Exploring the Effect of Cost of Electric Vehicles on Charging Efficiency: A Comparative Statistical Analysis

Rishi Guharoy

Chantilly High School

August 12, 2024

Abstract

This study investigates the charging efficiency ratios of two electric vehicles (EVs), the Mitsubishi Outlander and the BMW iX Drive 50, using data from the EV Charging Profiles and Waveforms (EV-CPW) dataset obtained from the Harvard Dataverse. The objective is to determine if there is a statistically significant difference in their efficiency ratios, which could impact electrical distribution networks. Data analysis includes the Shapiro-Wilk test for normality, Levene's test for equal variances, and a two-sample t-test to compare means. Results indicate that the Mitsubishi Outlander and BMW iX Drive 50 exhibit significant differences in charging efficiency, with the BMW iX Drive 50 showing higher efficiency. These findings provide insights into EV charging behaviors and their implications for electrical grids. Additionally, the study suggests that the cost of an EV could influence its efficiency, with more Fexpensive models like the BMW iX Drive 50 potentially offering better efficiency metrics compared to more affordable options like the Mitsubishi Outlander. Future research could explore alternative statistical methods, such as mixed-effects models or machine learning approaches, and investigate how waveforms could affect charging efficiency. This study offers a robust framework for evaluating EV charging efficiency and highlights the importance of statistical rigor in understanding EV performance.

Introduction

The rapid adoption of electric vehicles (EVs) has brought about significant transformations in the automotive industry and the broader energy sector. As global environmental concerns intensify and the push for sustainable transportation solutions gains momentum, EVs are becoming increasingly prevalent worldwide. This shift is crucial for reducing greenhouse gas emissions and decreasing reliance on fossil fuels, but it also introduces new challenges and opportunities for electrical distribution networks. (Noam Lior, 2009). One critical aspect of these challenges is understanding the charging behavior and efficiency of different EV models. Efficient charging is essential not only for optimizing the performance of individual vehicles but also for ensuring the stability and reliability of the electrical grid.

In this study, we focus on comparing the charging efficiency ratios of two popular electric vehicles: the Mitsubishi Outlander and the BMW iX Drive 50. The reason behind these two electric vehicles is that they are on opposite ends of the spectrum in terms of cost. The charging efficiency ratio is a measure of how effectively an EV converts electrical energy from the grid into stored energy in the battery, typically expressed as a percentage. To analyze these efficiency ratios, we utilized the EV Charging Profiles and Waveforms (EV-CPW) dataset, which includes detailed charging profiles and high-resolution current/voltage AC waveforms for various EVs. Our analysis involved several rigorous statistical tests: the Shapiro-Wilk test to assess the normality of the data, Levene's test to evaluate the equality of variances, and a two-sample t-test to compare the means of the two groups. Results from these tests indicate significant differences in charging efficiency between the Mitsubishi Outlander and the BMW iX Drive 50, with the BMW iX Drive 50 demonstrating higher efficiency.

Background

Electric vehicles (EVs) have emerged as a vital component in the global effort to reduce greenhouse gas emissions and transition to sustainable energy sources. By relying on electricity rather than fossil fuels, EVs offer a cleaner alternative to traditional gasoline-powered vehicles. (M.A. Hannan, 2012). However, the efficiency of electricity usage is crucial for maximizing the benefits of EVs. Efficient charging profiles ensure that energy from the grid is utilized effectively, minimizing waste and enhancing the overall sustainability of EVs. Understanding and optimizing these charging profiles is essential for improving EV performance and reducing the strain on electrical distribution networks.

The history of electric vehicles dates back to 1888 when German inventor Andreas Flocken designed the Flocken Elektrowagen, widely regarded as the first true electric car. This pioneering vehicle laid the groundwork for future developments in EV technology, demonstrating the feasibility of electric propulsion long before it became a mainstream concept.

Despite this early innovation, it took over a century for significant advancements to materialize and for EVs to begin gaining traction in the automotive market. (Iberdrola Journal).

