

The Electric Vehicle in the Automotive Industry - A Review of the Economic Barriers That Limit Its Large-Scale Adoption

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ABSTRACT: The electric vehicle is a sustainable solution designed to reduce the environmental impact caused by the automotive industry. It replaces the traditional combustion-engine vehicle with a drivetrain powered by battery technology, resulting in zero emissions at the point of use. Yet, as several studies have pointed out, the success of this mass-scale replacement has been minimal. This paper aimed to explain the cost barriers and implications that deter buyers from purchasing electric vehicles (EVs). Additionally, this paper considered whether the electric vehicle would be a beneficial solution for the current economy and automotive market. I utilized literature reviews on electric vehicle production systems and secondary data analysis of statistics to illustrate the effectiveness of EVs in the industry. The EV is nowhere near replacing the demand for the combustion-powered vehicle, due to its high initial price, low range, and lack of charging infrastructure. This is a barrier on the road to a sustainable future. Questioning the reasons for such failure will spark reviews of the weaknesses of the solution, leading to higher purchase rates of electric vehicles, depending on the nation and energy fuel mix.

KEYWORDS: Automotive Engineering, Electric Vehicle, Total Cost of Ownership, Internal Combustion Engine Vehicle, Automotive Industry.

■ Introduction

The automotive industry is responsible for 28% of the emissions released into the atmosphere.¹ The mainstream use of internal combustion engine vehicles (ICEVs) that rely on the burning of hydrocarbons to generate chemical energy results in high emission rates due to the release of carbon dioxide and other particulates.^{2,3} Despite the major environmental implications of the internal combustion engine vehicle (ICEV), its demand increases despite the various technological advancements in alternative solutions that promote zero emissions.

The alternative solution discussed in this review is the electric vehicle (EV). The powertrain of this vehicle is fueled by electric energy, releasing negligible tank-to-wheel emissions, which is preferable for the environment.⁴ This does not take into account charging effects on emissions.^{5,6} Several governments have pledged a complete transition to EVs in their countries. These nations further enforce policies that promote the production and purchase of EVs as part of the international commitment towards a sustainable future.⁷ However, these efforts have not led to large-scale growth in the EV industry. This raises questions as to why electric vehicles are not purchased at such a high rate.

Electric vehicles are significantly more efficient (from tank to wheel) than traditional gasoline-powered vehicles.⁴ The EV translates 60% of the energy generated to the wheels in comparison to 20%-40% in the ICEV.¹ In the year 2019, the total number of EV cars globally was 1%.⁷ Such low purchase rates of EVs are caused by several parameters outside the limits of sustainability. Several studies claim this is still a majorly unexplored territory^{4,7} with few reports analyzing the factors contributing to the stunted growth of the industry.^{1,4}

The paper is a narrative review with an exploratory secondary data analysis, which has the main objective of identifying and evaluating the reasons for the slow adoption rate of electric vehicles. Through an in-depth analysis of several total cost of ownership (TCO) reports and life cycle cost analysis (LCCA) studies, the paper gives insight into the factors that cause the automotive market to lean towards internal combustion engine vehicles. Additionally, we utilize an exploratory secondary data analysis of statistics on the rate of purchase and regional income budgets to explore the affordability gap between the two types of vehicles. Moreover, the study considers solutions to the issues suggested by other papers cited in this review. This research adds to existing literature by comparing economic factors with EV sales, giving a visual demonstration of ICEV and EV purchase rates, and elaborating on the weaknesses in the system that lead to the low purchase rates of EVs, which few papers focus on. Furthermore, the review will explore the external parameters and answer the important yet overlooked question: "Why is the EV unable to replace the demand for the ICEV?"

This paper is structured as follows. The first section covers the main limitations of the EV, leading to a low purchase rate. The second section of the paper covers the causes of the upfront price and high cost of production of the EV. The third section covers the methodologies commonly used by the papers cited in this review. The third section also includes a short secondary data analysis comparing the wealth distribution and the sales of EVs, showing the effect of price on market marginalization, and comparing the price and the range of several EVs, which would suggest the effect of increasing the battery capacity on the price of the EV. The fourth section covers the

solutions suggested to solve the named limitations that lead to the slow progress of the EV market.s

■ Main limitations of the EV

Initial cost of purchase:

As discussed in the introduction, the Electric Vehicle is considered to be significantly more efficient than the internal combustion engine vehicle. The electric vehicle is a better long-term solution due to a lower frequency of maintenance and reduced fuel costs, leading to a lower total cost of ownership (TCO), which is the sum of all the expenses of a product, in comparison to the ICEV.^{4,8}

The Consumers' focus on the initial purchase price serves as a major limitation towards EV adoption.⁹⁻¹¹ As several studies indicate, the initial purchase costs of EVs are higher than those of ICEVs, leading to the marginalization of several economic groups with lower incomes, due to the solution exceeding their financial ability.^{7,9,12}

According to a research study comparing the total cost of ownership of the EV in comparison to the ICEV, the main concern stated by consumers is whether the cost of a greener solution "can be recouped within a reasonable time of ownership."⁸ This statement further emphasizes the claim that consumers are concerned as to whether such a high price is worth the benefits of the EV, further illustrating the uncertainty in the market caused by the high upfront costs of the vehicle.

In addition, due to the advanced technology applied to the EV drive-train, the cost of general maintenance and repairs of the EV is high in comparison to the ICEV.⁹ This is another limitation that makes the market prefer ICEVs, as the complications that come with intricate and delicate electronics, paired with the uncertainty of the new technologies, further cause lower purchase rates.

