Team: 1101

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

Introduction

Given that the question open-ended we have defined some of the key terms in order to give a more specific and detailed answer.

"Lifetime" - To calculate the time in 'your lifetime', as the question had suggested, we took the median of the years of the birth of the four members of our team.

The median of 2000, 2001, 2001 and 2002 is 2001. Additionally, 2001 was a census year so it allowed for the most accurate estimations regarding life expectancy.

We used the life expectancy calculator from Stats New Zealand[1], which suggested that if you were born in 2001, 17, and Male (all of our team members are male), then you can expect to live to 89.7 years, assuming medium death rates. We chose the medium death rates figure as a study from ADA University, Azerbaijan deduced that there was not a causal relationship between CO_2 emissions and life expectancy at birth[2], therefore the next best alternative was to take the middle value (medium death rates), which

	A	B	C
1	**How long will I live?**		
2			
3	**To find out how long you'll live, enter your:**		
4			
5	Year you were born in:	2001	
6	Age (nearest birthday):	17	
7	Sex:	Male	
8			
9	**You can expect to live to:**		
10		**91.9**	years (assuming low death rates)
11		**89.7**	years (assuming medium death rates)
12		**87.1**	years (assuming high death rates)
13			
14	**Note:**		
15	1.Life expectancy indicates the average length of life. It does not indicate how long a specific individual will live. An		
16	individual's life expectancy can be affected by events such as accidents, epidemics, and wars, as well as experiences		
17	during their life (eg smoking, diet, environment). Life expectancy will also vary by ethnicity and socioeconomic position.		
18	2. For the calculation to work please click 'enable content' at the top of the page.		
19			
20	**Source:**		
21	Stats NZ, complete cohort life tables 1876–2016 (updated March 2018)		
22	and national population projections 2016(base)–2068, mortality assumptions (published October 2016).		

was 89.7 years. 89.7 years from 2001 means that it is expected that our lifetime will last from 2001 until 2091 sometime. Since we cannot undo any CO_2 emissions from the past, we will only look at CO_2 emissions avoided from 2018-2091

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1 http://archive.stats.govt.nz/browse_for_stats/health/life_expectancy/how-long-will-I-live.aspx

2 http://www.academia.edu/35759393/The_Relationship_Between_Life_Expectancy_at_Birth_and_CO2_Emissions

"Transition" - In this situation, a transition is a development from one stage to another over any period of time. Thus this would be the transition of any vehicle to an electric vehicle using a realistic process that reflects the New Zealand government and public opinion. This may vary for different types of transport.[3]

"Vehicle fleet" - Is a mode of transport that can be mass spread out throughout New Zealand in order to replace previous modes of transport.[4]

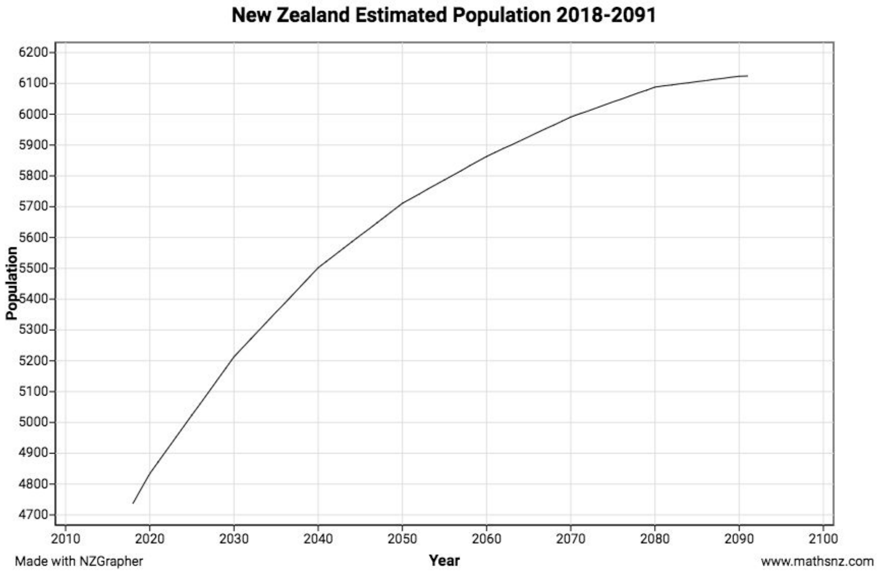
"Electric vehicle" - An electric vehicle is a type of vehicle that uses either an electric motor or cables to draw current to power the vehicle. This means that other vehicle and transport types other than cars need to be taken into the transition.

