Engineering Science Competition 2018 Team 1110

Introduction

In our society, many human activities have resulted in serious damages to the environment. These activities are mainly associated with the emission of carbon dioxide (CO2). CO2 is a colourless gas particle that can prevent solar radiation (heat) from escaping the earth's atmosphere; carbon gas can also result in various human diseases such as asthma. Due to its detrimental effects on both environment and human health, many countries thrive to impose policies to address the overemission of CO2, and the most prevalent tactic is to advocate the use of electric transportations. As an alternative energy source to diesel and petrol, electricity does not generate any environmentally harmful elements. Therefore, by pursuing this objective, the amount of CO2 in the society can be largely reduced. To provide evidence to this claim, it is worthwhile to investigate:

How many tonnes of CO2 emissions could be avoided in your lifetime if NZ transitions to a completely electric vehicle fleet?

Methodology:

The process of deriving the conclusion consists of four steps. Firstly, we will try and work out the annual amount of diesel and petrol consumed in NZ per capita. The second step is to compute the predicted population for each year of our team's remaining lifespan, adopting a logistic model. The third step is to multiply each year's expected population with the average per capita figures and work out the total emission amount. The final step is to subtract the figure with the CO2 emissions arising from a completely electrical vehicle fleet to calculate the total amount of CO2 that can be avoided.

With these assumptions involved, we can better adopt the available research information, and to simplify the mathematical computation aspects of the task.

Given the open nature of the question, our interpretations are as follows:

"**Your lifetime**" was interpreted to be the life expectancy of people born in 2000, with the life expectancy of 90.7 years (72.7 years from 2018). An completely electronic fleet contains all diesel and petrol vehicles including cars, buses, trucks and motorbikes. We assumed that commercialised electric airplanes would not be achievable in our lifetime due to technological limitations. A "**transition**" implies that time is needed for the change to electronic fleet to happen. It would be sensible to assume that the transition of land transportation will take time to happen. Although this transition will decrease the carbon emission, an electronic fleet requires a lot more electricity to be generated. The currently electricity generated is not enough to support the electronic fleet. As New Zealand generates a lot of electricity from renewable energy sources, we decided that building more hydroelectric power stations would be sensible to meet the electricity demand. However, this incurs extra carbon emission from the production of cement and steel which should be taken into account. Furthermore, population growth will also be taken into account as this would likely be a significant factor that will increase the demand for transportation, thus increasing the carbon emission if the transition to an electronic fleet does not happen.

Step 1: Annual average diesel and petrol consumption per person

To find the amount of carbon dioxide emission that could be avoided if petrol and diesel vehicles are replaced with electronic ones, we should find the total carbon emission that is incurred currently with no plan to change to an electronic fleet. According to the Ministry of Business, Innovation and Employment[1], from 2007 to 2017, an average of 2,296.90 kilotonnes of petrol was consumed annually. From this, we can find the carbon emission. The density of petrol is around 0.74kg/L ($\pm 4.05\%$). Hence, 2,296.90 kilotonnes equates to 3.1 billion litres. As 2.36kg is emitted per litre of petrol, average carbon emission from petrol annually is around 7.325 million tonnes ($\pm 4.05\%$).

Average population of New Zealand from 2007-2017 is 4.449million. Finding the emission from petrol per capita annually:

$$\frac{7.325 million\ tonnes (\pm 4.05\%)}{4.449 million} = 1.646\ tonnes\ (\pm 4.05\%)$$

Doing the same for diesel, an average of 1,790.85 kilotonnes of diesel was consumed annually from 2007-2017. The density of diesel is 0.832kg/L ($\pm 1.44\%$), thus annually 2.15 billion litres of diesel is consumed. 2.72 kg of carbon is emitted per litre of diesel. Therefore, carbon emission from diesel is 5.85 million tonnes($\pm 1.44\%$).

Finding the emission of carbon through diesel per capita annually:

[1] http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/statistics/oil

$$\frac{5.85 million\ tonnes (\pm 1.44\%)}{4.449 million} = 1.315\ tonnes (\pm\ 1.44\%)$$

Total carbon emission from land transportation is therefore
1.656 $(\pm\ 4.05\%)$ +1.315($\pm\ 1.44\%$) = **2.971** $(\pm\ 5.49\%)$ **tonnes per capita annually.**

Step 2: Logistic model for population growth

After obtaining the annual diesel and petrol consumptions per person, we will predict the population in NZ. Population is a variable that tend to increase based on its population growth rate. In this situation, the latest population data and its growth rate that we can find is that in 2016, therefore this is where we going to start our calculation. According to the life expectancy calculator, a New Zealand resident is expected to live for 89 years assuming medium death rates. Therefore for us who were borned in 2000, the remaining lifetime is on average $91 - 18 = 73$ years.