It is of the essence that companies produce a car that is affordable to the masses, and is at a competitive price to the ICEV. Otherwise, a major part of the automotive market will be financially excluded from purchasing a greener solution. This is a compromise that contains several complications, as discussed in the fourth section of this paper.

Range and convenience of fueling the Electric Vehicle:

Other limitations that concern consumers are the range of the EV and the availability of the charging infrastructure.^{3,13,14} The EV contains a power cost that is "75% lower" than other forms of energy.³ This leads to the operative costs of the EV being lower than those of the ICEV.⁹ This is a major benefit of the EV, as the cost of fuel is a concern raised by the automotive market when considering the type of car to purchase. The only problem that arises is the location of charging stations.

The availability of charging infrastructure is a concern that most consumers have.^{2,9,12} Buyers have the additional responsibility of locating the nearest charging stations, which, depending on the region, are not as widespread as gasoline stations.⁹ In addition, EVs take a longer amount of time to charge,² leading to further inconvenience. However, some previous literature counters this claim on the direct correlation of

charging infrastructure and EV uptake, stating that they are unrelated.⁹

The availability of charging infrastructure is worsened by the low range of the EV.⁴ This correlates with the limitation of charging infrastructure, as the lower range results in increased charging frequency, leading to "range anxiety"¹² and excessive planning when traveling long distances.⁹ Surveys conducted in a study covering the challenges faced by EVs claimed that the public saw mileage as the main limitation.⁷ The survey proves that this limitation is a determining factor in the decision to purchase a car. The inconveniences caused by these limitations lead to a lower adoption of EVs in the industry.

■ Causes of the limitations

Production Costs and an increase in demand:

The mass production of EVs is aimed at reducing the emissions caused by the ICEV industry.^{7,12} As the EV is powered by an electric powertrain, the basic components necessary for production are vastly different from those of a conventional vehicle. The mineral composition in the EV is "six times that of an ICEV",⁹ demonstrating the complexity of the EV system in terms of raw materials in comparison to the ICEV. The relatively new technology utilized in the EV leads to the cost of production being vastly different from that of the ICEV.

The components of concern are within the powertrain, specifically the electric motor and battery. The cost of manufacturing a battery takes a considerable amount of investment relative to other components in the EV.^{3,7,9} Most high-performance batteries and motors are manufactured using materials known as "rare-earth metals"⁷ such as cobalt and nickel.³ These metals have the benefits of increased battery performance, maximum output energy, increased range, and longevity of the vehicle.^{7,9} The utilization of rare-earth minerals leads to the cost of raw materials taking up "50% to 70% of the total battery cost,"⁹ which originates from the rarity and low yield of the metals.⁷

The large difference in supply in comparison to the demand leads to limitations in production costs. The demand for batteries is projected to "increase 6-fold from 2022 to 2030,"¹⁵ resulting in increased demand for limited and low-yield metals.^{7,15} This leads to a high cost of production, as the supply of materials used in the creation of high-performance EVs is outpaced by the demand of the market.

Supply Chain Disruptions:

The supply chain of EVs plays a pivotal role in the cost of production of the vehicle. The rise in demand for EVs leads to increased pressure on the supply chain.¹⁵ When paired with a low supply,⁷ the demand overrides the supply chain, leading to major shortages of materials.⁹ This is worsened by the centralization of rare-earth mineral processing in one area,⁹ such as the Tesla Mega-factory, resulting in delays due to the slow pace of sourcing the ores. This further causes a lower supply of materials, leading to a higher price of production.

The COVID-19 pandemic further exacerbated disruptions in the supply chain. This was demonstrated by the industry's reliance on semiconductors.⁹ During the pandemic, the short-

age of semiconductors, due to underestimation of the demand,⁹ led to losses of “7.7 million vehicle units in lost production and \$210 billion in lost revenue in 2021 alone.”¹⁵ These major losses shed light on the lack of a secure supply chain in the EV industry, leading manufacturers to opt for cheaper, lower-quality materials.

One of the reasons suggested by Alshahapy et al. is the integration of the EV supply chain into the JIT (just in time) manufacturing method utilized by conventional car producers.⁹ This method relies heavily on the overflow of a constant supply that the EV supply chain lacks.⁹ This causes further complications in the EV supply chain, leading to the high upfront price of the car.

■ Secondary Data Analysis

Methodology Analysis:

Most papers that were analyzed in this study utilized one of two methodologies: the life cycle cost analysis (LCCA) and the total cost of ownership (TCO).

The life cycle cost analysis (LCCA) methodology is used to analyze the EV. This methodology falls under the category of Life Cycle Analysis (LCA), which covers 4 main areas that include goal and scope definition, inventory analysis, impact assessment, and analysis.¹⁶ According to an LCA conducted by Raustad, the LCCA parameters were purchase price, fuel expenses, insurance, and registration costs,¹⁷ demonstrating an economic focus of the methodology. Alternatively, Gao and Winfield’s perspective on the defining parameters of the LCA contained the addition of GHG emissions and energy consumption, moving out of the scope of economic limitations or effects. Asiedu and Gu define the LCCA parameters as “costs to the manufacturer, user, and the society,”¹⁸ generalizing their definition to include manufacturing and design costs of a product, widening the gap of the economic factors of the life cycle cost analysis, which they claim contradict each other, as the optimization of price reduces the aesthetic of the product and vice versa.¹⁸ This demonstrates that the LCCA analysis methodology expands beyond the economic factors, which leads to a weakness as the other factors contrast with the economic parameters utilized to analyze products. The paper by Gao and Winfield further claims that “comprehensive LCA, specifically for advanced vehicles with commercial availability in today’s market, has not been fully investigated,”⁴ further illustrating the generalized approach towards parameters the LCCA utilizes, leading to insufficient data analysis on the cost of operations of the vehicle. This leads to further weakness in the methodology. However, contradictory to the claims of Gu et al., and Gao et al., Verma et al. define it as “The sum of total cost experienced during its lifespan,”¹⁶ including parameters such as the cost of ownership and the cost of operations,¹⁶ which covers most of the economic implications of a product under the LCA methodology, giving a similar definition to Raustad. The different views on the methodology focus points of the LCCA give a sense of unreliability in the method of analysis on the economic front.

