TEAM 1006

"How many tonnes of CO_2 emissions could be avoided in your lifetime if New Zealand transitions to a completely electric vehicle fleet?"

SUMMARY

Fully electric vehicles are a relatively new technology which allows for the elimination of all tailpipe emissions. They utilize the ability to store energy in rechargeable batteries which powers vehicles as an alternative to fossil fuel consumption. Petrol and diesel vehicles release tailpipe emissions which include carbon dioxide, a greenhouse gas. Direct tailpipe emissions from battery electric vehicles (BEVs) are significantly reduced by running cars on electricity. Consequently, direct carbon dioxide emissions are able to be reduced if BEVs replace all non-electric vehicles. However, carbon dioxide emissions will still occur throughout the production process and during electricity generation. For the purposes of this investigation, we consider electric vehicles as those which are fully electric and not hybrid.

Following this, we compared the total amount of CO_2 emission in tonnes if we were to continue in current trends (of population growth, vehicle ownership in population, distance travelled, and emissions per distance) with the emission of CO_2 for a complete fleet of electric vehicles in New Zealand over the remaining lifetime of an average 17 year-old New Zealander, as implied in the question phrasing "your lifetime", which we interpreted to be until 2082, as detailed below.

INTRODUCTION

To interpret this open-ended question, we must first specify definitions by making reasonable assumptions about its meaning and related terms. We have defined the timeframe of "your lifetime" to be the remaining lifespan of the average 17 year-old New Zealander. We understand from the wording of "How many tonnes of CO_2 emissions could be avoided" that we are expected to find the realistic maximum amount of emissions avoided possible. Since restrictions on budget are not specified, we are assuming we have a plentiful, but realistically limited, amount of money. Rather than defining a finite budget (which would require a significant portion of our report to be dedicated to cost-effectiveness, which would shift the focus from the purpose of the question) we have chosen to define our restrictions by what the money can be spent on, as follows: we will allow one-off spending on infrastructure required to sustain a fully electric vehicle fleet (new power plants to meet the increase in energy consumption, charging stations, etc), but we will avoid interfering with the vehicle market (it would be all too easy to simply say "the government will buy electric cars for all New Zealanders and so New Zealand will have a fully electric vehicle fleet immediately").

To transition to a fully electric vehicle fleet in the fastest and most realistic way, we are assuming the New Zealand government will introduce an immediate ban on the sale of non-electric vehicles. We have also recognised that achieving a 100% electric vehicle fleet is unrealistic considering the given timeframe - though we expect that the large majority of non-electric vehicles to be replaced relatively quickly, the last remaining vehicles may take a far longer (and less easily restricted) amount of time to be replaced. Due to this observation, we have defined "fully electric vehicle fleet" as at least 99% of vehicles operating entirely on electricity. We have defined the term "vehicle" as "a means of carrying or transporting something"[1] and specifically to New Zealand roads, NZTA's[2] classification of passenger vehicles of class category 'M' as opposed to including the L and N categories which refer to motorcycles/mopeds and goods vehicles, respectively. Due to limitations of data available and technology to replace these less common transportation vehicles, we did not account for these in our calculations.

To calculate the number of tonnes of CO_2 emission New Zealand can avoid in this timeframe we need to consider the amount of CO_2 which would be emitted following current trends in vehicles per capita, population growth, and average CO_2 emissions per car. We must then consider the amount of carbon emissions which would be produced if New Zealand transitions to a fully electric vehicle fleet. We will make similar models as for the current timeline, assuming that all variables stay constant with the exception of the percentage of electric vehicles and, as a result, the average CO_2 emissions per vehicle. By extrapolating historical data, we are able to model expected population growth, increased vehicle numbers and carbon dioxide emissions.