In order to answer the given question we will evaluate each of the vehicle types: Cars/ Road Vehicles, Planes, Boats and Trains.

Population Prediction

We used the United Nations, Department of Economic and Social Affairs - Population Division - World Population Prospects, the 2017 Revision[5] to estimate populations until 2091. Since the estimations were separated into decennial allotments of population, we took the total change of population over that decade and had a constant rate of growth from year to year for the years that weren't included. For example, there was an estimated population growth of 289,000 people between 2030 and 2040 (5.213m to 5.502m people), so we let all years between 2030 and 2040 exclusive have an estimated population growth of 28,900.

[3] https://www.merriam-webster.com/dictionary/transition
[4] https://dictionary.reverso.net/english-definition/vehicle+fleet
[5] https://esa.un.org/unpd/wpp/DVD/



This graph here gave us the equation for population over time.

Road Vehicles

There are approximately 4,000,000 road vehicles[6] in New Zealand with only 0.5% of these being hybrid or electric cars. As it is unknown how many of these hybrids could be considered purely electric cars, and because the percentage is already so small, for the purpose of the transition it is fair to assume that there are still around 4,000,000 road vehicles that run off fossil fuels. However, within this group, there are: 3,000,000 light vehicles, 650,000 diesel light vehicles and 150,000 heavy trucks and buses that also use diesel. At this current amount, each light vehicle produces 4.6 tonnes of CO_2 per year.[7] This figure was only for light vehicles, but as 4% of road vehicles are motor bikes and these use less fuel and another 4% of vehicles are trucks and buses that use more fuel than this.

We can thus assume that their emissions will continue to average near 4.6 tonnes of CO_2 per year and we can use this number for all road vehicles. If we then analyse the population growth over time and the cars per 1000 population we can calculate how the amount of cars will change over time. Developed countries are reaching peak 'car' per capita, a study by Auto experts say[8]. In 2018, there are 840 road vehicles per 1000 people in New Zealand. Therefore, based on the peak car research, we can assume that the road vehicles per capita in New Zealand will remain relatively constant at 840 per 1000 people.

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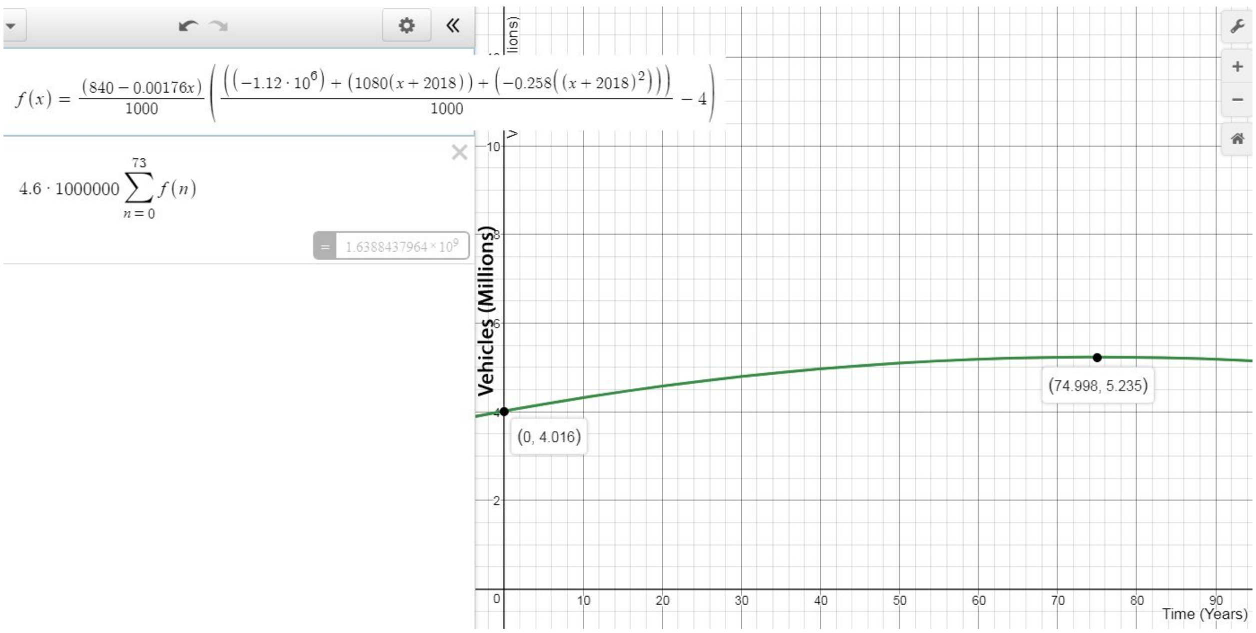
[6] https://www.transport.govt.nz/assets/Uploads/Research/Documents/NZ-Vehicle-fleet-fact-and-fiction-2017.pdf
[7] https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle
[8] https://www.schroders.com/ru/sysglobalassets/digital/insights/pdfs/m-the-end-of-the-road.pdf