The Total Cost of Ownership (TCO) considers several parameters, depending on the authors’ analysis and the spe-

cific areas the paper wants to discuss.¹⁹ According to Gao and Winfield,⁴ the TCO takes into account several parameters, including the initial cost of purchase and operational costs. The report by Alshahapy et al. expands the list of parameters to include “operation, maintenance, taxes and fees, financing, interest rates on loans, insurance, fuel, electricity, upgrades, and disposal.”⁹ These parameters cover the expenses of any type of conventional or electric vehicle. Sutakkul et al. describe the TCO’s main objective as determining the current and future costs of a product, taking into account any assumptions.¹⁹ This definition elaborates the purely economic scope of the TCO. Another format is utilized by Liu et al., which not only focuses on the economic implications of the vehicle but also on the social and environmental aspects. The TCO covers the economic implications of a product; however, depending on the assumptions chosen and other parameters taken into consideration, the TCO results may vary.

The TCO analysis covers the costs of operation in more depth than a life cycle cost analysis, and focuses on the economic parameters rather than a general analysis; this is the main methodology used to effectively analyze the parameters and was the main methodology used by most studies reviewed in this paper.

Analysis:

This paper utilizes secondary data analysis to further elaborate on the economic constraints of the EV through the range and find the correlation of EV sales compared to the economic strength of the region. As stated in the previous sections, one of the reasons that the EV is seen as inferior to the ICEV is the range, in contrast to the price, leading to low purchase rates. Furthermore, the high upfront price of the EV might serve as a barrier to citizens in lower-income countries. This additional information would be used to illustrate, firstly, the range in comparison to the price of the EV, the resultant effect on the purchase rates of the EV from a scope of economic strength, and the rate of ICEV sales in comparison to EV sales, dependent on the region. However, this data is highly exploratory and does not cover a large sample group.

Correlation between the price of EV and range:

The first data set analyzed was the purchase cost of several EVs in comparison to their range. My hypothesis was a positive correlation between the two variables. The higher the price of the EV, the higher the range of the EV.

Justifications:

This data analysis originated from the contrast between EVs and ICEVs in terms of range. The correlation between the price of the EV and the range of the EV demonstrates the value for money that the EV offers, and tests whether the price of the EV would shift the market to a position where the EV is comparable to the ICEV. The importance of this study is to show how the association between range and price is seen and whether the EV fails to reach the market’s expectation. The range per unit dollar comparison for each vehicle questions whether its battery capacity, before the inconvenience

of charging, is worth the price. One of the main limitations that leads to low purchase rates is the low range and increased frequency of charging. Demonstrating the value of range for every dollar would show how the EV either contradicts or supports the issues raised by the market.

Method:

The main methods of analysis used in this first study were descriptive statistics of the EVs' range per unit dollar and a linear graph analysis with a confidence interval of the range compared with the prices of the EVs in the sample group. The analysis was done by researching the best-selling EVs of the years 2025, 2021, and 2018. Eight cars in each list were selected. The vetting of the EVs used in the study was based on the popularity rating of the vehicle from data blogs and the availability of relevant information on the vehicle from credible sources. Their price and range were researched from company data and car overviews online, and the data gathered was summarized in Table 1.1. Figures 1.1 and 1.2 were formulated by comparing the range and price of each model. The range per unit dollar was calculated by dividing the range by the price of each EV, and the bars were arranged in order of increasing range per unit dollar. Figure 1.1 is a linear graph of the line of best fit of the range as a function of the price of each of the vehicles, containing a shaded area representing the true mean values. Figure 1.2 is a visualization of each model's range per unit dollar.

Limitations:

Table 1.1.: Data set collected for each EV, including price, model year, and range to 5 significant figures. The data in the table captures more expensive vehicles having lower ranges than cheaper models.^{20–25,25–42}

Vehicle	Year	Price/USD	Range/miles	Range per dollar/miles per USD
Tesla Model Y	2025	39990	321	0.00803
Chevrolet Equinox	2025	40790	319	0.00782
Geely Geomv Xingyuan	2025	9170	193	0.02105
Wuling Mini	2025	5570	75	0.01346
Chevrolet Bolt EV	2021	37495	259	0.00691
Volkswagen ID.4	2021	41190	190	0.00461
Audi e-tron	2021	66995	222	0.00331
Hyundai Kona	2021	49543	258	0.0052
Tesla Model S	2018	79200	259	0.00327
BJEV EC180/200 EV	2018	7146	96	0.01343
Nissan Leaf	2018	30885	150	0.00486
BYD e5 300/450	2018	32275	251	0.00778
Chevrolet Blazer EV	2025	46095	283	0.00614
Tesla Cybertruck	2025	80000	320	0.004
Honda Prologue	2025	48895	283	0.00579
Ford Mustang Mach-E	2025	39990	240	0.006
Hyundai Ioniq Electric	2021	34250	170	0.00496
Tesla Model X	2021	106440	335	0.00315
Porsche Taycan	2021	81250	199	0.00245
Tesla Model 3	2021	46440	272	0.00586
Kia Soul	2018	17095	111	0.00649
BWM i3	2018	48645	114	0.00234
Chevrolet Bolt	2018	37495	238	0.00635
Tesla Model S 100D	2018	97200	335	0.00345