In general, tonnes of CO_2 emissions avoided = current extrapolation - future prediction

CALCULATION FOR LIFE EXPECTANCY

Due to the wording of the question, we defined lifetime in terms of life expectancy. Life expectancy is an age-specific measure of average length of life left.[3] Our timeline is based on the remaining lifespan of a 17 year old living in New Zealand, under the assumption that the question is directed towards the average NZESC contestant. The majority of contestants in previous years were Year 12 and 13 and hence 17 was the chosen average age. Based on data from 2012-14[4] by gender, we have calculated an average life expectancy of 81.33 years. We are assuming that life expectancy is based off currently available data and does not change with the expected development of new technology. We cannot predict the rate of technological development, so all predictions are limited to the socio-economic factors relating to the period of

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[1] Merriam-Webster 2018 https://www.merriam-webster.com/dictionary/vehicle

[2] NZ Transport Agency https://www.nzta.government.nz/vehicles/vehicle-types/vehicle-classes-and-standards/vehicle-classes/

[3] Statistics New Zealand http://archive.stats.government.nz/browse_for_stats/snapshots-of-nz/nz-social-indicators/Home/Health/life-expectancy.aspx

[4] Statistics New Zealand https://www.stats.government.nz/topics/life-expectancy

the data used. The life expectancy used to calculate a timeframe is based on the assumption that life expectancy will stay constant, or relatively similar, throughout the entire period. The broad nature of the question has prompted us to assume that the transition into a fully electric vehicle fleet will begin over the remaining life expectancy of an average New Zealander who has already lived 17 years. Therefore, our transition will occur over a timeline of 64 years until 2082.

Average life expectancy= (Male+Female)/2 = (79.48+83.19)/2 = 81.335 years
Remaining: 81.335-17 = 64.335 years
Therefore, projections over a lifetime of 64 years will be until 2082.

CURRENT TREND

We are looking at how many tonnes of CO_2 emissions we can avoid, so we need a prediction of how many tonnes of CO_2 we are producing at our current rate. By tabulating and modelling latest data, we are able to extrapolate and extend the graph to produce an estimate for an amount of CO_2 emissions for the year of 2082. Our model produced a line of best fit which gave an mathematical equation showing the relationship between carbon dioxide emissions against year. The predicted cumulative value for 2082 will later be compared with the 2082 value for fully electric vehicle emissions.

DISCUSSION

EXPECTED CARBON EMISSIONS FOR CURRENT TIMELINE

We will model New Zealand's projected carbon emissions from vehicle usage (excluding production and disposal) for the next 64 years by projecting the number of cars per capita and New Zealand's population.

CALCULATION FOR POPULATION

We created a model that would be able to give us a projection of the population level until 2082 using data from Statistics NZ[5]. Given that the rate of population appears to be decreasing (i.e. the data appears to be fitting a curve that will be concave down), a logarithmic model was used to approximate the population. While noting that a logistic curve is typically used to model population growth, the complexity of such a model coupled with the relatively short time frame that our model is looking at means that a logarithmic model will be a fair approximation.

This gives us a model for the population of New Zealand at any given time to be

$$9.4407 * 10^7 * ln(y) - 7.1371 * 10^8 = p(y)$$

(Where p is the population and y is the year)