The amount of electric vehicles as a proportion of this 840 is increasing, and will continue to increase. In 2015 the proportion was 0.05%, with a linear increase to 4.9% in 2040 forecasted[9].
This is using the medium uptake projection, as the variables influencing whether or not a low or high projection are unknown - and thus the medium uptake is the best assumption to make based on no evidence either way. We assume that this linear increase will remain constant until 2091, as there is no research to suggest the trend will change. Therefore, by 2091 there will be approx. 14.9% of road vehicles being electric in New Zealand, with a 0.196% increase per year since 2015.

Now we can use the population graph and this information to create a graph of the amount of cars over time that will still use fossil fuels without any push towards electric cars. By then summing the amount of cars over the average life span from 2018 and multiplying the amount of CO2 produced by the average car we obtain a total CO2 production due to running cars of 1.6388437964×10^9 tonnes.

(Using https://www.desmos.com/calculator)



Manufacturing Cars (Electric vs non-electric)

Producing an electric car and a non-electric car requires almost identical energy, except that electric cars require a battery to be produced for the car. TNO, a Dutch organisation, investigated five different studies from 2008-2013 on holistic CO_2 use in producing car batteries for electric cars, and found that about 150kg of Carbon Dioxide are emitted per kilowatt hour of battery capacity in producing such

9 http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/modelling/electricity-demand-and-generation-scenarios/documents-image-library/electric-vehicle-model.pdf

batteries.[10] Given that an average electric car battery's capacity, as given by the TNO, is about 60kWh, this means it takes about 9 metric tons of CO_2 to produce one battery. That is Amount=9000kg CO_2 Both electric and non electric cars require about 8.5tons of CO_2 emissions for development of the car (without the battery for the electric car).[10] These are the same so they negate each other's effects. Also, we must account for the difference in emissions between gathering fuel for non-electric cars vs generating electricity for electric cars to run on. In New Zealand, approximately 0.167kg of CO_2 are emitted to produce 1 kWh of electricity[11]. Hence, given that a New Zealand car life is 14.3 years[12], and that *"On average, New Zealand men drive just over **12,000 km** per driver per year, while women on average drive just over **8,000 km** per driver per year,"*[13] we average these to 10,000km per year per car, so a car has a lifetime mileage of 14.3years*10,000km/year=143,000km. Now, the amount of energy required for a Nissan Leaf to travel 160km is 34kWh[14]. We assumed that the average electric car had a 60kWh battery which is twice that of a Nissan Leaf, so we double this to 68kWh/160km for our average car. Therefore, the amount of CO_2 given off due to the production of electricity in one electric car's lifetime is Amount=d*(E/d)*(Amount/E)

=143000km*68kWh/160km*0.167kg/Kwh

=10100 kg CO_2 (3s.f)

Combining for total (unique - i.e. not similar to non-electric) emissions of one electric car in its production and lifetime, we get

EMISSION=19100kg CO_2

=19.1tonnes CO_2 (per car)

The Road Vehicle Transition

The United Kingdom is to ban petrol based cars by 2040, switching to instead electric cars[15]. It seems realistic for New Zealand to undergo a similar process if transitioning to only an electric vehicle fleet. Other OECD countries have made a similar pledge, and so we propose that New Zealand will also makes this pledge in their transition to an all electric vehicle fleet. We propose this will involve a ban on all road vehicles other than completely electric vehicles. We propose this ban be announced today, on 4/08/18.

