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Article

Exponential regression analysis of the Canadian Zero Emission Vehicle market's effects on climate emissions in 2030

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SUMMARY

The electric vehicle (EV) market has ballooned in sales in recent years with promises of emissions targets to inhibit the proliferation of symptoms of climate change. Canada, having acceded to the guidelines set by international climate preservation organizations, has set emissions targets for itself. As a result, the government has recognized the relevance of EVs in the Canadian auto market and has begun to subsidize their development and use. However, there is very little information available about the capacity of emissions that EVs can reduce. We explored how viable EVs could be as a solution to substantially reduce emissions from the transport industry. We used regression algorithms to identify the possibility of a 45% reduction in emissions from the transport industry as suggested by the Canadian government. Based on our research, we have concluded that it is highly unlikely that Canada will be able to meet its 2030 emissions reduction targets through the sale and use of EVs.

INTRODUCTION

Emissions from the Canadian transportation sector contribute to around 27% of total greenhouse gas emissions in Canada (1). Of this, 85% can be attributed to passenger vehicles such as cars, vans, and trucks, among others (2). Optimizing the emissions from the transportation industry would be greatly beneficial to minimizing Canadian greenhouse gas emissions as well as provide a sustainable mode of transport to the general public. The Canadian government has recognized the substantial margins of emissions from the passenger transportation industry, approximately 23% of total emissions (3). While electric vehicles (EVs) do produce some emissions, they are marginal when compared to the total emissions from fossil fuel-powered vehicles (3). Emissions from EVs are derived from the outputs of electric grids while charging. Meanwhile, natural gas vehicles continually emit severely injurious gases, like nitrogen oxides and carbon monoxide, into the atmosphere (3).

Recognizing this, the Canadian Government has often subsidized the sale of EVs. For example, the Ontario Scrappage Incentive Program offers 1,000 Canadian Dollars (CAD) toward the purchase of a used fully electric or plug-in hybrid electric car when scrapping an old, gas-powered car (4). Another example is Quebec, which rebates up to 8,000 CAD on EVs under 60,000 CAD (4). Since cost is a prohibitive factor to the purchase of an EV, various incentives such as these may compel drivers to regard EVs as investments and as a profitable endeavor. Canada saw 54,353 EVs registered in total in 2020, which is 0.15% of all vehicles registered in Canada (5). While this does not seem promising, the increase in affordability of EVs only serves to improve the state of the industry and its ecological importance.

To combat rising emissions, the Canadian Government has put forth a goal of a 45% reduction of emissions from the 2005 level of 747 megatonnes, in accordance with the 2015 signing of the Paris Agreement (6). By interpolating this data, we can assume that this also means a substantial margin of reduction of emissions in the transport industry as well. We hypothesized that the total emissions from zero emission vehicles (ZEVs) in 2030 will allow Canada to achieve a 45% reduction in transport industry emissions from 2005 levels as forecasted by the regression model.

However, based on our results we determined that it was unlikely for Canada to achieve its emissions goals in the transportation sector at its current trajectory. The predicted emissions in 2030 is 146 megatonnes, a 15% reduction, which is greater than the required 94.3 megatonnes to keep in line with a 45% reduction in emissions in the transportation industry.

RESULTS

We began by identifying the total emissions emitted from a variety of EVs and fuel-powered vehicles. We discovered this through research regarding the current climate of the electric and gasoline vehicle market and their industrial standards **(Table 1)**. Using **Equation 1** we can find the well-to-wheel efficiency of a vehicle, which is the product of all efficiencies in each step of the process from extracting the fuel to storing it in the vehicle (7). The formula for well-to-wheel efficiency is derived from two separate percentages that are closely related – the well-to-tank efficiency of a vehicle and the tank-to-wheel efficiency (7). The well-to-tank efficiency is the efficiency of the extraction process of the fuel needed to run the car. This is followed by the tank-to-wheel efficiency, which is how efficient the car is at putting the fuel to use (7). Multiplying the two metrics gives us the actual efficiency of the vehicle.

$$Well\ to\ wheel\ efficiency = Well\ to\ tank\ efficiency\ x\ Tank\ to\ wheel\ efficiency \quad \text{[Eq 1]}$$

