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Carbon Dioxide Emissions Reduction in New Zealand Transport Sector

A thesis
submitted in fulfilment
of the requirements for the degree of
Master of Science at
The University of Waikato
by
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2016

Abstract

Carbon dioxide reduction from New Zealand transport sector can be reduced to 1990 levels if a wide range of methods are adopted such as fuel mix, electrification of vehicles and rail, and cycling. A comprehensive analysis of carbon dioxide emissions from electric, plug-in electric hybrid, hybrid and internal combustion engine vehicles was done under different scenarios. Five different models including each type of vehicle were chosen in this analysis. The main exercise for this analysis is to determine how much CO₂ can be reduced by PHEV's and EV's from the light passenger vehicles in New Zealand. It was found that that Toyota Prius, a plug-in hybrid vehicle, emits less CO₂ when compared to all different types of models. Since these vehicles are not manufactured in New Zealand the CO₂ emission due to manufacturing of the batteries and vehicles can be ignored.

This means that if only the tail pipe CO₂ emission is taken into consideration, then there can be a reduction of 50 to 60 percent of CO₂ emission from transport sector in New Zealand if all light passenger vehicles are PHEV's or EV's. The uptake of PHEV's and EV's depends on the number of initiatives taken by the local and central government.

Further analysis was done to determine the total ownership cost (TOC) of these vehicles. It was found that the capital cost and the battery cost plays a significant role in determining the total ownership cost for PHEV's and EV's. Based on estimates from the International Energy Agency there will be about 106 million PHEV's and EV's that will be sold in a year by 2050. With the current projected rate of lithium production, it will be difficult to meet the demand to manufacture lithium-ion batteries.

A survey was also carried out at Hamilton Girl's High School to determine the number of students that cycle to school. 450 students were surveyed, questions such as the mode of transport, the distance from school to their home, barriers to cycling, the engine size of the vehicle used to come to school and the suburb they live in were asked. This was done to estimate how much CO₂ emission can be reduced if

students who are keen to cycle and live within 10km radius of the school cycle to school in Hamilton City area. About 20 percent of the students at Hamilton Girls' High School are willing to cycle to school, however, according to them the major barrier to cycling was the safety followed by distance and cost of bicycles. If these barriers are minimised and they start cycling to school, about 60 tonnes of CO₂ can be reduced in a year only from HGHS students. If the sample size is applied to all the schools in the city and 20 percent of all secondary and intermediate students started cycling to school there would be a reduction of 6 percent CO₂ emissions from light passenger vehicles in Hamilton City.

Acknowledgments

This work was carried out, part-time, at the Energy Research Group, The University of Waikato. I would like to extend my deepest appreciation and thanks to the following people at the University of Waikato: **Associate Professor Dr Michael Walmsley** for his encouragement, advice and guidance and Senior Researcher, **Dr Martin Atkins** for checking and rechecking my work. Both have been really helpful throughout this research.

Without the support of my beautiful wife **Cinal Chand** and son **Avian Chand** this work would not have been possible. Cinal has sacrificed a lot of family time to make it possible for me to carry out this work. I am really blessed to have her in my life so that I can fulfil my dreams.

My well-wishers Mr Akash, Amir, James and Sanjiwan who checked part of my work and indulged meaningful discussions even though they were not interested in my topic.

The staff and students of **Hamilton Girls' High School** for helping me in doing the survey regarding cycling at school. Especially, thanking Mr Cochrane and **Mr Farrell** for checking my work at times. Special thanks to **Marie Gordon** principal of Hamilton Girls' High school and teachers in Science Department Mr Mounsey, Arti, Shashi, Janet, Melissa, Kirsty and Urmila.

Finally, this work is dedicated to my parents **Mr and Mrs Ramesh Chand** and my siblings Daniel, Ronil and Priya who have motivated me and supported me during this process. Also thanking my Dadi Mrs Iswar Pratap and late Mr Ishwar Pratap for always guiding me in the right direction. At last thanking all my teachers who taught me from primary school to University in **FIJI**.

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Nomenclature

Acronyms

EEF	Electricity Emission Factor	PHEV	Plug-in Hybrid Vehicles
GHG	Green House Gas	TOC	Total Ownership Cost
HEV	Hybrid Electric Cars	EV	Electric Vehicles
ICEV	Internal Combustion Engine Vehicles	TOC	Total Ownership Cost
IEA	International Energy Agency	RUC	Road User Charges
LCA	Life Cycle Assessment	SUV	Sports Utility Vehicles
NZD	New Zealand Dollar		

Symbolization

CO_2	Carbon dioxide		Max. No. Battery charge
$LiCO_{1/3}$	Lithium cobalt	c_{cycle}	
$Mn_{1/3}O_2$	Manganese dioxide		Max capacity of battery when full charged
$LiMn_2O_4$	Lithium manganese oxide	βcap	
$NiCd$	Nickel Cadmium	ϵ	Energy (W/km)
m_v	Mass of Vehicle (kg)	C	Cost
η_{fuel}	Efficiency of Fuel	$\$$	Dollars
$d_{travelled}$	Distance Travelled (km)	B	Battery
η_{ev}	Electricity used (kWh/km)	M	Maintenance
		W	Warrant of Fitness
		F	Fuel
		N	Number of vehicles
		P	Power

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Chapter 1

Introduction

1.1 Background

Climate is a phenomenon that changes with time. Climate change becomes a problem when the weather patterns around the globe drastically change and affects the life on the planet. Some scientist believe that it is a natural phenomenon that has a cycle, which depends on our solar system. However, some scientists also believe that the actions of humans also contribute to global weather pattern change. Industrialisation has modernised our society on a global scale, which has a huge impact on the environment.

More and more industrial factories have been built around the globe to cater for society's needs. To power these factories tonnes and tonnes of fossil fuels are burnt every day, which releases Green House Gases (GHG). GHG are comprised of many gases such as carbon dioxide, nitrous oxide, carbon monoxide, sulphur dioxide, and methane. According to the Inter-governmental Panel for Climate (IPCC, 2015), GHG is responsible for global warming. Charles David Keeling was the American scientist who first alerted the world to the possibility of anthropogenic contribution to the greenhouse effect and global warming from the recordings of carbon dioxide at the Mauna Loa Observatory. The greenhouse effect is when gases go up in the atmosphere and form a layer in the stratosphere that traps the heat inside as shown in Figure 1.1. This increases the temperature of the planet which in turn changes the weather pattern around the globe. Severe drought or rain at different places around the world can be experienced due to this.

The increase in GHG are caused by several factors. One of the factors mentioned above is the burning of fossil fuels. Fossil fuels are a readily available energy source in today's world. They can be used to run factories, transport, aviation, space projects, etc.

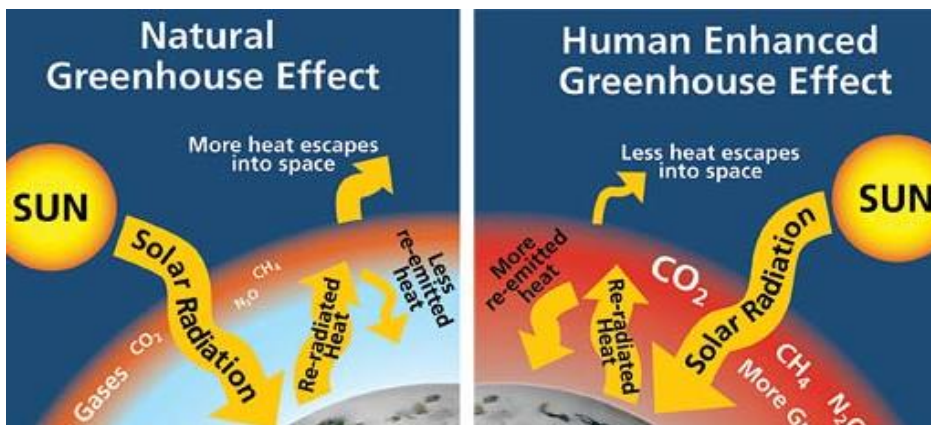


Figure 1.1: Greenhouse gas effect (Lallanila, 2015).

One of the biggest challenges facing the world is the replacement of traditional oil and natural gas based transport fuels with alternatives that are both technically and economically viable and environmentally, socially and politically sustainable. As transport energy demand rises, especially in developing countries like China and India, and oil and gas reserves become increasingly difficult to find and exploit, energy companies and nations are turning more and more to unconventional energy resources, like tar sands, shale oil, agricultural crops and silviculture forests, to try and solve the emerging energy replacement problem.

Increased motivation to address the transport fuels challenge is derived from the need to lower environmentally harmful emissions and to reduce air pollution in many of the world's major cities. At present unconventional energy sources, even after considerable research effort, are more technically difficult and more costly to transform into usable liquid fuels compared to oil or natural gas. In general they require much higher levels of energy to be expended to deliver the same amount of useable fuel. In turn this can result in a contraction of the rest of the economy, which can potentially affect industrial production, employment and general economic well-being of citizens.

Currently the transportation sector produces about 13 percent of GHG globally as shown in Figure 1.2. GHG in transportation mainly involves fuels burnt on roads, rail, air, and marine transport. Almost 95% of the world's transportation energy comes from petroleum-based fuels, largely gasoline and diesel (USEP, 2015).

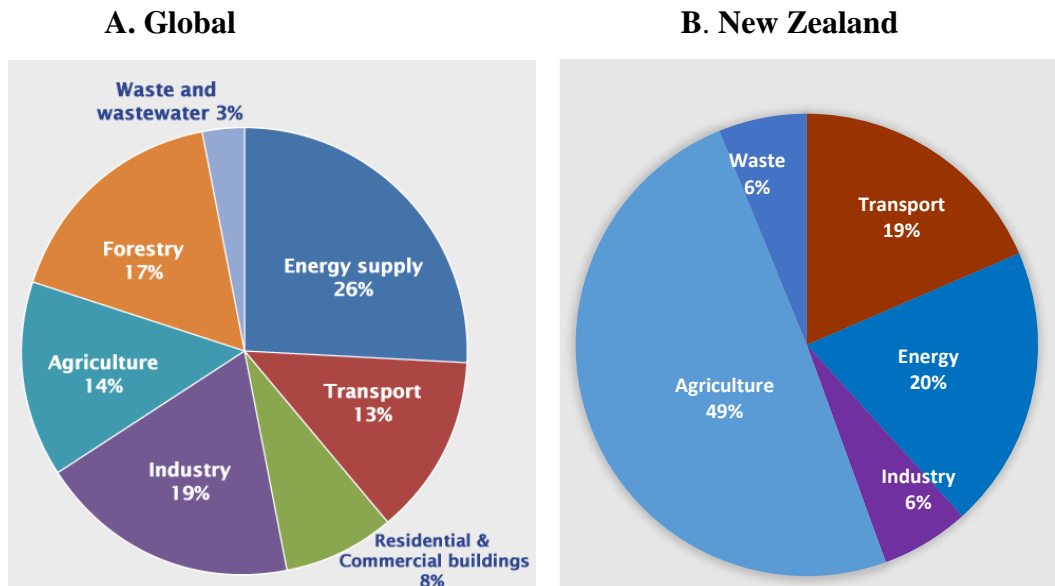


Figure 1.2: Carbon dioxide emission globally and in New Zealand. (Environment, 2014; USEP, 2015).

In New Zealand about 19% of the GHG is emitted by the transport sector; the majority from road transport as shown in Figure 1.2. Road transport can be further categorised into light passenger fleet, heavy fleet, motor cycle, light commercial fleet as shown in Figure 1.3. The amount carbon dioxide produced by road transport is significantly higher when compared to other kinds of transport such as rail, marine and aviation. Figure 1.4 shows the amount of carbon dioxide emitted annually from 1990 to 2013 and this trend is increasing.

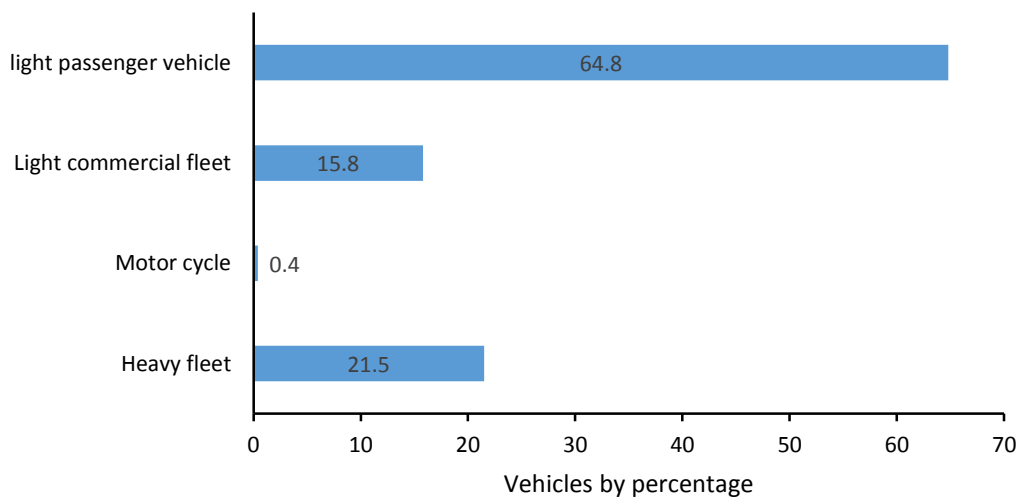


Figure 1.3: Vehicle type (Transport, 2014b).

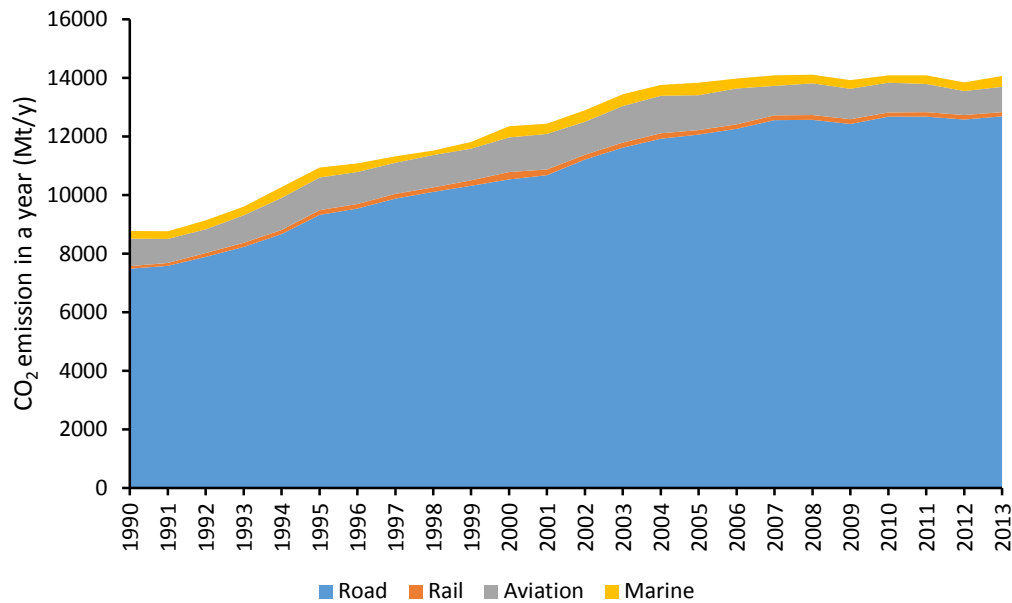


Figure 1.4: Amount of CO₂ from transport (Ministry of Transport, 2015).

There are number of ways by which GHG emission can be reduced from road transport. This may include fuel switching, more use of public transport, alternative methods of transport such as cycling, more energy efficient combustion engines, hybrid vehicles, electric vehicles, plug-in hybrid vehicles.

In New Zealand, the light passenger fleet is the biggest emitter of carbon dioxide from the road transport sector as shown in Figure 1.4. Introduction of electric or plug-in hybrid vehicle, fuel switching and encouraging students to cycle to school may reduce the emission of carbon dioxide from the light passenger vehicle.

1.2 Thesis Aim

The aim of this thesis is to use carbon emissions pinch analysis (CEPA) to determine how New Zealand can reach 1990 levels of CO₂ emissions from transport sector. Further analysis is done to determine the implications of introducing PHEV's and EV's in terms of CO₂ emissions reduction, total ownership costs and its effect on the electricity grid. A survey was carried out at HGHS to determine the barriers faced by students, in order, to cycle to school and quantify the amount of CO₂ reduction in Hamilton city due to students cycling to school.

1.3 Thesis Outline

Chapter Two uses carbon emissions pinch analysis (CEPA) to explore how New Zealand can meet its future transport demand in 2050 while reducing the associated carbon emissions to 1990 levels. Various methods to reduce CO₂ are investigated in this chapter.

Chapter Three investigates the different types of vehicle present in the market in New Zealand. One of these vehicles are chosen from each category and a life cycle assessment (LCA) was carried out for CO₂ emissions. LCA was carried out under three different scenarios such as battery life expectancy and fuel mix for PHEV's

Chapter Four investigates the total ownership cost (TOC) of the different types of light passenger vehicles considered in Chapter Four under different scenarios used in Chapter Three in the New Zealand context.

Chapter Five analyses the effect of PHEV's and EV's on the electricity grid and qualitatively determines the effect of government incentives on the uptake of PHEV's and EV's.

Chapter Six investigates the barriers faced by students of HGHS to cycle to school. This investigation was done as a survey and through student interviews. Further, analysis was done to quantify the amount of CO₂ reduction by the secondary and intermediate students in Hamilton City area.

Chapter 2

Carbon Emissions reductions in transport sector through to 2050

2.1 Introduction

Energy sector planning using engineering analysis tools, such as CEPA (Carbon Emissions Pinch Analysis) and EROI (Energy Return on Investment) analysis, is needed to ensure that the inevitable transition to a low fossil fuel transport energy sector occurs in a way that minimises the increase in cost and energy expended from the economy to meet the desired demand within the nation's carbon emissions targets.

EROI is essentially the ratio of the amount of useful energy produced for society to the amount of energy that has to be expended to obtain the useful energy in the first place. Effective production of energy with high EROI values is crucial to economic growth, industrial manufacturing, employment and the general economic well-being of citizens. CEPA, on the other hand, quantifies the environmental impact in terms of emissions of using energy. CEPA is a graphical method for showing how much carbon emissions are contributed from each part of an energy sector (e.g. electricity, transport) and exploring possible pathways for modifying the energy system to meet fixed emissions targets.

The aim of this chapter is to apply a modified CEPA method to explore how New Zealand can meet its future transport demand in 2050 while reducing the associated carbon emissions to 1990 levels. Various methods for reducing emissions are investigated including production of biofuels, electrification of the transport fleet using renewable resources, and increases in combustion engine efficiency through hybrid systems. The main work from this chapter was published as the journal paper "*Carbon Emissions Pinch Analysis for emissions reductions in the New Zealand transport sector through to 2050*" and a full copy of the paper is found in Appendix 1.

2.2 Methodology

2.2.1 A modified Carbon Emissions Pinch Analysis framework for transport sectors

CEPA was first developed by Tan, Foo, and co-workers (Ooi *et al.*, 2013), and is based on the application of traditional Pinch Analysis techniques beyond Total Site Analysis for large industrial sites to broader macro-scale applications such as regional and national electricity generation sectors (Crilly & Zhelev, 2008).

In the New Zealand context, CEPA has been applied to the national electricity sector to show how increased electricity demand in 2050 can be met and the generation mix optimised for minimum energy cost. However, the method has not been applied to the transport sector as far as the authors are aware and some degree of modification to the standard method is required to extend CEPA to analysis of a transport system.

In this work the CEPA method is modified for extended application to transport sectors. An underlying tool of CEPA is the construction of composite curves together with identification of the pinch, which is often caused by an emissions target that is lower than the current emissions level. The y-axis of the composite curve graph is carbon emissions equivalent in kt CO₂-e and the x-axis is the useful transport output in Mt-km, where the (t), tonnes represents people or freight depending on the purpose of the transport operation. The demand curve represents the transport's primary purposes (e.g. freight or passenger), mode (e.g. marine, air, rail) and class (e.g. buses, ships, trains, light passenger vehicles, etc.). The supply curve captures the fuel sources (e.g. petrol, diesel, electricity, compressed natural gas, etc.) used in the various transport operations, which are stacked beginning with the fuel with the lowest transport fuel emissions factor (ε_{TF}) and so on to the one with the highest. The transport fuel emissions factor can be determined by equation 2.1

$$\varepsilon_{TF} = \frac{\varepsilon_F}{\phi_w \eta_T} \quad (2.1)$$

Where ε_F is fuel emissions factor in kt CO₂-e/MJ, ϕ_w is the ratio of useful transport weight to gross vehicle weight in Mt/Mt_{gross} and η_T is the gross transport output efficiency in (Mt_{gross}-km)/MJ. ε_F is dependent on the fuel and is not affected by the transport method. ϕ_w is a function of the transport method and its fill-rate. η_T mainly relates to the engine efficiency and its aero- and/or hydro-dynamics.