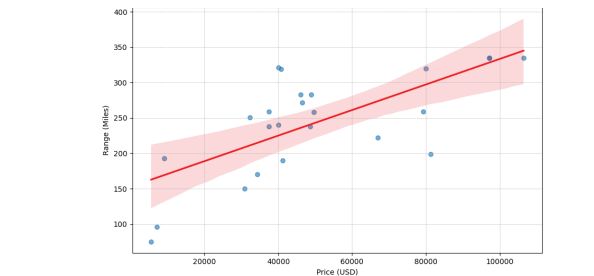


Figure 1.1.: A line graph of the price of the EV in comparison to the range of the EV using data from Table 1.1. The shaded area is the average mean or uncertainty surrounding the average value, and the confidence interval is 95%. The shaded area gets thinner as it approaches the mean region of the data. The blue dots are the actual values of the range and price of each vehicle, and the red line is the line of best fit. The graph shows a scattered correlation between the values, with many vehicle points deviating from the estimated mean.

The sample group of the vehicles analyzed was small due to several factors. Firstly, the data on the best-selling vehicles of each of those years was limited, with each list giving 10 vehicles that overlapped with other sources. Additionally, the data for some of the vehicles could not be found, leading to a low range of vehicles to choose from.

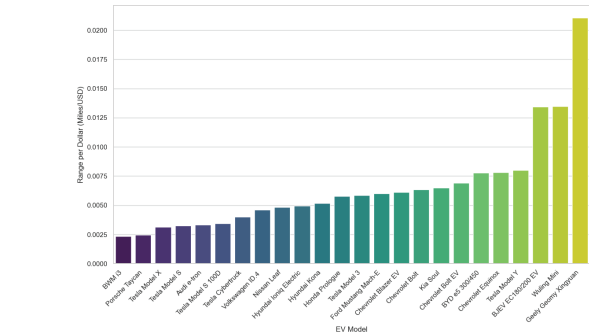


Figure 1.2.: A bar chart comparing the model of the EV and the range per dollar. All data is from Table 1. The graph shows cheaper models having higher values of range per unit dollar than expensive EVs.

EV sales in comparison to wealth distribution:

The second set of data analyzed was the EV sales in 14 countries: Brazil, the Netherlands, Germany, the United Kingdom, China, the United States, Canada, Chile, India, Israel, Japan, Mexico, Norway, and Italy. Their EV sales from 2015 to 2024 were compared to their GINI coefficient. Additionally, the ICEV sales in each country were recorded.

The GINI coefficient⁴³ is a commonly used parameter to evaluate wealth distribution. This parameter is utilized as a “measure of income inequality”⁴³ and contains a scale of 0-1. The higher the GINI index, the larger the income inequality in the nation. This was the parameter utilized to discuss the wealth distribution in relation to sales of EVs, to find a correlation between the two. I hypothesize that there is a direct correlation between EV sales and the GINI coefficient. Additionally, there would be a large difference between the sales of ICEVs and EVs.

Methods:

The main methods of analysis were a linear regression of the GINI coefficient and the EV sales of each country, and a visual representation of EV and ICEV sales demonstrated in a logarithmic graph. Data were sourced from Our World in Data on the EV sales, ICEV sales, and GINI coefficients of 14 countries. Table 2.1. summarizes this data. Figure 2.2. compares the wealth distribution and the EV sales, using a linear regression equation shown in Figure 2.1. to plot a dual bar graph. The GDP per capita and the urbanization rate of each country, sourced from the World Bank, served as the control variables used to formulate regression calculations seen in Figure 2.1. and Table 2.3. As another form of comparison, the sales of ICEVs and EVs in each country during the years 2015-2024 were sourced from Our World in Data, and the findings are summarized in Table 2.1. Figure 2.3. compares ICEV sales and EV sales in each country in a logarithmic graph. The countries were selected on an intended even distribution of economic

power and the availability of the data on EV and ICEV sales statistics.

Justification:

The study of EV sales in comparison to the GINI coefficient would show what association the EV sales have with each country's financial position. As the price of each EV affects the sale rate of the EV, the experimental data would show to what extent the EV sales are working towards the green effort if done on a larger scale. Additionally, the sales of the EV in comparison to the ICEV would show how low the EV sales are in comparison to the ICEV sales, proving the main thesis of this paper, that the EV has not reached large-scale adoption.

Regression analysis is important as the GINI coefficient is not the only known measure of wealth distribution and economic power of a country. Creating a graph that compares the EV sales vs the GINI coefficient of a country would be considering the assumption that the GINI coefficient is the only relevant determinant of economic strength and wealth distribution. The assumption would lead to a weakness in the analysis. Therefore, the use of linear regression using the GDP and urbanization rate as controls would allow for a more accurate analysis of the two factors.