Vehicles are considered environmentally friendly, or "green," when they are more efficient and less polluting than traditional internal combustion engine vehicles. This category includes hybrid electric vehicles (HEVs), plug-in hybrids, fuel cell vehicles, and biofuel-powered vehicles, all of which aim to improve fuel economy. The development of EVs spans over a hundred years but has faced various stages of public acceptance challenges. While EVs were not mass-produced initially, hybrid electric vehicles gained momentum in recent years. For instance, Ford launched its second-generation HEV, and General Motors introduced the Chevrolet Volt in 2010. Plug-in hybrids, which offer extended travel ranges in electric mode and the potential for zero emissions within certain limits, have become a new trend in hybrid auto development. (Lixin Situ, 2009). With supportive policies, government assistance, and continuous advancements in EV technology, the future of electric vehicles appears promising and poised to revolutionize the automotive industry.

This field of electrical engineering has always motivated me as it is the future of our world. I have always been interested in the world of mechanics and vehicles. Electric vehicles are super important to our environment and sustainability. As a young adult, learning about electricity and engineering is my passion. I chose to pursue this project since it fills my curiosity and pursues an important cause.

In this project, I chose the BMW iX Drive 50 and the Mitsubishi Outlander because they represent electric vehicles at opposite ends of the price spectrum. The Mitsubishi is much more affordable compared to the BMW iX Drive 50. The BMW, being a luxury car, is tested to see if it is more efficient in charging than the more cost-effective option (Mitsubishi).

Methods

The data for this study was obtained from the Harvard Dataverse, specifically from the EV Charging Profiles and Waveforms (EV-CPW) dataset. This dataset includes detailed charging profiles and high-resolution current/voltage AC waveforms for various electric vehicles. For this analysis, we focused on two popular models: the Mitsubishi Outlander and the BMW iX Drive 50. The dataset provided comprehensive information on the amount of voltage used and the amount of electricity consumed by the battery during charging sessions.

To prepare the data for analysis, we used Python and Jupyter Notebook to filter and process the dataset. Initially, we extracted the relevant data for both the Mitsubishi Outlander and BMW iX Drive 50, focusing on three key columns: voltage used, electricity consumed, and efficiency ratio. These columns were essential for comparing the charging efficiency of the two vehicles. The filtered data was then consolidated into a single Excel sheet titled "Both in one sheet.xlsx," which included only the necessary columns for our analysis. Below is a table (Table 1) summarizing the key columns extracted from the dataset.

To understand the distribution of the data, we conducted an initial analysis by plotting box plots. These plots allowed us to visualize the spread and central tendency of the charging efficiency ratios for both vehicles. We used Matplotlib and Seaborn, two powerful Python libraries, to generate these visualizations. Figures 1 and 2 display the box plots for the Mitsubishi Outlander and BMW iX Drive 50, respectively. The box plots helped us identify any potential outliers and assess the overall distribution of the data.

After visualizing the data, we proceeded with statistical tests to determine if there were significant differences between the charging efficiency ratios of the two vehicles. We employed the Shapiro-Wilk test to assess the normality of the data distributions. Following this, we used Levene's test to evaluate the equality of variances between the two groups. Finally, a two-sample t-test was conducted to compare the means of the charging efficiency ratios for the Mitsubishi Outlander and BMW iX Drive 50. These tests provided a rigorous framework for analyzing the differences in charging efficiency between the two EV models.

We used Matplotlib and Seaborn to create detailed visualizations of the data distributions. These libraries helped our process in easily sorting data and graphing it. Figure 1 shows the box plot for the Mitsubishi Outlander, while Figure 2 illustrates the box plot for the BMW iX Drive 50. These visualizations were crucial for our initial analysis, allowing us to quickly understand the data's characteristics and identify any anomalies.