A generic example of a transport system is presented in Figure 2.1 to demonstrate how the CEPA method may be modified for transport systems. Figure A is the conventional CEPA style plot that presents the overall fuel supply and transport demand with an associated emissions of 1000 kt CO₂-e. The solid black line is the average ε_{TF} for the entire system and called the overall Transport Emissions Factor (TEF). The new emissions target represents a 20% reduction goal of transport emissions. The point where the dotted diagonal line, which is based on the emissions target, intersects the fuel supply curve is the pinch point.

When considering how to achieve the emissions target, the overall CEPA graph lacks sufficient detail about transport modes and classes to base decisions of where emissions reduction efforts are best focused. The overall transport demand can be broken-down into the individual transport classes as shown in Figure 2.1B. Combinations of transport classes and fuels that contribute a high proportion of the total emissions can now be identified and emissions reductions methods considered.

Two options for emissions reduction are presented in Figure 2.1 C and D. The first option targets improving transport fuel efficiency of class B with fuel C. An example of this option is increasing public transport fill-rates by encouraging their use through measures such as increasing Government subsidies or, in the long-term, market driven increases in petrol prices. The second option switches some of fuel C for A within class B. An example of this can be electrification of the rail network, use of electric vehicle (EV's) and plug-in hybrid electric vehicle (PHEV's) where electricity is generated using a high proportion of renewables (e.g. hydro). There are many other situational options for reducing emissions such as switching transport classes such as cycling, which also can be considered. It is also useful to

plot the transport data on an emissions versus fuel use in PJ to understand the impact various emissions reduction options have on total fuel use.

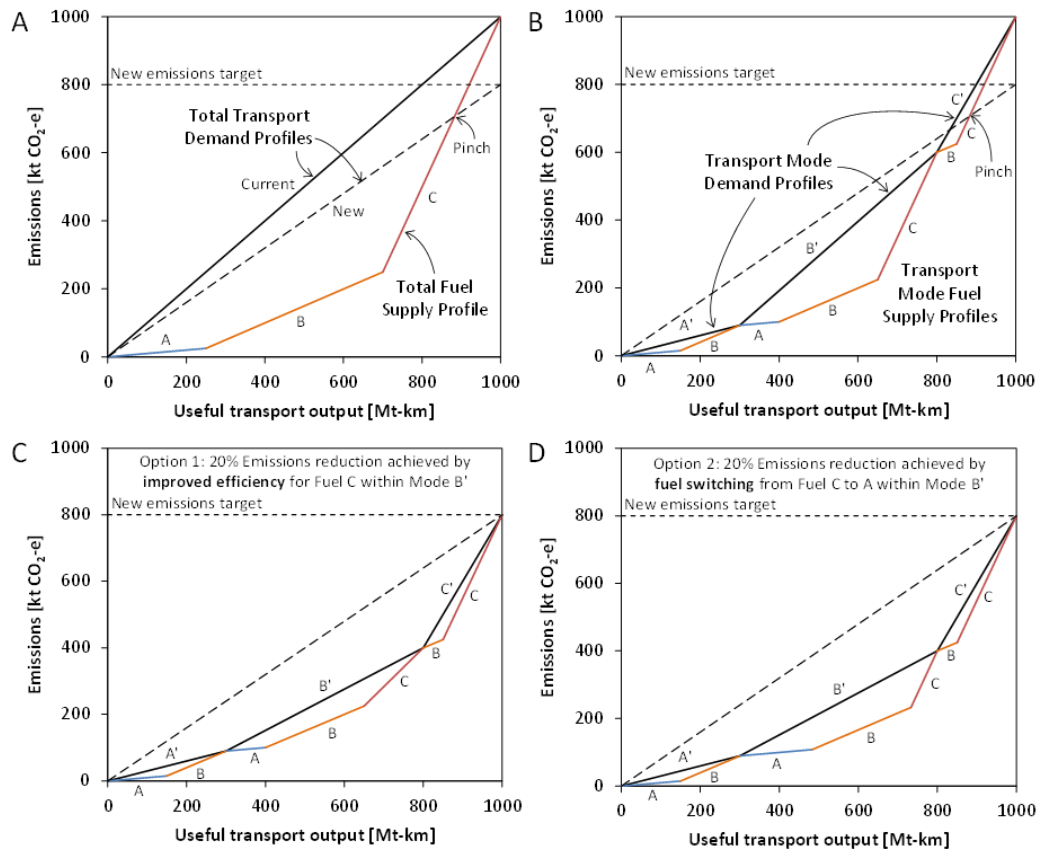


Figure 2.1: Methods for reducing emissions of a generic transport sector. (A) Total transport demand and fuel supply curves; (B) supply and demand profiles divided by transport classes; and, (C and D) two options for reducing emission.

2.3 Transport efficiencies and fuel emissions factors

There is a wide variety of transport modes (e.g. marine, air, road, and rail) and many classes of vehicles or vessels within these modes. For example, within the road transport mode there are light trucks, heavy trucks, and light commercial and passenger vehicles. Within these classes, there are further subclasses of specific vehicle or vessel makes and models made to common specification and/or performance.

At the vehicle class level, transport fuel use, emissions and useful transport output can be calculated with a reasonable degree of accuracy using the numerous data available from government agencies. This study uses transport data published by

the NZ Ministry of Transport and the Ministry of Business, Innovation and Employment and literature values of average transport fuel efficiencies in passenger-km/L and t-km/L, which are compared in Figure 2.2 for freight transport passenger transport. A log scale has been used to enable presentation of a wide range of transport modes on a single graph. Public transport methods like ferry, bus and rail potentially have good efficiencies provided passenger fill rates are high. Fill-rates for New Zealand's public transport are low, likely due to the comparatively low population density of New Zealand cities. Freight transport exhibit similar trends with ship and rail being the most efficient methods, followed by heavy and light truck, and air. LCV is a less energy efficient transport mode but most convenient. Transport class emission factors used in this study were calculated based on data from NZ's Ministry of Business, Innovation and Employment energy data set and are presented in Table 2.1. Useful transport output for passengers has been calculated by assuming passengers have an average mass of 75 kg.

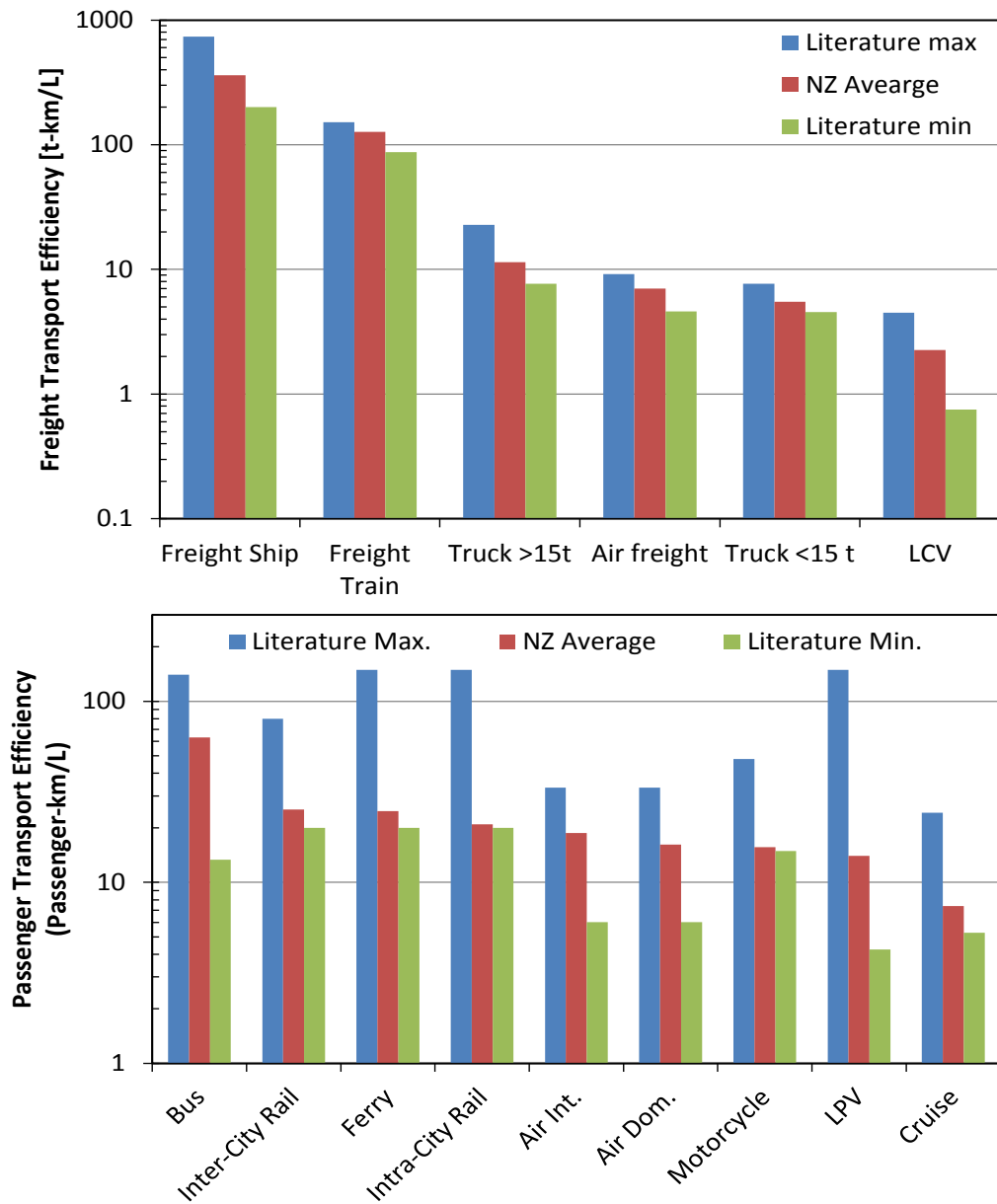


Figure 2.2: Freight (top) and passenger (bottom) transport efficiency by transport mode and class for New Zealand transport (Transport, 2013) compared literature values (US Department of Energy, Transportation Energy Data Book, 2013).

Table 2.1: Transport fuel emissions factors for fossil fuel energy supply.

TYPE	Class	E_{FT} [t CO₂-e/Gt-km]
<i>Freight Transport</i>		
Marine	Cargo ships domestic	9
Marine	Cargo ships international	11
Rail	Freight	18
Road	Truck B (>15 t)	200
Air	Freight	372
Road	Truck A (<15 t)	414
Road	Light Commercial Vehicles (LCV)	1013
<i>Passenger Transport</i>		
Marine	Ferry	21
Marine	Cruise ships international	137
Marine	Cruise ships domestic	137
Road	Bus	452
Rail	Commuter Inter-city	902
Air	International (Passenger + cargo)	936
Air	Domestic (Passenger + cargo)	1327
Rail	Commuter Intra-city	1361
Road	Motor cycle	1950
Road	Light Passenger Vehicles (LPV)	2177

2.4 New Zealand transport sector fuel and emissions growth projections

The New Zealand transport sector has experienced significant growth in fuel demand from 1974 to 2008 as illustrated in Figure 2.3. Petrol and diesel fuels dominate the growth in fuel use, followed by aviation fuels. Fuel oil declined in the 1980's and again increased in the 1990's. Responses to global recessions, oil price hikes and/or periods of economic restructuring are also evident in the fuel use data. As global oil prices rose in the late 1970's, economies like New Zealand were forced to spend more on foreign imported oil, which affected their balance of trade, which in turn forced other changes on the economy. The economic restructuring that took place in New Zealand in the 1980's was in many ways precipitated by the oil crisis of 1979.

The large increase in diesel fuel use and to a lesser extent petrol fuel use, as is seen in Figure 2.3, is related to the large increase in LPVs (light passenger vehicle) and LCVs (light commercial vehicle) that occurred during the 1990's and beyond when import regulations were relaxed in the early 1990s, along with road freight transport rules. Light vehicle numbers soared, especially diesel powered vehicles, and imported second-hand vans and trucks increased the overall freight transport supply at the expense of any growth in rail (Figure 2.4a).

The contribution of each transport mode to fuel use and emissions from 1990 to 2012 is illustrated in Figure 2.4. As discussed previously, road transport has dominated the growth in both fuel use and emissions. International air and marine have also risen most likely as a result of global tourism increases. Domestic air, marine and rail, have experienced only small increases. Significantly, about half of the international transport emissions are not formally included in New Zealand's emissions for this study. Only trips that fuel and begin in New Zealand, e.g. departing international flight, are counted.

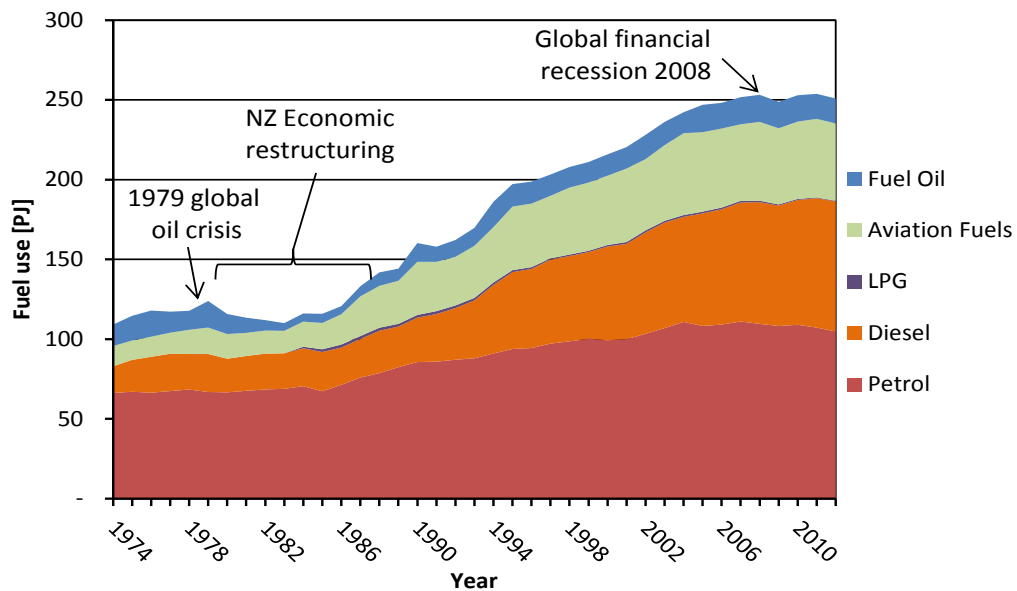


Figure 2.3: Transport fuel growth in NZ by fuel type from 1974 to 2013. Data taken from the NZ Ministry of Transport.

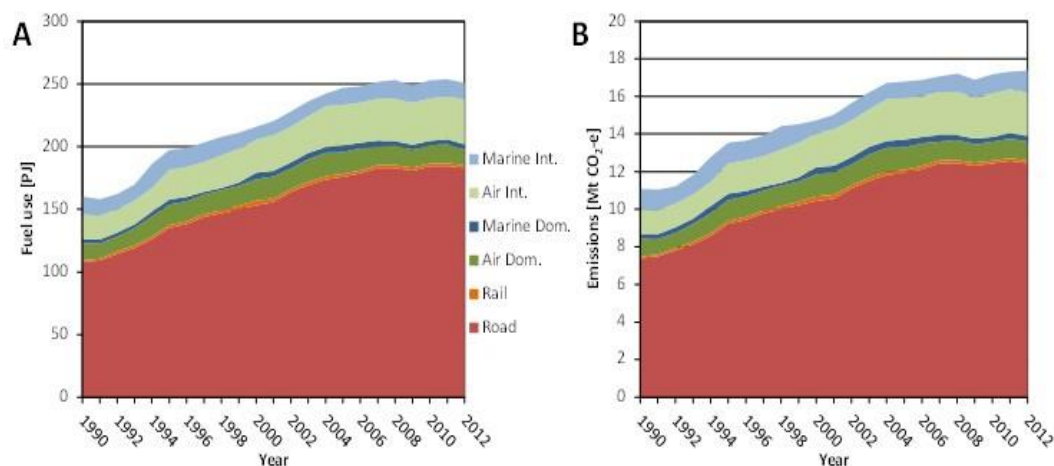


Figure 2.4: Transport fuel (a) and emissions (b) in NZ growth by transport mode from 1990 to 2012. Data taken from the NZ Ministry of Transport.

Since 2005 annual growth has slowed with negative growth in 2009 after the start of the global recession in 2008. Growth rates are expected to return to traditional levels from 2013 due to a rising population with continued reliance on fossil fuels for transport (Figure 2.5). The current population of 4.4 million is rising because of positive net migration and a higher than replacement birth rate of 2.1. It is projected by Statistics NZ, the country’s population is most likely to peak between 6 and 7 million after 2050. The increase in population will put pressure on energy, land and water resources.

For this study we have taken a conservative ‘business-as-usual’ approach and assumed passenger and freight transport demand will increase proportional with population through to 2050. This gives 2050 targets for CEPA of 107 G(passenger)-km for passenger transport demand and 126 Gt-km for freight transport demand, which equates to approximately 326 PJ of fuel use. Beyond population, transport demand is also closely tied to national and global economic states and the oil price, both of which have seen dramatic fluctuations over the past decade. Between the 1990 and 2005 transport demand per capita in terms of both freight and passenger transport increased by 29% and 25% respectively. From 2005 to 2012 the global financial crisis hit reducing freight and passenger transport demands per capita by 13% and 5% respectively. The future projections of transport demand have therefore a significant degree of uncertainty because of several forces that come into play that influence total transport demand.

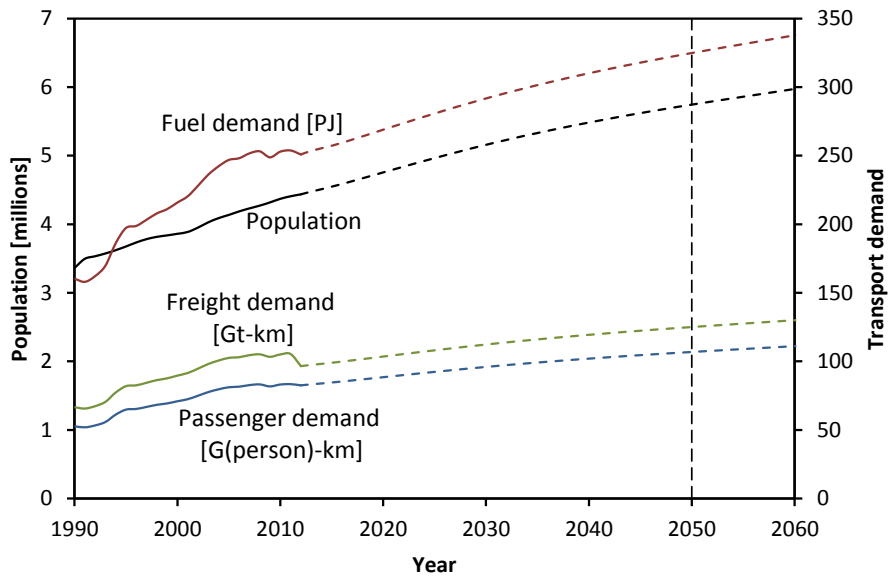


Figure 2.5: Projected population and transport demand growth in NZ to 2050 for business as usual.

2.5 Results and discussion for New Zealand transport case study

2.5.1 Carbon Emissions Pinch Analysis for the New Zealand transport sector in 2012

Using the CEPA composite curve method the freight and passenger transport demands in New Zealand for the year 2012 are illustrated in Figure 2.6. The fuel supply composite curve has not been included in Figure 2.6 because it cannot clearly be distinguished from the demand curve, which is due to all current transport fuels being derived from crude oil with very similar EFs within each vehicle class. Figure 2.6 shows passenger transport contributes 12% of the useful transport output but is responsible for 71% of transport emissions. The total freight transport demand and emissions for New Zealand in 2012 were 95.9 Mt-km and 5.0 Mt CO₂-e respectively (TEF = 0.052 Mt CO₂-e/Mt-km). The total passenger transport demand and emissions for New Zealand were 13.1 Gt-km and 12.4 Mt CO₂-e respectively (TEF = 0.944 Mt CO₂-e/Mt-km). In both cases the amount powered from renewable fuels was negligible.

EFs vary depending on the freight or passenger load factor, engine technology and tare weight differences rather than fuel differences. Marine transport is clearly very efficient at transporting both freight and people with marine vessels having the lowest emission factors in both demand classes. Freight rail is equally a low emissions transport method and road freight methods are the highest. It is important to note that although road freight methods have the highest emissions factors, they have additional cost benefits of being flexible giving point-to-point delivery with minimal handling stages.

