DATA 613 Final Project Report

Electric Vehicles

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Introduction

It appears inevitable that Electric Vehicles (EVs) will slowly become the norm. This change will come as prices drop and charging infrastructure becomes more frequent. With a push to lower CO_2 emissions, many car manufacturers (along with governments) are planning/ruling that only EVs will be produced in the future.

While many consumers look to making the switch to electric, there are still concerns about how making the switch will help fight climate issues. At what point will it be beneficial for consumers to switch to electric, while the energy produced to fuel these vehicles is still not “clean”? What about the environmental impact of producing the batteries required?

To enter the Electric Vehicle market, how costly is it to purchase a brand new vehicle? While governments provide subsidies to entice new buyers, what are the main aspects that make up an Electric Vehicle price, and does brand and drivetrain make a difference?

For those in colder climates, the efficiency of Electric Vehicles is still a primary concern. As manufacturers work on improving Electric Vehicles' efficiency, we look to see the main aspects of a vehicle that contribute to the efficiency and how efficiency and range differ in colder climates as opposed to warmer temperatures.

Methodology

Multiple data sources were collected using a variety of methods. Web-scraping, PDF-scraping and .csv loading were all necessary to acquire our data. We applied decision analytics techniques as well as regression modelling to investigate the current state of EVs.

Web Scraping

To answer questions regarding the price and range of an Electric Vehicle, we scraped data off the website https://www.ev-database.org/. This website has general information on over 100 Electric Vehicles, including top speed, range, efficiency, and price. Each vehicle has these specifications available on a separate page. For instance, if we wish to find more information on the Tesla Model 3 Performance, we will scrape data off of the webpage https://ev-database.org/car/1322/Tesla-Model-3-Performance. We decided to look at Electric Vehicles that had data for UK, Netherlands, and Germany prices. By doing this, we avoid looking at vehicles that are being sold exclusively to one country in Europe. This resulted in a dataset containing 98 Electric Vehicles with 45 variables.

PDF Scraping

Our project required CO2 emissions for electrical generation in each province. We sourced this information from a series of tables contained in a .pdf file of Canada's report to the UN Climate Change Convention as part of the Paris Agreement. The tabulizer package for R was used to scrape the necessary data from the tables within the .pdf.

Miscellaneous Datasets

A number of smaller datasets or tables were used:

- Wikipedia: Table of lifecycle CO2 emissions per kWh of electricity by generation source (coal, gas, solar, etc.)
    - Scraped using rvest package for R
- Environment Canada: Climate averages and deviation by month for Calgary
    - Available as a .csv, requires cleaning and extraction
- Canada Energy Future: Future electricity generation sources by province
    - Available as a .csv

Analysis Approach

We used decision analytics to determine whether EVs lower an individual's GHG emissions in Alberta. Using monthly weather averages and deviations for Calgary over 30 years, daily mean temperatures for 100 years was simulated. We used the results to decide the actual efficiency of battery-powered vehicles that operate worse in cold weather. Emissions per 100km were calculated for a selection of vehicles ranging from typical to most efficient. Finally, a projection of future electricity sources from Canada Energy Regulator was combined with an estimation of emissions by source to decide in which year an EV will have lower emissions than a gasoline car.