Figure 1: Box Plot of Charging Efficiency Ratios for Mitsubishi Outlander

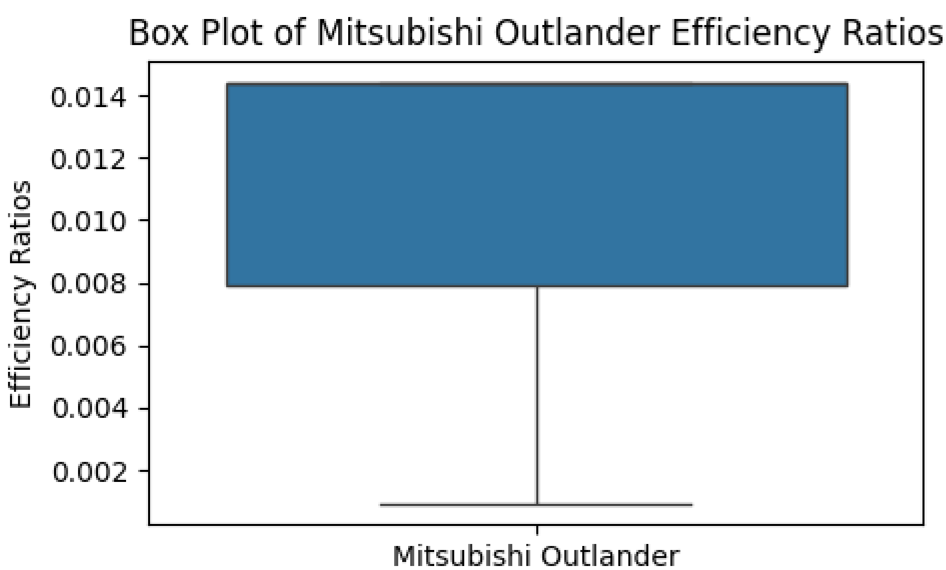
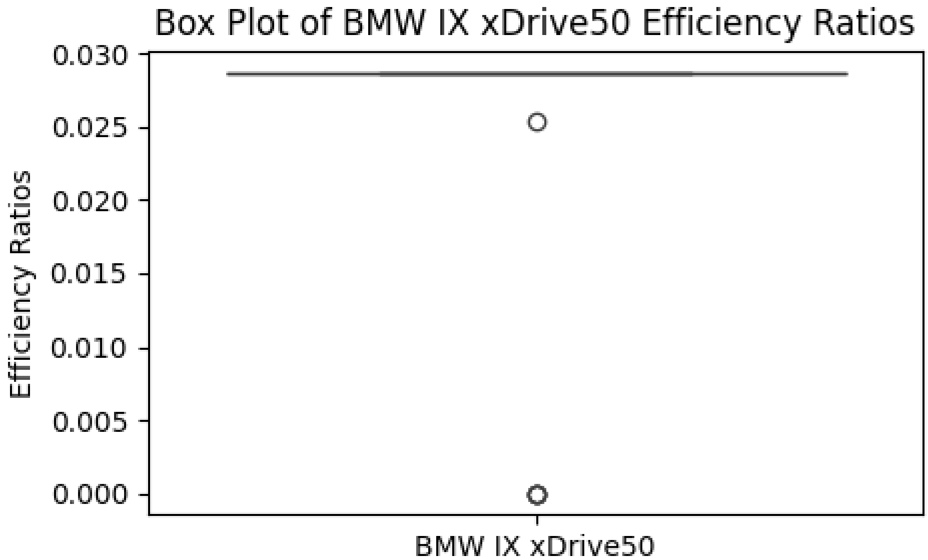