UK experts predict the uptake of electric vehicles will follow a logistic curve[16], as new technology regularly does when becoming available on the market. It is safe to assume both NZ and the UK will follow such a curve, as both countries have free car markets and thus will follow such an economical

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10 https://thecorrespondent.com/7056/why-electric-cars-are-always-green-and-how-they-could-get-greener/741917761200-afaa6e5d

11 https://www.ipcc.ch/pdf/special-reports/sroc/Tables/t0305.pdf

12 http://www.ehinz.ac.nz/assets/Factsheets/Released-2015/EHI10-11-AverageAgeOfVehicleFleetInNZ2000-2014.pdf

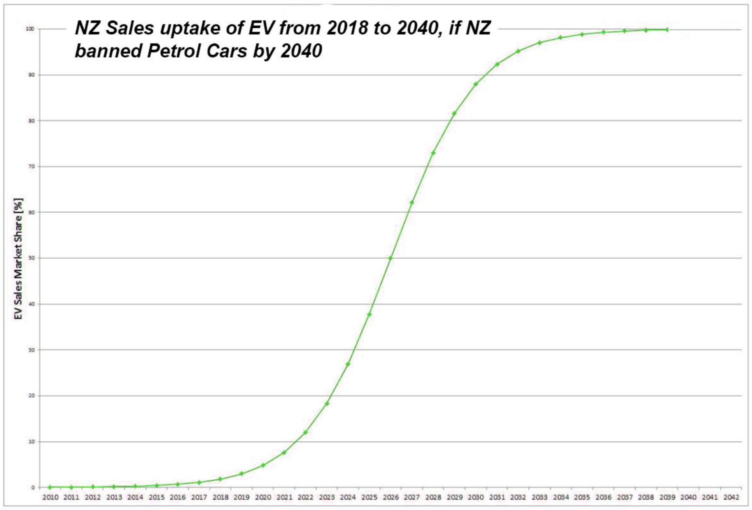
13 https://www.transport.govt.nz/assets/Uploads/Research/Documents/Drivers-2014-y911-Final-v3.pdf

14 https://www.greencarreports.com/news/1082737_electric-car-efficiency-forget-mpge-it-should-be-miles-kwh

15 https://www.nytimes.com/2017/07/26/world/europe/uk-diesel-petrol-emissions.html

16 http://myrenaultzoe.com/index.php/2014/04/how-and-when-will-electric-cars-replace-fossil-fuelled-cars-part-2/

pattern. We can assume that both curves for New Zealand and the UK will have the same steepness, as they both have very similar



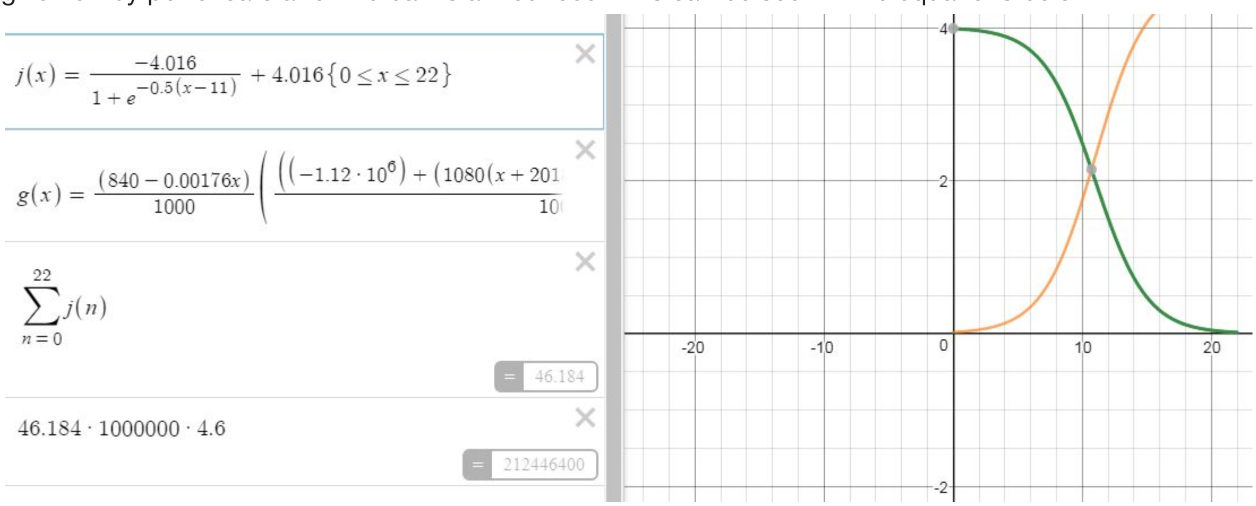
Assuming the curve is the same steepness as that which was found for the UK. Then the sales uptake curve can be found.