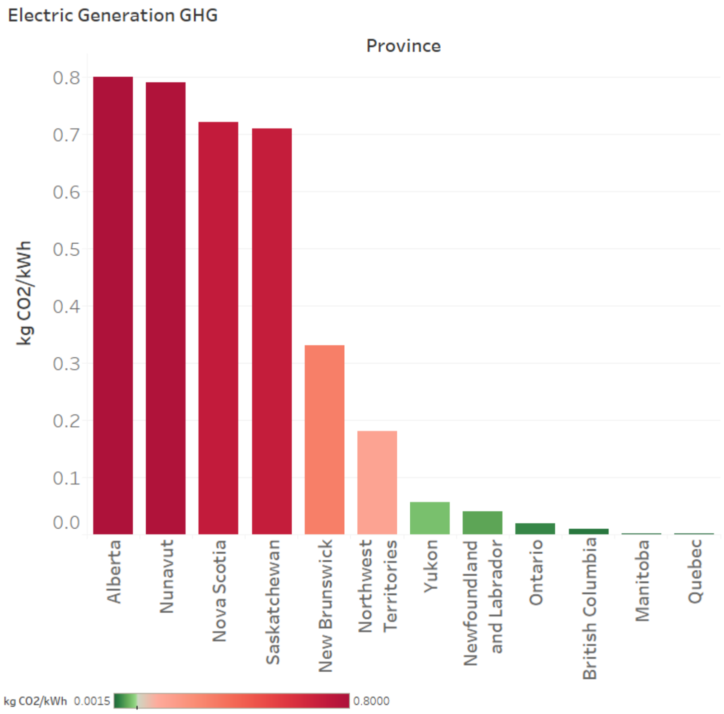
Regression Approach

For each predictive model we applied a similar approach. We removed variables which were highly correlated (known to cause model instability), then applied an automated approach to select the most predictive variables. Regression models make certain assumptions about their data, so those were checked. In the case that those assumptions failed, we applied transformations to the data in an attempt to resolve those issues. The final results were then explored and used to derive our insights.

Results

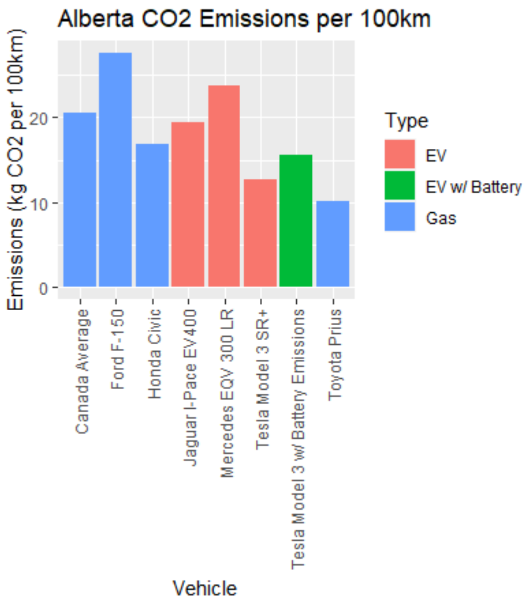
1. Dirty Electricity Emissions

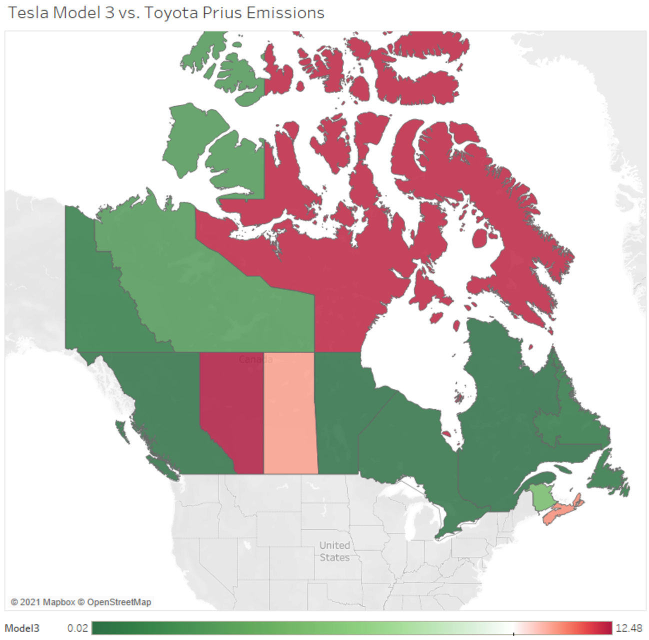
Alberta has the highest emissions per kWh of electricity generated out of any province or territory in Canada. These emissions are due to Alberta generating the vast majority of its electricity from coal and natural gas. Nunavut, Nova Scotia, and Saskatchewan have similarly high emissions for the same reasons.



Our first finding came from modelling Calgary's weather in order to predict its effect on EV efficiency. Our simulation model produced a "mildness" score of 0.416. This can be interpreted to mean that on 41.6% of Calgary days, an EV will be operating at its mild weather rated efficiency, and during the remaining 58.4% of days it will operate at its lower cold weather efficiency rating.

With this factored in, we found that in Alberta, gasoline cars are 20-30% *lower* emissions than Electric Vehicles. Specifically, the most efficient conventional vehicle, a Toyota Prius, produces lower CO2 emissions than the most efficient EV, a Tesla Model 3. This is also the case in 3 of the other 11 provinces/territories considered. We also noted that lifecycle emissions from battery manufacturing has a small, but measurable effect on the outcome, but does not dramatically change the result.

