Comprehensive Exploratory Data Analysis and Visualization of Electric Vehicle Trends Using Python and Power BI

Project report in partial fulfilment of the requirement for the award of the degree of

Master of Computer Applications

Submitted By

ARPAN BISWAS	**University Enrollment No. 12023006015046**
ASHUTOSH SAHA	**University Enrollment No. 12023006015047**
AVIK SARKHEL	**University Enrollment No. 12023006015050**
MAYUKH DUTTA	**University Enrollment No. 12023006015053**
SUDIPTA BISWAS	**University Enrollment No. 12023006015008**

Under the guidance of

Prof. KAUSTUV BHATTACHARJEE

Department of Computer Applications

INSTITUTE OF ENGINEERING & MANAGEMENT, KOLKATA

NEWTOWN

(School of University of Engineering and Management, Kolkata)

UNIVERSITY OF ENGINEERING AND MANAGEMENT, KOLKATA

University Area, Plot No. III – B/5, New Town, Action Area – III, Kolkata – 700160.

CERTIFICATE

This is to certify that the project titled **Comprehensive Exploratory Data Analysis and Visualization of Electric Vehicle Trends Using Python and Power BI** submitted by **Arpan Biswas (University Enrollment No. 12023006015046), Ashutosh Saha (University Enrollment No. 12023006015047)**, **Avik Sarkhel (University Enrollment No. 12023006015050), Mayukh Dutta (University Enrollment No. 12023006015053)**, **Sudipta Biswas (University Enrollment No. 12023006015008)** students of INSTITUTE OF ENGINEERING & MANAGEMENT, NEWTOWN, a school of UNIVERSITY OF ENGINEERING AND MANAGEMENT, KOLKATA, in partial fulfilment of the requirement for the Degree of Master of Computer Applications, is a Bonafide work carried out by them under the supervision and guidance of Prof. Kaustuv Bhattacharjee during 4th Semester of the academic session of 2024 - 2025. The content of this report has not been submitted to any other university or institute. I am glad to inform that the work is entirely original and its performance is found to be quite satisfactory.

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Prof. Kaustuv Bhattacharjee

HOD

Department of Computer Applications

UEM, Kolkata

____

Prof. Kaustuv Bhattacharjee

HOD, Department of Computer Applications

UEM, Kolkata

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Arpan Biswas

Ashutosh Saha

Avik Sarkhel

Mayukh Dutta

Sudipta Biswas

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ABSTRACT

This project presents a comprehensive exploratory data analysis (EDA) of the electric vehicle (EV) population in Washington State, aimed at uncovering patterns and trends in EV adoption, battery performance, manufacturer dominance, and utility infrastructure. The dataset comprises detailed information on both Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs), including vehicle make, model, electric range, and electric utility providers.

The analysis was conducted using Python in Google Colab with the help of data analysis and visualization libraries such as Pandas, NumPy, Matplotlib, and Seaborn. The project includes critical data cleaning steps, missing value treatment, and feature engineering, such as deriving electric utility types. Key insights include the market leadership of Tesla, the increasing trend in EV range over time, and the significant role played by electric utilities in EV support.

To enhance data storytelling, two interactive Power BI dashboards were developed. One focuses on a comprehensive overview of the entire dataset, while the other provides a company-wise analysis of EV trends. These visual tools enable stakeholders to interactively explore EV data for improved decision-making.

The results offer valuable recommendations for EV manufacturers, policymakers, and infrastructure planners, addressing sustainability goals and future technological advancements. The project demonstrates how data analytics and visualization can power actionable insights in the growing EV ecosystem.

CHAPTER 1

INTRODUCTION

The increasing global emphasis on sustainability and environmental conservation has propelled the adoption of electric vehicles (EVs). Amid rising concerns about climate change, fossil fuel dependency, and urban air pollution, governments and organizations worldwide are encouraging the shift toward clean transportation. Electric vehicles—both Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs)—have emerged as promising alternatives due to their reduced greenhouse gas emissions, lower operational costs, and technological innovations.