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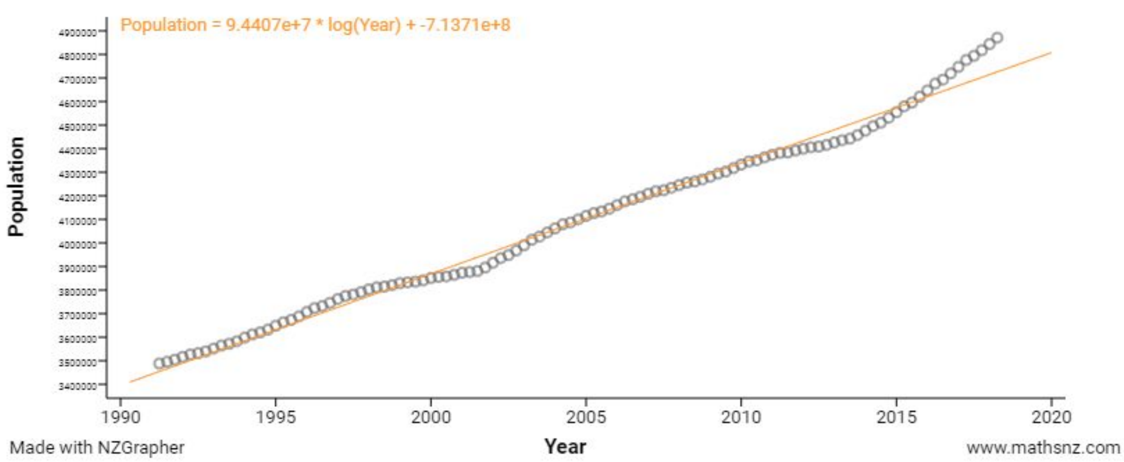
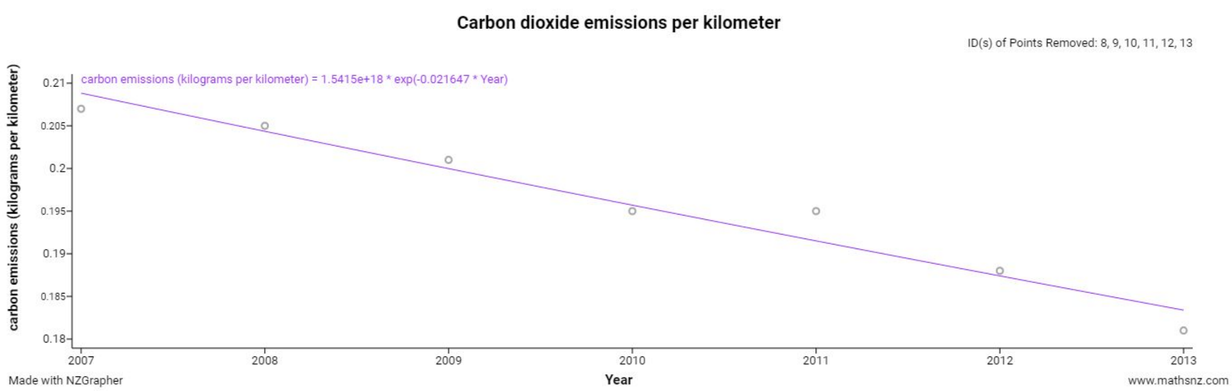
[5] Statistics New Zealand https://www.stats.government.nz/topics/population



CALCULATION FOR CARBON DIOXIDE EMISSION
A projection for the data on emissions (in kilograms) per kilogram in a year was then found according to data on NZTA[6]. The general trend shows an decrease and hence fitted with an exponential model with equation $\frac{\varepsilon}{d}(y) = 1.5415 * 10^{18} * e^{(-0.021647y)}$ where y is the year and ε is emission in kilograms per kilometer.



CALCULATION FOR DISTANCE PER VEHICLE [7]
For each vehicle, the number of kilometers it travels in a year should also be considered, and since the number of cars per capita is increasing in general this value decreases over time. With data from the Ministry of Transport[8], we then proceeded to medel this with an exponential curve

