Exploring Electric Vehicle Adoption Trends in Washington State

Literature Review

Student: Arunkumar Cherungot-Meppadathkalam

Student No.: 501277792

Supervisor: Tamer Abdou

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Ryerson University

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Introduction

The rise in electric vehicle (EV) adoption is a key component in the transition to sustainable transportation. This literature review aims to provide a comprehensive analysis of the factors influencing EV adoption in Washington State, focusing on geographic and infrastructure related factors, and to evaluate the use of machine learning models in predicting future EV adoption trends.

- **What is already known about the topic?**

  Electric vehicle adoption is influenced by a variety of factors, including environmental concerns, government policies, financial incentives, and advancements in EV technology. Socio-economic factors such as income, education, and occupation also play significant roles. Apart from these factors, geographic location and infrastructure such as electric utility provider also plays an important role in deciding the adoption rates of electric vehicles.

- **Critical analysis of what is already known?**

  Existing studies have established that financial incentives and government policies significantly impact EV adoption. However, there is a gap in understanding the combined effect of geographic and infrastructure related factors, particularly in Washington State. Moreover, the application of machine learning models for predicting EV adoption trends based on these factors is relatively underexplored.

- **Has Anyone Else Ever Done Anything Exactly the Same?**

  No studies have been found that exactly replicate the current research focus on Washington State using the same dataset and machine learning approaches. However, similar studies have been conducted in other regions, focusing on different aspects of EV adoption.

- **Has Anyone Else Done Anything That is Related?**

  Yes, related studies include:

  1. https://www.sciencedirect.com/science/article/pii/S0378775310003915 - Hybrid, plug-in hybrid, or electric—What do car buyers want? By Jonn Axsen, Kenneth S. Kurani

- Summary: This study by Axsen and Kurani explores consumer preferences for hybrid, plug-in hybrid, and electric vehicles. It examines the factors influencing these preferences, such as environmental benefits, cost, and performance.
- Relevance: Understanding consumer preferences is crucial for predicting EV adoption and tailoring policies to promote electric vehicle uptake.

2. https://www.sciencedirect.com/science/article/abs/pii/S0378775310003915
Analysis of plug-in hybrid electric vehicle utility factors by Thomas H. Bradley, Casey W. Quinn

   - Summary: Bradley and Quinn analyze the utility factors of plug-in hybrid electric vehicles (PHEVs), including their operational characteristics and potential benefits in reducing emissions.
   - Relevance: Insights from this paper help in assessing the practical benefits and limitations of PHEVs, which is valuable for modeling future adoption trends.

3. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0176729
Forecasting electric vehicles sales with univariate and multivariate time series models: The case of China by Yong Zhang, Miner Zhong, Nana Geng, Yunjian Jiang

   - Summary: Zhang et al. forecast EV sales in China using univariate and multivariate time series models, considering economic, policy, and market factors.
   - Relevance: This methodology can be applied to forecast EV adoption in Washington State, adapting the models to local socio-economic data.

4. https://www.sciencedirect.com/science/article/abs/pii/S0301421512005162
Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions by Ona Egbue, Suzanna Long

   - Summary: Egbue and Long investigate the barriers to EV adoption, focusing on consumer attitudes, infrastructure challenges, and technological limitations.
   - Relevance: Identifying barriers to EV adoption helps in developing strategies to overcome them, enhancing the effectiveness of policy interventions.

5. https://www.sciencedirect.com/science/article/pii/S0965856416302208
   Comparing high-end and low-end early adopters of battery electric vehicles by Scott Hardman, Eric Shiu, Robert Steinberger-Wilckens

   - Summary: Egbue and Long investigate the barriers to EV adoption, focusing on consumer attitudes, infrastructure challenges, and technological limitations.
   - Relevance: Identifying barriers to EV adoption helps in developing strategies to overcome them, enhancing the effectiveness of policy interventions.

6. https://www.sciencedirect.com/science/article/abs/pii/S1364032119307129
   Factors influencing early battery electric vehicle adoption in Ireland by Sanghamitra Chattopadhyay Mukherjee, Lisa Ryan

   - Summary: Egbue and Long investigate the barriers to EV adoption, focusing on consumer attitudes, infrastructure challenges, and technological limitations.
   - Relevance: Identifying barriers to EV adoption helps in developing strategies to overcome them, enhancing the effectiveness of policy interventions.

- **Where Does my Work Fit in With What Has Gone Before?**

  This research builds on existing studies by focusing specifically on Washington State and using a comprehensive dataset from the Department of Licensing. The application of machine learning models to predict EV adoption based on demographic and socio-economic factors is a novel contribution.

- **Why is this Research Worth Doing in the Light of What Has Already Been Done?**

  Understanding the factors driving EV adoption in Washington State can help policymakers and businesses develop targeted strategies to promote EV adoption. Predictive models can provide valuable insights into future trends, aiding in infrastructure planning and policy formulation. The analysis will be grouped based on city, county and legislative districts as these variables will be necessary to give an insight to the respective policy makers of the state.

  Based on my research, policy makers can have an insight on the growth rate of electric vehicles. From these insights, they can make important decisions related to changes in

electric vehicle registration policy, number of new charging stations to be installed, design new plans and policies to boost electric vehicle use in respective location and what changes electric utility companies can make in the future based on the growth rate of electric vehicles.