With passenger transport, LPV stands out as generating 65% of passenger transport emissions, while delivering only 28% of the useful transport output. High EFs for rail and bus are principally caused by low participation rates as a result of high LPV use, and as a result the useful transport output from these classes is relatively small. Air transport, including domestic and international travel, contributes 27% of passenger transport emissions and provides 25% of the useful transport output.

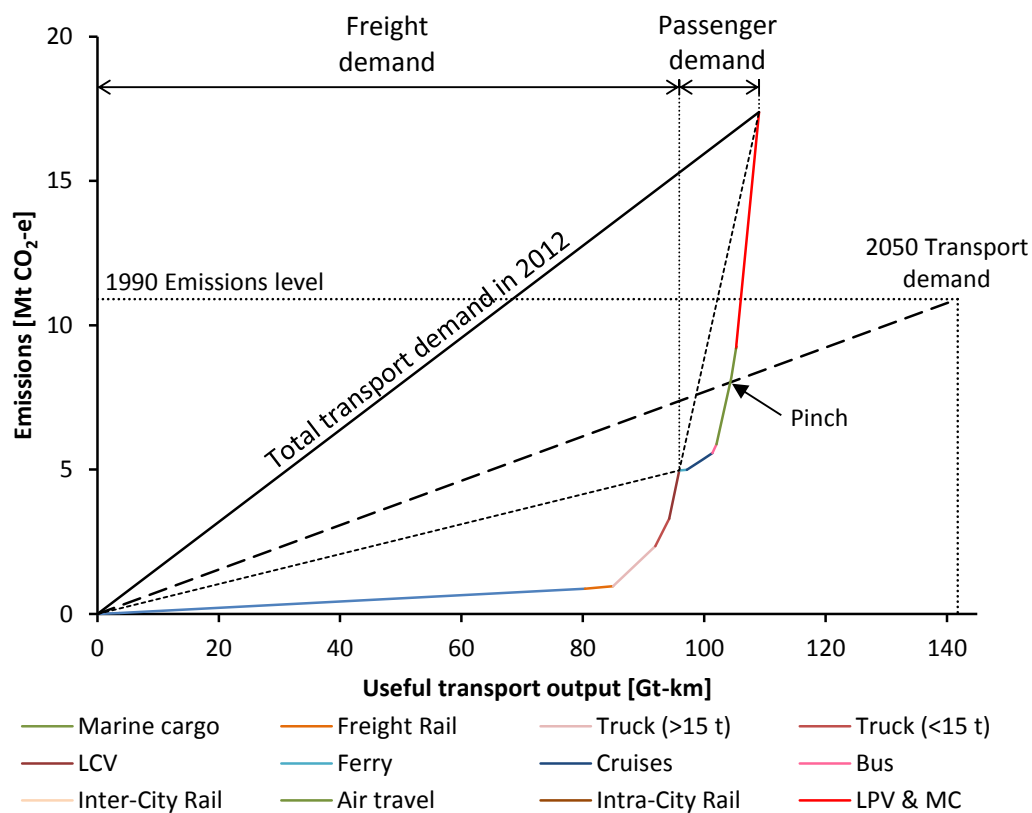


Figure 2.6: Combined emissions composite curve for freight and passenger transport demand by transport purpose and class in New Zealand for 2012 and the target for 2050.

2.5.2 Approaches to reducing CO₂-e emissions in transport energy sectors

2.5.2.1 Renewable liquid fuel production

Globally liquid fuels for transport vehicles are almost exclusively refined from crude oil. This refining process and the eventually fuel combustion emits a substantial amount of emissions. Producing drop-in liquid biofuels from sustainably grown biomass resources can begin to replace oil based fuels in the future when oil reserves are sufficiently low and the price of oil high enough for the economics of biofuel production to be economic. Jack and Hall (Jack & Hall, 2009) reported a detailed analysis of the potential biofuel production in NZ showing where and how much new afforestation may occur. Their results indicate that with the use of an additional 1.8 million hectares of low productivity land, currently returning less than NZ\$200 / (ha·y) mainly for sheep and beef farming, to produce woody biomass at a similar return rate, NZ could produce up to 232 PJ or 7.0 billion litres of petrol equivalent biofuel and could be economically competitive with conventional liquid fuels at an oil price of around US\$200 per barrel. Most biofuel conversion technologies are currently in the pre-commercialisation stage and, therefore, the efficiency of biofuel production and its cost competitiveness and rate of return for land use is likely to improve in the future.

2.5.2.2 Improved vehicle transport fuel efficiency

In the last decade the fuel efficiency of LPVs, LCVs and buses has been significantly improved by hybrid engine technology. HVs (hybrid vehicles) intelligently use a battery and electric motor in conjunction with a combustion engine to achieve high fuel efficiency. Based on data from the New Zealand Ministry of Transport, an estimate of 40 % reduction in fuel use can be obtained when switching from a normal combustion engine vehicle to a hybrid vehicle for the same total distance travelled under normal use. With rising fuel prices, it is anticipated that at least half of the LPVs, LCVs and Buses will contain some form of hybrid engine by 2050.

2.5.2.3 Increased integration of electricity in transport vehicles

Integration of electricity into the transport sector has traditionally focused on the electrification of rail. New Zealand has some opportunities to convert fossil fuel driven rail to electric rail and for purposes of this study it is assumed that by 2050 conversion has taken place. Beyond electrification of rail, there is growing popularity around the future adoption of EV (electric vehicles). Some organisations and politicians have campaigned on the misleading notion that EVs have zero emissions. In this section it is shown the actual emissions from an EV over its life are dependent on the weight of the car and battery, and the overall grid emissions factor (GEF) for electricity production in a given country. Where it means that additional coal will be burned to supply electricity to an EV, the overall emissions will be greater than the typical petrol engine car.

It is important when considering alternate LPVs that the lifecycle GHG emissions are included, especially for EVs where increased emissions occurs with the manufacture and replacement of the batteries. As the range of the vehicle in electric mode increases the mass of the battery must become greater. There is a large variation in the reported GHG emissions of battery manufacture from 6 kg CO₂-e/kg_{bat} to 22 kg CO₂-e/kg_{bat}. The variation is due in part to the different assumptions and system boundaries used in the LCA studies. A value of 15 kg CO₂-e/kg_{bat} has been used in this chapter. The GHG emissions associated with the production of the car is assumed to be 5 kg CO₂-e/kg_{bat} and is within the range of 4 to 6.5 kg CO₂-e/kg_{bat} reported in the literature. The extra battery emissions will normally be attributed to the country that makes the batteries, but in this analysis these emissions have been included as an operating and battery emissions factor (Table 2.2).

Table 2.2: Estimated emission factors for three light passenger vehicles.

	Embedded Car Emissions^a [kt CO ₂ -e]	Embedded Battery Emissions^b [kt CO ₂ -e]	Fuel Consumption [L/km] [kWh/km]	Operating Emissions Factor^c [kt CO ₂ -e/ 100 km]	Life Cycle Emissions Factor [kt CO ₂ -e/ 100 km]	Operating & Battery Emissions Factor [kt CO ₂ -e/ 100 km]
ICE (Internal combustion engine)	7500	-	0.072 L/km	17.57	21.32	17.57
P-HV (Plug-in Hybrid Vehicle)	7500	1800	0.0214 L/km 0.20 kWh/km	5.74	10.39	6.64
EV (Electric vehicle)	7800	8100	0.24 kWh/km	1.16	9.11	5.36

^a Based on 5 kg CO₂-e/kg_{car}

^b Based on 15 kg CO₂-e /kg_{bat}

^c Based on NZ 2050 GEF 0.049 kg CO₂-e/kWh, 50% EV mode for P-HV, Petrol EF 2.44 kg CO₂-e/L

The emissions as a function of distance for ICE (Internal Combustion Engine) vehicles, PHEV's, and EV's are presented in Figure 2.7 based on the 2050 GEF of 0.049 kt CO₂-e/GWh_e. The various emissions factors used to construct are given in Table 2.2. The slopes of the solid lines represent the operating EF for each vehicle type. The dashed lines in the Figure 2.7 represent the operating and amortised battery emissions for PHEV's and EVs, and is used to determine the actual GHG reductions possible by switching from ICE to PHEV's and EV's. The total reduction in GHG emissions over the total life of the vehicle is 49% and 43% for PHEV's and EV's respectively. The EV has greater final overall emissions than the PHEV's due to the significant increase in the emissions associated with the manufacture and replacement of the batteries. The overall lifecycle contribution of the fuel decreases as vehicles become more electrified. The fuel contribution for the ICE is 82 %, while the PHEV's and EV's have fuel contributions of 55 % and 13 % respectively.

The slope of the EV line in Figure 2.7 is derived from the GEF for electricity production. As the GEF increases, the slope of the EV (and PHEV) line also increases. For countries where the GEF is greater than 0.566 kt CO₂-e/GWh_e, the adoption of EVs is counter-productive in terms of reducing overall emissions. At present New Zealand has a GEF for electricity of 0.129 kt CO₂-e/GWh_e, Australia has a GEF of 0.811 kt CO₂-e/GWh_e, and the USA has a GEF of 0.530

kt CO₂-e/GWh_e (Walmsley *et al.*, 2014). Converting significant proportions of the electricity grids in Australia and the USA to renewables (e.g. wind and solar) and/or low carbon emitting fuels and generation technologies (e.g. nuclear power plant and coal power plant with CCS) are needed before EVs present themselves as a viable solution to reducing carbon emissions.

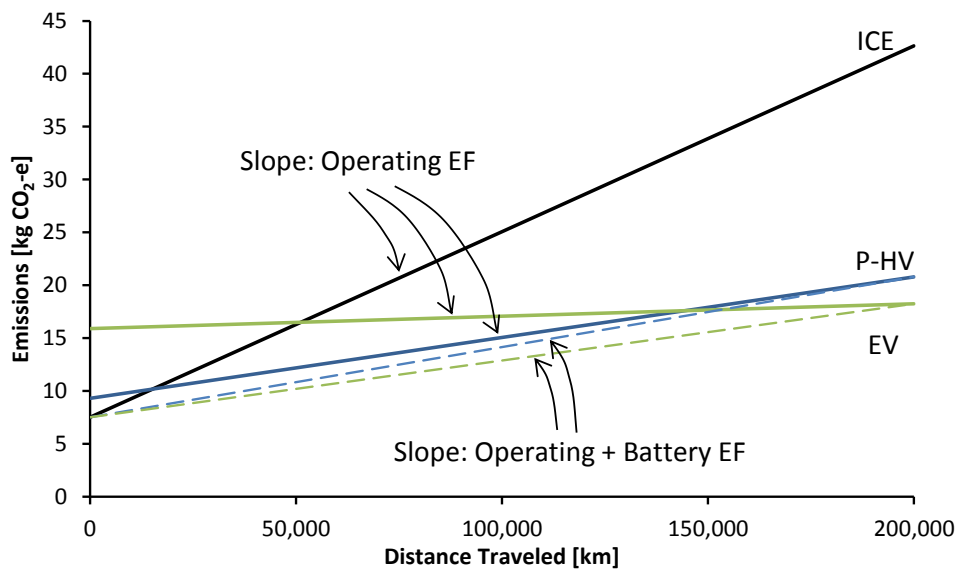


Figure 2.7: Emissions for LPVs based on the 2050 estimated electricity GEF for NZ (0.049 kg CO₂-e/kWh).

2.5.3 Transport planning for New Zealand through to 2050 with reduced carbon emissions

Three scenarios are illustrated in Table 2.3 and Figure 2.8 for achieving transport emissions reduction to 1990 levels by 2050 using the CEPA graphical method. A variety of transport fuel mixes are possible for reaching the demand and emissions target.

In Scenarios A and B, it is assumed 40% of the LPV, LCV and bus fleets will be hybrid vehicles, which improves the overall energy efficiency of these classes and results in a fuel savings 77 PJ. Scenarios A and B also assume PHEV's and, to a lesser extent, EVs in the LPV class (~40%) will enable replacement of 46 PJ of liquid fuels with 18 PJ (5.1 TWh) of electricity use. Freight and city rail is also electrified replacing a thermal fuel need of 2.9 PJ with 1 PJ (0.3 TWh) of electricity

use. An increase in demand of 5.4 TWh is equivalent to 7.3% of estimates of the NZ electricity grid (75 TWh) in 2050. The 2050 electricity demand projection from Walmsley et al. of 75 TWh assumed an uptake of electric powered vehicles of 6.5 TWh, which is close to the estimate in this work. The remainder of the transport demand for Scenarios A is met using oil derived fuels of 155 PJ and the minimum amount of biofuels of 47 PJ that is required to keep within the emissions target based on 1990 levels. In Scenario B, the remainder of the transport demand is met using Fischer-Tropsch (FT) liquid fuels from coal (31 PJ) and biofuels (169 PJ) while keeping under the emissions target. Scenario C is the same as A with the exception of assuming a 20% uptake of HVs, PHEVs, and EVs in the LPV, LCV and bus fleets, which means the energy savings is half the amount that was originally quantified. The lower uptake of energy efficiency technologies means an additional 53 PJ of input energy is needed in Scenario C compared to the first two scenarios (Figure 2.8). As a result, the minimum required biofuel production to keep within the emissions target is 106 PJ.

Table 2.3: Options for NZ to meet 1990 emissions level in 2050. Energy units PJ use a thermal basis.

	PHEV and EV fuel savings	Fuel replaced by electrification	Oil and gas fuels	F-T Coal	Biofuels needed
Scenario A	77 PJ	49 PJ (5.4 TWh _e)	155 PJ	-	47 PJ
Scenario B	77 PJ	49 PJ (5.4 TWh _e)	-	31 PJ	169 PJ
Scenario C	--	26 PJ (2.9 TWh _e)	-	31 PJ	106 PJ

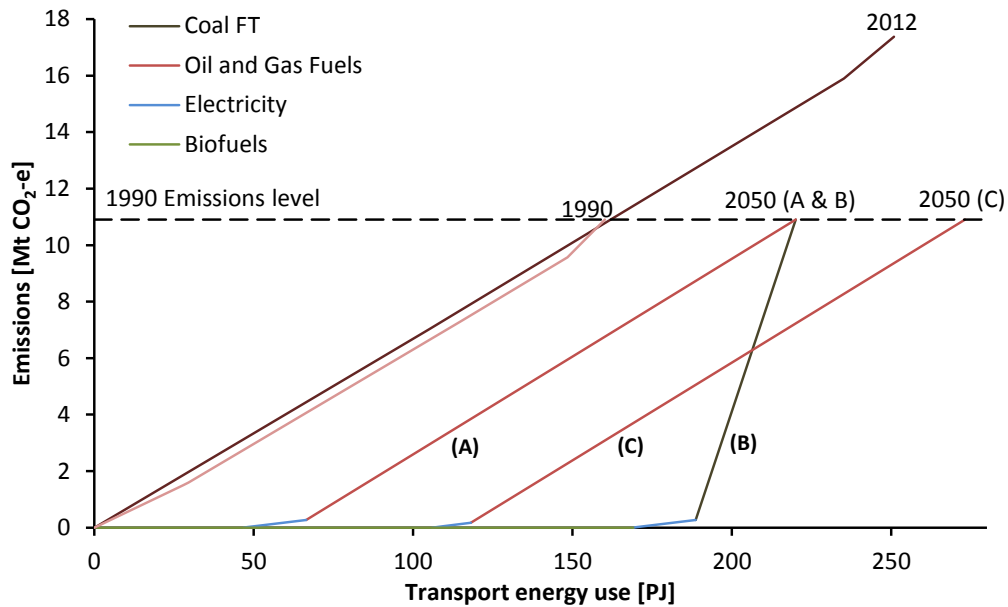


Figure 2.8: Emissions – transport energy use composite curves to meet 2050 over all transport demand for a 1990 emissions target.

The anticipated transport supply and demand profiles for freight and passenger transport from Scenario A in 2050 is plotted in Figure 2.8. Where a transport mode and class requires a liquid fuel, a blended fuels is assumed and its emissions is determined using a weighted emissions factor (53.5 kt CO₂-e/PJ) for renewable biofuel (zero emissions) and liquid fuel from oil (69.3 kt CO₂-e/PJ). LPVs benefit significantly from increased overall efficiency from the uptake of hybrid systems and from the integration of electricity as a main power source.

The presented scenarios assume that existing transport modes continue to be used in a similar manner and similar amount per capita as in 2012. Further emissions reduction can be achieved with further transport class switching; for example, more freight by rail and marine rather than truck and LCV and more public transport by light rail and bus, especially in New Zealand’s largest cities, i.e. Auckland, Wellington, Christchurch and Hamilton. The challenge of meeting the 1990 emissions level in 2050 critically depends on the uptake of energy efficient vehicles and production of biofuels. This needs to be done with the minimum amount of extra energy being expended by the economy to ensure that the transition to a new fuel source does not reduce New Zealand’s economic competitiveness.

The anticipated transport supply and demand profiles for freight and passenger transport from Scenario A in 2050 is plotted in Figure 2.9. Where a transport mode and class requires a liquid fuel, a blended fuels is assumed and its emissions is determined using a weighted emissions factor (53.5 kt CO₂-e/PJ) for renewable biofuel (zero emissions) and liquid fuel from oil (69.3 kt CO₂-e/PJ). LPVs benefit significantly from increased overall efficiency from the uptake of hybrid systems and from the integration of electricity as a main power source.

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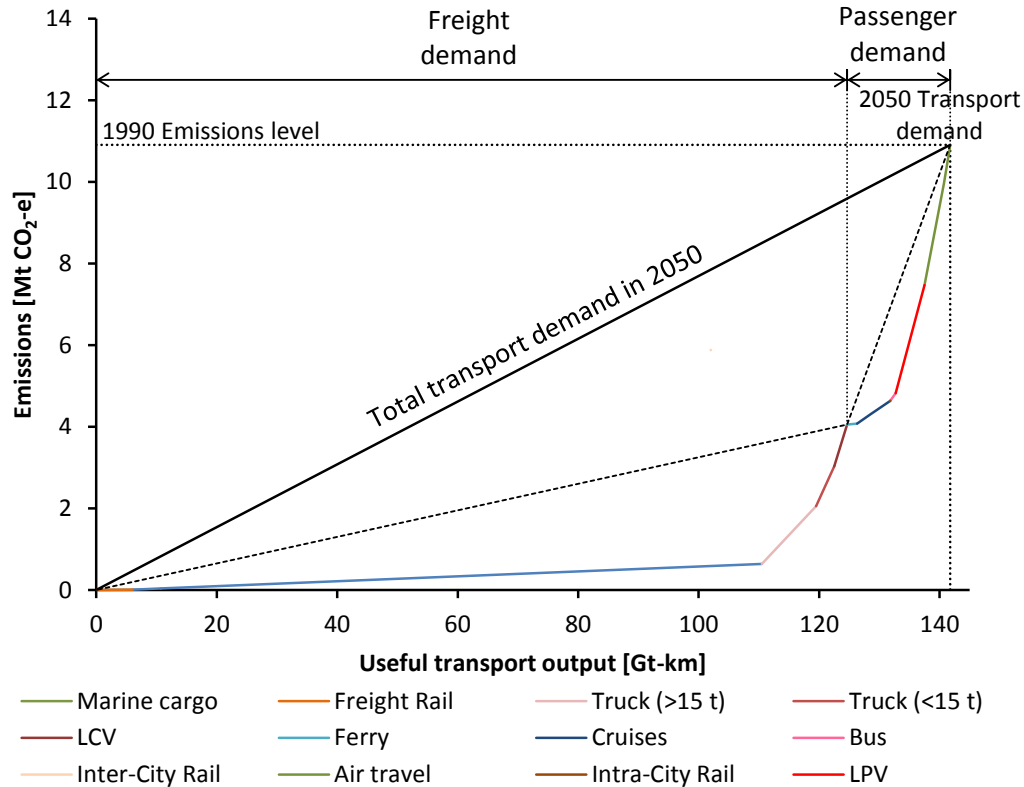


Figure 2.9: Combined emissions composite curve for freight and passenger transport supply and demand in New Zealand for 2050 Scenario A, i.e. minimum biofuels production.