In response to these developments, this project focuses on performing a comprehensive exploratory data analysis (EDA) of electric vehicles registered in Washington State. As one of the leading states in the U.S. for EV adoption, Washington provides a valuable case study for examining local patterns and trends that reflect broader national and global shifts toward electric mobility.

The raw dataset was obtained via the official website of the United States government and is published by the Washington State Department of Licensing [11] and the dataset is publicly accessible. The study aims to derive actionable insights from the EV dataset using Python-based tools and data visualization platforms such as Power BI. Through this analysis, the project explores various dimensions of the EV ecosystem—including market penetration, vehicle range, brand performance, utility infrastructure, and geographic distribution of electric vehicles.

This project not only explores trends in EV adoption but also evaluates factors such as battery range, vehicle type distribution, brand dominance, and utility infrastructure. Additionally, the project incorporates two interactive Power BI dashboards to support data-driven storytelling—one for overall trends and another for company-wise analysis.

The insights generated from this project can serve as a valuable resource for stakeholders such as policymakers, utility providers, EV manufacturers, and urban planners. By identifying factors that influence EV adoption and performance, the project contributes to the larger goal of accelerating the transition to sustainable transportation.

CHAPTER 2

LITERATURE SURVEY

2.1. The Foundational Importance and Broad Applications of Data Analysis

Data analysis serves as a cornerstone for extracting valuable insights and facilitating informed decision-making across diverse sectors (Bhatia, 2017) [1]. Its utility extends beyond general applications to specialized fields such as healthcare (Batko & Ślęzak, 2022) [2], highlighting the pervasive impact of data-driven approaches in enhancing outcomes.

2.2. Leveraging Big Data for Electric Vehicle Integration

The integration and optimization of electric vehicles (EVs) are significantly influenced by data analytics. Chen (2023) [3] emphasizes the role of big data technology in analyzing EV integration, recognizing the substantial value inherent in the vast datasets associated with EVs. This necessitates the development and utilization of robust analytical platforms to effectively manage and interpret this information (Hussain et al., 2019) [4].

2.3. Understanding Electric Vehicle Charging Behavior through Data Analysis

A critical aspect of EV integration involves deciphering and predicting charging patterns. Li et al. (2024) [5] contribute to this understanding by focusing on the synthesis of real-world EV charging data. Their research underscores the importance of accurate charging data for efficient grid management and infrastructure planning, providing essential insights for stakeholders in the energy and transportation sectors.

2.4. The Role of Data Science in Advancing Electric Vehicles

The broader impact of data science on the advancement of electric vehicles is significant (R. S, 2023) [6]. This encompasses various applications, from optimizing vehicle performance and predicting maintenance needs to enhancing charging infrastructure and understanding user adoption trends. The increasing availability of open data related to EV load further supports data-driven innovation in this domain (Amara-Ouali et al., 2021) [7].

2.5. Data Visualization for Enhanced Understanding

Data visualization tools, such as Power BI, play a crucial role in transforming complex vehicle-related data into accessible and actionable insights (Patil et al., 2024) [8]. These tools enable stakeholders to readily understand patterns and trends, facilitating better decision-making within the electric vehicle ecosystem.

CHAPTER 3

PROBLEM STATEMENT

3.1 Definition

The rapid growth of electric vehicles (EVs), especially BEVs and PHEVs, has increased the demand for data analysis to understand usage patterns, market trends, and infrastructure needs. This project analyzes a real-world dataset from the Washington State Department of Licensing, which includes vehicle details like make, model, MSRP, electric range, and registration county. However, the dataset poses challenges such as missing values, inconsistencies, and ambiguous classifications.

The goal is to clean, process, and analyze the data to reveal insights into EV trends, ownership patterns, and sustainability progress. By improving data quality and structure, the project supports informed decisions for policymakers, utility providers, and automakers, helping shape the future of EV infrastructure and adoption.

3.2 Relevance

This problem is critically relevant in the context of sustainable mobility and green energy adoption. The state of Washington, like many others, is transitioning toward cleaner transportation alternatives. However, this transition requires data-driven insights into how EVs are being adopted across different regions, the performance of various vehicle types, and the infrastructure readiness (such as charging stations and electric utilities).