The population growth will be calculated using the logistic model, which estimate the future total population with consideration to restraining factors, such as residential limits, affordability to raise children and etc. The equation for the rate of growth is:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right),$$

Where $P = population$
$r = growth\ rate$
$K = carrying\ capacity$

Since 15 million people is referred as the "target population" by the NZ government, it is arguable that this figure can be the carrying capacity because the government will impose policies to approach the population to this quantity and prevent it from exceeding it. The growth rate of NZ population is 2.1% in 2016.

To work out the population for each year in the future, we need to integrate this function which we will get:

$$P(t) = \frac{KP_0 e^{rt}}{K + P_0\left(e^{rt} - 1\right)}$$

In this equation, the t is the number of years after 2016, and P_0 is the initial population, which is 4.693 millions (2016), and r is the population growth rate at that year which is 2.1%. K, as mentioned in the last paragraph, is 15 millions.

Now, to work out P for every given year, we need to plot all the known constants K, r and P_0 into equation and set $t = 1, 2, 3, 4......71$. By doing so, we will obtain the expected population for each year of our remaining lifespan. This process will be done using Python programming:

```
Program.py

import math
import xlrd
from xlutils.copy import copy # Library to allow writing in excel

workbookR = xlrd.open_workbook("Data.xls")
workbookW = copy(workbookR)

Population = 4693000
GrowthRate = 0.021
K = 15000000 # Caring capacity
T = 75 # Number of year
counter = 0

def logistic (Years):
    Y = int(K*Population*math.exp(GrowthRate*Years)/(K+Population*(math.exp(GrowthRate*Years)-1)))
    worksheetW = workbookW.get_sheet(0)
    worksheetW.write(Years+1,1,Y)
    workbookW.save("Data.xls")

def diesel ()


while (counter<T):
    counter += 1
    logistic(counter)

```

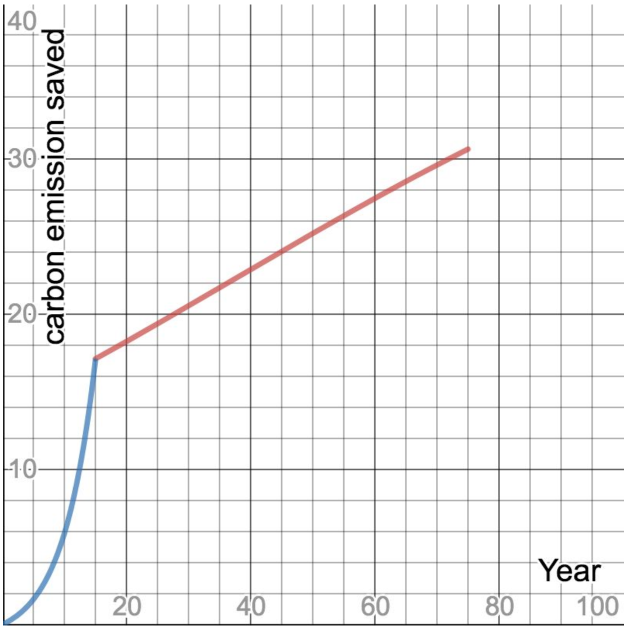
And the result is demonstrated below:

Year	Population		Year	Population		Year	Population		Year	Population
2016			2036	6139894		2056	7699635		2076	9242286
2017	4760983		2037	6216196		2057	7778305		2077	9316602
2018	4829490		2038	6292774		2058	7856913		2078	9390541
2019	4898512		2039	6369610		2059	7935442		2079	9464090
2020	4968037		2040	6446691		2060	8013876		2080	9537235
2021	5038058		2041	6523998		2061	8092197		2081	9609965
2022	5108563		2042	6601518		2062	8170388		2082	9682266
2023	5179541		2043	6679233		2063	8248433		2083	9754126
2024	5250982		2044	6757126		2064	8326314		2084	9825535
2025	5322875		2045	6835182		2065	8404016		2085	9896480
2026	5395207		2046	6913383		2066	8481521		2086	9966951
2027	5467966		2047	6991713		2067	8558813		2087	10036936
2028	5541141		2048	7070154		2068	8635876		2088	10106426
2029	5614718		2049	7148690		2069	8712695		2089	10175411
2030	5688684		2050	7227303		2070	8789253		2090	10243881
2031	5763027		2051	7305976		2071	8865536			
2032	5837732		2052	7384691		2072	8941527			
2033	5912786		2053	7463433		2073	9017212			
2034	5988173		2054	7542182		2074	9092577			
2035	6063881		2055	7620922		2075	9167606			

Step 3: Amount of CO2 emitted each year

Assuming that the carbon emission per capita annually stays the same in the future, multiplying 2.971 $(\pm 5.49\%)$ by the population predicted each year as modelled above will give us the carbon emission saved each year.