2.6 Summary

Freight and passenger transport demand in New Zealand is anticipated to increase by 30% from 2012 to 2050 due to population growth. An important element of reducing carbon emissions attributed to transport in New Zealand is electrification of all rail and partial electrification of light passenger vehicles through plug-in hybrid and electric vehicle technologies to the degree of 5.4 TWh_e, which replaces the equivalent of 49 PJ of conventional liquid fuels. New Zealand’s electricity is supplied by a high proportion of hydro and geothermal renewable generation, which in turn can help lower emissions from the transport sector when effectively integrated. With an uptake of 40% for all light passenger vehicles, buses and light commercial vehicles, hybrid engine technology is estimated to reduce liquid fuel use by 77 PJ in 2050 compared to using current transport technologies. In 2050 total transport energy use as a combination of liquid fuels and electricity is calculated to be 220 PJ. To reach the goal of reducing carbon emissions to 1990 levels in 2050, 47 PJ of biofuels is needed together with 174 PJ of conventional liquid fuels from oil.

Chapter 3

Emission Reduction via PHEV's and EV's

3.1 Introduction

One way to reduce dependence on petroleum/fossil fuels is by the use of electric vehicles (EVs) and Plug-in hybrid vehicles (PHEV's) which in turn has the potential to reduce carbon dioxide if a countries grid emissions factor for electricity is low. Or in other words electricity is made primarily from renewable and/or nuclear energy. EV technology has been around for some time in various places around the world. Different countries are introducing EV's at their own pace, and some are giving financial incentives to increase the rate of uptake. For example, California provides tax incentives on the purchase of hybrid electric cars (HEVs) (Diamond, 2009), which has the double benefit of reducing carbon emissions and enhancing air quality. As of 2014 there were about 184 PHEV's and 150 EV's in New Zealand (Ministry of Transport, 2015).

This chapter investigates how much carbon dioxide could be reduced if ICEV's are replaced with PHEV's and EV's in New Zealand. Different scenarios, such as type of vehicle and length of battery life, are modelled to determine the potential reduction in carbon dioxide emissions form light passenger vehicles

3.2 Vehicle Types

In New Zealand there are about 2.8 million light vehicles (2013). Most of them are internal combustion engine vehicles which run solely on fossil fuel. However, there are other kinds of vehicles that use battery power to operate as shown in Figure 3.1. This type of vehicle is called battery EV's.

EV's run solely on batteries and as a consequence EVs require larger battery so that it has enough power to propel the vehicle. Batteries are charged from an external power source, so there are no tailpipe emissions. An example of this is Nissan Leaf, which is available in New Zealand.

Hybrid electric vehicle (HEV's) are another kind of vehicle, which uses both battery power and an internal combustion engine. The batteries are charged using the internal combustion engine and a regenerative braking system. Its advantage is that it can charge its battery from the car braking mechanism. Hybrid technology has been available for 15 years (Husain, 2011) and has found widespread uptake in some areas, such as California, due in part to government incentives. The Toyota Prius is a well-known HEV's.

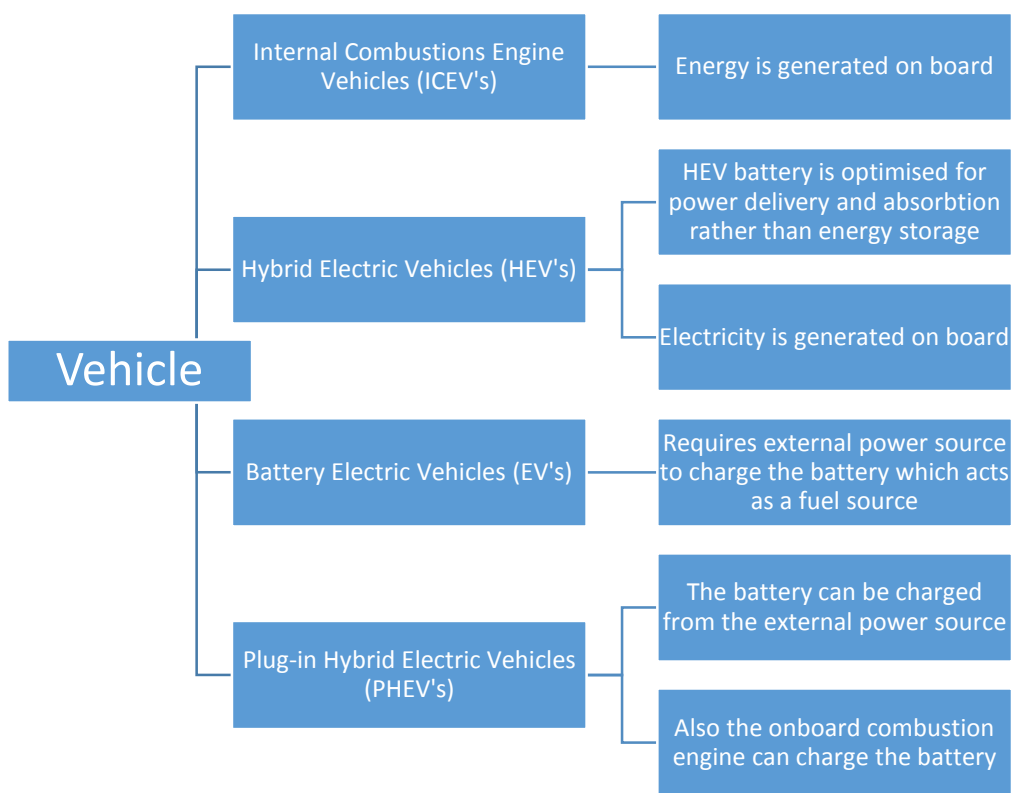


Figure 3.1: Different types of vehicles available in NZ.

A further development of HEV are batteries that can be charged externally. These are called plug-in hybrid electric vehicles (PHEV's). PHEV's are gaining attention all over the world due to their ability to reduce fuel consumption by using electricity from the grid and possible reduction in carbon dioxide emission (Ma *et al.*, 2012). With a charging efficiency of about 85 percent from grid to the battery these vehicles can save between 45 to 70 percent of the fuel compared to HEV's (Zhang *et al.*, 2011). PHEV's are also called extended range vehicles, because they can

travel up to 600km, similar to a petrol or diesel vehicle (Armand & Tarascon, 2008). The on-board battery, which can store the energy from the external source, makes the vehicle capable of travelling between 50 and 80 km solely in electric mode depending on driver behaviour and road conditions.

There are several different kinds of PHEV's available on the market. Prices can range from \$30,000 to \$100,000 NZD as shown in Table 3.1. PHEV's are of two types: parallel drivetrains and series drive trains. PHEV can have parallel drive trains and series drive trains. In a parallel drive train the battery or the internal combustion engine ICE can both drive the wheel depending on the power needed. However, in series drive train only the battery will be able to drive the wheel. The ICE will only charge the battery which will then run the axle.

Table 3.1: Different kinds of EVs and PHEVs available in the market (Lemon & Miller, 2013a).

Model	Type	Battery (kWh)	Electric Range (km)	Efficiency (kWh/km)
Mitsubishi i-MIEV	EV	16	100-160	0.168
Nissan Leaf	EV	24	115-175	0.189
Tesla Model S (40kWh)	EV	40	260	0.24
Chevrolet Volt	PHEV	16.5	60	0.22
Toyota Prius Plug-in	PHEV	4.4	20	0.27
Fisker Karma	PHEV	20.1	80	0.40

The most common type of vehicle available in the market are internal combustion engine vehicles (ICEV's). They are the most reliable and trusted technology. They use an on-board engine to supply the energy demands of the vehicle. For electric vehicles to compete with internal combustion engines they need to have the same or better performance qualities as the ICEV. This is where the type and size of batteries become a critical factor in determining how much energy the vehicle can store.

3.3 Batteries

For EV's and PHEV's to become widespread and successful, they need to have sufficient battery power, to enable thrust and longer running without the need for charging. This will enable the vehicle to have comparable performance to conventional vehicles and run longer distances without being charged. At present lithium-ion batteries appear to offer the best technical option for widespread uptake of EV's and PHEV's. Different types of lithium-ion battery chemistries have different dimensions in terms of cost, lifespan, performance, safety, specific power and specific energy as shown in the Figure 3.2.

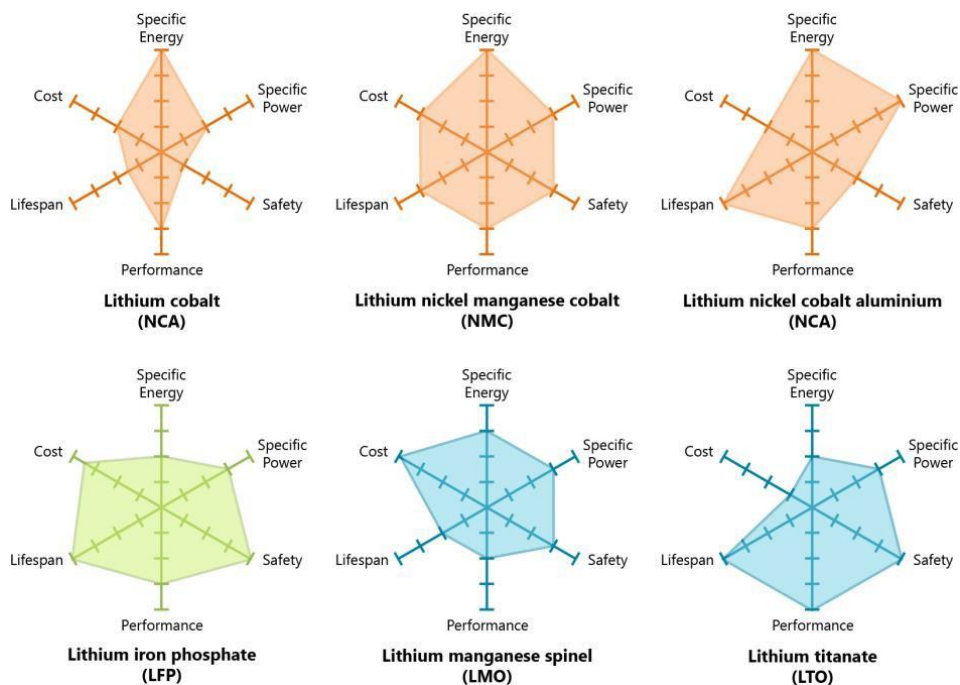


Figure 3.2: Different type of lithium-ion battery chemistries. Note that the further the chart extends along an axis the better the performance in that dimension (Lemon & Miller, 2013b).

Battery technology has improved significantly in recent years due to new products being made which have special battery requirements. For example, PHEV's require batteries with high energy density, where the battery is light in mass and small in size compared to the energy stored. To compete economically against other vehicle types it has been estimated that energy storage costs need to be around US\$300/kWh (International Energy Agency, 2013), and it is estimated that by 2020 it will reach US\$150/kWh.

Lithium Cobalt oxide is the oldest type of lithium-ion battery that has been produced since 1991 (Väyrynen & Salminen, 2012). Due to the high demand of energy densities of these batteries, other structures have been developed since such as $\text{LiCo}_{1/3}\text{Mn}_{1/3}\text{O}_2$ (NCM), LiMn_2O_4 (LMO).

The chemistry for the lithium-ion battery is the same as any other battery. Generally, the electrodes of Li-ion batteries are coated with metal foil such as copper foil for the negative electrode and aluminium foil for the positive electrode, separated by an electrolyte as shown in Figure 3.3.

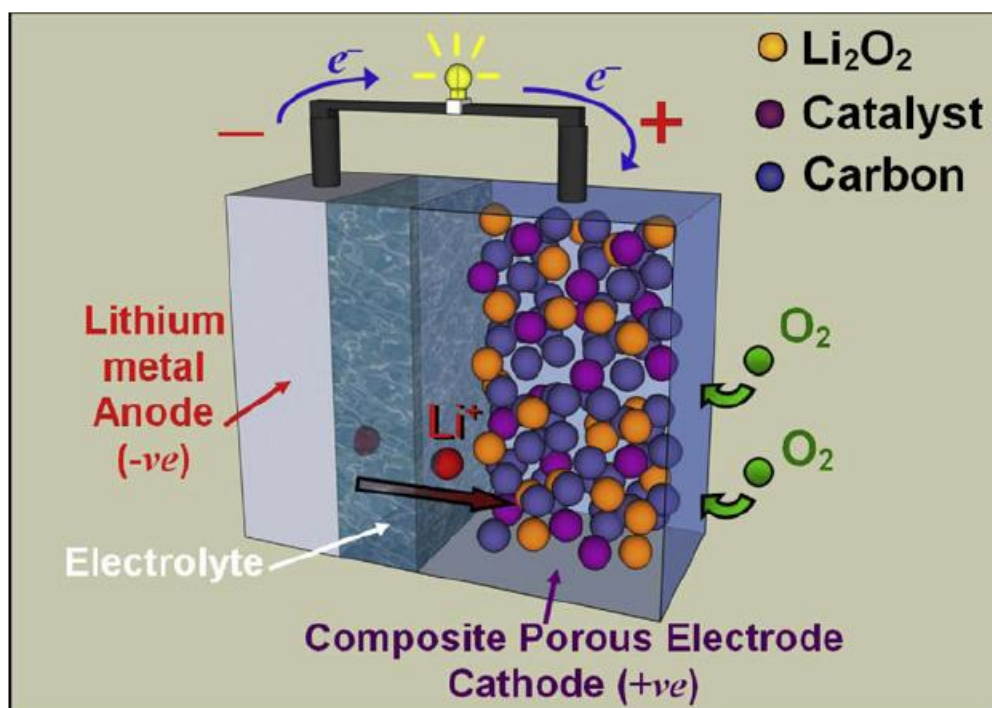


Figure 3.3: Lithium-ion battery design (Scrosati & Garche, 2010).

Typical electrolytes are derived from the solution of LiPF_6 salt in a solvent blend of ethylene carbonate and various linear carbonates such as dimethyl carbonate (Zhang *et al.*, 2002). The electrodes are rolled at the end of the coating and goes through many intermediate steps before it is ready to be used. Once it is ready it is then assembled with other parts such as a separator, cover bag, electrolyte and other components to form a cell. These cells can then be arranged in series to form battery.

The energy densities of different kinds of batteries are shown in Figure 3.4. Lithium-ion batteries have advantages over other batteries in terms of safety features and energy storage.

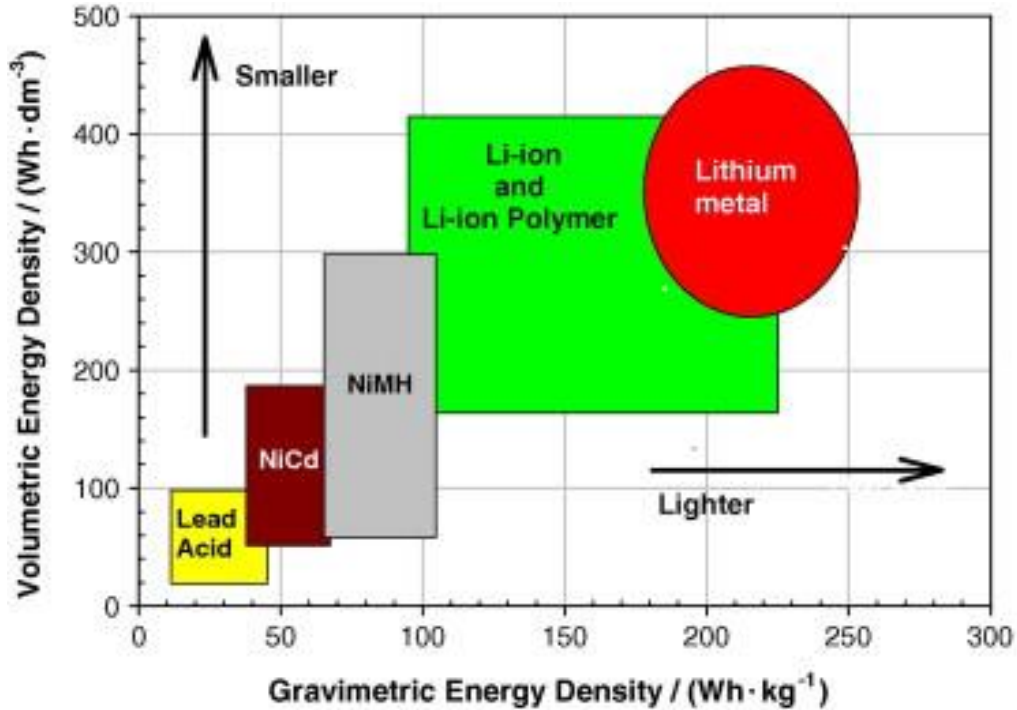


Figure 3.4: Energy density of lithium-ion batteries (Väyrynen & Salminen, 2012).

Lithium ion battery systems have gravimetric and volumetric energy densities of between approximately 100 to 225 Wh/kg and 180 to 420 Wh/dm³ respectively. This improved energy density compared to traditional battery systems, such as lead acid and Nickel Cadmium (NiCd), give huge advantages for applications where mobility is concerned such as consumer electronics and passenger vehicles. They also emit less CO₂ per energy density during manufacturing when compared to other kinds of batteries as shown in Table 3.3.

Table 3.2: Energy density and carbon emissions due to manufacturing.

Battery Type	Energy Density (Wh) per kg of battery Low--High	CO ₂ emitted (kg) per kg of battery Low--High	CO ₂ emitted (kg) per energy (Wh) Low--High
Lithium-ion	120--190	7--20	0.05—0.11
Lead Acid	10--35	1--5	0.1—0.14
Nickel cadmium	35--55	6--13	0.17—0.26
Nickel-metal hydride	55--85	10--19	0.19—0.22

However, if we compare different batteries with the amount of CO₂ produced per kg of battery, lead acid battery produced the least amount of CO₂ as shown in Figure 3.5.

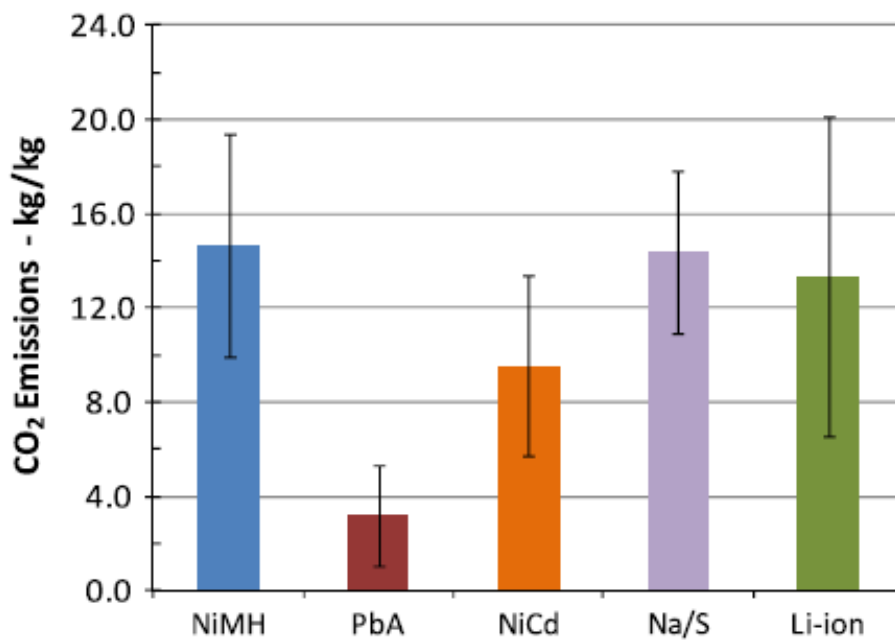


Figure 3.5: Different amounts of carbon dioxide emitted by different kinds of batteries (Sullivan & Gaines, 2012).

3.4 Life Cycle Assessment of Carbon-dioxide

Life-cycle assessment (LCA) is a technique for systematically analysing a product from cradle-to-grave, that is, from resource extraction through manufacture, and use through to disposal (Owens, 1997). In this research, the carbon dioxide emission from vehicles under study will be analysed. Carbon dioxide is emitted at various stages of the life time of a vehicle as shown in Figure 3.6. Total embedded or emitted carbon dioxide emissions can be calculated using the following equation:

$$CO_2 \text{ embedded} = CO_2 \text{ manufacture} + CO_2 \text{ running} + CO_2 \text{ end of life} \quad (2-1)$$

Where $CO_2 \text{ embedded}$ is the total carbon dioxide emitted over its life time, $CO_2 \text{ manufacture}$ is the carbon dioxide emitted at its production phase including any extra batteries and $CO_2 \text{ running}$ is the carbon dioxide emitted while the vehicle is in use and $CO_2 \text{ end of life}$ is the carbon dioxide emitted when the vehicle is dismantled or disposed. Currently, about 75 to 80 percent of the vehicle is recycled when it reaches end of its life (Gerrard & Kandlikar, 2007). Since a lot of materials from the disposed vehicle are recycled, this study will not take into consideration the carbon dioxide emitted from the end of life of vehicles.