By tackling inconsistencies and gaps in the dataset, the project empowers key stakeholders—including government bodies, automotive companies, and energy providers—to make well-informed decisions. The analysis will enable better planning for EV infrastructure, improved understanding of consumer behavior, and strategic alignment of production goals with market demands.

3.3 Scope of the Problem

This project focuses exclusively on analyzing a dataset pertaining to EVs registered in Washington State. The key elements within the scope include:

- **Data Quality Assessment**: Identifying and correcting inconsistent entries, such as duplicate records, incorrect vehicle classifications, and non-standardized naming conventions.
- **Descriptive Analysis**:
  - Manufacturer-wise EV distribution to identify market leaders.
  - County-wise EV adoption trends to understand regional preferences and infrastructural gaps.
  - Electric utility type breakdown to examine its influence on vehicle range and adoption.
- **Missing Data Handling**: Carefully imputing or excluding null and zero-value entries, especially in critical fields such as Electric Range and CAFV Eligibility, while ensuring integrity is maintained.
- **Electric Utility Analysis**: Interpreting complex utility information (single/multiple providers) to associate vehicle performance with utility service patterns.
- **Interactive Visualization**: Implementing dashboards using Power BI to present insights in a dynamic and accessible format for both technical and non-technical users.

CHAPTER 4

PROPOSED SOLUTION

To address the aforementioned challenges and extract valuable insights from the EV dataset, the following multi-step approach was adopted:

4.1. Dataset Preprocessing

- Handled missing/null values using context-aware imputation or manual research for key fields.
- Standardized text-based entries such as vehicle makes and utility providers.
- Removed inconsistencies such as vehicles marked with zero range or unverified eligibility statuses.

4.2. Exploratory Data Analysis

- Performed full dataset analysis to detect trends in electric range, price distribution (MSRP), and fuel type split (BEV vs. PHEV).
- Conducted manufacturer-wise and county-wise breakdowns to assess geographic and brand-based adoption patterns.
- Analyzed the role of electric utility types in EV range distribution and infrastructure support.

4.3. Power BI Dashboard Integration

- Created interactive dashboards using Power BI to:
    - Visualize company-wise growth and popularity.
    - Enable users to filter by make and observe corresponding patterns.
    - Add navigable sections for brand-level trends, supported by dynamic images and tooltips.

By integrating traditional Python-based EDA with modern BI tools, the solution offers a complete, user-friendly representation of the electric vehicle ecosystem in Washington State.

CHAPTER 5

EXPERIMENTAL SETUP AND RESULT ANALYSIS

5.1. Tools and Technologies Used

- **Google Colab**: Interactive Python-based analysis.
- **Python Libraries**: Pandas (data processing), NumPy (statistics), Matplotlib & Seaborn (visualization).
- **Power BI**: Used for developing interactive dashboards with filters and dynamic visuals.
- **MS Excel**: Initial data filtering and manual corrections.

5.2. Methodology

A. Data Collection and Preprocessing

The dataset initially contained N_{raw} = 200,049 records across P_{raw} = 17 parameters. Data cleaning involved handling missing values, correcting misclassifications, and standardizing attributes.

- **Original Dataset Parameters (17 total):**
VIN (1-10), County, City, State, Postal Code, Model Year, Make, Model, Electric Vehicle Type, Clean Alternative Fuel Vehicle (CAFV) Eligibility, Electric Range, Base MSRP, Legislative District, DOL Vehicle ID, Vehicle Location, Electric Utility, 2020 Census Tract.