The well-to-tank efficiency of gasoline powered vehicles is 88%, and tank-to-wheel efficiency of gasoline is 16% (8). Multiplying both the percentages gives us with the total efficiency of a gasoline car, which is approximately 14%. This means that for all the energy put into a car, only 14% is actually used to power the vehicle. Calculating the efficiency of an electric involves multiplying the efficiency of the extraction process and the efficiency of usage of energy in the vehicle

Vehicle Type	Energy Input	Carbon Dioxide Emissions
Unit	MJ/km	g/km
Electric Car	0.94	49
Fuel Cell Hybrid	1.5	86.8
Diesel Hybrid	1.2	89.4
Gasoline Hybrid	1.7	123
Diesel	2.0	146
CNG car	2.7	148
Gasoline	2.7	193

Table 1. Fuel and emissions efficiencies of vehicle types based on manufacturer data (14).

(8). The former value is 55% and the latter is 76%, nearly five times greater than that of electric vehicles (8). This resulted in a total value of 42% efficiency. Therefore, we concluded that electric cars are three times as efficient as conventional fuel cars in their energy consumption. In total, the mass of carbon dioxide emitted per kilometer driven for a gasoline car is 193 g CO_2/km while for an electric car it is measured to be 49 g CO_2/km, which has a difference of 144 g CO_2/km **(Table 1)**.

Next, we predicted the number of gasoline vehicles and EVs in Canada in 2030 using the least-squares regression method. The least-squares regression line attempts to draw a line through the data that minimizes the distance between the line and other data points, i.e., it finds the line with the best fit. Since the progression of gasoline vehicles sales is observed to be closely linear, a polynomial regression algorithm which gives more emphasis to recent data would not be of much use. Therefore, we chose a linear regression algorithm to model the data. A prediction of total vehicles in Canada by 2030 yielded an approximation of 43 million **(Figure 1)**. Based on the data, we can infer that the total number of registered cars in Canada will increase constantly by 1 million each year.

We predicted the number of EVs in 2030 using an exponential regression method of analysis which was very accurate to model the non-linear nature of the data. We used an exponential regression model to predict the total EVs in 2030, which was 4.5 million with an R-squared correlation of 0.9789 and an R correlation of 0.9884. The formula to calculate the total EV sales in the Canadian market 'x' years after 2011 as calculated by the exponential regression model is as follows,

$$e^{7.185211} \times e^{0.4074x} = Total\ EV\ sales \quad \text{[Eq 2]}$$

In Equation 2 where we found the predicted number of vehicles, we predicted the number of EV sales with respect to the number of years after 2011. According to the model, the number of EVs sold in 2011 was approximately 1319 and exponentially increased over time after 2011 **(Figure 1)**.

The results indicated that Canada could not achieve a 45% reduction in the light vehicle industry, vehicles primarily used to transport passengers and cargo, in the time frame. The predicted emissions in 2030 calculated using the derived Equation 2 is 146 megatonnes which is far greater than the required 94.3 megatonnes required for there to be a 45% decrease in emissions in the transport industry.

Substituting the values in **Equation 2** provided us with the actual number of electric cars in the Canadian light vehicle market needed to reach its goals. To realistically reach the goal, a total of 38,730,034 cars in the Canadian vehicle market must be electric. The remaining 4,269,965 cars are allowed to be fuel-powered for the light vehicle sector to reach