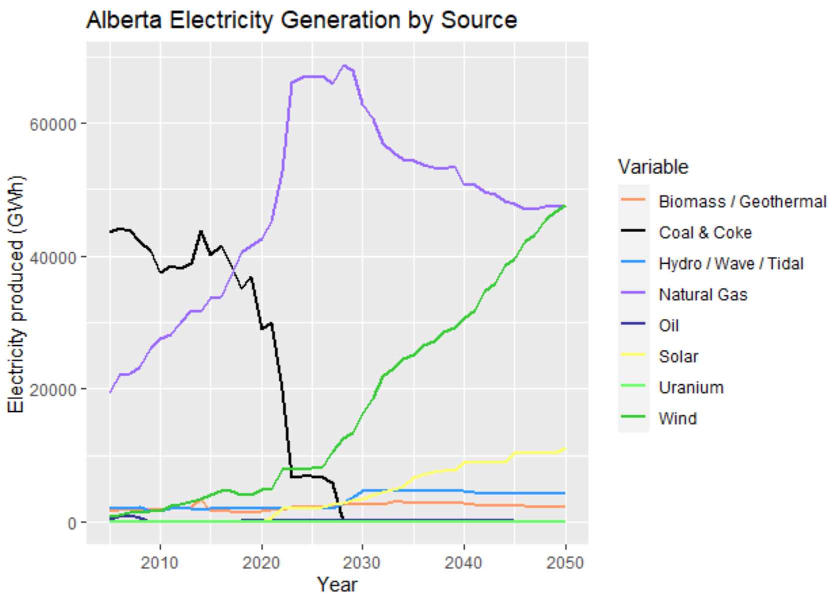


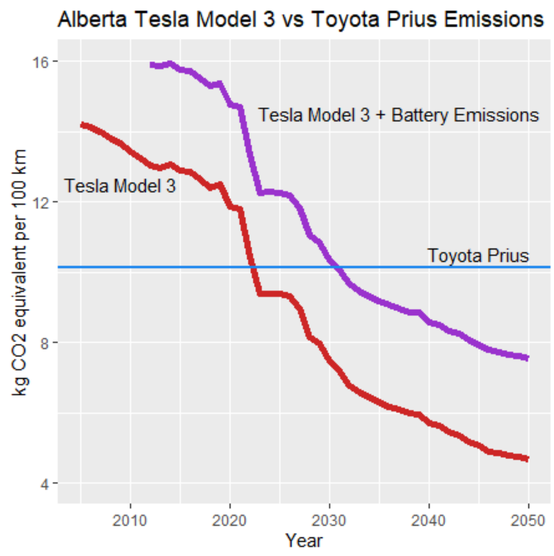


Figures: (left) A selection of vehicles by CO_2 emissions per 100km, (right) map of provinces where driving a Model 3 is greener than a Prius, by GHG emissions

1a. Alberta's Electricity Future

Alberta's electricity sources will be transitioning away from coal and natural gas and towards wind and solar over the next 30 years. The plot depicts a projection of Alberta's electricity generation from Canada Energy Regulator. Natural gas, which is greener than coal, will act as a bridge to future wind generation capacity in this province.





Using this projection, we determine that an Electric Vehicle will have lower emissions in Alberta as soon as 2024 before factoring the lifecycle battery emissions. Once battery emissions are considered, this slips to 2031. This is still soon enough that the purchaser of a new vehicle may already consider electric to minimize their emissions, perhaps by choosing a smaller capacity battery in their vehicle or by choosing a manufacturer using a greener battery source. Certainly, an owner of a home solar voltaic system would already be in a position to reduce their emissions by going electric. While Alberta has earned a reputation for dirty electricity, it will not remain that way for long.

2. EV Pricing

As Electric Vehicles are becoming more popular, we were curious about what information would be predictors for the price of an Electric Vehicle. We know that cars released more recently will be more expensive than vehicles released five years ago. However, there are a lot more predictors to think about for Electric Vehicles. For instance, an Electric Vehicle might be priced higher because of its advanced charging technology, which can fully charge an Electric Vehicle faster. Our dataset contains prices for the United Kingdom, Netherlands, and Germany, but we decided to focus on Electric Vehicles' prices in the United Kingdom. This is because the United Kingdom prices of all-Electric Vehicles include the direct incentive of the "Plug-In Car Grant." This discount of up to £3,000 on the price of a brand new low-emissions vehicle gives people more incentive to buy a car in the United Kingdom rather than in Germany.