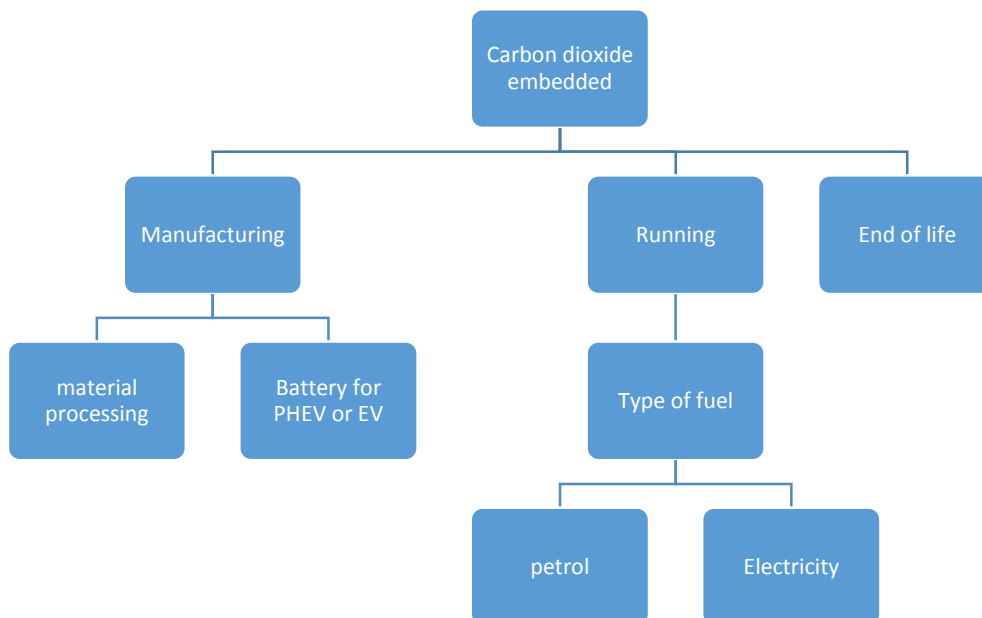


Figure 3.6: Carbon dioxide emission at different stages of a vehicle during LCA.

3.4.1 Carbon-dioxide Emissions from Manufacturing

Life cycle emissions of carbon dioxide from the vehicle manufacture can be very complex. Cars are made up of several different parts which are then assembled together. Parts are made at different locations or countries and they require different raw materials and expertise. This makes the predictions of carbon dioxide emissions from the vehicle manufacture very difficult to generalise for different car models. However, there are studies done about LCA on particular type vehicles such as Mercedes Benz as shown in Figure 3.7.

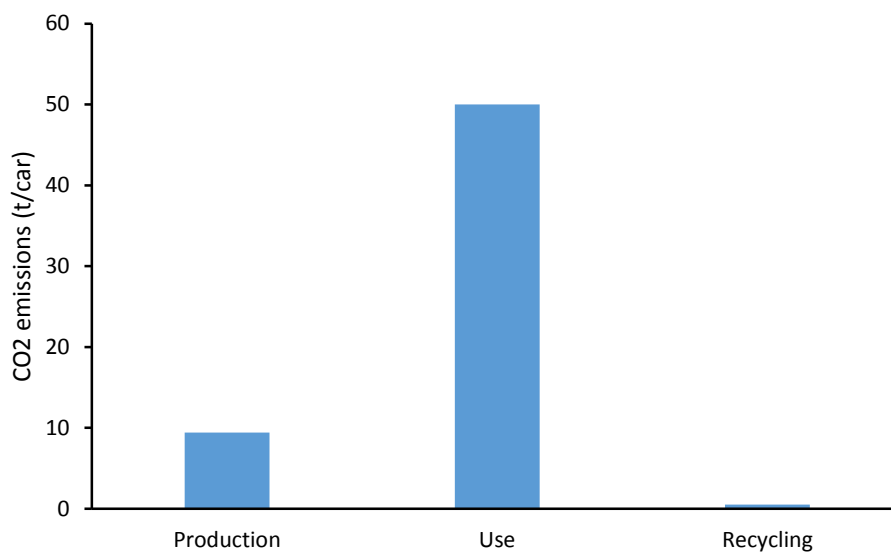


Figure 3.7: CO₂ emission from Mercedes Benz (Daimler AG, 2013).

Equation 2.2 shows how carbon dioxide is calculated in the manufacturing process.

$$CO_2 \text{ car manufacture} = EF_{\text{vehicle}} \times M_{\text{vehicle}} \quad (2.2)$$

Where EF_{vehicle} is emissions factor of the vehicle when it is being manufactured per kg (kgCO₂/kg_{car}) it is taken as 5 kgCO₂/kg_{car} (Hawkins *et al.*, 2013), M_{vehicle} is the mass of the vehicle (kg).

Table 3.3 shows how much carbon dioxide produced by different vehicles under study using the 5 kgCO₂/kg_{car}. However, for PHEV's and EV's the battery will also

contribute towards the manufacturing process of the vehicle. As expected the bigger the car mass the higher CO₂ emitted during manufacturing process.

Table 3.3: CO₂ emission from manufacturing of the vehicles.

	Toyota corolla GXL	Toyota Prius Hybrid	Toyota Prius PHEV	Holden Volt PHEV	Nissan Leaf
Curb Mass (kg)	1500	1500	1436	1721	1534
CO ₂ emitted when manufacturing a car (kg)	7500	7500	7180	8605	7670

3.4.2 Battery

The most common type of batteries used for PHEV's and EV's are lithium batteries. Lithium-ion batteries uses a variety of raw materials in its production. At different stages of the production different amounts of carbon dioxide are emitted. These stages could be summarised as follows-

- Extraction of raw material
- Transportation of materials
- Battery assembly

According to Dunn the amount of CO₂ produced while producing lithium-ion batteries varies at different stages (Dunn *et al.*, 2012). Figure 3.8 shows that different raw materials needed for the production of the lithium-ion battery emits different amounts of carbon dioxide. Since the proportion of wrought aluminium's is greater in the batteries, it is the major contributor of carbon dioxide. However, if aluminium is made in a country where most of the electricity generated is from renewable sources then this may not be the case.

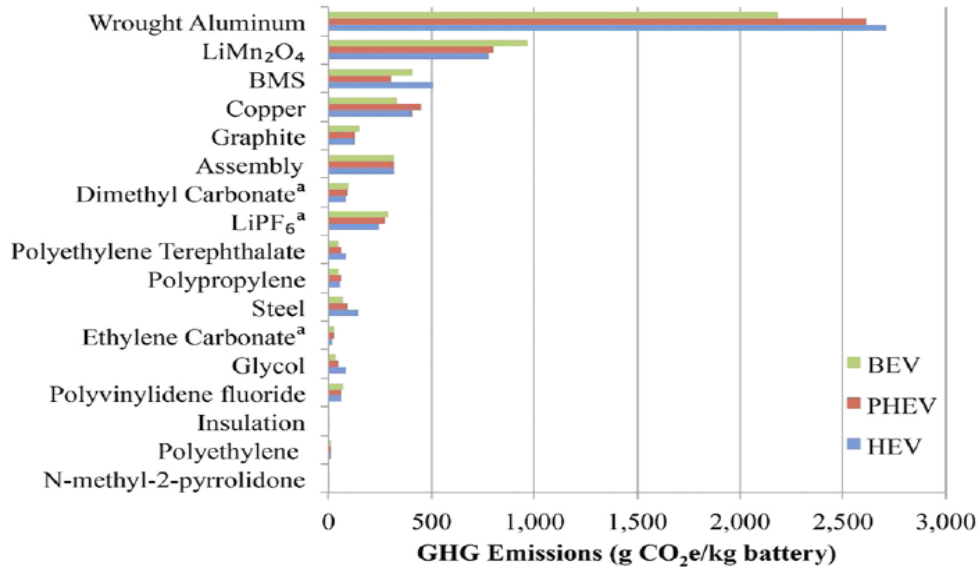


Figure 3.8: Carbon dioxide emissions from different components of batteries (Dunn, et al., 2012).

Researchers have come up with different values for carbon dioxide emission for the production of lithium-ion batteries. This is due to the complexity in battery production and methodology used. The average value of these is taken into consideration is shown in Table 3.4.

Table 3.4: Carbon dioxide emitted due to manufacture Lithium-ion batteries.

Researcher	Amount of CO ₂ produced per kg of battery [kg of CO ₂ /kg of battery]
(Dunn, et al., 2012)	~5.1kg
(McManus, 2012)	~12.5kg
(Sullivan & Gaines, 2012)	~13kg
Average values	~10.2kg

Equation 2.3 show how the CO₂ emission is calculated using the mass of the batteries of different vehicles.

$$CO_2 \text{ battery manufacture} = EF_{\text{battery}} \times M_{\text{Battery}} \quad (2.3)$$

Where $EF_{battery}$ is the emissions factor of the battery when manufactured per kg [kgCO₂/kg_{battery}] which is taken as 10.2 kgCO₂/kg_{battery} and $M_{battery}$ is the mass of the vehicle [kg]. The amount of CO₂ emitted during manufacturing process of batteries for PHEV's and EV's are shown in Table 3.5.

Table 3.5: Carbon dioxide emitted for on batteries and car chaises.

	Toyota Prius PHEV	Holden Volt PHEV	Nissan Leaf
Battery Mass (kg)	79	198	288
CO ₂ emitted when manufacturing a car (kg)	805	2019	2937

3.4.3 Emissions from Running Vehicle

Energy is needed to do work, in this case, to run a vehicle. This energy can be in a form of chemical or electrical. Most conventional vehicles use chemical energy which is derived from fossil fuels. However, some uses electrical energy which can be generated from either renewable source of energy or fossil fuel. Two kinds of fuel sources are used by the vehicles under study, petrol and electricity. When these fuel source are used to run vehicles they emit carbon dioxide either directly or indirectly. The fuel source can be used individually or in combination to run a vehicle as shown in equation 2.4.

$$CO_{2\ running} = CO_{2\ ice} + CO_{2\ electricity\ grid} \quad (2.4)$$

Where $CO_{2\ running}$ is the carbon dioxide emitted in the running mode $CO_{2\ ice}$ is CO₂ emitted due to internal combustion engine and $CO_{2\ electricity\ grid}$ is CO₂ emitted due to battery being charged from electricity.

3.4.3.1 Emission from Petrol

Ideally for working engines, petrol hydrocarbons are combusted with oxygen forming only carbon dioxide and water. When a litre of petrol is fully combusted, it will produce 2.44kg of CO₂. Equation 2.5 shows the amount of carbon dioxide emitted while running an internal combustion engine.

$$CO_{2\ ice} = (EF_{ICE} \times \eta_{fuel} \times d_{travelled-ICE}) \quad (2.5)$$

Where EF_{ICE} is the emission factor of the internal combustion engine (ICE) [kgCO₂/L] which is taken to be 2.44 kgCO₂/L, η_{fuel} is the amount of fuel needed to travel a kilometre or fuel economy [L/km]. The fuel economy depends on the vehicle type and engine size as shown in Table 3.6. $d_{travelled-ICE}$ is the distance travelled in the ICE mode [km].

Table 3.6: Fuel economy of the engine (U.S. Department of Energy, 2014) (New Zealand Toyota, 2014a) (New Zealand Holden, 2014) (Nissan New Zealand, 2015).

Vehicle Type	L/100km	kWh/km
Toyota Corolla	6.6	-
Toyota Prius Hybrid	3.9	-
Toyota Prius PHEV	4.7	0.12
Holden Volt PHEV	6.3	0.18
Nissan Leaf EV	-	0.14

As mentioned above, vehicles in the study use different sources of energy to run. ICE vehicles have a combustion engine which burns fuel to release energy while EV's run on electrical energy and PHEV's use both types. As shown in the Table 3.7 that the carbon dioxide emitted by these vehicles to cover a distance of 1km that were used to calculate the carbon dioxide emission by these vehicles over its life time.

Table 3.7: Carbon dioxide emission from different vehicle types.

Vehicle Type	Carbon dioxide produced from ICE when in use [kg/km]
Toyota Corolla	0.152
Toyota Prius Hybrid	0.089
Toyota Prius PHEV	0.114
Holden Volt PHEV	0.153

Further investigation was done in order to determine the amount of carbon dioxide that is emitted due to the curb masses of the car. This is applicable to mostly electric

vehicles which have to carry the mass of the battery. Although, the mass of the lithium-ion battery may not be significant compared to the curb mass of the vehicle, some energy will be required to carry this extra mass. To find out how much of the energy will be used up in carrying the weight of the battery a sample calculation was done on the Toyota Prius.

According to Zackrisson the energy used to carry the mass of the vehicle is about 30% of the total energy used to travel a distance (Zackrisson *et al.*, 2010). Since thirty percent of carbon dioxide produced while the vehicle is running comes from carrying its mass, some of this amount may be contributed by the mass of the battery as it is part of the mass of the vehicle. It is argued, that if the mass of the battery is significantly large compared to the curb mass then a large proportion of the carbon dioxide emitted can be due to carrying the extra mass of the battery.

Figure 3.9 shows that the battery mass of the PHEV's and EV's are significantly less than the curb mass. This suggests that battery mass is not significantly greater compared to curb mass which in turn means, carrying battery mass may not be a major contributor to carbon dioxide emission while the vehicle is running.

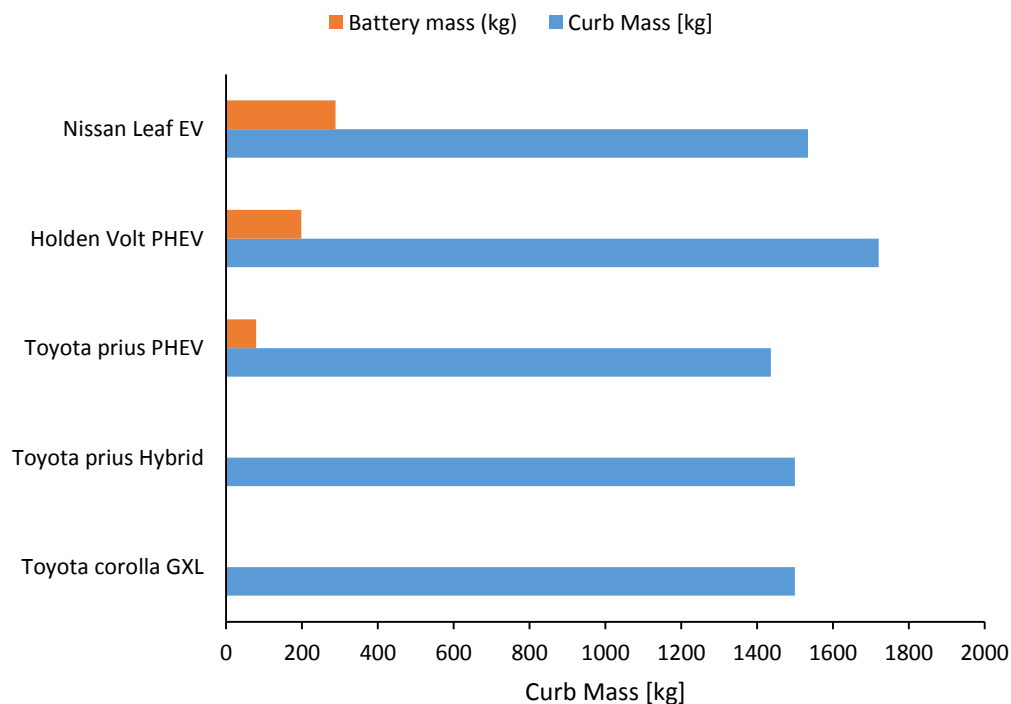


Figure 3.9: Car mass versus the batter mass.

3.4.3.2 Electricity

Different countries have different carbon dioxide emissions factor for electricity generation. The carbon dioxide emission factor depends on the type of fuel used to generate electricity. Some fuels will emit a large quantity of carbon dioxide while generating kWh of electricity while other fuels emit less. Electricity can be generated through coal fired power generation, oil fired power generation, natural gas fired power generation, nuclear power generation, hydro power generation, geothermal power generation and photo voltaic power generation. A case study of Japanese power plants show that the coal and oil fired power plants produce the maximum amount of carbon dioxide compared to other kinds of power plants as shown in Figure 3.10 (Hondo, 2005).

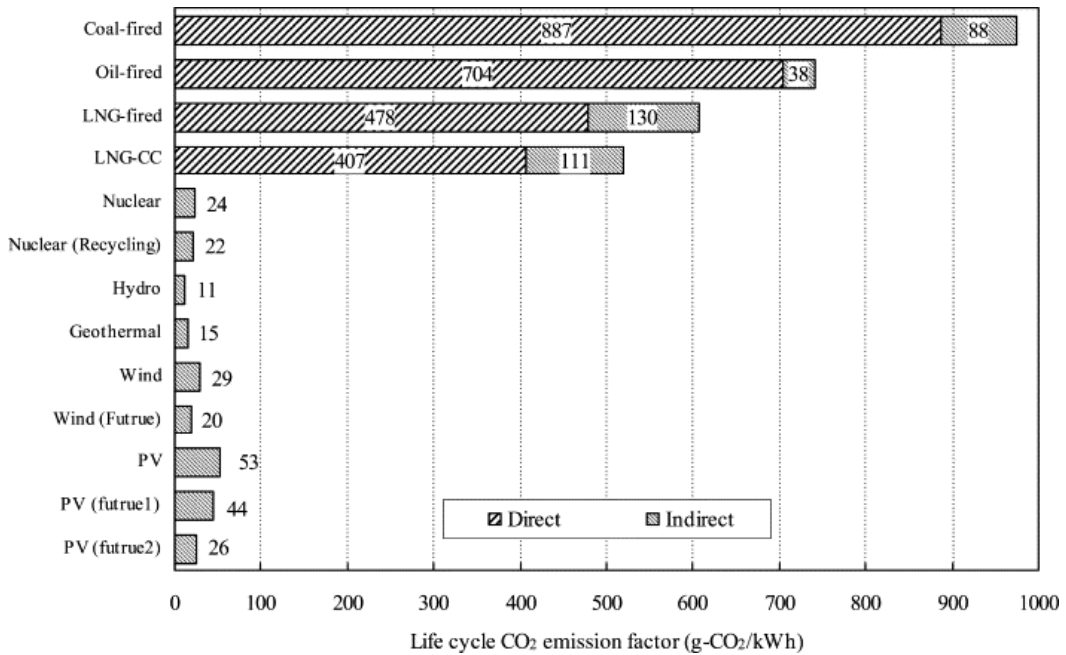


Figure 3.10: Typical values of carbon dioxide emissions factor from the Japanese power plants (Hondo, 2005).

Different countries will have different values of electricity factor based on the electricity generation mix. As can be seen from Figure 3.11 that the hydro power generation produces the least amount of carbon dioxide per kWh of electricity. Equation 2.6 show the amount of carbon dioxide emitted by PHEV's or EV's when it used battery to run.

$$CO_2 \text{ electricity grid} = (EF_{grid} \times \eta_{ev} \times d_{travelled-ev}) \quad (2.6)$$

EF_{grid} is the emission factor of the electricity grid [kg/kWh], η_{ev} is the amount of electricity used to cover a distance of 1 kilometre [kWh/km] and $d_{travelled-ev}$ is the distance travelled in the electric mode [km]. Table 3.8 shows that Toyota Prius produces least amount of CO₂ when compared to Holden Volt and Nissan Leaf.

In New Zealand the emissions factor varies depending on climatic conditions and the generation mix. For this study that focused on New Zealand a value of 150 g/kWh was used. The effect of varying this emissions factor and how it affects the emissions in other countries is examined later.

Table 3.8: CO₂ produced in EV mode.

Vehicle Type	Carbon dioxide produced in EV mode (kg/km)
Toyota Prius PHEV	0.018
Holden Volt PHEV	0.027
Nissan Leaf EV	0.02115

3.5 Discussion

3.5.1 Carbon dioxide Reduction under Different Scenarios

Lifetime carbon dioxide emissions from PHEV's and EV's are analysed under three scenarios as shown in

Table 3.9 and are compared against HEV and ICEV's. The three scenarios are a short, medium and long term battery. The vehicle life or the life time distance travelled is assumed to be 200,000 km for each scenario that is approximately 15 years based on the average distance travelled per year (14,000 km).

Table 3.9: Vehicles modelled under different scenarios for CO₂ emissions.

Scenario 1	1000 charge cycle (Battery life Approx.: 3-5 yrs.)		
	100% EV	75%EV and 25% petrol	50%EV and 50 % petrol
Scenario 2	2000 charge cycle (Battery life Approx.: 6-8 yrs.)		
	100% EV	75%EV and 25% petrol	50%EV and 50 % petrol
Scenario 3	3000 charge cycle (Battery life Approx.: 9-15 yrs.)		
	100% EV	75%EV and 25% petrol	50%EV and 50 % petrol

For different scenarios, a batteries end of life has different charge cycle. A life cycle is how many times a battery can be charged before its efficiency gets below the critical level that means that it is no longer able to hold a charge for a longer period and needs replacement.