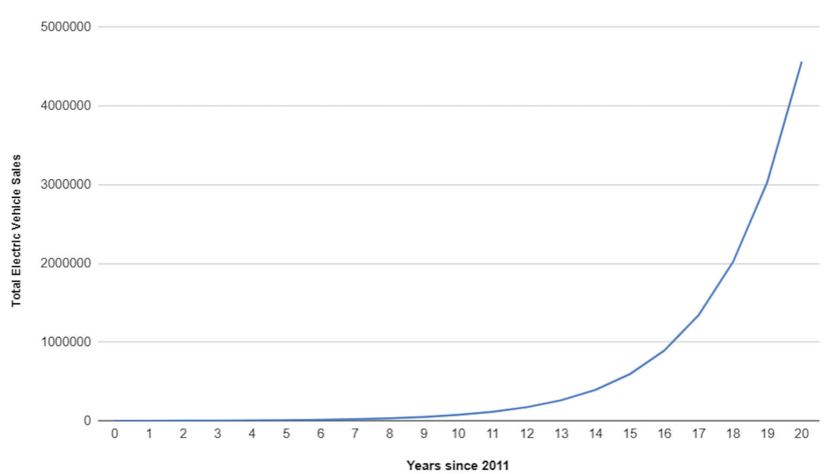

Figure 1: Total electric vehicle sales in Canada since 2011. Blue curve is modelled by an exponential model that represents the growth of Canadian EV sales x years after 2011. An exponential linear regression model was used on data from the Canadian government reporting Canadian EV sales to predict future growth in the Canadian market **(Equation 2)**. An R-squared accuracy of 0.98 was achieved using this model.

its goals of reduced emissions. Therefore, these results show the trajectory of greenhouse gas emissions in Canada, which shows the need for further investment in the Electric Vehicle Industry to fuel growth.

DISCUSSION

Calculation of the fuel emissions of EVs and gasoline vehicles did inform us of how EVs are far more efficient than conventional gasoline vehicles. However, to varying degrees, there were inbuilt factors which may have dictated the carbon efficiency of the vehicle, such as the type of car. For example, Sports Utility Vehicle (SUV) ZEVs are known to produce far more carbon emissions than regular ZEV sedans due to the size of the vehicle and the energy needed to propel the larger mass (9). The differences may not be substantial – therefore, we used a generalization of the EV industry. Comparing the two fuel sources, electric and gasoline, we found that EVs were far more efficient than gasoline vehicles, but this is not to say that EVs, despite being referred to as Zero Emission Vehicles, were without emissions. This is due to the ecological consequences of the extraction of the fuel source.

We determined **Equation 2** to have a 98% goodness-of-fit, which meant that the results could be safely interpreted and applied. We calculated that the efficiency of EVs was four times greater than that of conventional fuel vehicles. Additionally, a few possible avenues where an error could occur include the efficiency of vehicles over time. Since the efficiency of vehicle over time is not easily predicted, it could be possible that the amounts of emissions caused by gasoline vehicles reduces over time. Another source of error might be the differences in fuel efficiency in manuals and automatics since they are different. A potential source of error in regression algorithms is overfitting – adapting too closely to a particular set of data and not being able to apply knowledge from the dataset to new data.

However, therein lies possible measures the government can take to ensure even a marginal increase in efforts towards a 45% reduction in transport industry emissions. The first perspective we can analyze is the outlook from an industry subsidization standpoint through grant models. Research put forward by Gunther *et al.* states that models with a 25% grant on product value over a period of 10 years provide a substantial increase to the electrical vehicle market (10). For example, the same product model was utilized in China which yielded margins of over ten million units of EVs (11). Similarly, if the Canadian government were to enact similar policies which will protect the production costs of these vehicles, it will be a long measure to ensure the sustainability of this industry. Approximately 38 million vehicles must be electric to meet emissions targets, with only 4 million being conventional fuel source vehicles. While this may seem like a large figure, the growth of the EV market in Canada has been observed to be exponential **(Figure 1)**. Therefore, investments in this industry are crucial to sustaining progress towards emissions goals.

Therein also lies the factor of fuel economy, which is the amount of gasoline a vehicle consumes for the distance it travels. Since fuel economy is inversely related to the amount of CO_2 emitted, it would make sense to increase the fuel economy of a vehicle to reduce the amount of carbon dioxide emitted for the particular distance. There are various factors which affect the fuel economy of a vehicle, such as the speed of the vehicle as well as driver behavior (12). Over time, the fuel efficiency of passenger vehicles has been optimized, and within a certain respect, it has certainly become much more of an efficient mode of transport compared to the start of the century (13). Increasing the efficiency of these vehicles is pivotal to reducing overall greenhouse gas emissions from the industry despite the results not being promising. Since the rate of development of the technology in EVs is exponential, more customers are enticed to buy EVs over time. This factor alongside others such as government rebates incentivize people to buy them. If Canada chooses to ramp up its investments in the production of EVs and benefits offered to citizens for purchasing EVs, it will certainly observe tangible benefits that will help it reach its goals of carbon neutrality.