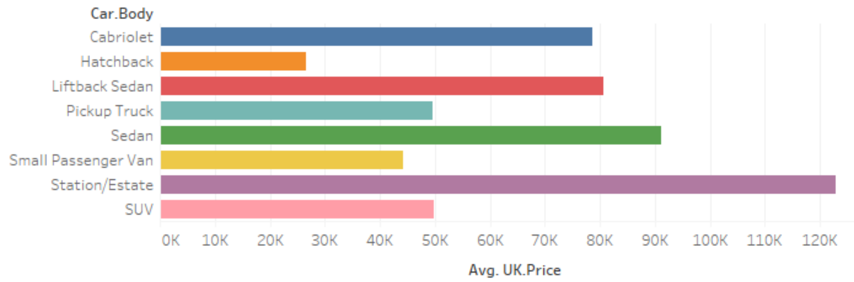
We found that car width, type of drive, and car body were the best three predictors for an Electric Vehicle's price. Width was an unexpected variable in this model. When looking at the price of a vehicle, most of the time, buyers do not care for the exact dimensions of a car. However, a buyer would care about other variables that relate to width, such as the number of seats or car body.

The two other variables, type of drive and car body do make a lot of sense when determining a car's price. The variable type of drive has three levels: Front-wheel, rear-wheel, and all-wheel drive. An all-wheel-drive car requires more electric motors or a more complex transmission and will be more expensive than a front or rear-wheel-drive car.

We can confirm the statement above with our dataset. The average price of an all-wheel-drive car is £81,340.57, while the average price of a front-wheel drive is £31,670.73.

Drive	avg_price
AWD	81340.57
Front	31670.73
Rear	39170.56

The variable car body is the classification of a car and includes levels such as SUV, Small Passenger Van and Sedan. In our data on average, the most expensive car body is station/estate, while a hatchback is the cheapest.



Our final model to predict the price of a car in the United Kingdom is:

$$UK.Price = -329633.2 + 223.87Width - 16919.4(Drive = Front)$$

$$- 23512.2(Drive = Rear) - 12733.7(Car.Body = HatchBack) - 22694.5(Car.Body = LiftbackSedan)$$

$$- 1976.0(Car.Body = Sedan) - 18690.5(Car.Body = SmallPassengerVan) - 22034.8(Car.Body = SUV)$$

Our base level is all-wheel drive and with a cabriolet car body. We can see that for every millimeter increase in the width of an Electric Vehicle, the price of the car increases by £223.87. We will test the performance of our model using data from the most popular Electric Vehicle, the Tesla Model 3 Performance.

Car.Name <chr>	Car.Body <chr>	Width <dbl>	Drive <chr>
Tesla Model 3 Performance	Sedan	1849	AWD

We can see that a Tesla Model 3 Performance is an all-wheel drive sedan with a width of 1,849 millimeters. Plugging this into our model we get:

$$\begin{aligned} UK.Price &= -329633.2 + 223.87(1849) - 16919.4(0) - 23512.2(0) - 12733.7(0) - 22694.5(0) \\ &\quad - 1976.0(1) - 18690.5(0) - 22034.8(0) \\ &= -329633.2 + 413935.63 - 19760.0 \\ &= 64542.43 \end{aligned}$$

Our model predicts that the price of a Tesla Model 3 Performance will be £64,542.43, however the actual price is £56,490. You can see from this example that we predicted the price of the car to be £8,052.43 more than it actually is.

One explanation for our model inaccuracy is our variable choice. At one point in our process, we removed variables which were highly correlated with others. This removed variables that we believe are more explainable predictors for the price such as charge time, total power, and range.

Another explanation is that our model did not meet all of its assumptions required for soundness. This indicates that we may be able to find a better model to accurately predict the price. The third and most optimistic explanation we can offer is that the Tesla Model 3 Performance offers exceptional value for the specifications. Our model simply is not able to capture this outlier in price for the specifications that the vehicle offers.