The second aspect in each scenario is the amount of time operated using the internal combustion engine and the under electric mode. Three modes were analysed, 100% EV mode, 75% EV mode, and 50% EV mode.

Equation 2.7 is used to calculate life span of a batteries based on the scenarios. This method is also been used by Zackrisson (Zackrisson, *et al.*, 2010).

$$Battery\ life = \frac{(\zeta\ cycle \times \beta\ cap)}{\epsilon} \quad (2.7)$$

Where *Battery life* is the kilometres travelled by car using the battery, $\zeta\ cycle$ is the maximum number of times a battery can be charged charge before its efficiency gets down, $\beta\ cap$ is the maximum capacity of the battery when fully charged and ϵ is the amount of energy used to travel a kilometre by car.

Toyota Prius that uses 0.12 kWh to travel a km and stores 4.4kWh of energy each charge when charged will travel a distance of 36.7km in scenario one. If Toyota Prius is only used in EV mode, then the battery has to be replaced five times during its lifetime. Figure 3.11 show how many times the batteries will be replaced for different vehicles under different scenarios.

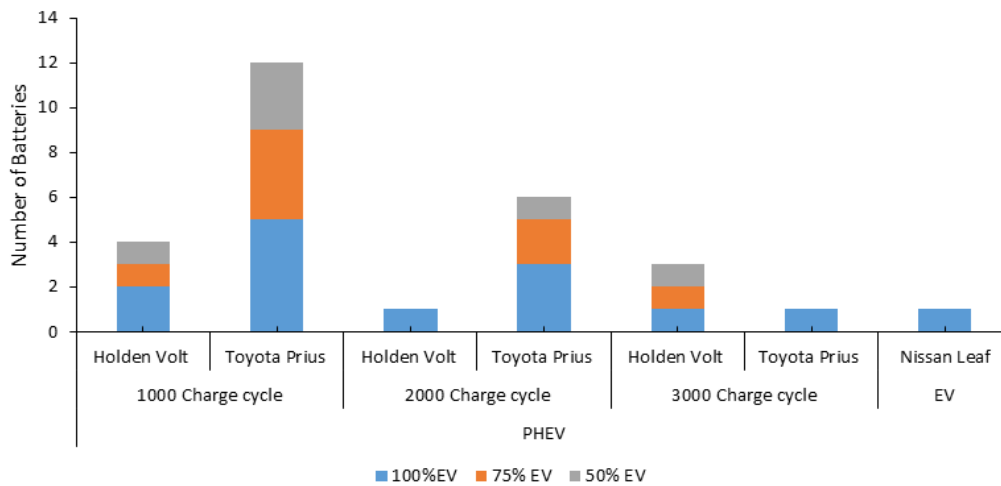


Figure 3.11: Number of batteries for different vehicles.

Life Cycle Analysis (LCA) of CO₂ emission from EV's and PHEV's is about 30 to 40 percent less when compared with HEV and ICEV under all different scenarios as shown in Figure 3.12; Figure 3.13; Figure 3.14. This shows that the introduction of EV's and PHEV's in NZ is a good idea for reducing CO₂ emissions. Since these vehicles are manufactured overseas, the CO₂ emitted from manufacturing process is typically included in the country of origin's emissions. This further increases the amount of CO₂ emission to about 50 to 60 percent.

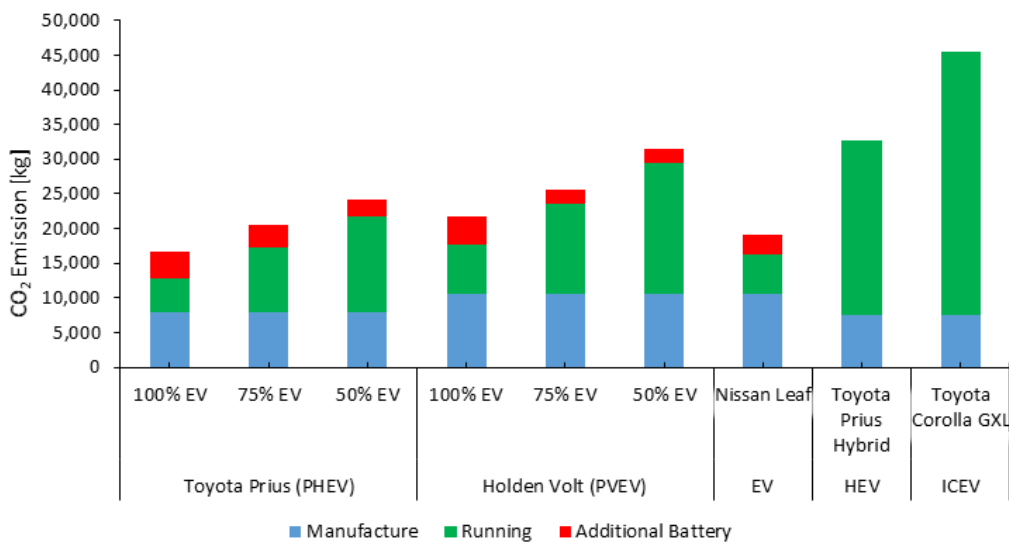


Figure 3.12: CO₂ reduction under scenario 1.

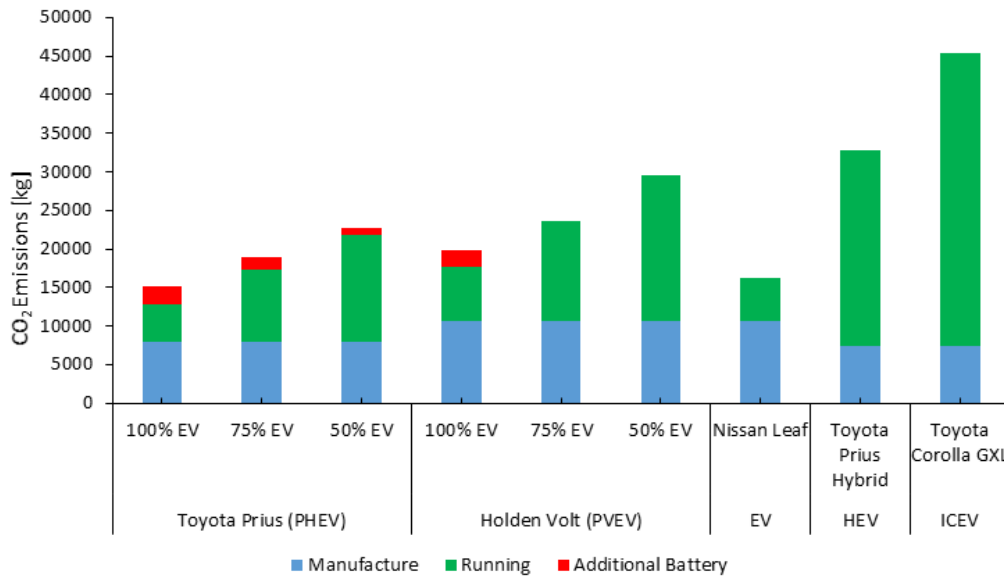


Figure 3.13: CO₂ reduction under scenario 2.

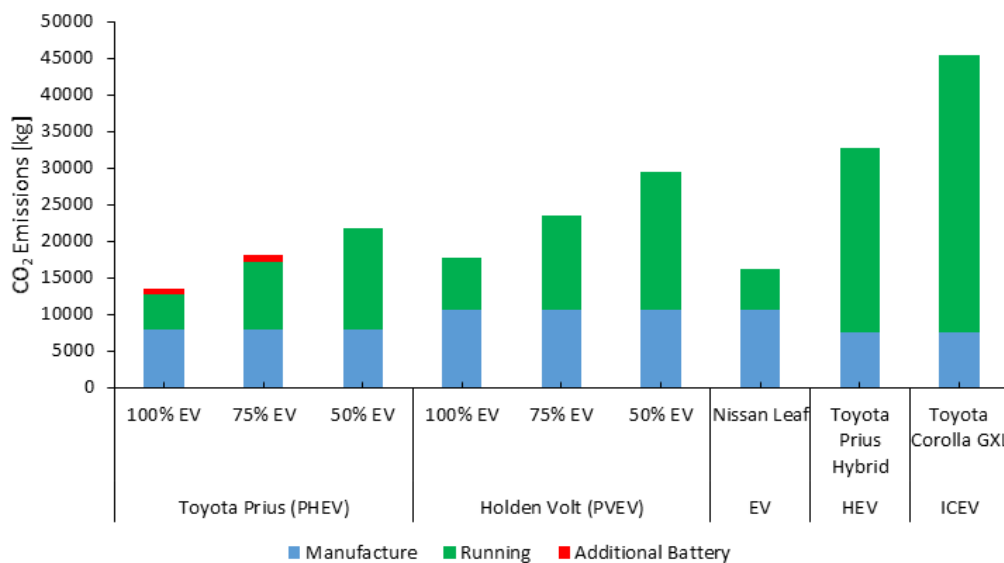


Figure 3.14: CO₂ reduction under scenario 3.

As well as a reduction in carbon emissions there are additional benefits from electric and hybrid vehicles. For example, air quality will be improved due to a reduction in particulate emissions. This will result in a reduction in the number of deaths caused by poor air quality and lower the burden in the public health system. Currently there are estimated to be over 1,000 premature deaths in NZ due to air pollution, with a social cost of 4.38 billion NZD (Kuschel *et al.*, 2012).

Furthermore 22% of anthropogenic air pollution is thought to be caused by motor vehicles.

3.5.2 Further Analysis of these Vehicles using Scenario 3

Practically most of the PHEV's will use ICE to run and this means that the battery may last up to 10 years, in this case scenario three is the best practical model to apply in the NZ situation. When all vehicles are compared under scenario three with ICEV's, Nissan Leaf had the biggest reduction as it does not have the ICE as shown in Figure 3.15.

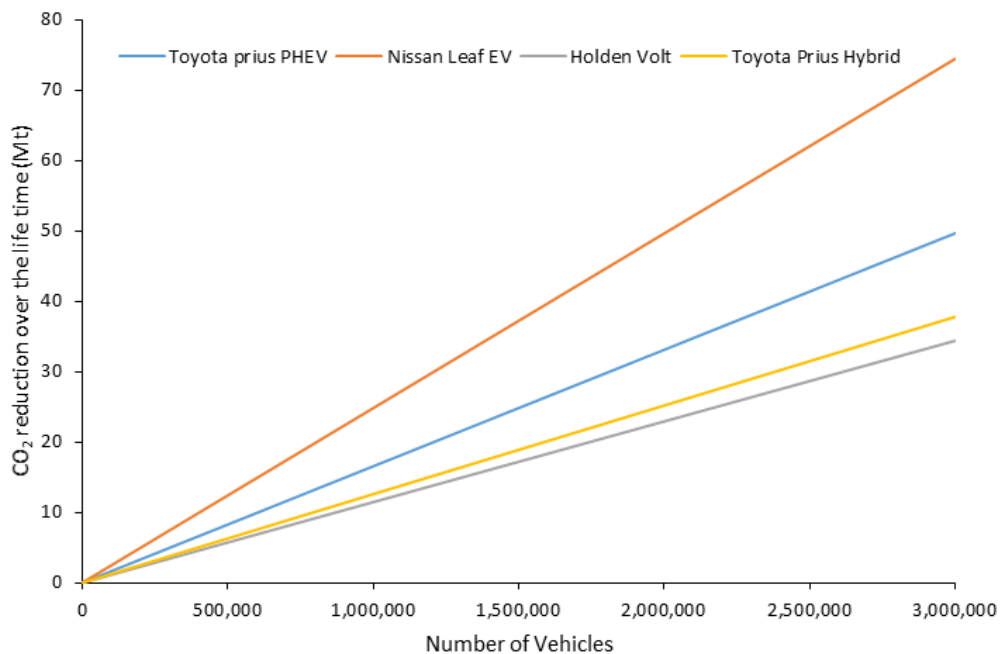


Figure 3.15: CO₂ reduction from different kinds of vehicles when compared to ICEV's.

One reason for the huge reduction in CO₂ is that a lot of renewable energy sources are used in electricity generation. This reduces electricity emission factor (EEF) for the country that means that 150 grams of CO₂ is emitted when a kilo-watt of energy produced in an hour. New Zealand has about 150g/kWh which is low when compared to countries like Australia and United States of America. The low EEF contributes to low CO₂ emission from PHEV's and EV's to run as shown in

Figure 3.16. This may imply that it is not suitable to introduce PHEV's in order to reduce CO₂ from vehicles.

Table 3.10: Emissions factors for several countries based on 2007 data.

Country (2007 Data)	Grid Emissions Factor (kg/kWh)	Renewables %	Nuclear %
NZ	0.162	67	0
Australia	0.99	8	0
USA	0.67	11	18
UK	0.61	7	20
Canada	0.23	54	12
France	0.10	12	78
Germany	0.67	11	24
Sweden	0.02	51	45
China	0.96	15	2

The number of PHEV's and EV's that entered the New Zealand market, as shown in Figure 3.17, has increased in recent years. Figure 3.18 shows some forecasts of the total number of PHEV's and EV's in New Zealand based on the recent growth trends from Figure 3.17.

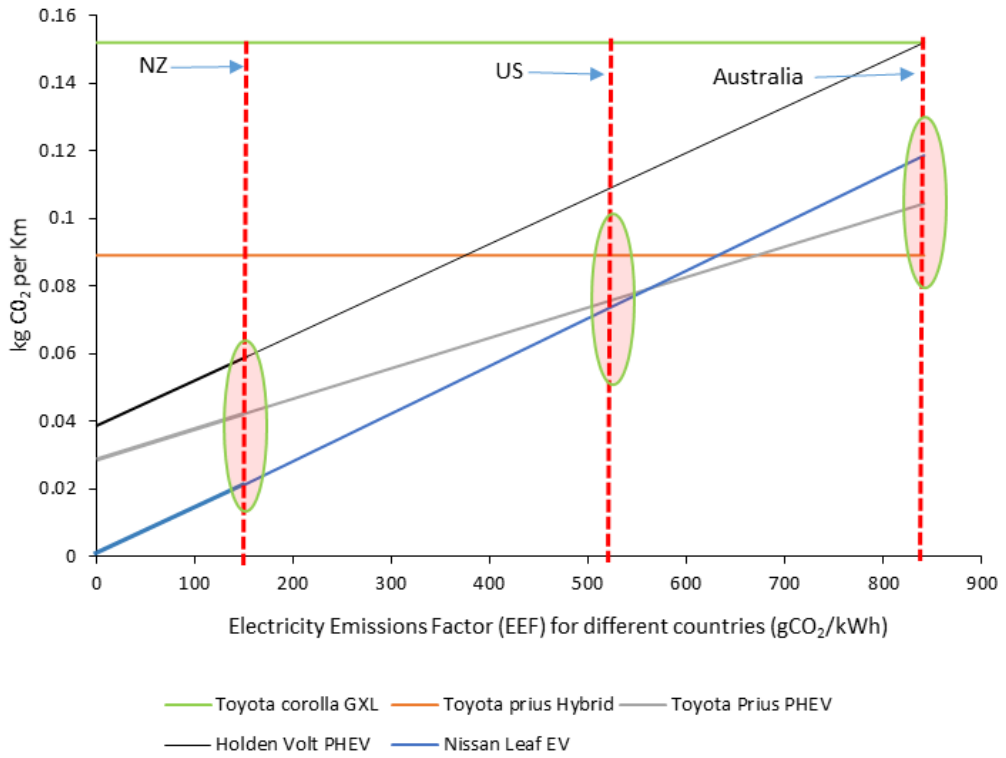


Figure 3.16: EEF of different countries versus kgCO₂/km.

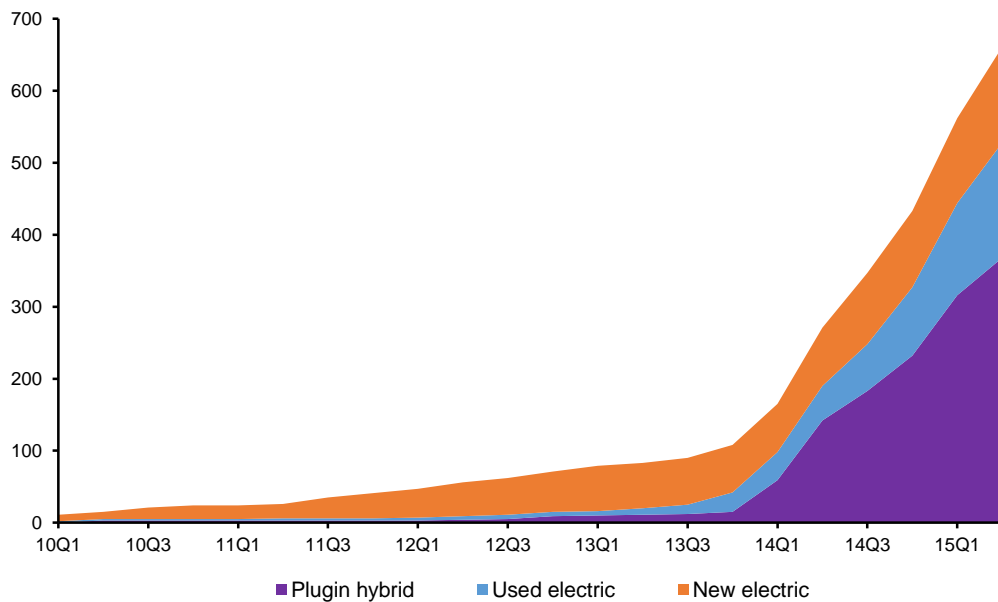


Figure 3.17: Number of PHEV's and EV's in New Zealand till 2050 (Ministry of Transport, 2015).

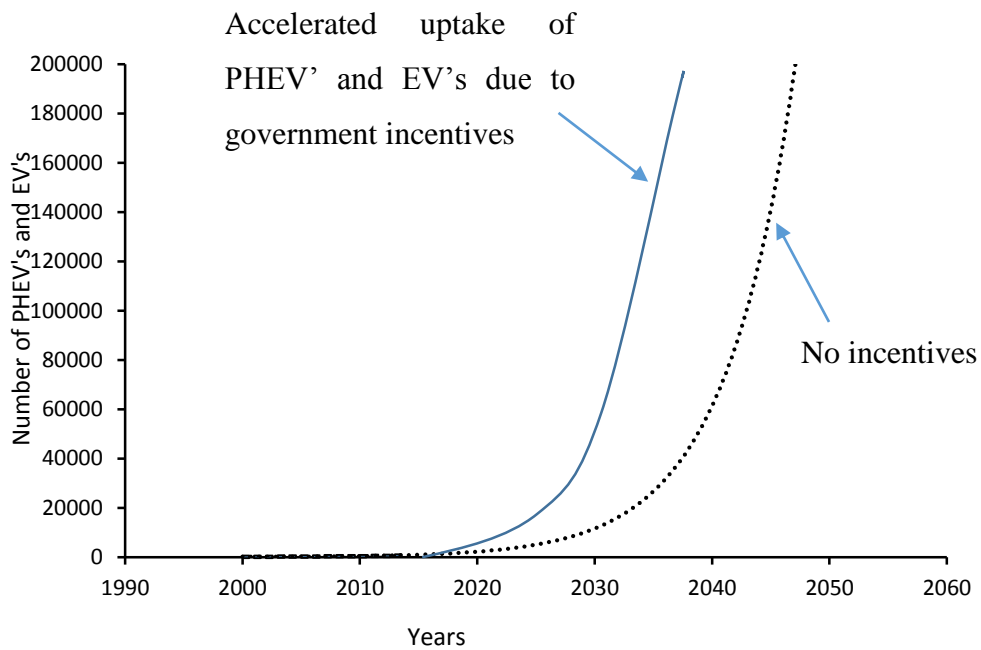


Figure 3.18: Prediction of PHEV's and EV's.

The prediction indicates that there may be 160,000 PHEV's and EV's by 2035 and based on these numbers it will be about 10 percent of the total light weight vehicles. Based on this prediction, it is estimated that there will be an overall 0.5 Mt reduction (4%) reduction in CO₂ annually as shown in Figure 3.19.