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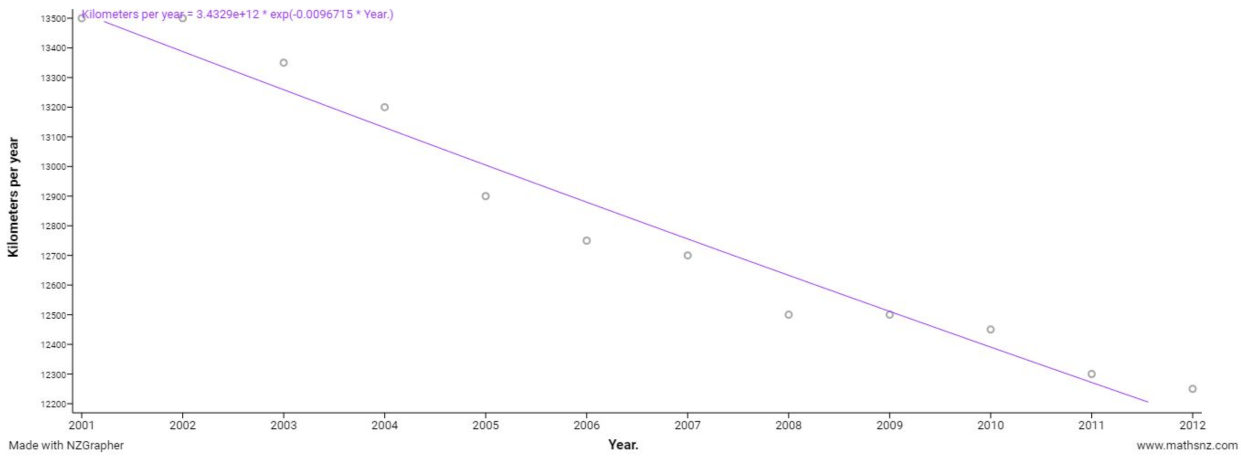
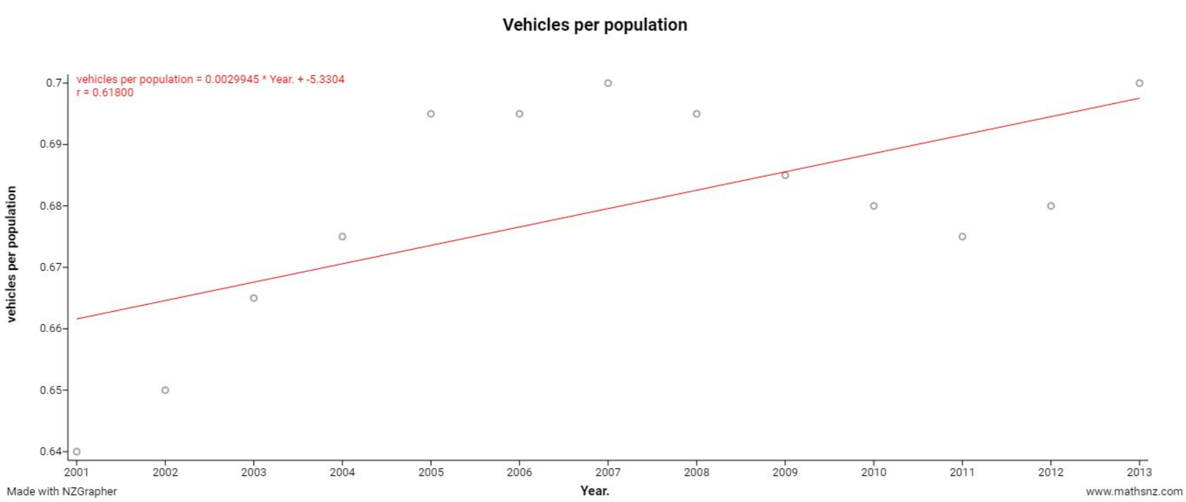
[6] Ministry of Transport 2016
https://www.transport.government.nz/assets/Uploads/Research/Documents/Fleet-reports/The-NZ-Vehicle-Fleet-2016-web.pdf
[7] ibid
[8] ibid

with equation $\frac{d}{c}(y) = 3.4329 * 10^{12} * e^{(-0.0096715y)}$ where y is year and d/c is the distance travelled per vehicle in kilometers.



VEHICLES PER PERSON

Using the data on vehicles per 1000 population available from the Ministry of Transport[9], we can approximate a model with the equation c(y) = $0.0029945 * y - 5.3304\ - 0.022cos(2\pi y/11 - 5.5)$. This model was derived by analysing the increasing general trend line and then implementing a sinusoidal graph based on analysis of the residuals.