This is based on the curve modelled by *T. Larkum*[17], with an equation of:

$$y = \frac{100}{1 + e^{-0.5(x-25)}}$$

Due to the curved nature of the EV uptake, there will be CO_2 emissions given off even after petrol cars will be announced to be banned, until the entire road vehicle fleet is electric.

Translating this logistic curve to model the amount of petrol cars enables us to find the amount of CO_2 given off by petrol cars after the ban is announced. This can be seen in the equations below.



Thus, the amount of CO_2 given off by operating road vehicles after a ban is announced and the transition begins is 212446400 tons of CO_2.

[17] http://myrenaultzoe.com/index.php/2014/04/how-and-when-will-electric-cars-replace-fossil-fuelled-cars-part-2/

Planes and Boats

The Oxford definition of a vehicle is *"A thing used for transporting people or goods, especially on **land,** such as a car, lorry, or cart."*[18] Based on this definition, we interpreted planes and boats not to be vehicles, as they are primarily operated on either air or water, rather than land. Additional to this, a 2017 NZ Government report on *"NZ Vehicle Fleet"*[19] didn't mention these modes of transport at all.

Aside from the definition of a vehicle, the question strongly implies that NZ will be converting all possible vehicles to electric. Numerous articles have discussed, however, that with current technological and scientific knowledge, electric planes are impractical. The LA Times reports that *"The jet fuel capacity of a Boeing 787 Dreamliner is about 223,000 pounds, according to an airport planning document released in December. The estimated weight of a battery pack with equivalent energy would be 4.5 million pounds…."*[20 21] From this we can gather that battery use in planes is quite impractical, considering that the maximum takeoff weight for such a Boeing 787 is about 500,000 pounds[22], so the battery would be 800% too heavy for the plane! Hence, using current electrical technology, it is very unlikely that enough New Zealand air-vehicles will be transitioning to electric within our lifetime to have any significant effect on Carbon Dioxide emissions.

Based on these definitions and reports, we have decided to exclude boats and planes from the NZ Vehicle fleet in our investigation.

Trains (which are vehicles which transport goods and peopl)

In 2015, 155 kilo-tons of CO_2 equivalent was emitted by rail vehicles in New Zealand[23] from 148 diesel using trains[24]. According to the US rail system, their diesel locomotives emit approx. 47437000 tonnes of CO_2. The other emissions are so small in comparison I am assuming them to be negligible. The only trains which emit CO_2 in New Zealand are also Diesel locomotives. Therefore, using the US rail system as a model we can see that approx. 100% of the emissions from trains in New Zealand will be CO_2. Therefore, in 2015 approx. 155Kt of CO_2 was emitted by rail vehicles.

According to the Ministry of Transport, the growth of rail freight is expected to be 100% by 2040 in terms of tonne-kms of freight. This freight will influence the amount of train trips, and therefore the amount of CO_2 emissions per year by rail vehicles. We can assume this would double the amount of trips and thus double the amount of CO_2 emissions as the freight is doubled. After graphing a possible graph with these points we can find that 25,000,000 tonnes of CO_2 will be emitted from now until 2091. This means that if 148 new electric trains were built with renewable energy to replace the existing ones, 25,000,000 less tonnes of CO_2 would be emitted.