Descriptive Statistics and Exploratory Data Analysis (EDA)

The dataset includes over 181,000 observations with variables such as VIN, County, City, State, Postal Code, Model Year, Make, Model, Electric Vehicle Type, CAFV Eligibility, Electric Range, Base MSRP, Legislative District, DOL Vehicle ID, Vehicle Location, Electric Utility, and 2020 Census Tract.

Description of Variables:

- VIN (1-10): The first ten characters of the Vehicle Identification Number, which uniquely identifies each vehicle.
- County: This is the geographic region of a state that a vehicle's owner is listed to reside within. Vehicles registered in Washington state may be located in other states.
- City: The city in which the registered owner resides.
- State: This is the geographic region of the country associated with the record. These addresses may be located in other states.
- Postal Code: The 5-digit zip code in which the registered owner resides.
- Model Year: The model year of the vehicle, determined by decoding the Vehicle Identification Number (VIN).
- Make: The manufacturer of the vehicle, determined by decoding the Vehicle Identification Number (VIN).
- Model: The model of the vehicle, determined by decoding the Vehicle Identification Number (VIN).
- Electric Vehicle Type: Indicates whether the vehicle is a Battery Electric Vehicle (BEV) or a Plug-in Hybrid Electric Vehicle (PHEV), distinguishing between different types of electric vehicles.

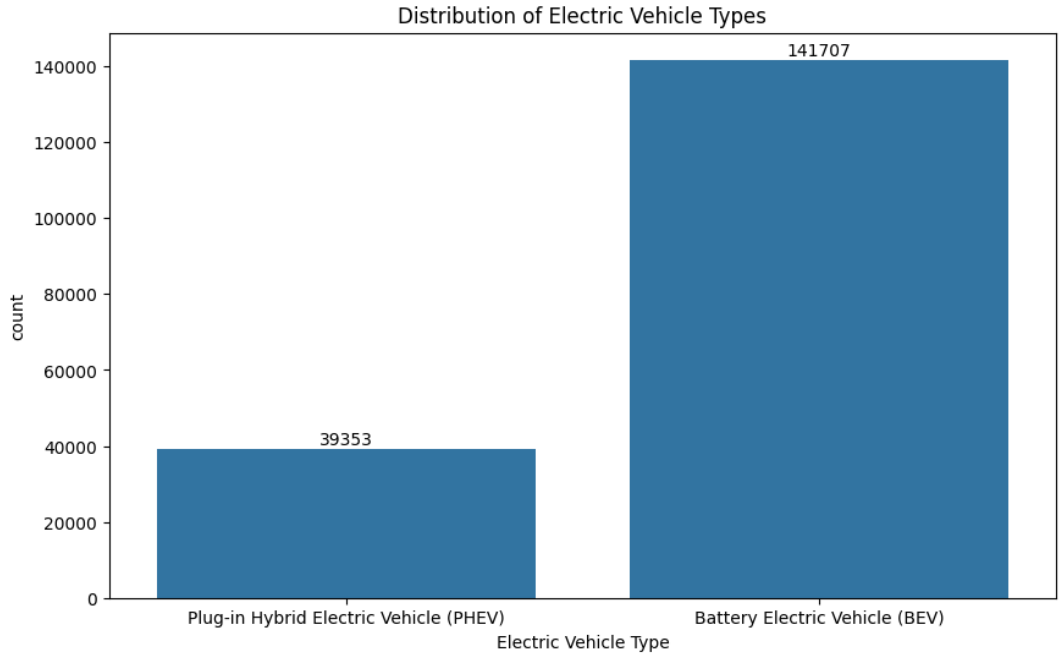
- Clean Alternative Fuel Vehicle (CAFV) Eligibility: This categorizes vehicle as Clean Alternative Fuel Vehicles (CAFVs) based on the fuel requirement and electric-only range requirement in House Bill 2042 as passed in the 2019 legislative session.
- Electric Range: Describes how far a vehicle can travel purely on its electric charge.
- Base MSRP: This is the lowest Manufacturer's Suggested Retail Price (MSRP) for any trim level of the model in question.
- Legislative District: The specific section of Washington State that the vehicle's owner resides in, as represented in the state legislature.
- DOL Vehicle ID: An identification number assigned by the Washington State Department of Licensing, serving as a unique identifier within the licensing system.
- Vehicle Location: The center of the ZIP Code for the registered vehicle.
- Electric Utility: This is the electric power retail service territories serving the address of the registered vehicle. All ownership types for areas in Washington are included: federal, investor owned, municipal, political subdivision, and cooperative. If the address for the registered vehicle falls into an area with overlapping electric power retail service territories, then a single pipe | delimits utilities of same TYPE and a double pipe || delimits utilities of different types.
- 2020 Census Tract: The census tract identifier is a combination of the state, county, and census tract codes as assigned by the United States Census Bureau in the 2020 census, also known as Geographic Identifier (GEOID).