CO_2 EMISSIONS BY 2082 ACCORDING TO CURRENT TRENDS

This can be found using the carbon dioxide emissions per kilometer travelled, average kilometers travelled per car, population and cars per population and integrating across the time period of our lifespan.

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[9] ibid

$$\varepsilon(y) = \frac{\varepsilon}{d}(y) * \frac{d}{c}(y) * \frac{c}{p}(y) * p(y)$$

That is, that the amount of carbon dioxide emissions in kilograms as a function of the year, ε(y) can be given as the product of four functions all dependent on the year. These functions are the emissions per distance (which changes due to increasing efficiency of vehicles) - $\frac{\varepsilon}{d}(y)$, distance per vehicle $\frac{d}{c}(y)$, which decreases due to the increase in the number of cars, the amount of cars per capita $\frac{c}{p}(y)$, which can be modelled as increasing but having seasonal sinusoidal variations, and p(y), which has been modelled by a logarithmic approximation of the second half of a logistic function. The given value will be in kilograms and should be converted to tonnes.

Given the equations found:

$$p(y) = 9.4407 * 10^7 * ln(y) - 7.1371 * 10^8$$
$$\frac{\varepsilon}{d}(y) = 1.5415 * 10^{18} * e^{(-0.021647y)}$$
$$\frac{d}{c}(y) = 3.4329 * 10^{12} * e^{(-0.0096715y)}$$
$$\frac{c}{p}(y) = 0.0029945 * y - 5.3304 - 0.022cos(2\pi y/11 - 5.5)$$

Substituting these equations,

$$\varepsilon(y) = (9.4407 * 10^7 * ln(y) - 7.1371 * 10^8)(1.5415 * 10^{18} * e^{(-0.021647y)})$$
$$(3.4329 * 10^{12} * e^{(-0.0096715y)})(0.0029945 * y - 5.3304 - 0.022cos((2\pi y/11) - 5.5)$$

In order to find the total emission of carbon dioxide in our defined lifetime, we should find the area under this curve by definite integration:

$$\int_{2018}^{2082} \varepsilon(y)\, dy = \int_{2018}^{2082} [(9.4407 * 10^7 * ln(y) - 7.1371 * 10^8)(1.5415 * 10^{18} * e^{(-0.021647y)})$$
$$(3.4329 * 10^{12} * e^{(-0.0096715y)})(0.0029945 * y - 5.3304 - 0.022cos((2\pi y/11) - 5.5)]\, dy$$
$$= 2.34501341526809 * 10^{11} = 2.345 * 10^8 \text{ tonnes}$$

Note that due to the large nature of this equation, a software-based numerical integration tool was utilised.

EXPECTED CARBON EMISSIONS FOR SALE BAN TIMELINE

According to the trend of global vehicle sales, it may be possible for New Zealand to transition sales of only electrical vehicles similarly to the plans of the Netherlands (2025), France (2040) and Norway (2030) [10]. If New Zealand were to take action as of 4th August 2018 and ban all non-electric vehicles immediately, and assuming that New Zealand has a similar rate of replacement of vehicles as the United States of around 21% annually[11], and given that EV make up approximately 1% of the total New Zealand vehicle fleet today[12], it can be estimated that the proportion of non EV vehicles for a given year after 2018 can be modelled by an expression of

$$0.79^{y-2018} - 0.01$$

And likewise, the proportion of EV vehicles for a given year after 2018 can be modelled by

$$1.01 - 0.79^{y-2018}$$

Where y is the year. Note that 0.01 and 1.01 are used in order to compensate for the fact that 1% of the current vehicle fleet in the country is electric. Further note that given that this is a power function, it is inherently asymptotic, and as such, it is impossible to achieve a situation where 100% of New Zealand's vehicle fleet is replaced. This is a realistic factor, as it would be impossible to remove all non EV simply by banning the sales of EV, as some non EV will always continue to be maintained.

