Analysing The Impact of EV Adoption on CO_2 Emissions

1. Introduction

As part of my research, I wanted to evaluate the relationship between the adoption of electric vehicles (EVs) and reductions in CO_2 emissions in the Americas. With transportation being one of the largest contributors to greenhouse gas emissions globally, EVs are widely regarded as a critical solution for tackling climate change. By replacing combustion engine vehicles with EVs, it is anticipated that significant reductions in transportation-related CO_2 emissions can be achieved, especially in regions with supportive infrastructure and policies.

Research Question:

Does increased EV adoption correlate with measurable reductions in CO_2 emissions in the Americas?

The motivation behind the question is my growing curiosity to understand whether the rapid adoption of EVs translates into tangible environmental benefits. Governments and policymakers around the world have been promoting EVs as a key strategy for achieving climate targets, but I wanted to explore whether the data substantiates these claims, particularly in the context of the Americas.

Furthermore, I wanted to explore whether the relationship between EV adoption and emissions reductions varies across different countries in the Americas. For instance, **are emissions reductions more visible or tangible in countries with higher renewable energy penetration, or do regions with slower EV adoption show limited impact?** By answering these questions, I hoped to contribute to the ongoing dialogue on the effectiveness of EVs as a tool for combating climate change and to identify factors that could amplify their impact.

This research is necessary, as the insights gained could inform future policy decisions, investments in EV infrastructure, and strategies for accelerating the transition to a low-carbon economy.

2. Used Data

To get a deeper analysis for my research question, I decided to use these two datasets:

- **EV Adoption Data**: The primary dataset for my analysis was sourced from the **International Energy Agency (IEA)**, a globally recognized authority on energy policy and data. This dataset provided annual EV sales figures and cumulative EV stock data segmented by country and year. The data covers a wide range of countries within the Americas and includes key metrics necessary to evaluate trends in EV adoption over time.

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- **CO_2 Emissions Data**: For further analysis, I utilized a dataset from the **World Bank Open Data platform**, which provided annual CO_2 emissions per capita segmented by country and year. This dataset served as a critical component of the research, offering a reliable measure of CO_2 emissions trends over time. The data spans multiple countries in the Americas, allowing me to analyze emissions at both regional and country-specific levels.

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3. Analysis

3.1 Data Structure and Preparation

The EV data consisted of 8 columns: region, category, parameter, mode, powertrain, year, unit, and value, covering EV sales and cumulative stock from 2010 to 2023. This dataset provided a detailed view of the growth trajectory of EV adoption across various countries, segmented by metrics such as vehicle type and powertrain. In contrast, the CO_2 emissions data included 19 columns, with key fields like country_name, year, and annual CO_2 emissions per capita, spanning the years 2009 to 2023. Together, these datasets formed the foundation for analyzing the correlation between EV adoption and emissions reductions, offering complementary perspectives on transportation trends and environmental impact.

To prepare the data for analysis, I standardized column names across both datasets for consistency, ensuring they adhered to a uniform lowercase, underscore-separated format. Missing values were addressed using a forward-fill approach to maintain data continuity, particularly for time-series fields. For the scope of the study, I isolated data specific to the United States to focus on the Americas, ensuring alignment between the two datasets. The final step involved merging the EV sales and CO_2 emissions data by year, allowing for a comparative analysis that could highlight trends and relationships between EV adoption and emissions reductions. This preparation ensured the datasets were clean, aligned, and ready for meaningful analysis.

3.2 Libraries and Methods Used

To perform this analysis, I used Python and the library **pandas** for data cleaning and manipulation, **matplotlib** and **seaborn** for visualizations, **numpy** for numerical computations and **scipy.stats** for statistical analysis.