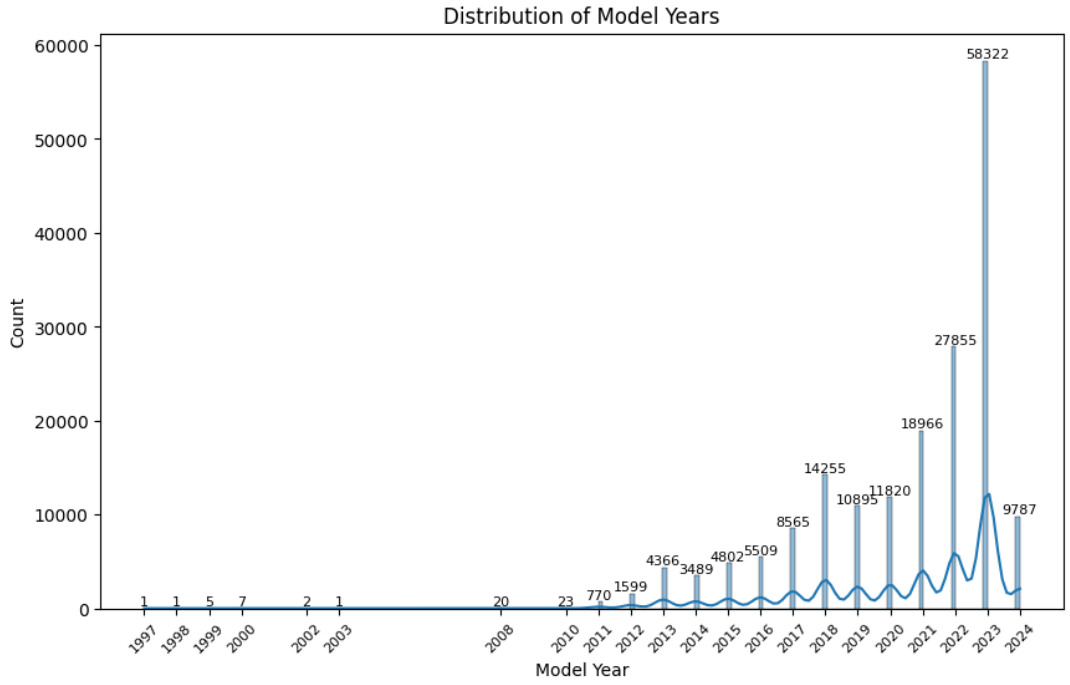
Univariate Analysis and Bivariate Analysis:

A descriptive statistic including data types of each variable, missing values, correlations and data distribution is done using the y-data profiling library in python. The output, in HTML format is uploaded in GitHub repository.

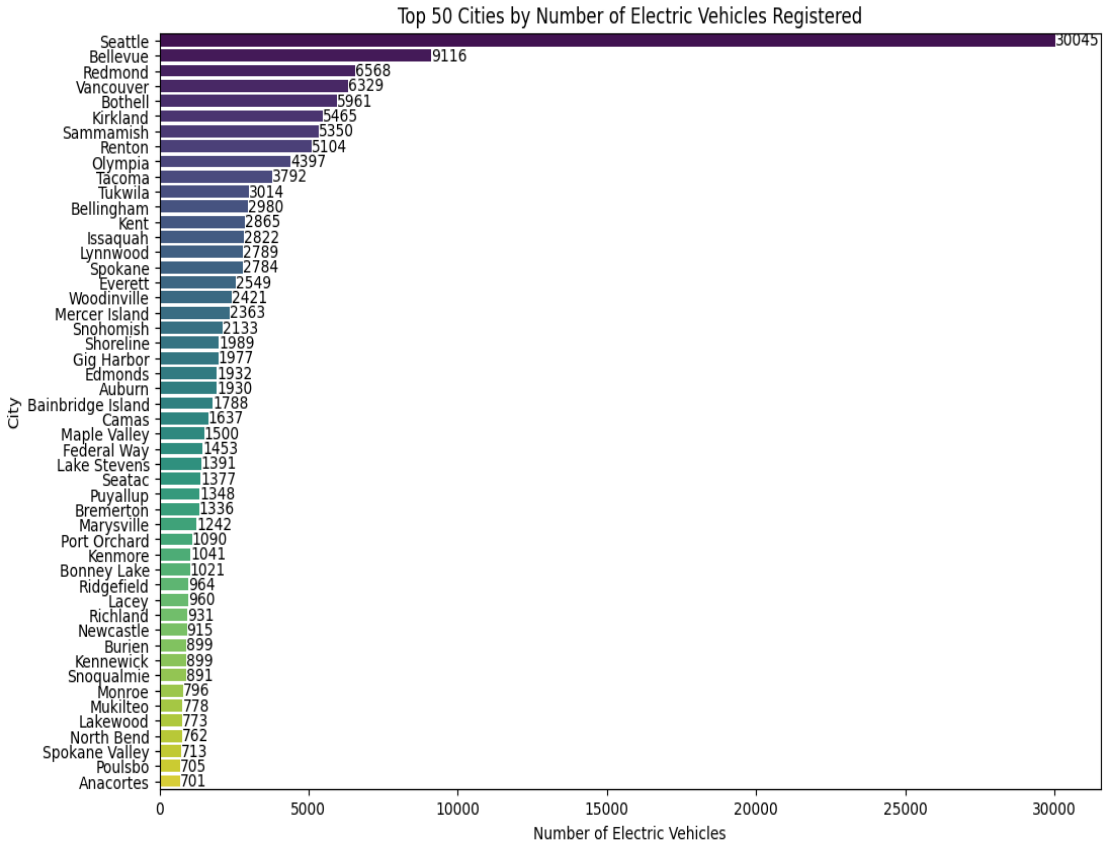
To draw a better picture, visualization tools of python have been used to depict the univariate and bivariate analysis of electric vehicle population data and the same are mentioned below. This will help in understanding the variable fluctuations and relationships:

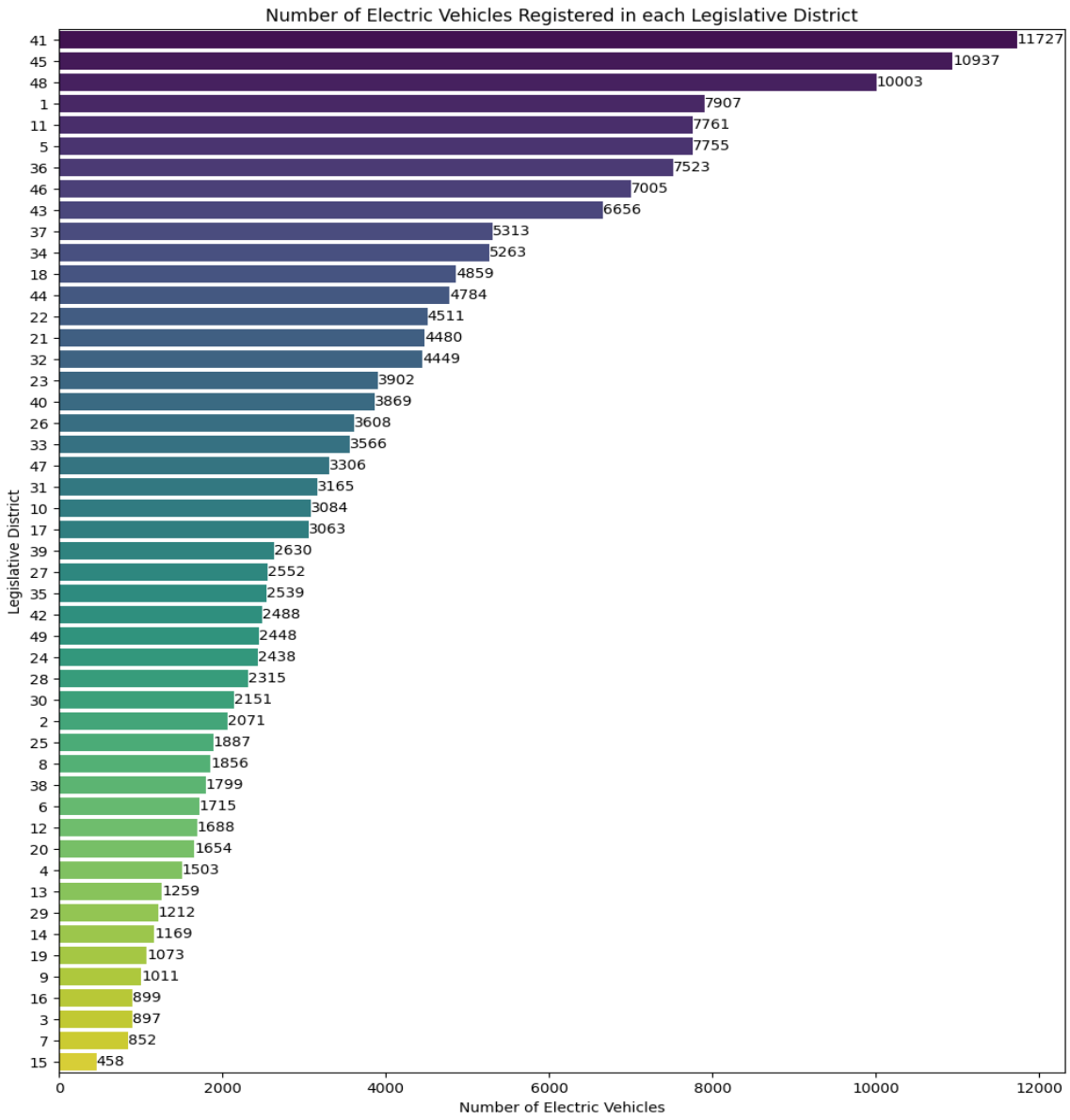
Univariate Analysis:





Bivariate Analysis:




Number of Electric Vehicles Registered in each Legislative District
Legislative District
Number of Electric Vehicles
41 11727
45 10937
48 10003
1 7907
11 7761
5 7755
36 7523
46 7005
43 6656
37 5313
34 5263
18 4859
44 4784
22 4511
21 4480
32 4449
23 3902
40 3869
26 3608
33 3566
47 3306
31 3165
10 3084
17 3063
39 2630
27 2552
35 2539
42 2488
49 2448
24 2438
28 2315
30 2151
2 2071
25 1887
8 1856
38 1799
6 1715
12 1688
20 1654
4 1503
13 1259
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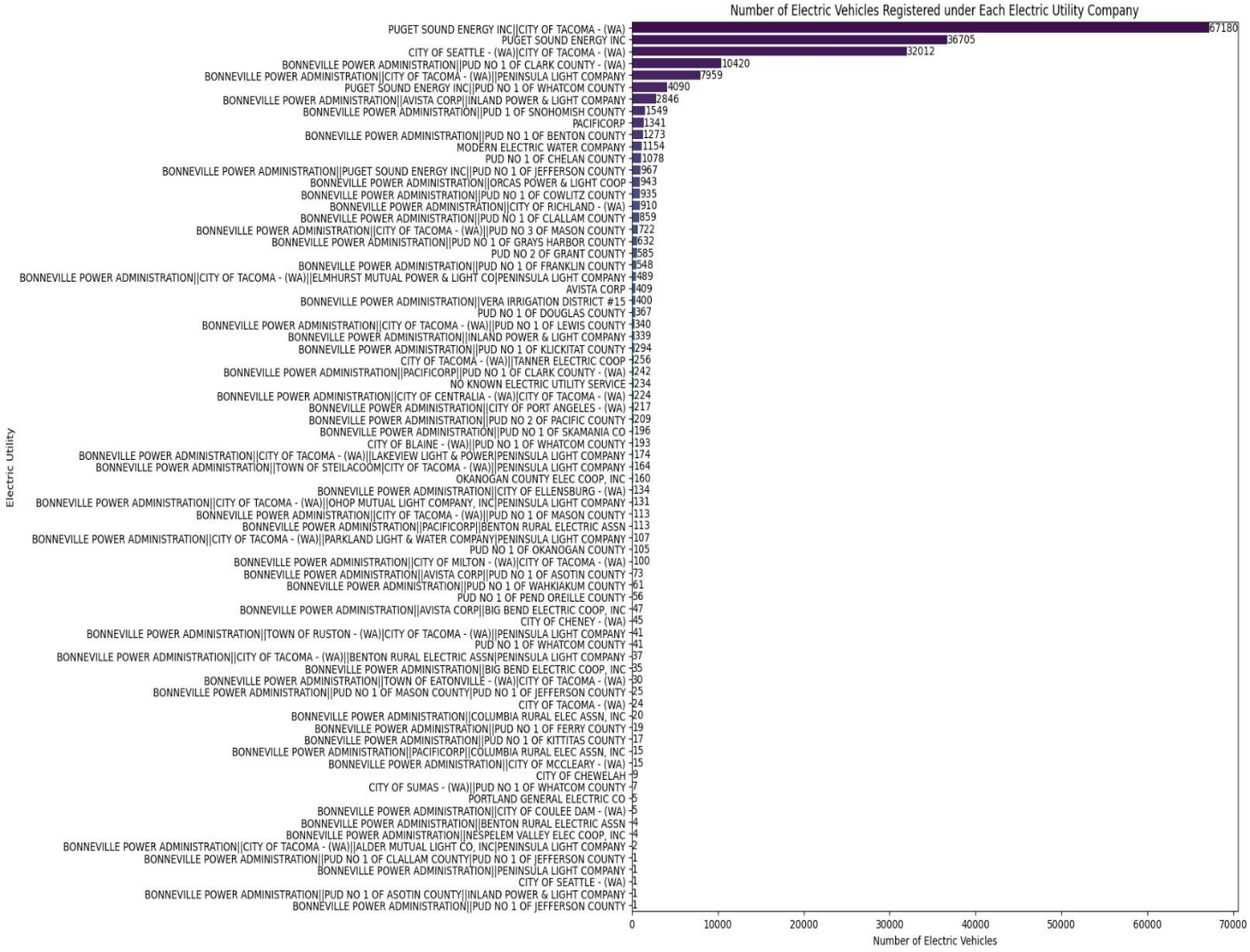
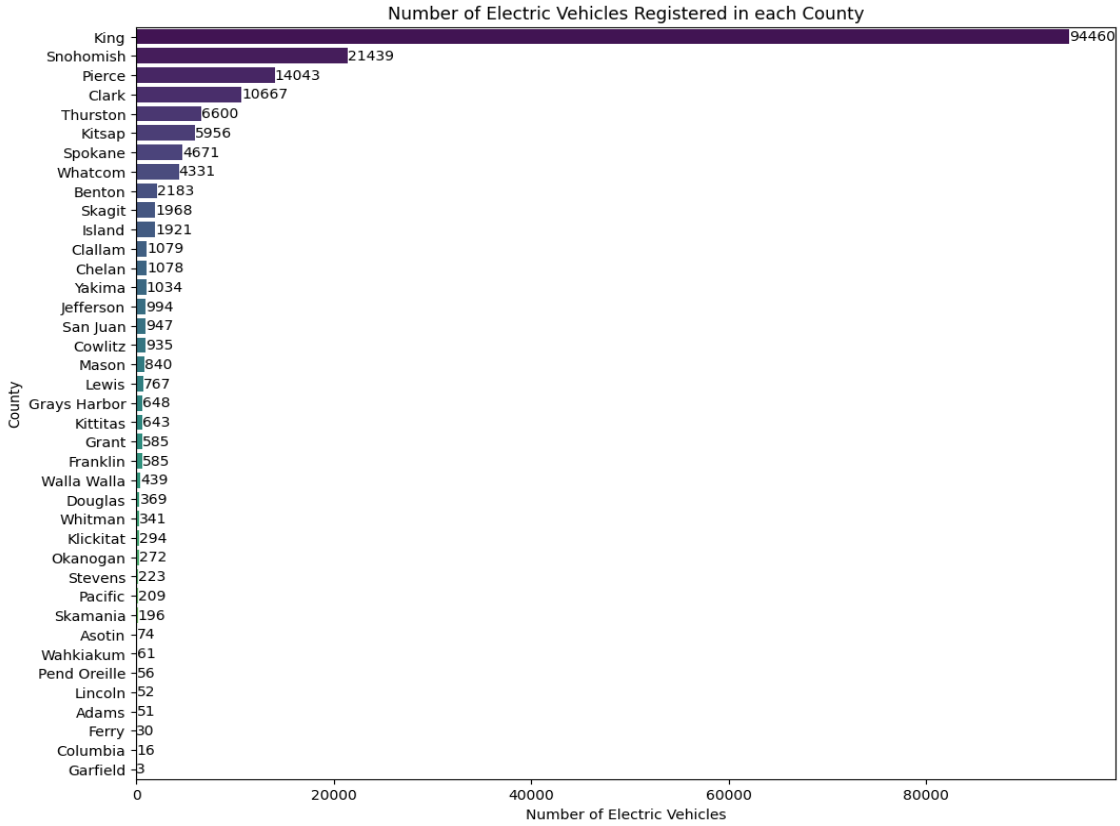
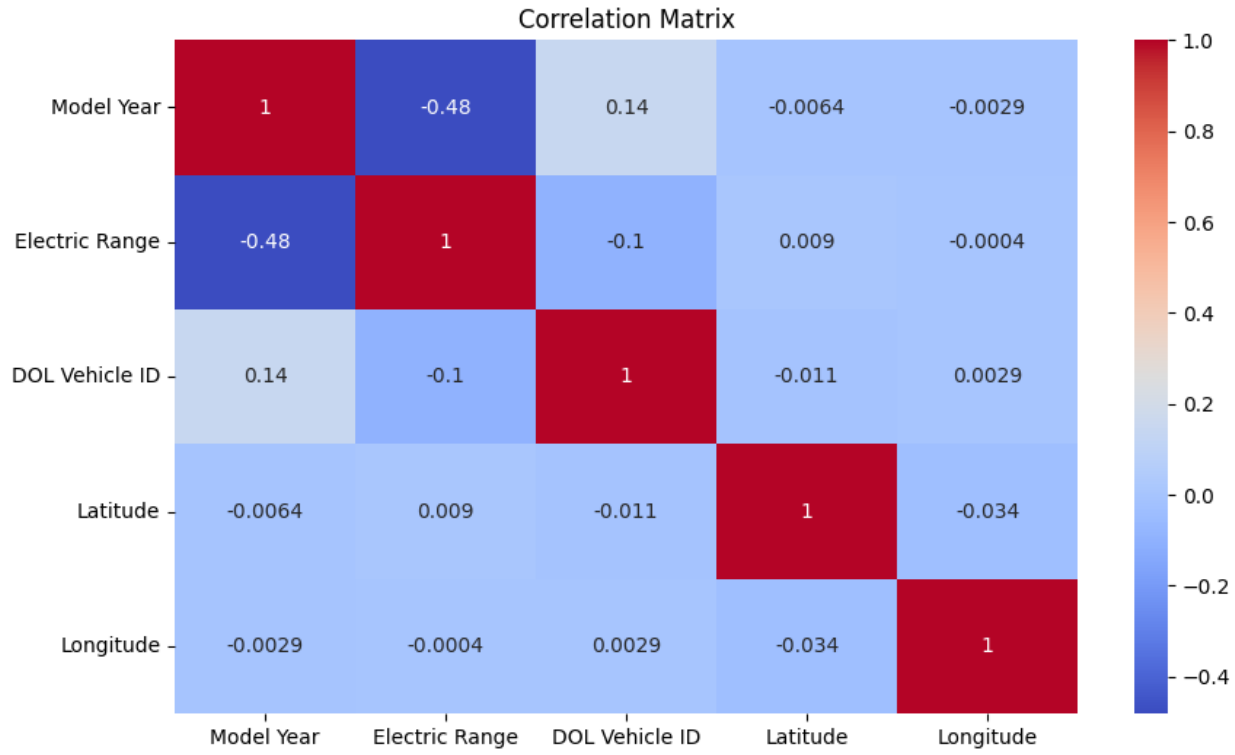
8000
10000
12000