Following this, we now create a new function ζ(y) that describes the emissions should this ban be put in place. By comparing the definite integrals between 2082 and 2018 of ζ(y) with ε(y), we will be able to derive a number for the amount of CO_2 emissions reduced in our lifetime by such a ban.

We now hold the assumptions that even with the introduction of this ban, the distance travelled per car, the cars per capita and the population growth functions will remain the same. As a result, the only difference will be the emissions per distance travelled, or ζ/d(y). In order to calculate this, several new functions and assumptions were required.

Firstly, given that electric vehicles made up such a small number of the initial vehicle fleet (>1%), we assumed that the ε/d(y) for the entire vehicle fleet was equivalent to the emissions per unit distance as a function of the year for non EV, as the effect of EV on this function was thought to be negligible. This was done because of the significant difficulty in sourcing information regarding the emissions of only non EV.

Secondly, through research, we found that the Nissan Leaf was the most common fully electric car in New Zealand, constituting 61.35% of all electric cars in New Zealand[13]. Because of this,

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[10] Alanna Petroff 2017 https://money.cnn.com/2017/07/26/autos/countries-that-are-banning-gas-cars-for-electric/index.html

[11] Horst Stipp (2018) https://www.statista.com/statistics/250351/replacement-rate-for-cars-in-the-us/

[12] NZTA, (2018) https://www.nzta.government.nz/resources/new-zealand-motor-vehicle-register-statistics/national-vehicle-fleet-status/

[13] Sigurd Magnusson, 2017, http://www.gw.government.nz/assets/NZ-Electric-Car-Guide-4April2017.pdf

we assumed the Nissan Leaf's rate of energy consumption of 0.1744 kWh/km[14] to be a fair estimate of the energy consumption for an average EV.

On the assumption that the average electric vehicle requires 0.1744 kWh/km to run, we then used data from the Ministry of Business and Innovation and Employment to break down this 0.1744kWh based on the percentage shares of capacity for energy creation in New Zealand for 2014[15]; that is : 54% hydro, 20% gas, 10% geothermal, 7% wind, 6% coal, 2% oil and 1% solar. By combining this with data from the Intergovernmental Panel on Climate Change[16] that details the median amount of CO_2 emissions from each source of energy generation, (Hydro - 0.024kg/kWh, Gas - 0.49kg/kWh, Geothermal - 0.038kg/kWh, Wind - 0.011kg/kWh, Coal - 0.820kg/kWh, Oil - 0.49kg/kWh, Solar - 0.027/kWh), and by running the appropriate calculations (ie multiplying 0.1744 by the percentage than the quantity of CO_2 emissions for each method of energy production, then adding them together, it can be calculated that an average kilometre for an electric vehicle will produce 0.03048512kg of CO_2.

As such, the function for the emissions for an average car per kilometer travelled should the ban be in place, ζ/d(y), can be given as the proportion of non EV * ε/d(y) + the proportion of EV * 0.03048512, or

$$\frac{\zeta}{d}(y) = (0.79^{y-2018} - 0.01)(1.5415 * 10^{18} * e^{(-0.021647y)}) + (1.01 - 0.79^{y-2018})(0.03048512)$$

As done above for ε(t), ζ(y) can now similarly be described as

$$\zeta(y) = \frac{\zeta}{d}(y) * \frac{d}{c}(y) * \frac{c}{p}(y) * p(y)$$

$$\zeta(y) = ((0.79^{y-2018} - 0.01)(1.5415 * 10^{18} * e^{(-0.021647y)}) + (1.01 - 0.79^{y-2018})(0.03048512))$$
$$(9.4407 * 10^{7} * ln(y) - 7.1371 * 10^{8})(3.4329 * 10^{12} * e^{(-0.0096715y)})$$
$$(0.0029945 * y - 5.3304 - 0.022cos((2\pi y/11) - 5.5)$$