2a. Brand Impact

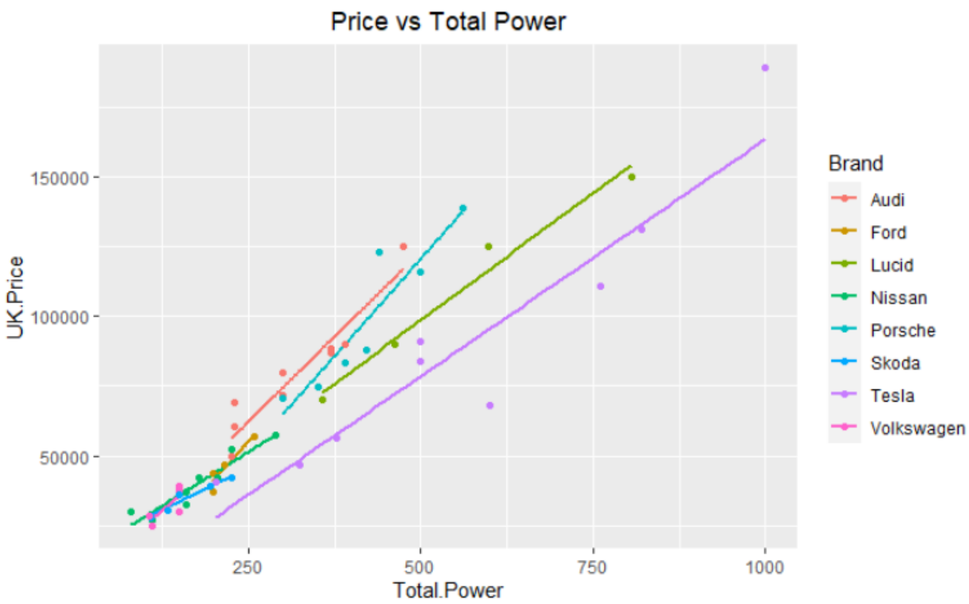
We know that Tesla is the most popular and recognizable electric car manufacturer by far as they delivered just under 500,00 Electric Vehicles in 2020. As electric cars are becoming more popular, more manufacturers are entering the market. We were curious if any manufacturers have specialized in exclusively selling "higher-end" Electric Vehicles. In other words, can we predict if the price of an Electric Vehicle will be higher or lower depending on the manufacturer?

Brand	no_rows	avg_price
Lucid	4	108750.00
Porsche	7	99270.29
Tesla	12	84155.83
Audi	10	77430.00
Ford	4	46252.50
Nissan	8	40036.88
Skoda	5	35080.00
Volkswagen	5	32150.00

From our data, we can see that, on average, Lucid, Porsche, Tesla, and Audi are selling higher-end cars while manufacturers such as Ford, Nissan, Skoda, and Volkswagen are producing lower-end cars. Therefore, this suggests that the price depends on the manufacturer. As we expected, Tesla sells the greatest number of options at 12 Electric Vehicles.

As stated in question 2, we removed the variable total power due to having high collinearity with other variables. Total power is one of the most important factors in determining the road performance of a car, measured here in kilowatts (though it is commonly measured in horsepower in North America). In an electric vehicle, it is necessary to use larger battery packs and more electric drive motors in order to increase total power.

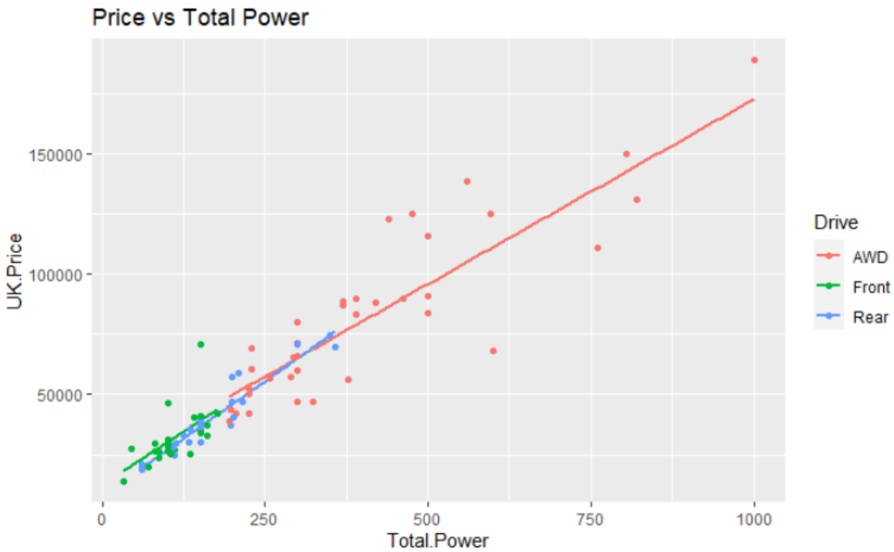
We believe that total power is a major predictor in predicting the price of a car. Now that we know that the manufacturer is at least somewhat predictive of price, we will now ask the question: Does the manufacturer moderate the impact of total power on price? In other words, does the relationship of total power and price depend on the manufacturer of the car?