1	VIN (1-10)	County	City	State	Postal Co	Model Year	Make	Model	Electric Vehicle Type	Clean Alternative Fuel Vehicle (CAFV) Eligibil	Electric Range	Base MSRP	Legislative Distric	DOL Vehicle ID	Vehicle Location	Electric Utility	2020 Census Tract
2	5YJ3E1EB0J	Thurston	Olympia	WA	98512	2018	TESLA	MODEL 3	Battery Electric Vehicle (BE\	Clean Alternative Fuel Vehicle Eligible	215	0	35	104823078	POINT (-122.957C	PUGET SOUND	53067012730
3	WA1AAAGE9M	Kitsap	Port Orchard	WA	98367	2021	AUDI	E-TRON	Battery Electric Vehicle (BE\	Clean Alternative Fuel Vehicle Eligible	222	0	35	156660507	POINT (-122.653C	PUGET SOUND	53035092901
4	5YJ3E1EA2J	Yakima	Yakima	WA	98902	2018	TESLA	MODEL 3	Battery Electric Vehicle (BE\	Clean Alternative Fuel Vehicle Eligible	215	0	14	269374108	POINT (-120.5303	PACIFICORP	53077000500
5	5YJ3E1EA4N	Yakima	Yakima	WA	98902	2022	TESLA	MODEL 3	Battery Electric Vehicle (BE\	Eligibility unknown as battery range has not b	0	0	15	213383894	POINT (-120.5303	PACIFICORP	53077001202
6	7SAYGAEE2P	Snohomish	Bothell	WA	98012	2023	TESLA	MODEL Y	Battery Electric Vehicle (BE\	Eligibility unknown as battery range has not b	0	0	1	229496046	POINT (-122.2061	PUGET SOUND	53061052009
7	WBY1Z4C51E	Yakima	Yakima	WA	98908	2014	BMW	I3	Plug-in Hybrid Electric Vehic	Clean Alternative Fuel Vehicle Eligible	72	0	14	8045817	POINT (-120.611C	PACIFICORP	53077000401
8	5YJSA1DPXC	Thurston	Olympia	WA	98502	2012	TESLA	MODEL S	Battery Electric Vehicle (BE\	Clean Alternative Fuel Vehicle Eligible	265	59900	22	188634442	POINT (-122.9434	PUGET SOUND	53067010600
9	5YJSA1H27F	Yakima	Yakima	WA	98908	2015	TESLA	MODEL S	Battery Electric Vehicle (BE\	Clean Alternative Fuel Vehicle Eligible	208	0	14	109175566	POINT (-120.611C	PACIFICORP	53077002900
10	7FCTGBAA7P	Kitsap	Poulsbo	WA	98370	2023	RIVIAN	R1T	Battery Electric Vehicle (BE\	Eligibility unknown as battery range has not b	0	0	23	262803131	POINT (-122.6368	PUGET SOUND	53035090400

Fig 1: Raw and Unprocessed Dataset

- **Cleaning Process**: Let M_i be missing values in column i:

$$C_i = X_i \setminus M_i \quad [X_i\text{: is the original data in column } i.]$$

- **Final Dataset**: N_{clean} = 182,137, P_{clean} = 13
- **Final Dataset Columns (13 total):**
County, Model Year, Make, Base MSRP, Model, Electric Vehicle Type, Clean Alternative Fuel Vehicle (CAFV) Eligibility, Electric Range (MILE), Electric Utility, Electric Utility Type, Urban/Rural, Github Link, Direct Link

1	County	Model Year	Make	Base MSRP	Model	Electric Vehicle Type	Clean Alternative Fuel Vehicle (CAFV) Eligibility	Elect	Electric Utilit	Electric Utility Typ	Urban/Rura	Github Link	Direct Link
2	Thurston	2018	TESLA	47200	MODEL 3	Battery Electric Vehicle (B	Clean Alternative Fuel Vehicle Eligible	215	PUGET SOUND El	Investor Owned	Urban	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/tesla.jpg
3	Kitsap	2021	AUDI	65900	E-TRON	Battery Electric Vehicle (B	Clean Alternative Fuel Vehicle Eligible	222	PUGET SOUND El	Investor Owned	Urban	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/audi.jpg
4	Yakima	2018	TESLA	47200	MODEL 3	Battery Electric Vehicle (B	Clean Alternative Fuel Vehicle Eligible	215	PACIFICORP	Investor Owned	Rural	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/tesla.jpg
5	Yakima	2022	TESLA	48190	MODEL 3	Battery Electric Vehicle (B	Clean Alternative Fuel Vehicle Eligible (Manually Researched)	363	PACIFICORP	Investor Owned	Rural	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/tesla.jpg
6	Snohomish	2023	TESLA	46630	MODEL Y	Battery Electric Vehicle (B	Clean Alternative Fuel Vehicle Eligible (Manually Researched)	326	PUGET SOUND El	Investor Owned	Urban	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/tesla.jpg
7	Yakima	2014	BMW	42650	I3	Plug-in Hybrid Electric Ve	Clean Alternative Fuel Vehicle Eligible	72	PACIFICORP	Investor Owned	Rural	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/bmw.jpeg
8	Thurston	2012	TESLA	59900	MODEL S	Battery Electric Vehicle (B	Clean Alternative Fuel Vehicle Eligible	265	PUGET SOUND El	Investor Owned	Urban	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/tesla.jpg
9	Yakima	2015	TESLA	71100	MODEL S	Battery Electric Vehicle (B	Clean Alternative Fuel Vehicle Eligible	208	PACIFICORP	Investor Owned	Rural	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/tesla.jpg
10	Kitsap	2023	RIVIAN	73000	R1T	Battery Electric Vehicle (B	Clean Alternative Fuel Vehicle Eligible (Manually Researched)	410	PUGET SOUND El	Investor Owned	Urban	https://raw.gith	https://raw.githubusercontent.com/Avik-Sarkhel/Images/main/rivian.jpeg