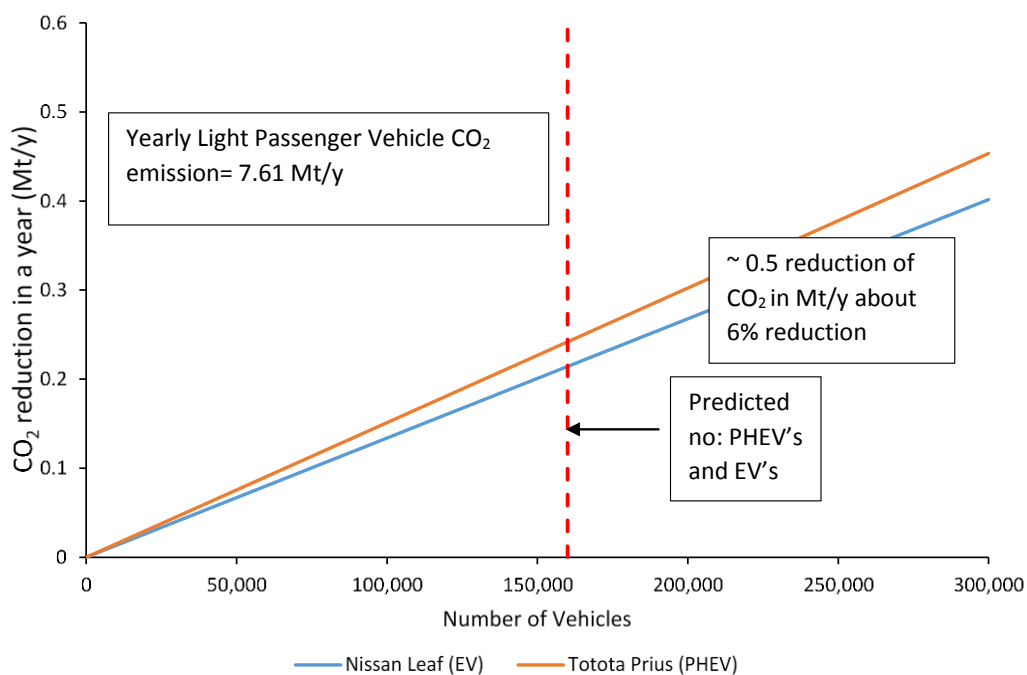


Figure 3.19: CO₂ reduction in a year from light passenger vehicles due to PHEV' and EV's.

As the vehicle technology and awareness increase, the uptake of these vehicles will increase. Figure 3.20 shows the reduction in CO₂ from light passenger vehicles as a percentage of the entire light passenger vehicle fleet becomes PHEVs or EVs. If all the vehicles become PHEVs and EVs, there will be a reduction on 60 percent of CO₂ emission from the light passenger vehicles. The total reduction in CO₂ over time is shown in Figure 3.21.

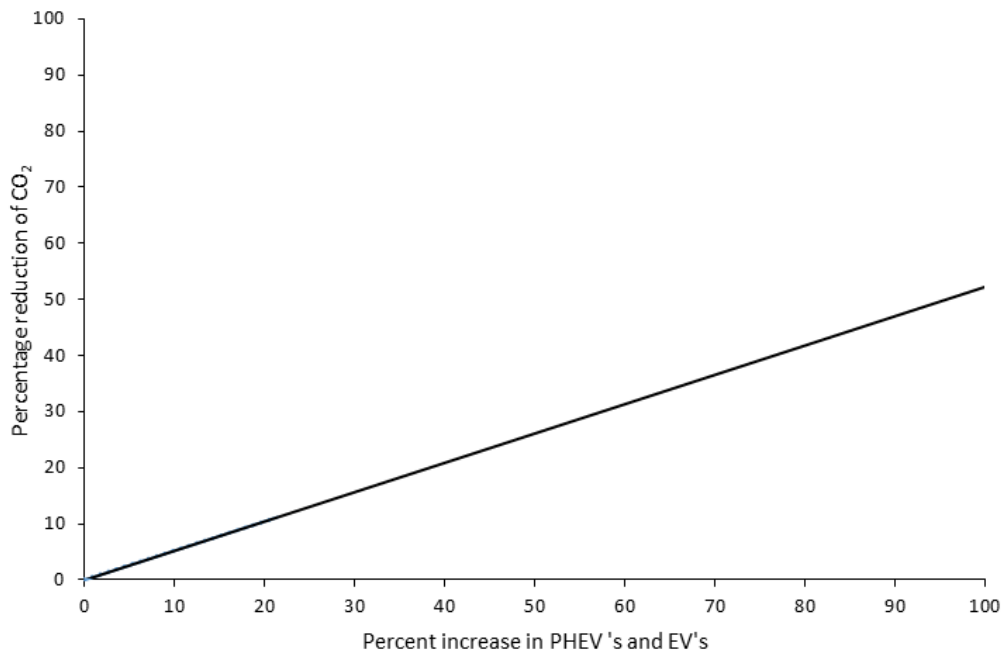


Figure 3.20: CO₂ reduction due to the increase in PHEV's and EV's in NZ.

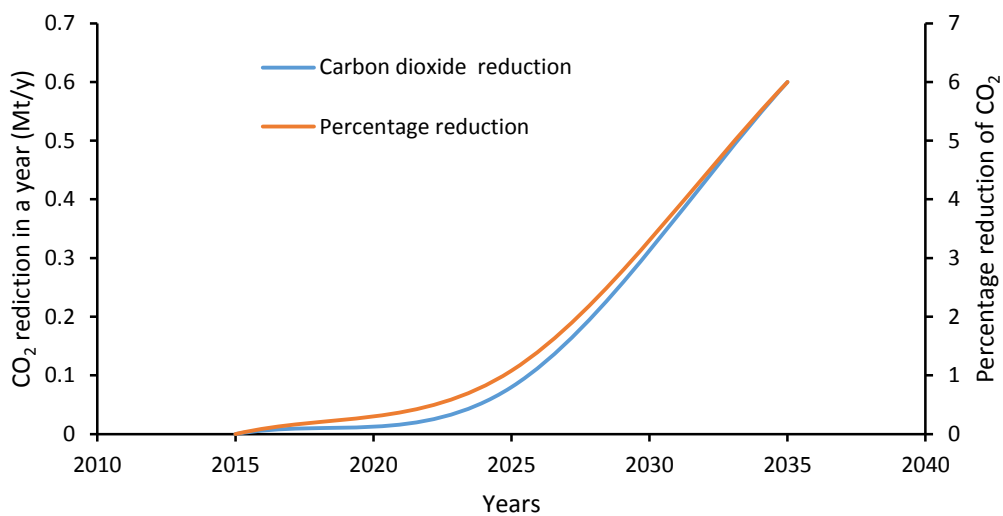


Figure 3.21: CO₂ emission reduction on a yearly basis.

3.6 Summary

Introduction of PHEV's and EV's will no doubt reduce the CO₂ emissions from the light passenger vehicles in New Zealand. Although this reduction will not be the same under different scenarios, it will depend on battery life, fuel mix and electricity emissions factor. Battery life does not directly emit CO₂ in our atmosphere as these are manufactured in other countries. However, a larger battery life will lower even further the overall carbon footprint of PHEV's and EV's.

The fuel mix is another factor that determines the CO₂ emissions from PHEV's. If PHEV's are run solely on electric mode their tail pipe emission is nil. However, as they run on combustion mode they start emitting CO₂. Since the electricity emissions factor of New Zealand is low the indirect CO₂ emission from PHEV's and EV's when running in electric mode is low when compared with Australia and United States of America.

Chapter 4

Vehicle Cost

4.1 Introduction

The cost of a vehicle is a major factor in determining its success in the market. To become attractive to the consumer electric vehicle and plug-in hybrid vehicles have to be competitively priced, reliable, trusted and have readily available spare parts. New Zealand being a small country with average distance travelled in major cities being 20 to 30 km (Ministry of Transport, 2014), will be an ideal place for PHEV's or EV's as they can travel using the battery power for short distances. Each country needs to have the infrastructure and expertise available to service the fleet and in the absence of this, it will affect the rate of transition. Although there are currently no road user charges on electric vehicles the uptake is currently not high,

However, the important thing when investing in new technology is its sustainability and financial gain. The running cost of these vehicles is analysed with the current market price. Therefore, it is important that the analysis of money invested (MI) per distance travelled (DT) is properly analysed for PHEV's and EVs to boost business confidence.

This chapter investigates total ownership (TOC) of five different kinds of vehicles with a similar engine size which has been used in chapter one. TOC refers to cost incurred by the vehicle during its life time, manufacturing to disposal.

4.2 Total Ownership Cost

Total ownership cost, TOC_{cost} is made up of two major expenses; the capital cost, $C_{capital}$ [\$] and the operating cost, $C_{operating}$ [\$] as shown in equation 3-1. The capital cost includes the initial purchase price of the car plus any additional battery replacement over its lifetime.

$$TOC_{cost} = C_{capital} + C_{operating} \quad (3-1)$$

4.2.1 Capital Cost

The capital cost can vary as the technology improves in future. It also depends on the exchange rate of New Zealand and the shipping cost. Since New Zealand is not close to the manufacturing source of these vehicles, the cost may be slightly higher than those countries where the vehicle is manufactured. Capital cost can be divided in the cost of manufacturing of a vehicle which is shown in Table 4.1 and any additional batteries required for the plug-in hybrid vehicle (PHEV's) and electric vehicle (EV's) as shown below.

$$C_{capital} = C_{car} + C_{additional\ battery} \quad (3-2)$$

Table 4.1: Capital cost of the vehicles.

Vehicle Type	NZD
Toyota Prius PHEV	45000
Holden Volt PHEV	65000
Toyota corolla GXL (1.8L)	38000
TOYOTA PRIUS HYBRID –(I-TECH)	51000
Nissan Leaf (EV)	39900

4.2.2 Cost of additional battery

Lithium-ion batteries may have a life span of up to 10 years (Marano *et al.*, 2009). Materials used in the manufacturing process and the way it is being used determines the lifetime of the battery. Equation 3.3 can be used to find the life of a battery.

$$Battery\ life = \frac{Charge\ cycle \times Battery\ size}{Energy\ use} \quad (3-3)$$

Where *Battery life*(km) is the kilometres travelled by the car during a battery's life time, *Charge cycle* is the maximum number of times a battery can be charged before its efficiency goes down to critical level, and *Energy use* is the amount of energy from the battery needed to travel per kilometre [kWh/km]. Different scenarios will be taken into consideration to determine the life of the battery as shown in Table 4.2.

Using scenario one the total distance travelled by the battery of Toyota Prius (PHEV), battery size of 4.4 kWh before it expires can be calculated as follows:

Total energy needed to a charge a battery 1000 times is 1000 cycles \times 4.4kWh = 4,400 kWh. Since it takes 0.12kWh to travel a km the total distance travelled in electric mode will be 4,400 kWh/0.12 kWh = 36,666 km. The total distance travelled by the vehicles under three scenarios is shown in Table 4.2.

Table 4.2: Distances run by the vehicles under different scenarios if only travelled in electric mode.

Car Type	Scenario 1 1000 cycles	Scenario 2 2000 cycles	Scenario 3 3000 cycles
Toyota Prius (PHEV)	36,666	73,333	110,000
Holden Volt (PHEV)	91,666	183,333	275,000
Nissan Leaf (EV)	170,212	340,425	510,636

Additional batteries will be required by the vehicle over its life span for PHEV's and the number can be calculated as shown in equation 3.4.

$$Additional_{battery} = \frac{D - D_{ice}}{D_{ev}} \quad 3.4$$

Where $Additional_{battery}$ is the number of additional batteries required, D is the total distance travelled by the car which is taken as 200,000km, D_{ice} is the distance travelled by the PHEV using internal combustion engine and D_{ev} is the distance travelled by the PHEV using the battery power. The number of batteries required under different scenarios is shown in Figure 4.1.

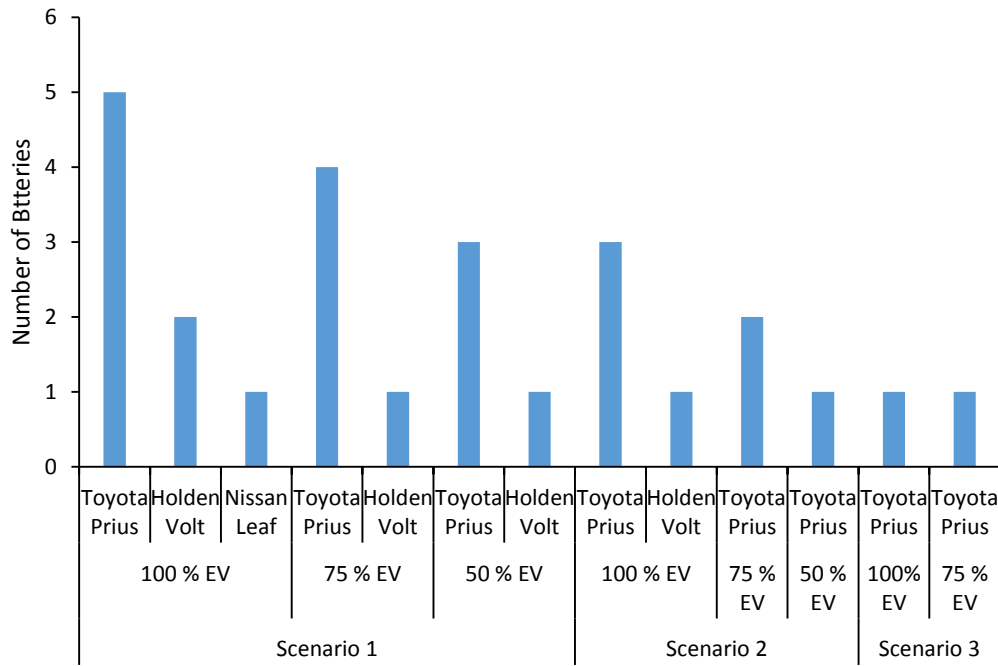


Figure 4.1: Number of batteries under three battery life scenarios: Scenario 1 = 1000 cycles, Scenario 2 = 2000 cycles, Scenario 3 = 3000 cycles.

It is predicted that the price of these batteries will decrease as the availability of the raw materials becomes readily available and technology improves. Figure 4.2 shows the prediction of battery pack till 2030. As shown the price for the battery is predicted to decrease in future, however, this will be further investigated in Chapter Five as what happens to the availability of lithium as the demand increases.

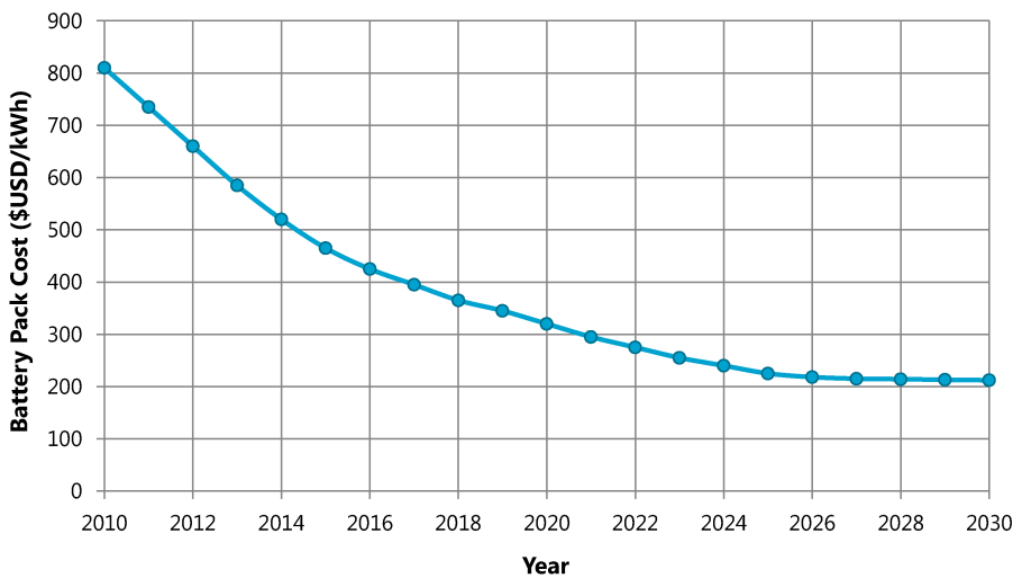


Figure 4.2: Predicted cost of the lithium-ion battery (Cluzel & Douglas, 2012).

It is very difficult to determine the cost of lithium-ion batteries as the cost vary from different sources as shown in Table 4.3. The average price of NZD\$741.25 between 2010 and 2020 is used in this study.

Table 4.3: Battery cost per kWh (Miller, 2011) \$1US~\$0.8NZD.

Source	Battery cost (\$/kWh, based on nominal capacity)		
	2010	2015	2020
Argonne National Lab	--		200-400 Average (300)
Deutsche Bank	900-1000 Av Average (800)	500-600 Average (550)	400-500 Average (450)
National Academies (NAS)	825-875 Average (850)		535-575 Average (555)
TIAX LLC	--		211-398 Average (305)
Average	825	550	403
Average cost of all averages = (825 + 550 + 403)/3 = US\$593~NZ\$741.25			

The overall cost of the battery can be calculated using the formula.

$$C_{battery} = B_{cost} \times B_{size} \quad 3.5$$

Where $C_{battery}$ [\$] is the battery cost, B_{cost} [\$] is the average cost per kWh of battery and B_{size} [kWh] is the size of the battery.

The battery capacity increases the battery cost significantly. The variation in the battery price between vehicles can also be high as process are not stable yet (Figure 4.3). This shows that the bigger the battery capacity the higher variation in cost.

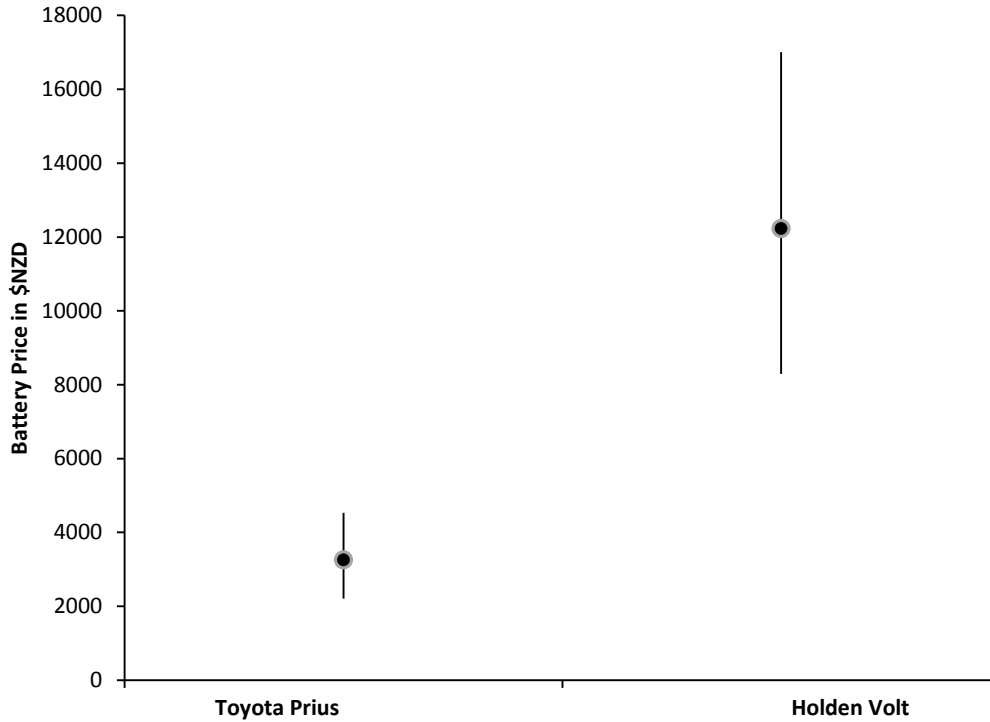


Figure 4.3: Battery price of Toyota Prius and the Holden Volt.

4.3 Operating Cost

The operating cost of a vehicle in the study is comprised

$$C_{operating} = C_{petrol} + C_{electricity} + M + W \quad (3-6)$$

Where $C_{operating}$ is the running cost of the vehicle, C_{petrol} is the petrol cost, $C_{electricity}$ is the electricity cost, M is the maintenance cost and W is the warrant of fitness cost. Maintenance and warrant of fitness cost will be very similar for the vehicles under study, therefore it is not included in the analysis. Internal combustion engine vehicles (ICEV's) will only incur the cost of the petrol which is taken it to be \$0.23 cents a litre. However, EV's and PHEV's will use electricity which can be given by

$$C_{electricity} = E_{use} \times C_{grid} \quad (3-7)$$

Where $C_{electricity}$ [\$] is the cost of electricity to travel a kilometre, E_{use} is the energy used to travel a km [kwh/km] and C_{grid} is the electricity cost in New Zealand

[\$/kwh]. Energy use can be calculated by battery capacity divided by battery range as shown in equation 3.8.

$$Energy_{use} = \frac{Battery_{capacity}}{Battery_{range}} \quad (3-8)$$

Where $Energy_{use}$ is energy used in electric mode to travel a kilometre (kWh/km), $Battery_{capacity}$ is the fully charged battery capacity of the vehicle (kWh) and $Battery_{range}$ is the distance travelled in EV mode until the battery is drained (km). The cost of fuel consumed by the vehicles can be shown using

$$C_{petrol} = P_{use} \times P_{cost} \quad (3-9)$$

Where C_{petrol} is the cost of the fuel used, P_{use} is the fuel consumption per kilometre and P_{cost} is the fuel cost per litre. The cost of the fuel is taken to be \$2.23 per litre. For the Corolla Hatchback GX the fuel consumption is taken to be 6.6 litre/100km and for the Toyota Prius Hybrid the fuel consumption is taken to be 3.9 litre/100km. (New Zealand Toyota, 2014a, 2014b).