Number of Electric Vehicles Registered under Each Electric Utility Company
Electric Utility
PUGET SOUND ENERGY INC||CITY OF TACOMA - (WA) 67180
PUGET SOUND ENERGY INC 36705
CITY OF SEATTLE - (WA)|CITY OF TACOMA - (WA) 32012
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF CLARK COUNTY - (WA) 10420
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||PENINSULA LIGHT COMPANY 7959
PUGET SOUND ENERGY INC||PUD NO 1 OF WHATCOM COUNTY 4090
BONNEVILLE POWER ADMINISTRATION||AVISTA CORP||INLAND POWER & LIGHT COMPANY 2846
BONNEVILLE POWER ADMINISTRATION||PUD 1 OF SNOHOMISH COUNTY 1549
PACIFICORP 1341
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF BENTON COUNTY 1273
MODERN ELECTRIC WATER COMPANY 1154
PUD NO 1 OF CHELAN COUNTY 1078
BONNEVILLE POWER ADMINISTRATION||PUGET SOUND ENERGY INC||PUD NO 1 OF JEFFERSON COUNTY 967
BONNEVILLE POWER ADMINISTRATION||ORCAS POWER & LIGHT COOP 943
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF COWLITZ COUNTY 935
BONNEVILLE POWER ADMINISTRATION||CITY OF RICHLAND - (WA) 910
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF CLALLAM COUNTY 859
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||PUD NO 3 OF MASON COUNTY 722
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF GRAYS HARBOR COUNTY 632
PUD NO 2 OF GRANT COUNTY 585
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF FRANKLIN COUNTY 548
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||ELMHURST MUTUAL POWER & LIGHT CO|PENINSULA LIGHT COMPANY 489
AVISTA CORP 409
BONNEVILLE POWER ADMINISTRATION||VERA IRRIGATION DISTRICT #15 400
PUD NO 1 OF DOUGLAS COUNTY 367
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||PUD NO 1 OF LEWIS COUNTY 340
BONNEVILLE POWER ADMINISTRATION||INLAND POWER & LIGHT COMPANY 339
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF KLICKITAT COUNTY 294
CITY OF TACOMA - (WA)||TANNER ELECTRIC COOP 256
BONNEVILLE POWER ADMINISTRATION||PACIFICORP||PUD NO 1 OF CLARK COUNTY - (WA) 242
NO KNOWN ELECTRIC UTILITY SERVICE 234
BONNEVILLE POWER ADMINISTRATION||CITY OF CENTRALIA - (WA)|CITY OF TACOMA - (WA) 224
BONNEVILLE POWER ADMINISTRATION||CITY OF PORT ANGELES - (WA) 217
BONNEVILLE POWER ADMINISTRATION||PUD NO 2 OF PACIFIC COUNTY 209
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF SKAMANIA CO 196
CITY OF BLAINE - (WA)||PUD NO 1 OF WHATCOM COUNTY 193
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||LAKEVIEW LIGHT & POWER|PENINSULA LIGHT COMPANY 174
BONNEVILLE POWER ADMINISTRATION||TOWN OF STEILACOOM|CITY OF TACOMA - (WA)||PENINSULA LIGHT COMPANY 164
OKANOGAN COUNTY ELEC COOP, INC 160
BONNEVILLE POWER ADMINISTRATION||CITY OF ELLENSBURG - (WA) 134
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||OHOP MUTUAL LIGHT COMPANY, INC|PENINSULA LIGHT COMPANY 131
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||PUD NO 1 OF MASON COUNTY 113
BONNEVILLE POWER ADMINISTRATION||PACIFICORP||BENTON RURAL ELECTRIC ASSN 113
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||PARKLAND LIGHT & WATER COMPANY|PENINSULA LIGHT COMPANY 107
PUD NO 1 OF OKANOGAN COUNTY 105
BONNEVILLE POWER ADMINISTRATION||CITY OF MILTON - (WA)|CITY OF TACOMA - (WA) 100
BONNEVILLE POWER ADMINISTRATION||AVISTA CORP||PUD NO 1 OF ASOTIN COUNTY 73
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF WAHKIAKUM COUNTY 61
PUD NO 1 OF PEND OREILLE COUNTY 56
BONNEVILLE POWER ADMINISTRATION||AVISTA CORP||BIG BEND ELECTRIC COOP, INC 47
CITY OF CHENEY - (WA) 45
BONNEVILLE POWER ADMINISTRATION||TOWN OF RUSTON - (WA)|CITY OF TACOMA - (WA)||PENINSULA LIGHT COMPANY 41
PUD NO 1 OF WHATCOM COUNTY 41
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||BENTON RURAL ELECTRIC ASSN|PENINSULA LIGHT COMPANY 37
BONNEVILLE POWER ADMINISTRATION||BIG BEND ELECTRIC COOP, INC 35
BONNEVILLE POWER ADMINISTRATION||TOWN OF EATONVILLE - (WA)|CITY OF TACOMA - (WA) 30
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF MASON COUNTY|PUD NO 1 OF JEFFERSON COUNTY 25
CITY OF TACOMA - (WA) 24
BONNEVILLE POWER ADMINISTRATION||COLUMBIA RURAL ELEC ASSN, INC 20
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF FERRY COUNTY 19
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF KITTITAS COUNTY 17
BONNEVILLE POWER ADMINISTRATION||PACIFICORP||COLUMBIA RURAL ELEC ASSN, INC 15
BONNEVILLE POWER ADMINISTRATION||CITY OF MCCLEARY - (WA) 15
CITY OF CHEWELAH 9
CITY OF SUMAS - (WA)||PUD NO 1 OF WHATCOM COUNTY 7
PORTLAND GENERAL ELECTRIC CO 5
BONNEVILLE POWER ADMINISTRATION||CITY OF COULEE DAM - (WA) 5
BONNEVILLE POWER ADMINISTRATION||BENTON RURAL ELECTRIC ASSN 4
BONNEVILLE POWER ADMINISTRATION||NESPELEM VALLEY ELEC COOP, INC 4
BONNEVILLE POWER ADMINISTRATION||CITY OF TACOMA - (WA)||ALDER MUTUAL LIGHT CO, INC|PENINSULA LIGHT COMPANY 2
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF CLALLAM COUNTY|PUD NO 1 OF JEFFERSON COUNTY 1
BONNEVILLE POWER ADMINISTRATION||PENINSULA LIGHT COMPANY 1
CITY OF SEATTLE - (WA) 1
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF ASOTIN COUNTY||INLAND POWER & LIGHT COMPANY 1
BONNEVILLE POWER ADMINISTRATION||PUD NO 1 OF JEFFERSON COUNTY 1
0
10000
20000
30000
40000
50000
60000
70000
Number of Electric Vehicles