From this graph, we can see that there is a positive relationship between the price and the total power of an Electric Vehicle. The slopes of the lines do not seem to be that different meaning that this relationship does not depend on the manufacturer of an Electric Vehicle.

2b. Drive Type Impact

As stated before, we know all-wheel drive cars are more expensive than front or rear wheel drive. Now we ask the question: Does the type of drive moderate the impact of total power on price?

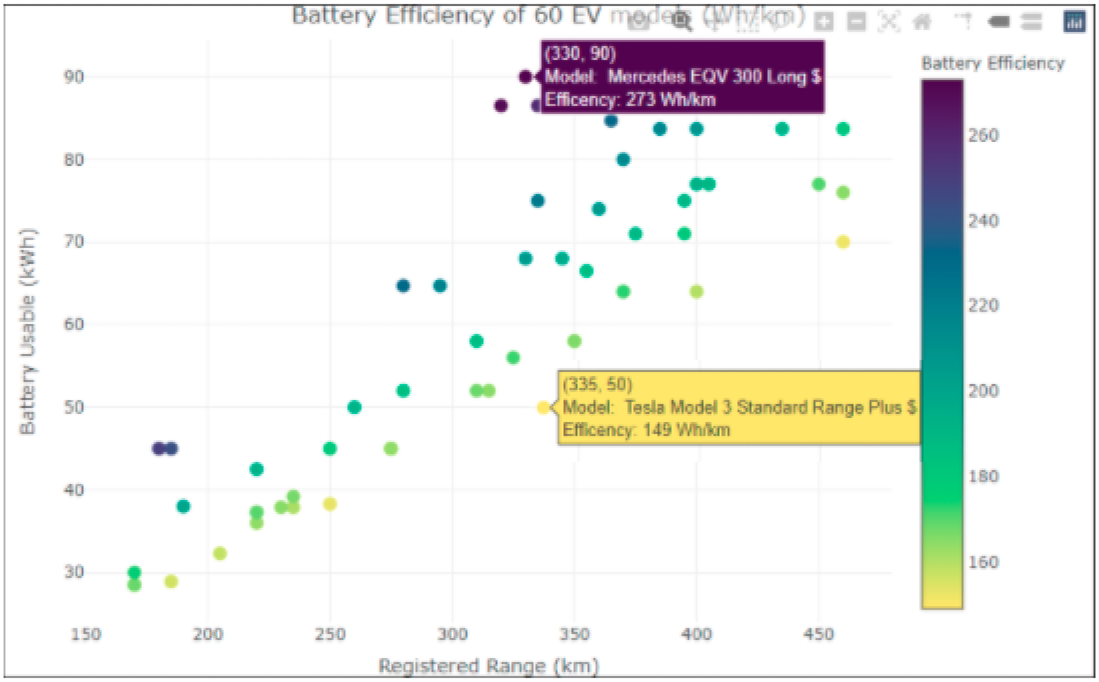


From this graph, we can see that the slopes are very similar. This indicates that the relationship between total power and price does not depend on the type of drive. All in all, we conclude that the higher the total power of a car, the more expensive it will be no matter the type of drive or the manufacturer.

3. EV Range

For those in the market of purchasing an Electric Vehicle, the vehicle range is one of the main factors customers are thinking about when making the switch to electric. With the adaptation of charging locations becoming more affluent, the vehicle range's emphasis is becoming less and less. However, people do not think that waiting 20/30 minutes to charge their vehicle is ideal.

With this in mind, Electric Vehicle manufacturers target their Electric Vehicles' efficiency on an aspect to continuously improve. As we see what variables play a large role in what makes a vehicle more efficient, we try to find which elements of the vehicle design manufacturers should focus on. In order to calculate efficiency, we take the capacity of a battery, and divide it by the calculated range of a vehicle.



While we compare the Electric Vehicles on our Data Set, we can see some significant differences between the different car models. For example, the Tesla Model 3 Standard Range Plus and the Mercedes EQV 300 Long share roughly the same range; however, the Mercedes has a 180% bigger battery. As these vehicles are different body styles, the Tesla being a sedan, while the Mercedes being a Small Passenger Van, this could infer that a vehicle's body type does play a large role in its efficiency.