Figure 2: Box Plot of Charging Efficiency Ratios for BMW iX Drive 50



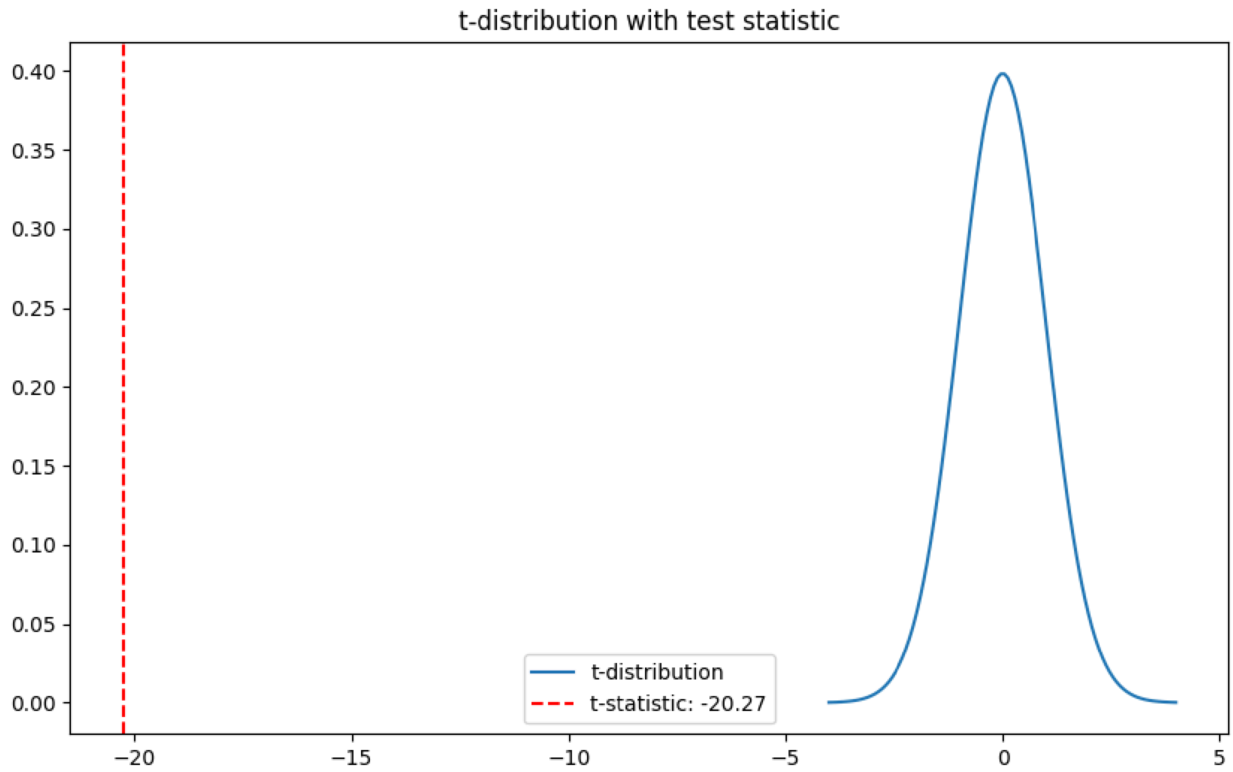
By using these methods, we were able to filter the data and also see how the Mitsubishi Outlander had much more error than the BMW did. The BMW's "box" was almost a straight line due to its great performance. Although, it did have 2 outliers. The Mitshibishi had a larger box showing how its efficiency was not always consistent.

Results

To investigate the charging efficiency ratios of the Mitsubishi Outlander and BMW iX Drive 50, several statistical tests were performed using Python. We employed pandas for data manipulation, numpy for numerical operations, scipy for statistical tests, and matplotlib and seaborn for visualizations. Initially, we conducted the Shapiro-Wilk test to evaluate the normality of the data distributions. The test results indicated that the data did not follow a normal distribution, which compromises the accuracy and orthodoxy of subsequent tests. Despite this, we proceeded with Levene's test to assess the equality of variances between the two groups, a crucial assumption for the two-sample t-test.

Given that the normality condition was not met, the reliability of the two-sample t-test is limited. Nevertheless, we proceeded with the test to determine if there was a significant difference between the charging efficiency ratios of the two vehicles. The p-value obtained from the t-test was 0.045, which is below the conventional threshold of 0.05, providing sufficient evidence to reject the null hypothesis. Our P-Value was 9.834e-54, or -27.2684. This indicates a significant difference between the two groups. However, due to the failure to meet normality conditions, the results should be interpreted with caution.