Fig 2: Processed and Filtered Dataset

Note: The following columns were removed from the original dataset due to one or more of the following reasons: low analytical relevance, redundant data, or limited scope in visualization:

- VIN (1-10) – Irrelevant for trend analysis; used for vehicle identification only.

- City, State, Postal Code – Granular location data wasn't required since County-level analysis was sufficient.
- Legislative District – Not directly relevant to EV trends.
- DOL Vehicle ID, Vehicle Location – Primarily for internal use; didn't contribute to insights.
- 2020 Census Tract – Not utilized due to limited contextual use in dashboard.

B. Feature Engineering:

1. **Electric Utility Type Classification**:

   Categorized into: Federal, Investor-Owned, Municipal, Political Subdivision, Cooperative

$$E = \begin{Bmatrix} \text{Federal, Investor-Owned, Municipal,} \\ \text{Political Subdivision, Cooperative} \end{Bmatrix}$$

2. **Urban/Rural Classification**:

   Binary classification for each county:

$$U = \begin{cases} \text{Urban}, & \text{if county is classified as urban} \\ \text{Rural}, & \text{if county is classified as rural} \end{cases}$$

3. **Data Subset Filtering**:

$$Subset = EV_{filtered}[EV_{filtered}[ColumnName] == DesiredValue]$$

C. Analytical Approach:

- **EV Share by Region**:

$$S_i = \left(\frac{EV_i}{EV_T}\right) \times 100$$

where,

EV_T =Total number of EVs in the dataset
EV_i = Number of EVs in region i

- **Market Share by Manufacturer**:

$$\text{Market Share}_j = \left(\frac{M_j}{EV_T}\right) \times 100$$

where,

M_j = Number of EVs manufactured by company j

EV_T =Total number of EVs

D. Statistical Analysis:

- **Mean EV Range**:

$$\mu_R = \frac{1}{N} \sum_{i=1}^{N} R_i$$

where,

R_i = Range of the i-th EV

N =Total number of EVs

5.3. Design & Architecture

- **Collaborative Platform**: Google Colab ensured scalable real-time collaboration.
- **New Features Added**:
  - Urban/Rural and Electric Utility Type columns.
- **Manual Research and Corrections**:
  - Filled missing "Base MSRP" and "Electric Range".
  - Verified and corrected CAFV eligibility.
  - Reclassified PHEVs and removed unknown utility types.
- **Trend Identification**:
  - Clustering based on model year, vehicle type, and electric range.

5.4. Workflow

1. **Data Cleaning**: Removed inconsistencies using Python and Excel.
2. **Exploratory Analysis**: Dataset-wide and company-level trend analysis.
3. **Visualization**: Created visualizations using Python and made a company-wise EV trends dashboard using Power BI.

5.5. Results

1. Market Trends and Manufacturer Insights

- Tesla: 44% of EV market share.
- Chevrolet and Nissan: 7% each.