MATERIALS AND METHODS

We predicted the total cars registered by 2030 in line for national goals, using a linear regression algorithm. The data was analyzed using a machine learning library on Python known as scikit-learn. The reason for opting for a linear regression algorithm was because the slope was relatively linear for registered cars. As the production line for EVs experienced exponential growth from 2011, which is the earliest record of EV sales **(Figure 1)**, an exponential regression algorithm was utilized. The next step we took was to calculate the predicted number of registered cars in 2030, which, using the algorithm, was predicted to be about 43 million registered vehicles. Of the predicted 43 million, an approximate 4.356 million will be EVs. This is 10.46% of total vehicles.

The reason why the EVs were added and not subtracted from the predicted number of total vehicles is because the consumer demand is for the vehicle and not the specific type of vehicle. With prices of EVs expected to decrease, it is only natural for the percentage of fuel vehicles to decrease to keep up with the demand for vehicles.

To keep in line with the goal of a 45% reduction of total vehicle emissions in the heavy and light vehicle sector, we must measure the total optimized reduction in this regard. The following formulas present the emissions in the year from each kind of vehicle.

We predicted the number of gasoline vehicles by subtracting the number of EVs from total vehicles in the year 2030. We calculated the emissions for each kind of vehicle by multiplying the predicted number of vehicles of each type with the average emissions per kilometer and the average number of kilometers driven, as described by **Equation 3** and **Equation 4**. We then added the emissions for each type of vehicle to give the total estimated emissions in 2030.

$$\#\ of\ GV_{2030} \times Avg\ Emissions_{GV} \times Avg\ Annual\ Mileage = Total\ Emissions_{GV\ 2030} \quad \text{[Eq 3]}$$

$$\#\ of\ EV_{2030} \times Avg\ Emissions_{EV} \times Avg\ Annual\ Mileage = Total\ Emissions_{EV\ 2030} \quad \text{[Eq 4]}$$

The datapoints for the sales of EVs from the year 2011 to 2020 is exponential in nature **(Figure 1)**. This being the case, we had to choose between multiple regression algorithms which served the purpose of creating a line of best fit which most closely predicted the values in the dataset. Like before, this data was analyzed using models from the scikit-learn library on Python As the data has a non-linear curve, a model which predicts exponential or non-linear growth was best suited for the data. For that reason, we chose to adopt and compare the following algorithms to complement the data.

The reason the exponential model was chosen, and is arguably the most effective, was because the expansion of the EV market can only increase and never decrease. This removes the possibility of the algorithm predicting a reduction in size, thereby, making the model more accurate. The average rate of increase in the EV market in 2020 was 31,000 vehicles/year. This was calculated by calculating the derivative of the function used to model the EV market.

Among the models tested for accuracy purposes was a polynomial regression, XGBoost regression, and the exponential regression model. The polynomial regression model was not as effective as the exponential regression model since its tendency to predict depressions in its curve throws off the accuracy. The exponential model assigns a single consistent array of weights to data points ensuring which was more effective in this scenario. The XGBoost function used various optimization objectives to properly predict the nature of the data, including regression with squared loss, logistic regression, and regression with squared log loss. These functions optimize the learning parameters of the algorithm which allow it to properly adapt to the data. However, the data had a strict pattern which caused the predictions to be thrown off a little.

$$\text{Total Emissions}_{2030} = \text{Total Emissions}_{GV\ 2030} + \text{Total Emissions}_{EV\ 2030} \quad \text{[Eq 5]}$$

As described by **Equation 5**, adding these two values gave us the total emissions from the light transportation sector in 2030, which accounts for 19.55% of total emissions in Canada. In conclusion, at the current rate of increase in EV sales, Canada will not be able to reach its goal of a 45% reduction in emissions from the light vehicle sector. The data has a high level of accuracy evidenced by the R-Squared correlation of 0.98.

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