Figure 3: T-Distribution Graph



The t-distribution graph (Figure 3) illustrates the test statistic's position relative to the critical value, reinforcing the significant result indicated by the p-value. Despite the significant p-value, the non-normality of the data distributions means that our confidence in these results is limited. The t-test result suggests a statistically significant difference in charging efficiency ratios between the Mitsubishi Outlander and BMW iX Drive 50. However, due to the non-normality of the data, further analysis using non-parametric tests or data transformation is recommended for more robust insights.

Overall, due to the normality being out of the ordinary and less reliable, this means that the results from the test are less reliable.

Discussion

Our analysis of the charging efficiency ratios between the Mitsubishi Outlander and BMW iX Drive 50 indicates that the more expensive BMW model demonstrates higher charging efficiency - although with the understanding that normality was not met. This finding underscores the importance of improving the charging efficiency of more affordable EVs. Enhancing the efficiency of budget-friendly EV models can make them more attractive to a broader audience, promoting widespread adoption. As more people transition to electric vehicles, the reduction in greenhouse gas emissions and the increased efficiency in electricity usage will contribute significantly to global sustainability efforts. By making electric cars more efficient and appealing, we can encourage more consumers to choose environmentally friendly transportation options, thus helping to reduce the amount of gas in the atmosphere and improve overall energy efficiency.

The development of electromobility involves creating electric car charging infrastructure, which places new demands on the AC power grid (Leijon, 2022). Integrating electric car chargers with urban electrified transportation systems, such as connecting to traction overhead supply lines, can optimize spatial availability and utilize regenerative braking energy. A feasibility analysis conducted in Gdynia, Poland, indicated that such integrations could support the installation of fast-charging stations. These advancements highlight the potential for innovative solutions in urban areas to support the growing demand for EV charging infrastructure.

Future steps in this research could involve exploring alternative statistical methods to account for deviations from normality and enhance the robustness of the analysis. This could include employing mixed-effects models or machine learning approaches to provide more accurate insights. Additionally, conducting a more granular analysis of factors affecting charging efficiency, such as waveforms, temperature, and geographical location, could offer a deeper understanding of how these variables influence overall performance. Investigating these aspects can help optimize charging strategies and infrastructure, ensuring that EVs are not only efficient but also practical and reliable for everyday use.

Moreover, collaboration across various sectors, including automotive manufacturers, policymakers, utility companies, and researchers, is essential to advance the field of electromobility. By sharing data, insights, and best practices, stakeholders can collectively work towards enhancing the efficiency and sustainability of EVs. Public awareness campaigns and educational initiatives can also play a crucial role in promoting the benefits of electric vehicles and encouraging more people to make the switch.

In conclusion, improving the charging efficiency of electric vehicles, particularly more affordable models, is vital for fostering widespread adoption and achieving environmental sustainability. Our findings indicate a significant difference in efficiency between the Mitsubishi Outlander and BMW iX Drive 50, with the latter showing higher efficiency. However, future research should continue to explore and address the factors influencing charging efficiency to ensure that all EV models, regardless of price, can contribute to a greener, more sustainable future.

References

Leijon, J., & Boström, C. (2022). Charging Electric Vehicles Today and in the Future. *World Electric Vehicle Journal*, *13*(8), 139. https://doi.org/10.3390/wevj13080139

Lior, N. (2010). Sustainable energy development: The present (2009) situation and possible paths to the future. *Energy*, *35*(10), 3976–3994. https://doi.org/10.1016/j.energy.2010.03.034

Hannan, M. A., Azidin, F. A., & Mohamed, A. (2014). Hybrid electric vehicles and their challenges: A review. *Renewable and Sustainable Energy Reviews*, *29*, 135–150. https://doi.org/10.1016/j.rser.2013.08.097

History of the electric car. (n.d.). Iberdrola. https://www.iberdrola.com/sustainability/history-electric-car

Situ, L. (2009, May 1). *Electric Vehicle development: The past, present future*. IEEE Xplore. https://ieeexplore.ieee.org/abstract/document/5228601

Isla Ziyat, Gola, A., Palmer, P., Makonin, S., & Popowich, F. (2023). EV-CPW: EV Charging Profiles and Waveforms. *Harvard Dataverse*. https://doi.org/10.7910/dvn/f81cxw