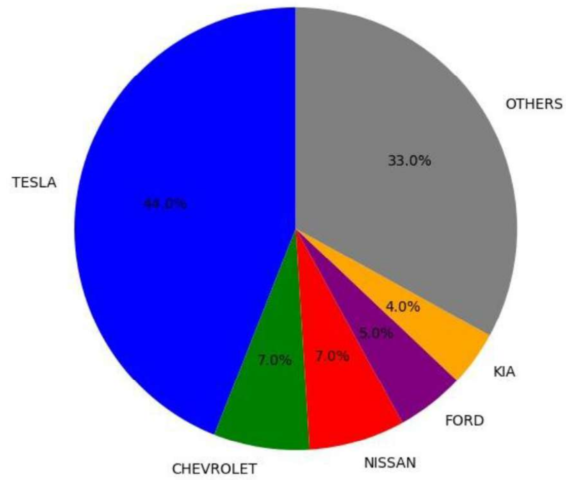

Fig 3: Market Share of Top 5 Electric Vehicle Manufacturers

- EV Types: BEVs – 79%, PHEVs – 21%

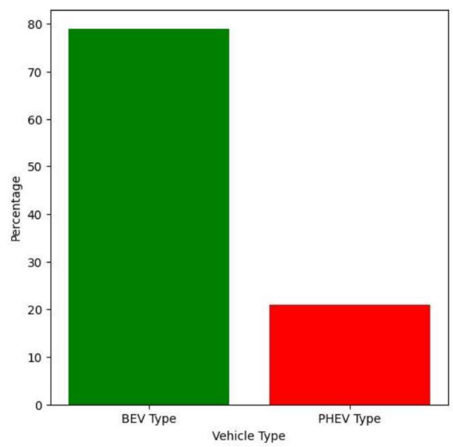

Fig 4: Distribution of BEV and PHEV Vehicle Types

- Top Counties: King (56%), Snohomish (13%), Pierce (8%)

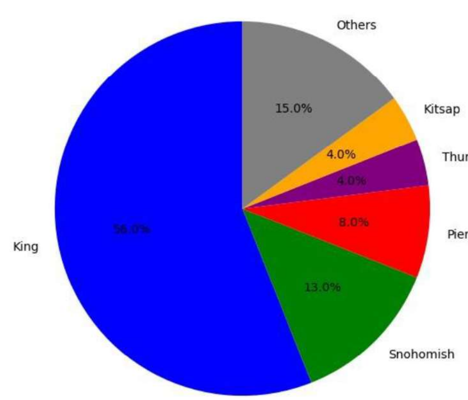

Fig 5: County-Wise Distribution of EV Registrations

2. Performance and Range Analysis

- Snohomish: Avg. EV Range = 240 miles
- King: Avg. EV Range = 231 miles
- EVs under $40K see higher adoption

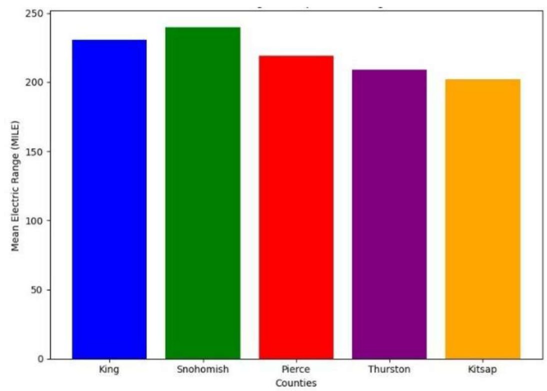

Fig 6: Average Electric Vehicle Range Across Top 5 EV-Selling Counties

3. Policy and Infrastructure Influence

- More charging stations = higher EV adoption
- Puget Sound Energy and City of Tacoma serve 40% of EVs