For our final model that looks at predicting the efficiency, we have the following outcome:

$$Range = 253.6 - 14.2(Drive = Front) - 14.5(Drive = Rear) - 0.082(Gross.Vehicle.Weight)$$
$$- 8.00(Cary.Body = Hatchback) - 18.32(Car.Body = Liftback\ Sedan)$$
$$- 24.76(Car.Body = Sedan) + 25.63(Car.Body = Small\ Passenger\ Van)$$
$$+ 12.65(Car.Body = SUV) + 0.000026(Gross.Vehicle.Weight)^2$$

With this formula, we can see the variables that play a significant role in making a vehicle more efficient. As more power is needed to the wheels when a vehicle is operating in AWD, a vehicle is more efficient when only providing power to either the front or the rear.

The body styling of a vehicle plays an integral part in efficiency as well. As SUVs tend to weigh more and be less aerodynamic, we can assume that they would be less efficient than their smaller counterparts.

This brings us to the weight variables in our model. There may be other contributing factors as in our model; if weight increases, the vehicle range should also increase, which may not be the case in reality. We believe that there is an interaction with the body style and weight; however, our modeling did not conclude that this effect was significant enough to add. We may have a bias in our data, where manufacturers that provide more commercial vehicles, such as the small passenger vans, or more luxury SUVs, focus more on the efficiency of their batteries.

While our model does an excellent job of predicting efficiency for smaller, lighter vehicles, it underestimates efficiency for larger vehicles.

Model	***Actual Range***	***Predicted Range***	***Difference***
Tesla Model 3 Standard Range Plus (Sedan)	149	150	+1
Mercedes EQV 300 Long (Small Passenger Van)	273	283	+10
Jaguar I-Pace EV400 (SUV)	160	178	+18

3a. Cold Weather Effects

As with any vehicle, Electric Vehicles are susceptible to cold weather conditions. This is exacerbated by needing to use electric heating elements which divert power from the batteries whereas gasoline cars can use waste heat from the engine for that purpose. How an Electric vehicle can handle in a cold weather climate such as Alberta puts many consumers off on making the switch to electric. For their gasoline counterparts, many manufacturers bring their cars to colder climates for cold climate performance testing.

With the data collected in our data set, we look to see how a colder climate affects:

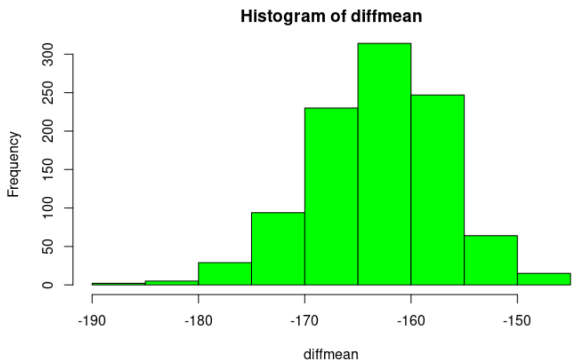
1. City Range
2. Highway Range
3. City Efficiency
4. Highway Efficiency

To have a benchmark in place to see what is defined as a cold climate report, and a mild climate report, we have the following stipulations:

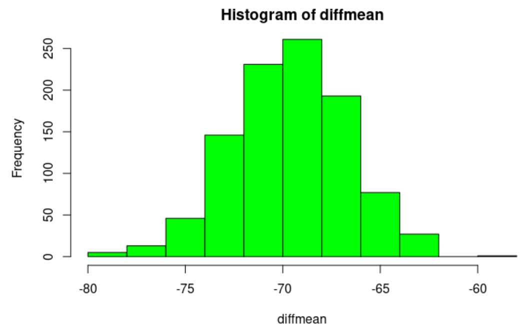
Cold climate: *Worst case testing is based on -10℃ with the use of heating in the vehicle*

Mild climate: *Best case testing is based on 23℃ with no use of A/C in the vehicle*

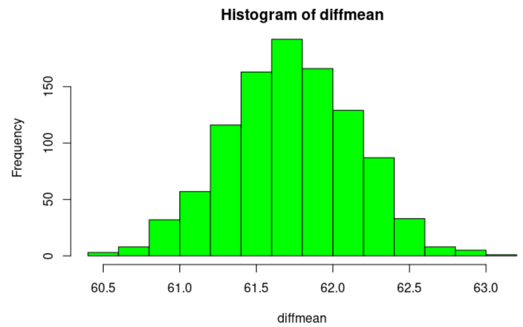
After comparing our sample of Electric Vehicle models cold climate range and efficiency, we have found the following statistical significant conclusions:



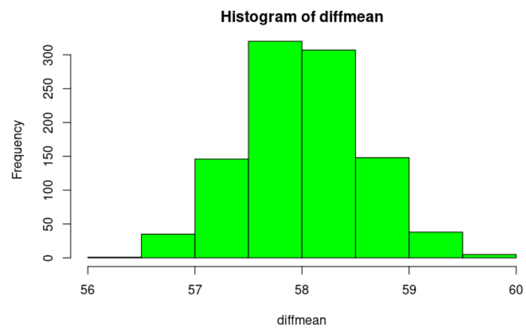
1. For city range, there is an observed drop in range in colder climates by a mean of 162.90 km



2. For highway range, there is an observed drop in range in colder climates by a mean of 69.54 km



3. For city efficiency, there is an observed drop in efficiency in colder climates by a mean of 61.73 Wh/km



4. For highway efficiency, there is an observed drop in efficiency in colder climates by a mean of 58.04 Wh/km

While we observed a vast difference between city and highway range in colder climates, vehicles' efficiency drops by roughly by 58 - 61 Wh/km in both city and highway driving situations. For some vehicles, this is a drastic drop in range and efficiency. We suggest that manufacturers start, and continue, winter test these vehicles and see where cold climate performance improvements can be made.

Discussion

The overall landscape of Electric Vehicles is developing quickly. Alberta may be currently hindered by our dirty electricity mix and our colder weather, but consumers could be reducing their emissions by driving Electric Vehicles within the next 10 years. A competitive market for Electric Vehicles has emerged, with a wide variety of options already available in the European market. Manufacturers are pricing their cars competitively, leveraging their brand loyalty as well as features such as All Wheel Drive.

Our model suggests that the variables to predict the price of an Electric Vehicle are width, type of drive and car body. As the type of drive and car body are very self-explanatory as to why they would predict price, it was hard to explain why the width of a car was one of our main predictors. On the main page of ev-database.org, we see that the main variables that buyers look at in cars is its 0 to 100, top speed, range efficiency and fast charge, but we do not see any of these variables in our model. This is due to our model selection and removing any variables that were highly correlated with each other. In the end, we would suggest not using this model to predict the price of an Electric Vehicle as the model can be improved by removing unnecessary variables before creating our model. Without removing variables that were correlated with each other, we found that total power was the variable with the biggest impact on price. We discovered that the manufacturer or type of drive of an Electric Vehicle does not affect the relationship of total power and price and in the end you can count on a car being more expensive if it has a higher total power.

While our model suggests that the main factors of an Electric Vehicle's efficiency stems from the body type and drive, we do see that the weight is also significant. In looking to provide more insight, our model may be improved in the future with more insight to the battery technology itself. When comparing the efficiency of these vehicles in cold weather climates, we observe a drop in efficiency by roughly 60 kWh/km for both city and highway usage. There is still a significant difference between cold weather and mild weather range performance for Electric Vehicles.

Future Work

Our exploration of Alberta's dirty electricity mix could be expanded on in a few ways. Further research into battery lifecycle emissions could have a significant impact on when Electric Vehicles will cross over to lower emissions than gasoline. Better modelling of the emissions intensity by generation source is available and could be applied to improve accuracy. A more complete consideration of other provinces would also have value to car purchasers and decision makers. A decision tool to help consumers decide on which vehicles will reduce their carbon footprint would also prove valuable.

In the future, we would like to find a better model that will accurately predict the price of an Electric Vehicle. This could mean instead of including almost all variables in the model, we remove variables beforehand that we know would not play a significant role in the price. Many industry experts suggest that battery cost is the most important influencer on electric vehicle price[1], so a model focused on battery capacity may prove more accurate. Because we focused on the prices in the United Kingdom, it would be interesting to see how this grant has actually affected demand. If we were able to have data on the demand of Electric Vehicles for each country, we could determine how much this grant actually increases sales.

While we do experience a statistical loss in range and battery efficiency in colder climates for Electric Vehicles, it would be interesting to see how internal combustion vehicles are affected by cold weather as well. Analysis of real world data could illuminate some answers to these questions. Have we reached a point where the Electric Vehicle is now more efficient in cold weather climates as opposed to internal combustion vehicles?

[1] https://www.bloomberg.com/news/articles/2020-12-16/electric-cars-are-about-to-be-as-cheap-as-gas-powered-models

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