By similarly integrating this definitely between 2082 and 2018, we can then derive the amount of CO_2, in kg, that can be expected to be emitted in that time.

$$\int_{2018}^{2082} \zeta(y)\, dy = 2.58146527372881 * 10^{10} kg$$

Note that because of the complexity of this function, the software struggled to integrate this function. Given the oscillating nature of the cos section of the function, it was omitted from the

[14] Fuel Economy, 2018
https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=39860
[15] MBIE, 2014
http://www.mbie.government.nz/info-services/sectors-industries/energy/energy-data-modelling/publications/energy-in-new-zealand/previous-editions/Energy-in-New-Zealand-2014.pdf/view
[16] Steffen Shlomer *et al*, 2014, https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_annex-iii.pdf

calculation; we estimate that the potential error from numerical integration is likely to be a far greater factor than the error from this omission.

CONCLUSION

Our predicted estimate for the reduction in carbon dioxide, given as the difference between the definite integrals of ε(y) and ζ(y) between 2082 and 2018, is $2.09*10^{11}$ kg, or **$2.09*10^{8}$ tonnes** if New Zealand was to convert to electrical vehicles.

EVALUATION OF ASSUMPTIONS AND LIMITATIONS

Our calculations are limited to our knowledge of the advancement of technology in the decades to come. Due to the difficulty of predicting any futuristic level of innovation, we have decided to limit our investigation to the current level of technology.

ASSUMPTIONS:

- "Your lifetime" is the remaining lifespan of an average 17 year-old New Zealander, based on current life expectancy data
- NZ government will immediately introduce a ban on non-electric vehicles as of 2018
- NZ government will not interfere with the vehicle market in any other way (i.e no subsidies or monetary contributions)
- NZ government will provide the money required to build the necessary infrastructure to support a fully electric vehicle fleet (i.e power plants, charging stations)
- The rate of population growth and vehicle numbers follow the historical trends
- We must assume that the demand of electric vehicles in New Zealand if we were to transition to a completely electric fleet can be met by international suppliers at an unfailing rate.
- As it is incredibly difficult to predict the shares of energy generation in the future, despite pledges like the Government's 2030 100% renewable energy target, we have elected to assume that the percentage shares of the respective methods of energy generation will remain constant and can keep up with the demand for power of a completely electrical vehicle fleet.[17]
- As the Nissan Leaf is the most common electrical vehicle in New Zealand[18], we have based our calculations on one model. In this way, we reduce the complexity of our model, allowing us to generate a useful approximation with the available resources.

[17] Ministry of Business, Innovation and Employment 2017
http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/publications/energy-in-new-zealand

[18] Sigurd Magnusson (2017)
https://www.hbrc.government.nz/assets/Document-Library/Fact-Sheets/NZ-Electric-Car-Guide-4Aug2017.pdf

LIMITATIONS:

- Because electric vehicles are a relatively recent technology, attempting to predict future improvements in efficiency are likely to be very inaccurate. We have therefore chosen to assume that electric vehicles used in New Zealand for the given timeframe will remain constant. Although this is very unlikely, the relatively short time frame reduces the inaccuracy of this assumption.
- According to EHINZ[19], light vehicles made up 91% of the motor vehicles in 2015. Due to limited information available on other types of vehicles and seeing as light vehicles are a large majority of the entirety, we decided to focus purely on this component.
- We have not taken into account the differences in carbon dioxide emissions of production of electric and non-electric vehicles, due to lithium-ion battery production for EVs. However, it is likely that improvements in technology will increase the lifespan of batteries, which would mean that the effects of the differences in emissions would not have a very significant impact.

[19] Massey University (2017)
http://www.ehinz.ac.nz/assets/Factsheets/Released-2017/EHI8-9-NumberOfVehiclesInNZ2000-2015-release-201701.pdf