The use of a logarithmic graph was to visibly show a distribution of EV and ICEV sales in a bar graph. Using the ICEV sales scale would lead to the EV sales bars becoming too small and the data not being easily visible. The logarithmic scale creates a balanced visual that accommodates the scales of the EV and ICEV sales.

Limitations:

Full Regression Formula and Symbol Definitions

Regression Equation:

$$EV_Sales = 6,190,199.80 + (33,538,733.10 \times GINI) + (20.20 \times GDP) + (-221,443.01 \times Urbanisation)$$

Symbol Definitions:

- **EV Sales:** Total Electric Vehicles sold (2015-2024)
- **GINI:** GINI Coefficient (Income Inequality index, 2021-2023)
- **GDP:** GDP per Unit Capita (USD, 2024)
- **Urbanisation:** Urbanisation rate (%)

Calculated Constants & Coefficients:

- Intercept (β_0): 6,190,199.7968
- GINI (β_1): 33,538,733.1034
- GDP (β_2): 20.1980
- Urbanisation (β_3): -221,443.0082

Figure 2.1.: The regression formula used to create the linear regression analysis demonstrated in Figure 2.2.

Table 2.1.: The data set collected from Our World in Data^{44,45} that contains total EV sales in a decade compared with the GINI coefficient of each country (average from 2021-2023) and total ICEV sales in a decade. All the data on the sales are actual unit sales to 4 significant figures.

Country	Total Evs sold (2015-2024)	Average GINI coefficient (2021-2023)	Total ICEVs sold (2015-2024)
Brazil	215000	0.6918	18100000
China	33040000	0.5646	204300000
Germany	3470000	0.4712	30280000
Netherlands	819200	0.3888	3395000
United Kingdom	2127000	0.4738	21690000
United States	6095000	0.5869	157100000
Canada	806100	0.3111	13550000
Chile	11280	0.4304	2320000
India	238300	0.2551	19920000
Israel	225500	0.3789	3006000
Mexico	67460	0.4345	10890000
Japan	606400	0.3234	39770000
Norway	926400	0.2653	566200
Italy	603000	0.3434	15940000

The main limitation is the lack of many developing countries outside Europe, Southeast Asia, and North America in the study. Most nations have their GINI coefficient, GDP, and

Urbanization rate documented on Our World in Data or the World Bank website. However, most developing countries do not have any data on EV and ICEV sales; therefore, the study only has a limited range of second- and first-world countries, with very few developing countries.

Table 2.2.: Data from the World Bank Organization,^{46,47} including the urbanization rate in percentage and GDP per Capita of USD used as economic controls in the linear regression comparison model.

Country	Urbanisation rate/%	GDP Per Capita (2024)/USD
Brazil	88	10310.5
China	66	13303.1
Germany	82	56103.7
Netherlands	96	67520.4
United Kingdom	83	53246.4
United States	80	84534
Canada	83	54340.3
Chile	89	16709.9
India	35	2694.7
Israel	92	54176.7
Mexico	80	14158.8
Japan	92	32487.1
Norway	83	86785.4
Italy	70	40385.3

Table 2.3.: Linear Regression calculation table of EV sales as the dependent variable, GINI coefficient as the independent variable.

Variable	Coef.	Std. Err.	t	P> t	[0.025	0.975]
Intercept	6,190,199.7967	13,383,702.0916	0.4625	0.6536	-23,630,546.8171	36,010,946.4104
GINI Coefficient	33,538,733.1035	19,663,626.0431	1.7056	0.1189	-10,274,556.0541	77,352,022.2610
Urbanisation Rate (%)	-221,443.0082	178,665.0143	-1.2394	0.2435	-619,533.4681	176,647.4517
GDP Per Capita (USD)	20.1980	97.2238	0.2077	0.8396	-196.4301	236.8262

R-squared: 0.2791 | Adj. R-squared: 0.0628 | F-statistic: 1.2904 | Prob (F-stat): 0.3306 | Observations: 14

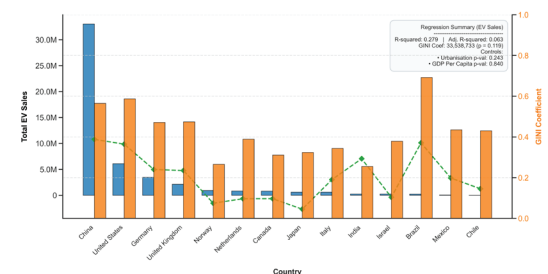


Figure 2.2.: A graph that compares the sales of EVs in each country and the nation's GINI Index; dashed lines are projections through the regression analysis; yellow bars represent the GINI coefficient, and the blue bars show the total EV sales. The results clearly show a mixed correlation of EV sales of each country vs their GINI coefficient.

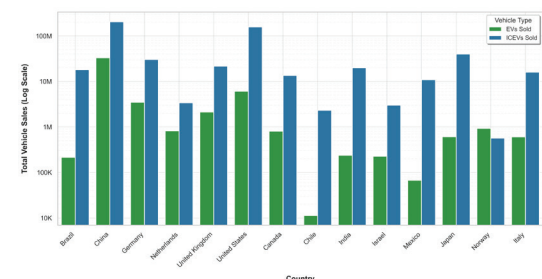


Figure 2.3.: A comparison of sales of ICEVs and EVs in the last 10 years (2015-2024) using a logarithmic scale. The graph shows a large gap between ICEV and EV sales.