For the transition of petrol/diesel cars to electric cars to happen, it will take many years to happen. Currently, New Zealand does not generate enough electricity if all the vehicles become electric, and also it will take time for consumers to switch their cars to electric ones. If NZ were to transition to a completely electric fleet, with the help of the government facilitating the change, we assumed that the transition would take 15 years to be complete(15 years to change all land transportation to electrical). Thus, we should take into account this transitional period, where the carbon emission gradually decreases until all vehicles are being swapped out. We assumed the transition to form an exponential curve, because initially people would be more reluctant to switch due to inconveniences such as lack of charging stations, and some transportation firms who need time to adjust their operations. Thus, as roads and services are changed to better suit electric cars, more people will be increasingly willing to switch to electric cars.



The graph of above shows the carbon emission (million tonnes) that is saved as petrol and diesel cars are switched to electric cars. The first 15 years the carbon emission saved grows exponentially modelled by the equation $y = e^{0.19269x} - 1$. From 15 year onwards, the graph follows a very flat sigmoid function modelled by the equation $y = \frac{9.495*3.196e^{0.021x}}{15+4.693(e^{0.021x}-1)}$ (population growth equation). To find the carbon emission saved in the first 15 years, we can find the definite integral of the function $y = e^{0.19269x} - 1$ between 0<x<15:

$$\int_0^{15} e^{0.19269x} - 1 \, dx =$$ 88.22 million tonnes

To find the total carbon emission saved for the remaining years (obtained from table on previous page)=

$\sum emissions\ each\ year\ from\ 2034\ to\ 2090$

= 135,462,9871 million tonnes

Total carbon emission saved by switching from petrol/diesel cars to electric cars:
135,462,9871 + 88.22 = **1,354,629,959 tonnes = 1354.63 million tonnes (** $\pm 5.49\%$)

Step 4: CO2 emissions arising from an electrical vehicle fleet

The construction of a hydroelectric dam is required to sustain the rapid growth in electric vehicle usage throughout the country.
This was calculated by using the approximate energy in kWh needed to replace 1L of vehicle fuel (petrol and diesel)

This data reveals the most popular electric cars that are in use currently, whose energy usage per 100km was averaged evenly.

Brand	Electricity kWh/100 km
2017 BMW i3 (94 Ah battery)	18.02
2017 Ford Focus Electric	19.26
2017 Nissan Leaf (30 kWh battery)	18.64
2017 Tesla Model S 75D	20.50
2017 Volkswagen e-Golf	17.40
Average	18.76

This data reveals the most popular petrol cars in use currently, whose litre consumption per 100km was averaged relative to their usage in New Zealand.

Brand	Petro L/100 km	Share
Porsche 911 Carrera (Sport car)	10.60	0.05
VW Tiguan (SUV)	8.60	0.1
Mercedes E-Class (Full size car)	7.40	0.3
Audi A8 (Luxury Car)	9.10	0.15
VW Golf VI (small family car)	5.30	0.15

Opel Insignia (large family car)	7.00	0.25
Average	7.52	1

The average energy usage of electric cars were then divided by the average fuel that was consumed.

$\frac{18.76kWh/100km}{7.52L/100km}$ = 2.49kWh/L

The current use of petrol and diesel is expressed in the table below for the past eight years, expressed in metric kilotonnes.

(kt)	2010	2011	2012	2013	2014	2015	2016	2017
LTP	2315.84	2275.91	2226.83	2215.66	2221.55	2285.45	2342.06	2394.03
LTD	1682.69	1732.53	1751.70	1799.91	1831.21	1915.90	1960.03	2167.16

This was then converted into millions of litres of petrol and diesel respectively.

(ML)	2010	2011	2012	2013	2014	2015	2016	2017
LTP	3149.54	3095.23	3028.49	3013.30	3021.30	3108.21	3185.21	3255.88
LTD	1988.93	2047.85	2070.51	2127.50	2164.49	2264.59	2316.75	2561.58

Finally, the equivalent amount of electrical energy needed to replace petrol and diesel was calculated using the value found previously, at 2.49kWh/L

(GWh)	2010	2011	2012	2013	2014	2015	2016	2017
LTP	7857.10	7721.62	7555.11	7517.22	7537.18	7753.98	7946.07	8122.39
LTD	4961.75	5108.72	5165.25	5307.43	5399.72	5649.44	5779.55	6390.33
Total	12818.85	12830.34	12720.36	12824.65	12936.91	13403.42	13725.63	14512.72

Therefore, to accomodate for the number of electric vehicles that will need to be replaced, the electrical energy needed to power all electric vehicles is equal to 14512.72gWh.