Number of Electric Vehicles Registered in each County
King 94460
Snohomish 21439
Pierce 14043
Clark 10667
Thurston 6600
Kitsap 5956
Spokane 4671
Whatcom 4331
Benton 2183
Skagit 1968
Island 1921
Clallam 1079
Chelan 1078
Yakima 1034
Jefferson 994
San Juan 947
Cowlitz 935
Mason 840
Lewis 767
Grays Harbor 648
Kittitas 643
Grant 585
Franklin 585
Walla Walla 439
Douglas 369
Whitman 341
Klickitat 294
Okanogan 272
Stevens 223
Pacific 209
Skamania 196
Asotin 74
Wahkiakum 61
Pend Oreille 56
Lincoln 52
Adams 51
Ferry 30
Columbia 16
Garfield 3
County
0
20000
40000
60000
80000
Number of Electric Vehicles


Correlation Matrix
Model Year 1 -0.48 0.14 -0.0064 -0.0029
Electric Range -0.48 1 -0.1 0.009 -0.0004
DOL Vehicle ID 0.14 -0.1 1 -0.011 0.0029
Latitude -0.0064 0.009 -0.011 1 -0.034
Longitude -0.0029 -0.0004 0.0029 -0.034 1
Model Year
Electric Range
DOL Vehicle ID
Latitude
Longitude
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4

Approach

The approach adopted for the three research questions are as follows:

Cleaning of Data:

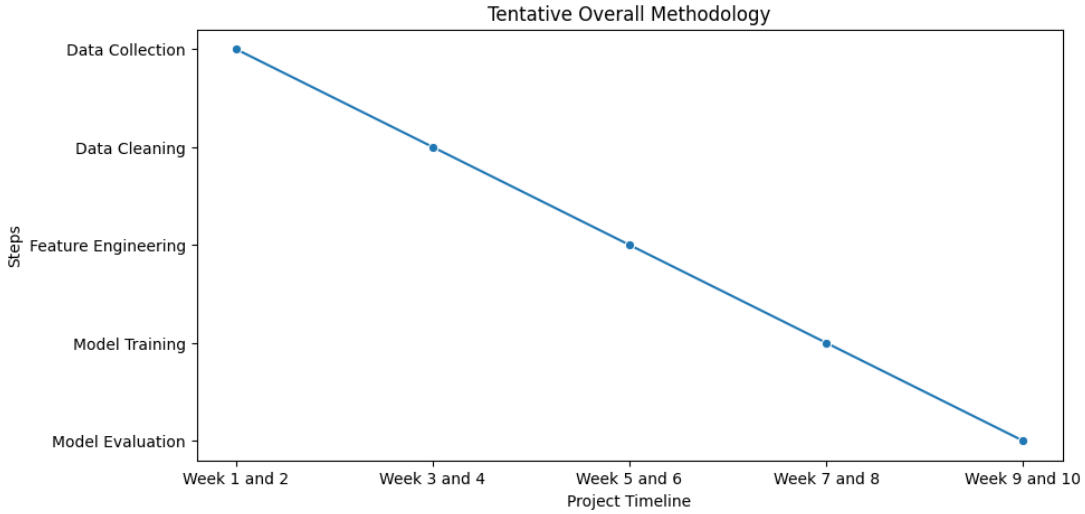
- After carefully summarising the data, 398 observations having the registration details of states other than Washington were removed.'
- The vehicle location variable having geographical coordinates of the registered vehicle location, has been cleaned and split into two named Latitude and Longitude.
- As Postal Code, Legislative District and 2020 Census Tract are categorical variables, they have been converted to string data type.
- Base MSRP variable was removed as 98% of its data have the value 0.
- No duplicate values were found in the data.

Research Question	**Definition**	**Approach**
1.What makes people in Washington State decide to buy BEVs and PHEVs?	This question aims to identify the factors that influence the decision to purchase Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) in Washington State.	**Feature Engineering:** Create new features if necessary and aggregate continuous variables **Exploratory Data Analysis (EDA):** Creating bar plots, and heat map for correlation analysis **Statistical Analysis:** Hypothesis testing, Logistic Regression
2. Can we use machine learning to predict how many more people will start using electric cars in the future, based on things like where they live and how much money they make?	This question explores the feasibility of using machine learning models to forecast the adoption of electric vehicles based on geographic and infrastructure related data.	**Feature Engineering:** Create features from geographic data **Modeling:** Use time-series analysis, linear regression, and random forests for prediction.

		Validation: Split data into training and testing sets, use cross-validation to assess performance.
3. How do geographic location and local infrastructure (electric utilities) impact EV adoption in Washington?	This question investigates the influence of geographic factors and the availability of local infrastructure, like electric utilities, on the adoption rates of electric vehicles.	**Geospatial Analysis:** Map EV adoption rates to geographic locations using GIS tools. **Modeling:** Use spatial regression models and clustering algorithms. **Evaluation:** Use tools to see if areas close to each other have similar adoption rates. Identify and explain patterns, like which areas have higher or lower adoption and why.

Tentative overall Methodology

This structured timeline ensures a systematic approach to the project, covering all critical stages from data collection to model evaluation. Each phase is allocated sufficient time to thoroughly address its objectives, ensuring the final model is robust and reliable. This detailed approach will provide a comprehensive understanding of EV adoption trends in Washington State, supporting future strategic planning and policy-making efforts.



References

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