Results:

Figure 1.1 is a linear regression line graph comparing the range and the price of EVs in the sample group. The line of best fit shows there is an estimated positive correlation between range and the price of the EV, and the red region

indicates the true average mean values. 8 vehicles seem to have a ratio of range to price that falls under the average region, showing that a third of the vehicles analyzed follow the suggested trend. However, the number of extremes on the graph shows the association is not directly positive. 15 vehicle ratio values had a large range above or below the line of best fit. This indicates that the relationship displayed by the line of best fit is not proven to be positive. The data in the table supports the non-positive correlation, as it shows several vehicles collectively containing ranges that do not correlate with their value, such as the Volkswagen ID. 4 that costs 40,000 USD yet has a range of 190 miles, which is lower than the Geely Geomy Xingyuan at 193 miles with a price of 9170 USD. The extremes in the graph demonstrate an indirect correlation of the price as a function of range.

Figure 1.2. is a bar graph that compares each model's range per dollar ratio. The results show a mixed negative correlation between the price per unit dollar and the value of the model. More expensive models such as the BMW i3 (\$48,645) and Porsche Taycan (\$10,6440) have a low range per unit dollar (averaging at 0.002 miles per dollar), in comparison to the Geely Geomy Xingyuan (\$9,170) and the Wuling mini (\$5,570) having a higher range per unit dollar (0.021-0.013 miles per dollar). This shows that the range of the EV does not increase with price; instead, it decreases. However, this trend is contradicted by several vehicles such as the Tesla Model Y (\$39,990) and Chevrolet Equinox (\$40,790), which have a relatively high price in comparison to the cheaper models but are within the upper bound of range per unit dollar values (0.007-0.008 miles per unit dollar). This shows that the relationship between the range and price of each EV is not direct in this exploratory analysis.

Figure 2.2. is a dual bar graph containing a linear regression that compares the GINI coefficient and the sales of EVs in the period 2015-2024. The results vary depending on the nation; however, some of the sample countries seem to show a partial correlation between the GINI coefficient and EV sales. Countries such as the USA, Germany, and the UK have high values of the GINI coefficient and have relatively high values of sales of EVs, in decreasing order from the USA to Germany. This displays a positive trend in the GINI coefficient and EV sales, which is projected by the values shown by the regression line, and a negative trend in EV sales for countries with a lower GINI coefficient. However, seeing the trend in several countries contradicts the claim of a valid association. Nations such as Norway, the Netherlands, Canada, Japan, and Italy have variant GINI coefficients, with Norway visibly the lowest of the group and the Netherlands the highest. Nevertheless, all these nations have a similar number of EV sales, demonstrating that sales are not dependent on wealth distribution. Other countries, such as Israel, India, Brazil, Mexico, and Chile, have relatively high GINI coefficients in comparison to the rest of the sample group; however, the EV sales are the lowest in those countries compared to the rest of the group. This renders the association between the two factors very weak due to the extreme cases displayed by 11 of the 14 countries studied. China shows a great deviation from the correlation, as it has a GINI

coefficient lower than the USA, but has more than triple the number of EV sales in the USA. This demonstrates a weak association between the two factors.

Figure 2.3. compares the sales of EVs and ICEVs in the years 2015-2024 in a dual bar graph with a logarithmic scale. The graph clearly shows the large margin between the EV and the ICEV sales. Most of the countries have ICEV sales above 10 million units, except the Netherlands, Chile, Israel, and Norway. This demonstrates a generally high ICEV purchase rate. The range of EV sales is all lower than 10 million units, except in China. This shows the ICEV sales over the last decade are extremely high compared to the EV sales. However, this is relative depending on the country. In several nations, such as the USA, China, Brazil, Germany, Mexico, India, Italy, Canada, Chile, the UK, and Japan, the purchase rates of ICEVs have a large margin compared to the purchase rates of EVs. In the Netherlands, Norway, and Israel, the rate of purchase of each car is almost equal. These differences in purchase rates show that the correlation in sales of both types of parameters is completely dependent on the nation in some cases; therefore, no direct connection can be determined from this exploratory data analysis.

■ Discussion

The first section of the Secondary Data Analysis compares the price as a function of the range of the EV. The summary derived from the data in both studies is that a weak and partial association exists between the two parameters. Several extreme values weakened the association between the range and price relationship, leading to the conclusion that range does not have a strong effect on the price of the EV. This trend could be caused by other factors affecting the price, such as the raw material costs and supply chain disruptors affecting the industry, as discussed in earlier areas of the paper. Additionally, different car manufacturers would focus on different needs when designing the EV. The results of the study are contrary to my hypothesis, as I predicted a direct and positive correlation between the two parameters. However, when taking into consideration Figure 2.2., there is a negative correlation displayed by the majority of vehicles studied. More affordable vehicles had a higher range per unit dollar in comparison to more expensive models, with a few outliers breaking the trend. This leads to the conclusion that the most expensive models do not exceed or equal the range in comparison to more affordable EVs in this study.