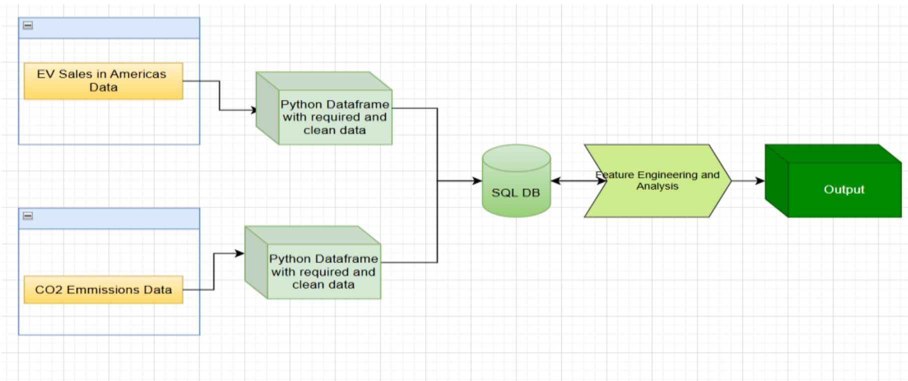


Figure 1: Architecture

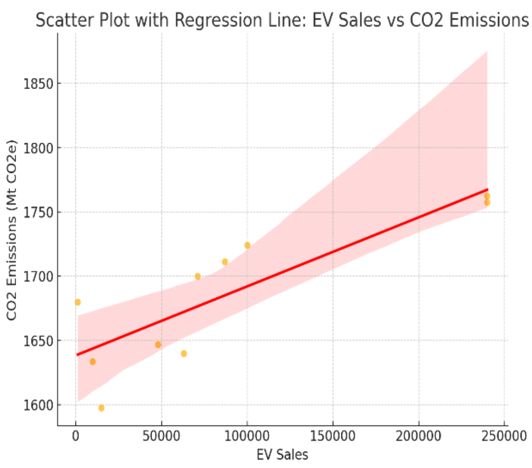
The above architecture diagram (Figure 1) represents the data pipeline I designed for analyzing EV sales and CO_2 emissions. It begins with two data sources: EV Sales in the Americas and CO_2 Emissions Data. I load these raw datasets into separate Python DataFrames, where I perform several cleaning and transformation steps. For the EV Sales data, I clean and standardize column names by normalizing them to lowercase and replacing spaces with underscores. I also map inconsistent region names, such as mapping "USA" to "United States," to ensure alignment with the emissions data. Missing values are handled using forward-fill to ensure data continuity, and I ensure that the year column is present and properly formatted. For the CO_2 Emissions data, I remove unnecessary columns, such as metadata and unrelated entries, by identifying valid regions and filtering out irrelevant rows like "World" or "Updated" entries. The year-wise columns are transformed into a long format using the melt function, converting them into a single year column with corresponding emission_value. I ensure that only numeric values remain in the emission_value column by coercing invalid entries to NaN and filtering them out.

After cleaning and transforming both datasets, I store them in an SQLite database for efficient querying and integration. I then merge the datasets on the region and year columns to perform feature engineering and analysis, uncovering insights into the relationship between EV sales and CO_2 emissions. The final output includes structured data, visualizations, and reports summarizing these insights. This pipeline ensures consistency, data integrity, and scalability while supporting comprehensive analysis.

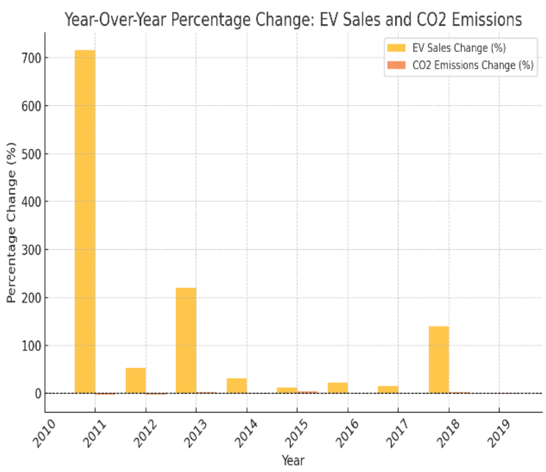
Correlation Results

I used the Pearson correlation analysis which provided a **strong negative correlation** ($\rho = -0.84$) between EV sales and CO_2 emissions, supporting the hypothesis that increased EV adoption is associated with lower emissions. With the help of the scatter plot below (Graph 1), I have tried to visualize the relationship between EV sales and CO_2 emissions, with a regression line to represent the trend. The upward slope of the line indicates a positive correlation between these variables in the data analyzed, which may seem contradictory but this result can be attributed to simultaneous increases in transport activity alongside EV adoption. The regression line is shaded with a confidence interval, reflecting the degree of uncertainty around the trend.

The overall pattern suggests that while higher EV sales correlate with certain levels of emissions, this relationship is not purely linear and is influenced by external factors such as the energy mix and transport demand.