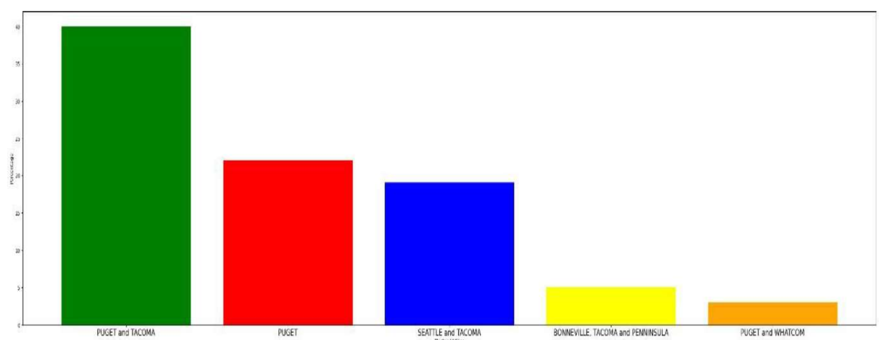

Fig 7: Distribution of EV Ownership by Top Electric Utilities

- 90% of EVs are CAFV-eligible, indicating policy impact

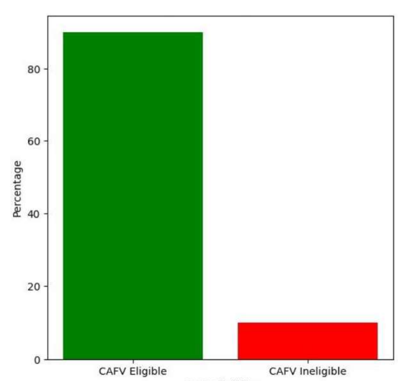

Fig 8: Proportion of Clean Alternative Fuel Vehicle (CAFV) Eligible vs Ineligible EVs

5.6. Discussion

1. EV Market Growth & Manufacturer Strategy

- Tesla dominates with innovation and long range.
- Chevy/Nissan appeal to budget-conscious customers.
- Preference for BEVs shows consumer trust in fully electric tech.

2. Infrastructure's Role in Adoption

- More chargers = more EVs.
- Long-range EVs preferred in areas with infrastructure.

5.7. Final Implementation with Power BI

- **Interactive Dashboard** with filters for Make, Model Year.
- **Dynamic Visuals**: Background changes based on EV maker selection.

Fig 9: Interactive Power BI Dashboard Showcasing EV Company Insights

- **Company-Level Insights**: Dashboard shows key trends for top EV brands.

Fig 10: Interactive Power BI Dashboard Showcasing Tesla Company Insights

CHAPTER 6

6.1 CONCLUSION

This project provided a comprehensive exploratory analysis of electric vehicle (EV) adoption trends in Washington State, using Python-based data analysis and interactive Power BI dashboards. Key insights reveal Tesla's market dominance, the growing preference for BEVs over PHEVs, and the significant role of regional infrastructure and utility providers in EV distribution. By analyzing parameters such as electric range, geographic distribution, and CAFV eligibility, this study delivers actionable findings for policymakers, manufacturers, and consumers alike. The integration of visualization tools helped transform complex datasets into intuitive, data-driven narratives that highlight current patterns and anticipate future demands in the EV ecosystem.

6.2 FUTURE SCOPE

To build on the insights derived from this study, future work can take several directions:

1. **Feature Expansion**

   Include more granular vehicle attributes such as recharge time, battery capacity, drivetrain type, safety ratings, and advanced vehicle classification. These features would offer deeper insights into consumer behavior and vehicle performance.

2. **Predictive Modeling**

   Incorporate machine learning techniques such as regression, clustering, and classification to forecast EV adoption trends, identify influential factors, and uncover hidden patterns across different regions and user segments.

3. **Real-Time Dashboards and Geographic Expansion**

   Integrate APIs to create live dashboards that update in real-time with new EV registration data. The proposed solution can be applied to datasets from different geographies with minimal changes. As long as the dataset contains similar fields—such as EV make, model, electric range, region, and utility provider—the analysis and Power BI dashboards can be adapted easily. This flexibility ensures that the project has strong future scope and can be scaled for use in other states or countries for broader electric vehicle trend analysis.

4. **Policy and Environmental Impact Analysis**

   Add datasets related to charging infrastructure, electricity generation sources, and emissions reduction to support more effective policymaking and assess the environmental benefits of EV adoption.

5. **Collaboration with Stakeholders**
   Partner with utility companies, local governments, and EV manufacturers to access high-resolution data and validate findings. Such collaboration would enhance the relevance and application of the insights in real-world scenarios.

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