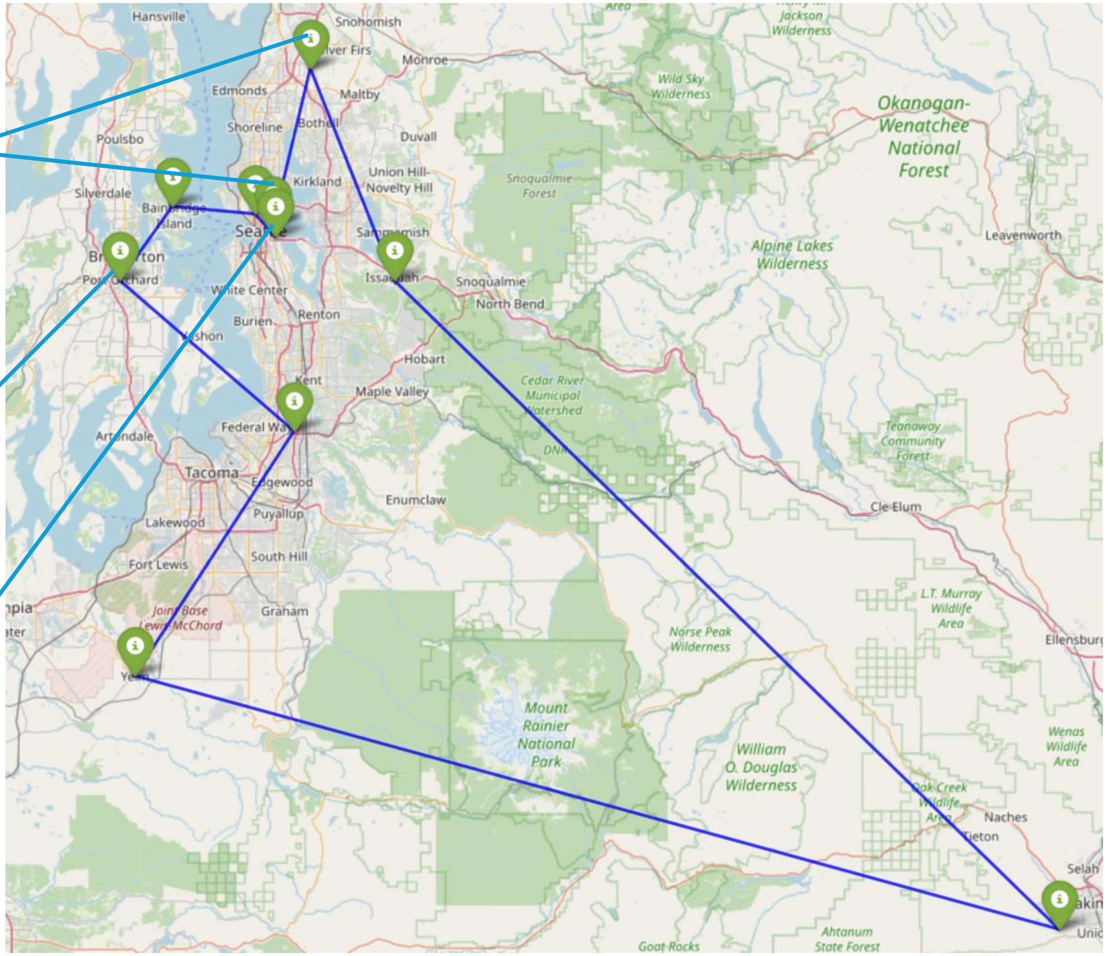
Charger	Level 2	Level 3
Reliability	95%	90%

Model	Total Charging Capacity per Hour (miles/ hour)	Total Environment Impact (gha)	Total Cost	Total number of Stations	Total Range fulfilled by Type 2 Chargers (miles)	Total Range fulfilled by Type 3 Chargers (miles)	Total number of Type 2 Chargers	Total number of Type 3 Chargers
Breakdown	225,288	490.8	$ 127.1 M	271	646,380	1,606,500	4,536	850
Base	225,270	481.3	$ 119.9 M	265	681,900	1,570,800	4,546	748

Extension 4: Traveling Maintenance Man

A maintenance man is hired to maintain the 10 stations below. What is the best route to take to optimize his distance traveled?

Order	ZIP Code	City/Town
1. Start	98122	Seattle
2	98012	Bothell
3	98027	Issaquah
4	98903	Yakima
5	98597	Yelm
6	98001	Auburn
7	98366	Port Orchard
8	98110	Bainbridge Island
9	98109	Seattle
10. End	98144	Seattle



Conclusions

Our optimization model identifies:

- The ideal locations for charging stations.
- The optimal number of chargers at each site, with a cap on the number of L2 and L3 chargers.

This model addresses:

- **Service gaps:** Optimizing demand coverage for all locations.
- **Environmental impact**: Avoiding excessive deployment and waste.
- **Economic efficiency**: Reducing underutilization and minimizing costs.

==> *By benchmarking the current strategy against this optimized solution, Washington can refine its infrastructure to ensure efficient allocations.*

Conclusions

Next Steps:

- Assess opportunities for gradual realignment/relocation of existing chargers to optimize efficiency.
- Model can be modified based on changes to EV infrastructure, local regulations, and growing EV demand.

Future Considerations:

- Account for out of state cars, since we only have data from cars registered in Washington.
- Get charging data from stations to predict demand fluctuations using ML.


CHARGING
60 %
Thank You

Appendix 1: Electrical Upgrade Information

Upgrade Tier	Costs	Electric Capacity Available for Use (amps)
0	$0	≤ 200
1	$30,000	$201\ to\ 500$
2	$75,000	$501\ to\ 950$
3	$100,000	≥ 951

References

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- (4): https://www.cascadepbs.org/news/2024/08/wa-rolls-out-one-nations-most-generous-ev-rebate-programs#:~:text=Washingtonians%20drove%20194%2C232%20passenger%20EVs,and%202.94%20million%20by%202035
- (5): https://doi.org/10.1016/j.prime.2023.100398
- (6): https://www.transportation.gov/rural/ev/toolkit/ev-basics/charging-speeds
- (7): https://1charging.com/the-80-20-ev-charging-rule-ev-battery-charging-best-practices

Dataset

- https://www.kaggle.com/datasets/utkarshx27/electric-vehicle-population-data