No papers were found that conducted such a comparison between EV range and price; therefore, no direct comparative analysis can be conducted. However, some papers made their own forms of analysis and inferences on the effect of the range on the price of an EV. The paper by Adeptu and Keshav comments on the limitation of range, stating that the solution needed to solve the limitation is to increase the size of the battery. The authors state, however, that the larger batteries are expensive, which would increase the cost of the car.⁴⁸ This shows an association between the two parameters, due to the mention that increasing the range would lead to an

increased production price. This claim contradicts the results found by this analysis, as more expensive models had a lower range. However, the expense of an EV is not directly tied to the use of advanced batteries that increase the range; therefore, the contradiction cannot be verified. Another study by Kim et al. states that both the range limitation and price of the EV are affected by the “high cost of battery.”¹³ This adds to the point made by Adeptu and Keshav, enforcing the perspective that both parameters are affected by a similar denominator, the size of the battery. This claim could be quantified if the sample group compared the cost of the battery used to the range rather than the upfront price of the EV. This perspective is countered by Woodley et al. The model used by Woodley et al in their empirical paper demonstrates that “a 1 percent increase in range is associated with a 0.423 percent decrease in price.”¹⁰ This elaborates a contrary perspective, that an increase in range leads to a decrease in price. This does align with the range per unit dollar study, as higher-priced cars had a lower range per unit dollar, showing that the statistics could support this claim if the association were tested over a larger sample group.

The second section of the analysis compares the GINI coefficient of a nation and the sales of EVs in the country over a decade (2015-2024). The results of the analysis show a weak positive correlation between the two parameters, which is greatly contradicted by several outliers in the sample group. An increase in the GINI coefficient led to an increase in EV sales in nations such as the UK, Germany, and the USA. Several outliers, such as China, the Netherlands, Italy, and Brazil, showed results that contradicted the trend, leading to the conclusion of a partially positive correlation. Other results were found in nations such as India and Norway, where both nations have similar GINI coefficients; however, EV sales in Norway were higher than in India. The hypothesis predicted that there would be a direct correlation. Several instances of outliers in the sample group counter this claim. The main result gained from the data is that wealth distribution is not a direct contributing factor to the sale of EVs, and other factors lead to the increase in sales. Such results could be explained by government intervention through EV incentive schemes, the availability of charging infrastructure, and external factors in each region. There are no papers that explore the wealth distribution as a function of sales of EVs; therefore, no comparative analysis can be formulated on these results.

The third set of data analyzed compares the sales of ICEVs and EVs in several countries. The results showed a minor gap in purchases over the decade, with nations such as the Netherlands, Israel, and Norway demonstrating minor differences between the sales of EVs and ICEVs. The majority of countries studied were outliers, such as the USA, Japan, Brazil, Germany, Mexico, India, Italy, Canada, Chile, the UK, and China, where the difference between the sales of ICEVs and EVs was significant. This leads to the conclusion that the ICEV is sold more than EVs, and the differences are dependent on the region. This trend could be explained by the economic efficiency in some nations due to the energy fuel mix used to fuel the cars, or enforced government policies that promote the EV industry. No other papers have created a graph plotting

data on vehicle sales; therefore, no comparative analysis can be conducted. Yet, several papers discuss the gap between the ICEV and EV industries. Several authors, such as Bhat et al. and Wang et al., elaborate on the vast gaps between the sales of ICEVs and EVs. Both papers claim that the percentage of EVs in the car population as of 2019 was 1%,^{7,47} and 16% in 2023.¹² This vividly demonstrates the gap between the EV industry and the ICEV industry, supporting the large differences in sales of the two vehicles in many of the countries in the sample group. Several other authors state the projection of EVs to increase by 22.5% from the year 2022-2030⁹ or 5-fold from 2024-2029.⁴⁹ The increase in EV sales demonstrated by projections could explain the lower difference in the sales of both forms of vehicles in Norway, the Netherlands, and Israel. The projected growth shows an increase in the adoption of EVs.¹⁴ Furthermore, a study by Costa et al. projects “parity between ICEV sales and EV sales will be achieved in 2037,”¹⁴ which can be demonstrated in the example of the Netherlands, where EV sales in the last decade are nearly equal to the ICEV sales in the same period. The results of the analysis and readings studied show a steady increase in EV sales compared to ICEV sales, yet the outliers demonstrate that the EV industry still is not able to take over the ICEV market, despite the projections. However, a larger sample group of countries would be needed to verify this claim.

■ Solutions

Government Incentives:

One of the main limitations toward the large-scale adoption of the EV is the high purchase price of the vehicle.^{9,10} There are several solutions suggested by other reviews to reduce the purchase price of the EV. Firstly, several governments have implemented fiscal incentives, such as tax reductions,^{9,12} to increase the sales of the EV. Nations such as the USA have increased the federal tax credit income to boost the purchase rates of the EV.⁹ Norway has seen significant progress through the use of federal incentives aimed at increasing consumer leniency towards the EV¹² leading to a 280% increase in purchase rates between the years 2018-2020.⁴⁸ Furthermore, India’s investment of \$1.2 million USD into the growth of the EV market through incentives and other projects,⁴⁷ shows further support for government investment effects on the rate of EV sales. Several studies indicate that Federal incentives have a direct positive correlation with the adoption of EVs by consumers,¹² with “the absence of studies” leading to the high price gap between EVs and ICEVs,⁷ further limiting the sales of EVs.

This solution, however, is partially effective. The solution is completely dependent on the nation’s enthusiasm towards EVs and its commitment to the electrification of the transportation sector.¹² “Some nations are skeptical”¹² about EVs, fearing a greener solution would damage their economy and threaten their industries. This lack of effort leads to further limitations in several regions,¹² lowering the rate of EV adoption. Additionally, when the “EV sales increase by a certain amount, the subsidies will be canceled.”⁷ This will lead to the price of the EV increasing, resulting in more limitations due to the mar-

ginalization of the EV from the masses on the economic front. The gap in government intervention leads to EVs globally accounting for 1%⁷ of the car population as of 2019.