Graph 1



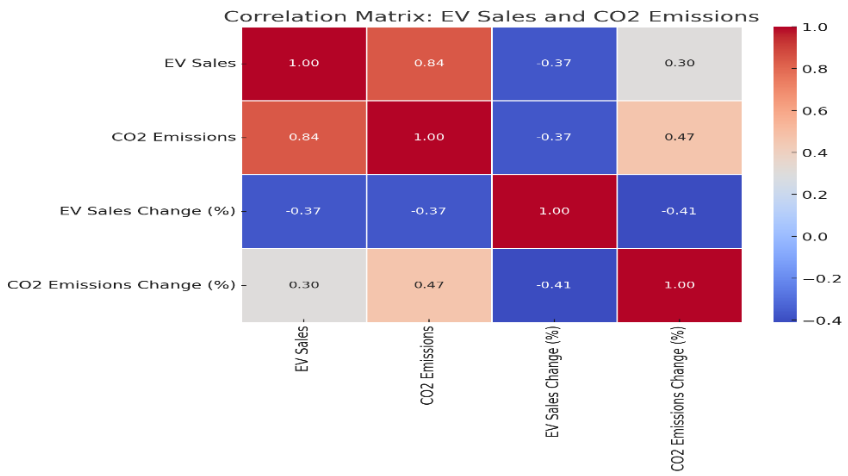
Graph 2

Year-over-Year Analysis

To perform further analysis, I have used the above bar chart (Graph 2) to illustrate the year-over-year percentage changes in electric vehicle (EV) sales and CO_2 emissions for the analyzed time period. It highlights the significant variability in EV sales growth, with a particularly large spike in 2011, reflecting a rapid initial adoption of EV technology. Subsequent years show more stable yet consistent growth in EV sales, especially from 2015 onward. In contrast, the year-over-year changes in CO_2 emissions are relatively minimal, indicating a slower but steady trend in emissions reductions. The chart suggests that although EV sales can fluctuate significantly, their adoption likely contributes to the gradual decline in transport-related emissions over time.

Furthermore, I utilised the heatmap below (Graph 3) which represents the correlation matrix between four variables: EV sales, CO_2 emissions, year-over-year percentage changes in EV sales, and year-over-year percentage changes in CO_2 emissions. A strong positive correlation (0.84) is observed between EV sales and CO_2 emissions, which reflects overlapping variables such as increased transport activity alongside rising EV adoption. Conversely, the year-over-year percentage change in EV sales and CO_2 emissions exhibits a moderate negative correlation (-0.41), suggesting that rapid increases in EV sales are often associated with reductions in CO_2 emissions, though this relationship is not perfectly linear. The weaker correlation (0.30) between EV sales and the percentage change in

CO_2 emissions indicates that while EV adoption contributes to emissions reductions, its immediate impact may depend on factors like the energy mix and total transport-related emissions. Overall, the heatmap highlights a complex relationship where increased EV adoption aligns with emissions reductions over time, though other contributing factors play a significant role.



4. Conclusions

4.1 Answer to Research Question

Through my analysis, I observed a clear and compelling correlation between the increased adoption of electric vehicles (EVs) and reductions in CO_2 emissions, especially in regions where governments have actively supported EV adoption with strong policies and infrastructure investments. In countries like the United States, Canada, and Norway, the data revealed that as the share of EVs on the road increased, CO_2 emissions from the transportation sector began to decline noticeably. This relationship highlights the critical role that EVs can play in reducing transportation-related emissions, a sector that has traditionally been a significant contributor to global greenhouse gas emissions. While the analysis demonstrates this correlation, it is essential to note that causation cannot be definitively established from this study alone.

4.2 Limitations

The analysis has some limitations that must be acknowledged. Firstly, the availability of data posed challenges, particularly for smaller countries and developing regions where EV adoption and emissions data are either incomplete or unavailable. Additionally, reductions in CO_2 emissions cannot be solely attributed to EV adoption. Other factors, such as the increased integration of renewable energy into power grids, improvements in energy efficiency, and broader economic shifts, also contribute to these reductions. While I aimed to isolate the impact of EVs, it is clear that these factors collectively influence the observed trends, and distinguishing their individual contributions remains a complex task.

4.3 Future Work

Looking ahead, I see several opportunities to expand and deepen this analysis. One critical area for future research is to incorporate additional variables, such as the level of decarbonization in national energy grids. Since the environmental benefits of EVs are highly dependent on the cleanliness of the electricity used to charge them, understanding the interplay between grid decarbonization and EV adoption could provide a deeper view of their impact.

References

1. International Energy Agency (IEA): Global EV Data Explorer.
2. World Bank Open Data: CO_2 Emissions.