The CO2 emissions in the construction of a dam able to generate the equivalent amount of electrical energy was calculated relative to the Three Gorges Dam in China, which produces approximately 98.8 TWh. For the construction of the Three Gorges Dam the following materials were needed:
27.15 million cubic metres of cement
281,000 tonnes of metal structures

An assumption was made that the entirety of that cement was used to construct concrete for the dam.

The following information was used to calculate the carbon dioxide emissions of the construction of the equivalent amount of concrete:
Density of cement: 1000-1300 kgm^{-3}
900kg CO2 is emitted per 1000kg cement produced
Production of cement accounts for 88% of CO2 emissions for the production of concrete

$\frac{27.15\times10^{-6}m^3\times1000kgm^{-3}\times\frac{900kg}{1000kg}}{0.88}$ = 27.8 million tonnes of CO2 emitted
$\frac{27.15\times10^{-6}m^3\times1300kgm^{-3}\times\frac{900kg}{1000kg}}{0.88}$ = 35.3 million tonnes
This is the range of CO2 emitted from concrete production, due to the varying density of cement.

The ratio of CO2 emission in mass per unit mass of steel produced is:
1.2-3.8 tonnes of CO2 emitted per 1 tonne of steel

$281\times10^6kg\times1.2$ = 0.337 million tonnes of CO2 emitted
$281\times10^6kg\times3.8$ = 1.067 million tonnes
This is the range of CO2 emitted from steel production, due to the varying amount of emissions dependent on the method used.

The minimum of each value and maximum of each value were found and the average calculated between them and the half range rule was used to find the uncertainty.

28.114 million tonnes is the minimum value.
36.327 million tonnes is the maximum value.

The average value of CO2 emitted when constructing a dam equivalent to the Three Gorges Dam is 32 ± 4 million tonnes.

14.51 TWh is needed to power all electric vehicles in NZ. This means that an equivalent dam approximately 14.51/98.8 in size of the Three Gorges Dam is needed.

$\frac{14.51}{98.8} \times 32 \approx 4.8$ million tonnes of CO2 emitted in the construction of a dam suitable for powering vehicles for the current population of NZ.

However, the population grows by a factor of 2.15, shown in . Therefore, the number of stations must increase accordingly.
4.8 * 2.15 = 10.33 million tonnes

Conclusion

Therefore, to find the total carbon emission saved:

1,354,629,959 tonnes $(\pm 5.49\%)$ - 10.33 million (±12.5%)
= 1344.3 million tonnes $(\pm 17.99\%)$

In conclusion, we found that we could avoid the emission of 1,344.3 million tonnes ($\pm 17.99\%)$ of CO2 in your lifetime if New Zealand transitions to a electronic fleet. The 18% uncertainty means there is quite a large variability in our answer. The final answer takes into account the potential population growth of NZ, the emission from petrol/diesel vehicles, and the counter effect of needing to produce more electricity generating stations that emits carbon dioxide.

Evaluation:

The number we got was very large. This was mainly due to the the large population growth that we anticipated from our modelling that almost triples over 73 years. There were many limitations to our calculations, such as that the carbon emission per capita would be the same in the future, and that it is possible to transition to an electronic fleet in just 15 years. These assumptions may be unrealistic, therefore making our answer inaccurate.
Most of our assumptions have come from our current models of our populations. This may not reflect the true growth in population due to the varying levels of development in New Zealand from a Stage 4 to a Stage 5 developmental country. This would, in turn, lower the birth rates, resulting in an overestimation of the population growth that would occur in the future.
As well as this, the assumption that the growth in electric vehicles would remain constant relative to the population may also not be accurate and reflect the true relationship between vehicle transport and population in New Zealand. However, due to time constraints, the relationship wasn't able to be further developed.

References

Government data about diesel and petrol consumption:
http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/statistics/oil
https://www.transport.govt.nz/assets/Uploads/Research/Documents/Fleet-reports/The-NZ-Vehicle-Fleet-2016-web.pdf

Carry capacity:
http://www.stuff.co.nz/national/politics/8024613/Optimal-size-for-New-Zealand-15-million

Dam
http://www.china-embassy.org/eng/zt/sxgc/t36512.htm

Population growth rate:
https://www.google.co.nz/publicdata/explore?ds=d5bncppjof8f9_&met_y=sp_pop_grow&hl=en&dl=en

NZ population:
https://www.google.co.nz/publicdata/explore?ds=d5bncppjof8f9_&met_y=sp_pop_totl&hl=en&dl=en

Photos:
https://www.istockphoto.com/nz/photos/carbon-dioxide?excludenudity=true&sort=mostpopular&mediatype=photography&phrase=carbon%20dioxide

Intro:
https://www.youtube.com/watch?v=HK8LLWSIIm4

Life expectancy NZ population calculator
http://archive.stats.govt.nz/browse_for_stats/health/life_expectancy/how-long-will-I-live.aspx

https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

Industry reports:
http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/statistics/oil