Increased access to charging infrastructure:

The lack of charging infrastructure is another limitation of the EV that needs to be addressed. The low range of the EV leads to a more frequent need to fuel, inconveniencing buyers who are in regions with limited charging infrastructure.⁴ Several studies show a direct correlation between an increase in charging infrastructure and the purchase rate of the EV, with Alshahapy et al. stating that the “investment in charging infrastructure is potentially more effective than financial incentives”⁹ as a form of government intervention towards the sales of the EV, demonstrating the effectiveness of this solution. Some limitations with this solution include the location of the EV charging stations, permits and other legal parameters, and a proper source of electricity,¹² especially when aiming to have a larger EV fleet of vehicles in a country. However, some literature studies disagree with the direct correlation between lack of infrastructure and EV adoption.⁹

Supply chain disruptions:

As stated in the earlier sections of the paper, the supply chain disruptions caused by low supply of rare-earth materials, high demand, and concentrated processing lead to the increased price of EV production.⁹ The supply chain disruptions are a major barrier to the adoption of EVs, as the initial cost of purchase is affected by the high cost of production.^{7,9} To lower the main costs of production, several methods can be utilized to reduce the supply chain disruptions.

Firstly, one method is the use of alternatives to replace rare-earth metals in the battery and the permanent magnet. Materials such as ferrite are cheaper in cost compared to rare-earth metals, which are in low demand.⁷ However, such materials contain limitations such as lower energy capacity and coercivity, reducing the overall quality of the permanent magnets.⁷ The use of these materials leads to low-performance EVs with reduced range, further implementing its low adoption rate. In addition, battery alternatives such as Solid-State Batteries, Silicon Anode Batteries, and Lithium-Sulfur batteries are being adopted due to increased battery capacity and energy density, which increases the performance of the vehicle.¹² However, these solutions are still in the stages of research and trials, and are not yet able to be produced at a large scale due to safety concerns.¹²

Secondly, scientists are working on the disassembly of EV batteries for reuse to lower rare-earth metal demands. Methods such as pyrometallurgical recovery, physical separation, and robotic disassembly are being assessed to both decrease the life cycle impact of the EV and the cost of production of the vehicle.^{14,49} This solution is not without its challenges. EV battery disassembly contains safety risks, such as explosions and chemical hazards, due to the handling of hazardous materials that pose a threat to the workers who conduct this process.⁴⁹ Additionally, the lack of data and technology needed to deconstruct these batteries, and the high cost of operation of these

solutions, lead to the deconstruction of batteries being an inconvenience rather than a solution that can be adopted on a large scale.⁵¹

Furthermore, the decentralization of battery production would help increase the supply of batteries, resulting in lower prices for the EVs.⁹ International collaboration and innovation are required to decrease pressure on the supply chain. However, this would require the handling of several political and social minefields associated with the mining and ore industries.⁹

■ Conclusion

This review covers the limitations that constrain the adoption of EVs on a large scale. The EV is yet to replace the demand for the ICEV, leading to a hindrance on the road to sustainability. The main limitations discussed were the high purchase price, marginalizing major consumers in the automotive industry;^{7,9,12} lack of charging infrastructure, and lower range of the EV,^{13,14} leading to customer inconvenience and further lack of interest from the market.

The reasons behind these limitations include high production costs of the battery, which takes up a significant part of the manufacturing costs.^{3,7,9} Through the mass-scale use of rare-earth metals that are in low supply, the raw material costs take up to 70% of the expenses of battery production.^{7,9} This is worsened by the centralization of processing the rare-earth materials, increasing supply chain disruptions.⁹ This prompts the high purchase price of the EV, or manufacturers opting for cheaper alternatives, leading to EVs with lower ranges.⁷

The secondary data analysis conducted was highly exploratory and limited to covering comparisons of range and EV price, rate of ICEV and EV sales, and EV sales in comparison to wealth distribution. My hypotheses were a direct correlation between range and EV price, a direct correlation between wealth distribution, and a large margin between EV and ICEV sales within the nations analyzed. The results proved weak partial associations between the two factors (range vs price) and (wealth distribution vs EV sales), with outliers demonstrating the indirect effect of each of the compared parameters on sales and price of EVs. Additionally, the large gap between ICEV and EV sales differed regionally, proving wealth distribution is indirectly correlated with vehicle purchase rates. The secondary data led to the conclusion that several factors combined affect EV sales and prices. However, for more valid results, the studies need to be conducted with larger sample groups and more control variables taken into consideration.

The solutions suggested include government incentives, which have proven to be successful to some extent, with nations such as Norway reaping the benefits.⁵⁰ However, as stated in the paper, EV sales pertain to a minuscule part of the automotive industry, raising further questions of the profitability of increased incentives and charging infrastructure towards EV adoption. Additionally, the use of disassembly methods and rare-earth metal alternatives requires further research and investment to be adopted on a large scale.^{12,48} Therefore, literature on potential alternatives to rare-earth metals is required to reduce production and price costs.

The EV is a solution that aims for a greener future. Several gaps in the field need to be addressed to improve the rate of EV purchase. One of the main gaps is the creation of effective government incentives and programs that propel the EV industry, through the study of countries that have such measures and their success rates. Additionally, the development of environmentally friendly and cost-effective batteries that increase the range of EVs needs to be researched to ease the manufacturing process and increase the market's confidence in EVs. The suggestions given would aid in advancing the EV field.

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