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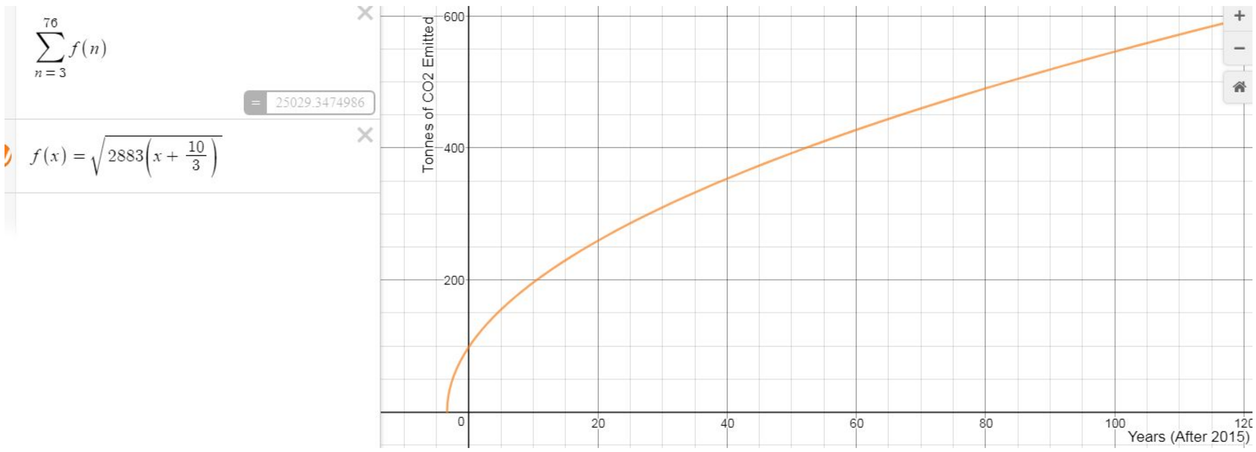
18 https://en.oxforddictionaries.com/definition/vehicle
19 https://www.transport.govt.nz/assets/Uploads/Research/Documents/NZ-Vehicle-fleet-fact-and-fiction-2017.pdf
20 http://www.latimes.com/business/la-fi-electric-aircraft-20160830-snap-story.html#
21 http://www.boeing.com/assets/pdf/commercial/airports/acaps/787.pdf
22 http://www.modernairliners.com/boeing-787-dreamliner/boeing-787-dreamliner-specs/
23 https://www.transport.govt.nz/resources/tmif/environmental/ei001/
24 https://en.wikipedia.org/wiki/Locomotives_of_New_Zealand



Importing Electric Cars

To calculate the CO_2 emissions from importing electric cars into New Zealand, we first had to calculate from what area the electric cars would be coming from. Assuming that the proportion of New Zealand imports of vehicles will stay the same as gas-powered cars, we took the proportion of imports from each area of the world from New Zealand's 2016 imports[25]and therefore were able to begin calculating the CO_2 emissions of imports. Since we decided to exclude boats due to our definition of vehicles, there will still be CO_2 emissions from moving the vehicles to New Zealand. We calculated then that 59.4% of vehicles would be imported from Asia, 31% from Europe and 9.6% from the United States.

We then had to calculate how many vehicles would be imported into New Zealand over this time period. This is not as simple as it first appears, as people tend to replace their cars, and not every electric car (if any at all) which is purchased in 2018 will still remain in the fleet until 2091. The average age of vehicles in New Zealand currently is 14.3 years[26], so we decided to make the assumption that there would be cars replaced on a constant scale, with a full rotation occurring eventually over 14.3 years. We then decided to take an average of electric cars per year in New Zealand, and multiply that by 73 (years remaining in lifetime) divided by 14.3, which is the approximate amount of rotations of new cars in New Zealand. Do calculate this, we had to find sums of the formulae in our piecewise function. We set n=27 as we made an assumption that the majority of people would keep their new electric car for approximately 5 years (after 2040) before replacing it.

$$\sum_{n=27}^{73} \frac{840-0.00176n}{1000}\left(\frac{-1.12\cdot 10^{6}+1080(n+2018)-0.258(n+2018)^{2}}{1000}-4\right)-0.111=232.56709.$$

$$\sum_{n=0}^{27} \frac{4.626}{1+e^{-0.5(n-11)}} = \frac{4.626}{e+1} + 75.05817\ldots$$

[25] http://archive.stats.govt.nz/browse_for_stats/industry_sectors/imports_and_exports/GoodsServicesTradeCountry_MRYeDec16.aspx

[26] http://www.ehinz.ac.nz/assets/Factsheets/Released-2015/EHI10-11-AverageAgeOfVehicleFleetInNZ2000-2014.pdf

This meant that there would be a total of 308.87 million electric cars from 2018-2091 in New Zealand, without replacement (meaning that if you have the same car in 2020 and 2021 that counts as 2 cars), an average of 4.23 million cars per year. Multiplying this by 73 and then dividing by 14.3 (the average car age in New Zealand in 2018) calculates the approximate total number of unique electric cars in New

Commodity/service	Source	2016		
Vehicles, parts, and accessories	Japan	2,034	32.42%	Asia
Electrical machinery and equipment	China, People's Republic of	1,957		
Vehicles, parts, and accessories	European Union	1,947	31.04%	EU
Mechanical machinery and equipment	European Union	1,767		
Mechanical machinery and equipment	China, People's Republic of	1,613		
Other personal travel	Australia	1,547		
Textiles and textile articles	China, People's Republic of	1,485		
Mechanical machinery and equipment	United States of America	1,203		
Transportation services	European Union	1,175		
Vehicles, parts, and accessories	Thailand	1,175	18.73%	Asia
Other business services	Australia	1,093		
Aircraft and parts	United States of America	1,012		
Petroleum and products	United Arab Emirates	927		
Other business services	United States of America	702		
Furniture, furnishings, and light fittings	China, People's Republic of	663		
Petroleum and products	Singapore	653		
Petroleum and products	Korea, Republic of	647		
Pharmaceutical products	European Union	639		
Transportation services	Australia	617		
Vehicles, parts, and accessories	United States of America	601	9.59%	USA
Mechanical machinery and equipment	Japan	553		
Other personal travel	European Union	541		
Business travel services	Australia	540		
Vehicles, parts, and accessories	Korea, Republic of	515	8.21%	Asia
Other personal travel	United States of America	512		

Zealand to be 21.60 million.

As 59.4% of these vehicles would be imported from Asia, 31% from Europe and 9.6% from the United States, we then needed to calculate the number of shipments required from each area. RORO (Roll-on/roll-off carrier ships) can each carry 550 cars. Dividing the amount of cars into full shipments (and rounding up the final shipment) gave a total amount of shipments from each region.

Region	Cars	Shipments
Asia	12830400	23328
Europe	6696000	12175
USA	2073600	3771

There will be a total of 23328 shipments of electric cars from Asia, 12175 from Europe and 3771 from USA between 2018 and 2091. We then needed to calculate the carbon emissions for a trip from each of these areas (as electric boats isn't realistic). Using an online calculator[27] and a CO_2 emission/km of 0.49

[27] https://planetcalc.com/4315/

grams[28], and an average weight per car as 5279 lb (based on an average weight of cars at 4079 lb[29] and an estimated electric engine weight at 1200 lb[30], we were able to calculate that shipping the 21.6 million cars to New Zealand would use a total of 75.78 million tonnes of CO_2 emissions.

Final Amount of Carbon Emissions

Total CO_2 emitted by operating road vehicles, **without** intentional complete electrical transition (In Tonnes of CO_2)	1,638,842,796.4 Tonnes of CO_2
Total CO_2 emitted by operating road vehicles **with** intentional complete electrical transition	212,446,400 Tonnes of CO_2
Total CO_2 emissions **avoided** with intentional train complete electrical transition	25,000,000 Tonnes of CO_2
Total CO_2 **extra** emission in production and electricity generation of electric cars	21.6million cars*19.1Ton= 431,000,000 Tonnes of CO_2
Total CO_2 emissions from importing electric cars into New Zealand	75,783,127 Tonnes of CO_2

(1,638,842,796 - 212,446,400) + (25,000,000) - (431,000,000) - (75,783,127) = A total of 945,000,000 Tonnes of CO_2 to (3 sf) avoided by switching to an electric vehicle fleet.

Based on the approximations made in this report, we give this final value to be accurate within 8%.

[28] https://www.ecta.com/resources/Documents/Best%20Practices%20Guidelines/guideline_for_measuring_and_managing_co2.pdf
[29] https://www.nytimes.com/2004/05/05/business/average-us-car-is-tipping-scales-at-4000-pounds.html
[30] https://www.quora.com/How-much-would-an-average-electric-car-weigh-as-opposed-to-a-comparable-gasoline-powered-car