4.4 Discussion

Cost plays a major role when deciding what kind of vehicle a consumer wants to buy. Based on the different scenarios and constraints the total ownership cost of the vehicles are shown on Figure 4.4, Figure 4.5 and Figure 4.6.

In summary, the TOC of Nissan leaf is the least under scenarios 1 and 2. However under scenario 3 Toyota Prius (PHEV) is the lowest as the battery life is longer. However, Holden Volt has the highest TOC in all the scenarios because of its high capital cost.

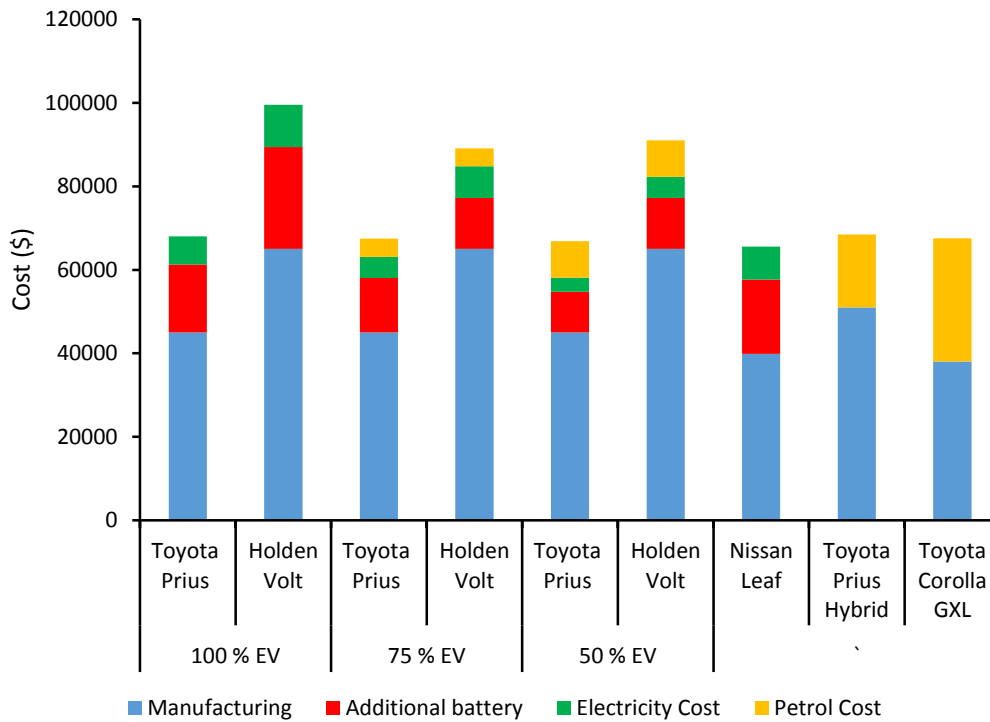


Figure 4.4: Cost of cars using scenario 1.

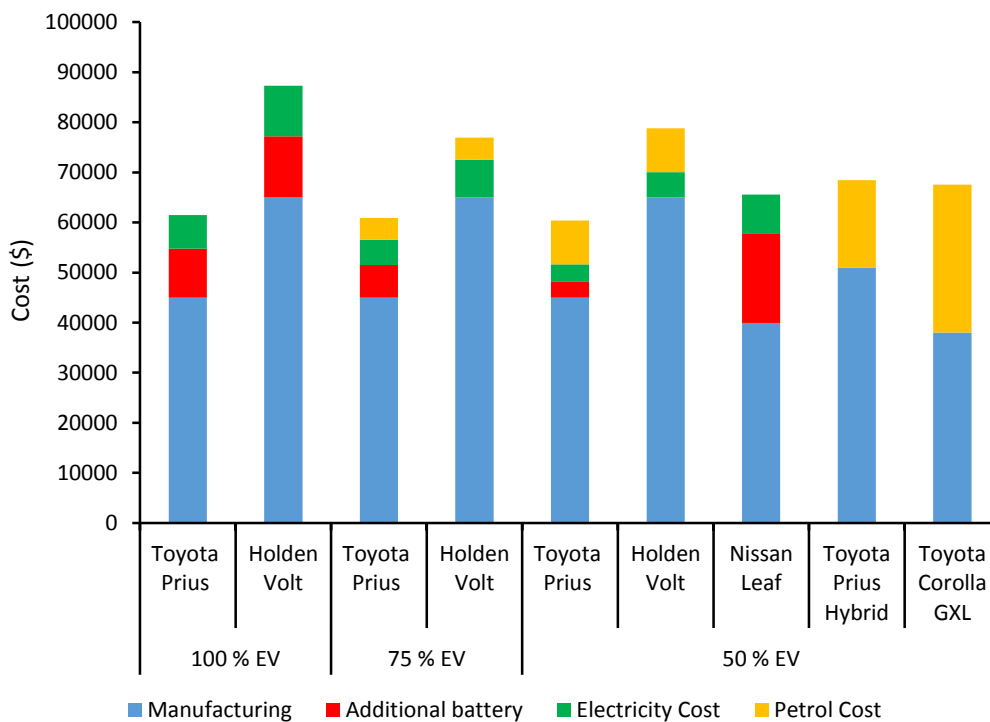


Figure 4.5 Cost of cars using scenario 2.

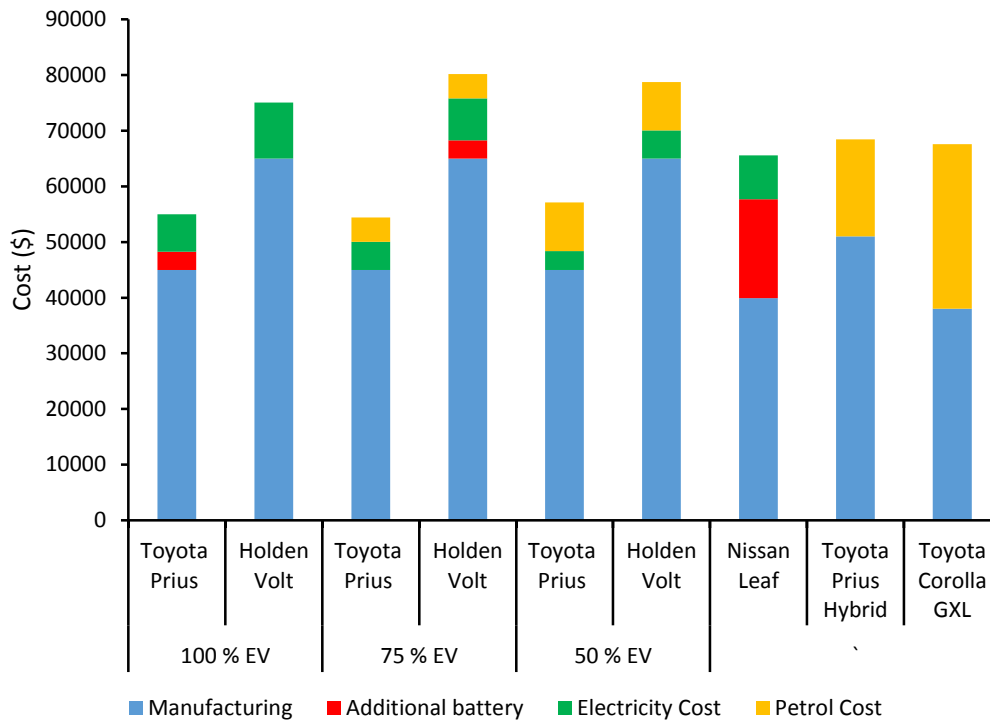


Figure 4.6 Cost of Cars using scenario 3.

It is also important to look at the TOC of these vehicles as their mileage increases. Figure 4.7 shows that even though Toyota Prius PHEV will have more capital cost its TOC is less compared to other kinds of vehicles during its life span. The breakeven cost when compared to Toyota hybrid is about 60,000km. This is because the electricity cost is lower in New Zealand when compared to petrol cost. This makes the running cost of PHEV's and EV's lower in NZ provided there is no government levy imposed on these vehicles. Over the lifetime of Toyota Prius PHEV, the savings made by the owner will be anywhere between 10,000 to 15,000 NZ dollars as seen in Figure 4.6.

PHEV's will be cost effective if the vehicle is kept for more than five years to make the breakeven point. Battery life and the distance travelled by the vehicle in the electric mode can significantly change the running cost of the vehicle as batteries cost a lot of money to replace. Advantages of PHEV's over EV will be that PHEV will be able to travel longer distances and will require smaller batteries meaning that the cost of replacing the battery will be less for PHEV's.

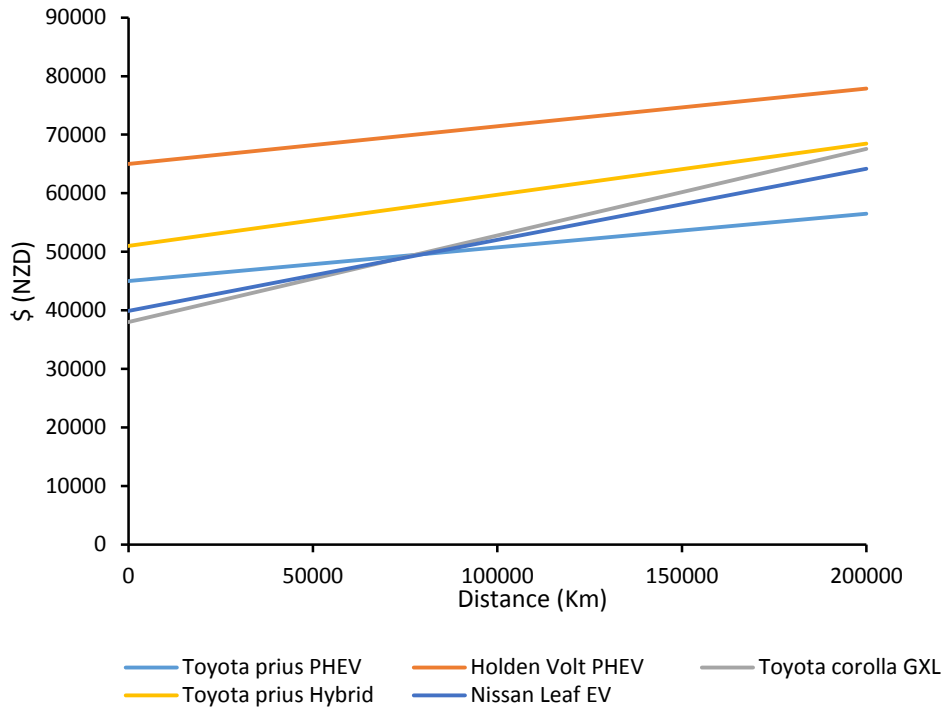


Figure 4.7: Cost of the vehicle under scenario 3.

As mentioned that the running cost of PHEV's are lower because of electricity cost. However, PHEV's uses both petrol and electricity to run. If the petrol price goes up then the Figure 4.8 shows that even though the petrol price goes up the running cost of PHEV's will not go up significantly when compared to other kinds of vehicles.

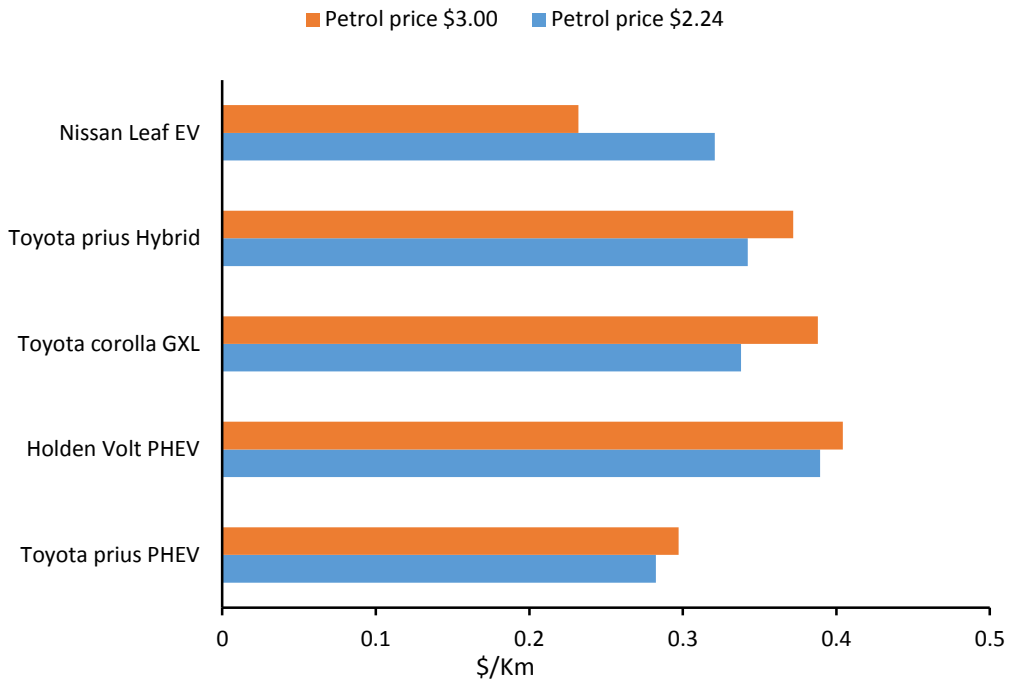


Figure 4.8: Cost of the vehicle over its life span under scenario 3.

4.5 Summary

In summary, battery life, vehicle cost and fuel mix all contribute to total ownership cost (TOC) of these vehicles. The most significant of all is the cost price of the vehicle. Longer battery life will lower the TOC of the PHEV's and EV's as lithium-ion battery is quite expensive. Vehicles that run on electric mode is cheaper to run when compared with vehicles that run on combustion engines.

Under scenario 2 and 3 Toyota Prius (PHEV) had the lowest TOC when compared with other types of vehicles. This is because the cost to buy Toyota Prius (PHEV) is not much dearer than combustion engine vehicles and also it can run on electric mode which is cheaper than petrol.

Although Toyota Corolla was the cheapest vehicle to buy its TOC increased as it was used. The breakeven point between Toyota Prius (PHEV) and Toyota Corolla was about 67,000km. After this point Toyota Prius (PHEV) becomes cheaper.

Chapter 5

Factors Affecting Uptake of PHEV and EV

5.1 Introduction

Although electric and plug-in hybrid vehicles help reduce carbon dioxide from light passenger vehicles and are reasonably priced they have some limitations over internal combustion vehicle's (ICV's) especially in terms of range of operation and power.

The uptake of PHEV's in NZ is at the same rate as some overseas countries, as people are scared to invest large amounts of money into vehicles which they are not familiar with. The other reasons are the backup maintenance services and the travel range. Most mechanics in NZ are not familiar with this technology and will have to attend training courses to learn about with technology behind PHEV's. Local and central government agencies need to come up with plans and incentives if they want more uptake form the general public as done in overseas countries. Charging facilities should be made available for the general public in towns and cities. This might mean converting parking meters to charging meters or changing the building codes so that newer apartments will have charging facilities in their car parks. The uptake of EV and PHEV's in NZ will be dependent on the market price and the flow on effect from overseas as we import more second hand vehicles than brand new ones and also any policy incentives.

This chapter investigates the potential effect on the uptake of PHEV's and EV's due to government incentives, the availability of lithium due to the increasing demand of the vehicles, and their effects on electricity sector.

5.2 Government Incentives

Figure 5.1 show the type of incentives given in USA and the level of uptake of EV's and PHEV's in the market. In California the uptake is the highest when compared

to other states. In this state, the incentives include subsidies, carpooling, car charger, and free test emissions.

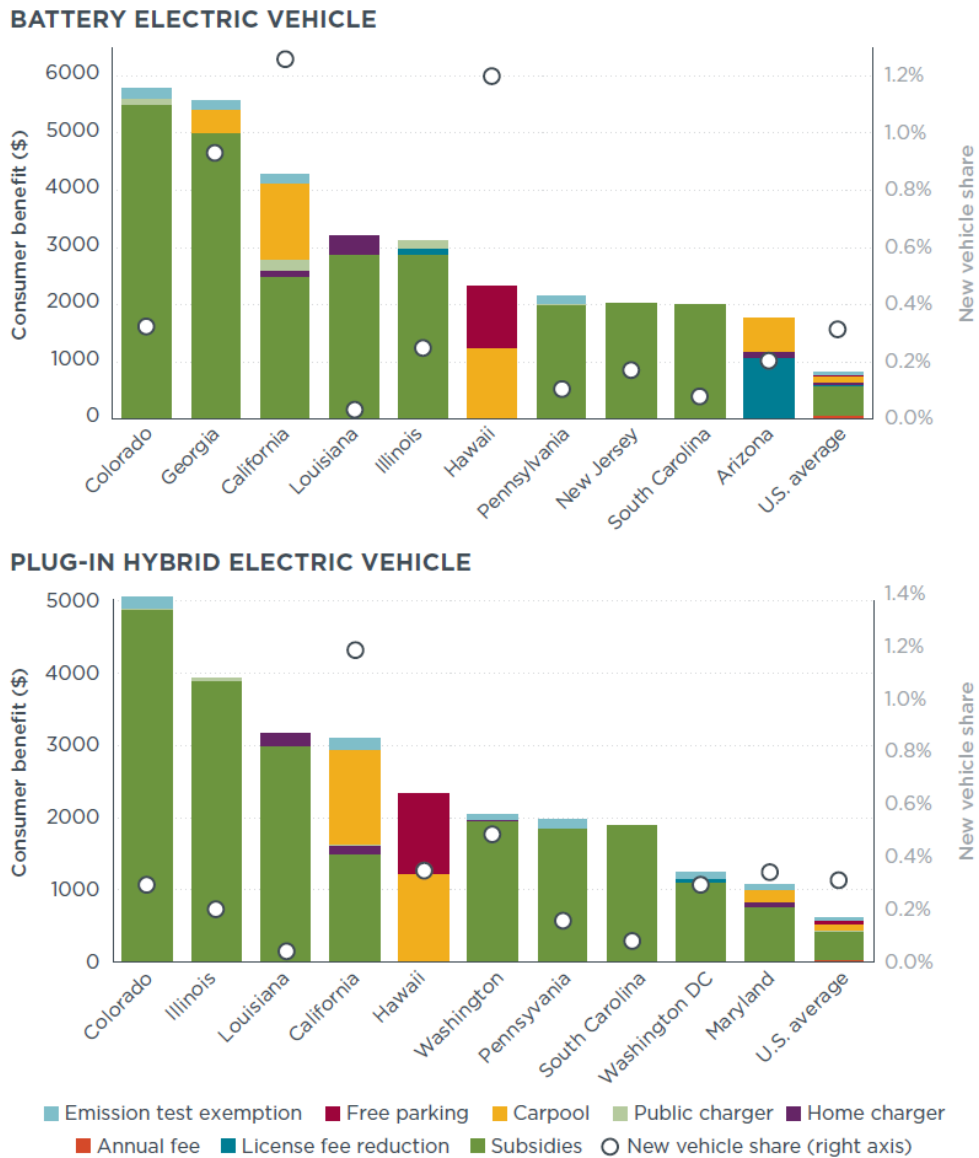


Figure 5.1 Type of incentives given in USA (Kane, 2014).

If consumer response is the same here in New Zealand then the government needs to use a variety of tactics, in order, to increase the PHEV's and EV's share in the market. This can be in the form of awareness among car owners about PHEV's and EV's, subsidies, tax rebates, home charger, license fee reduction, free parking. However, there are not many incentives given to consumers apart from road user charges. Table 5.1 shows the incentives taken by five different countries in order to increase the uptake of these vehicles. It shows that New Zealand gives the least

amount of incentive towards the vehicle. It is predicted that if the government increases the incentive the uptake will be high as shown in Figure 3.18. This will translate to 6 percent reduction in CO₂ as shown in Figure 3.20 per year from light passenger vehicles.

Table 5.1 Shows in incentives from five different countries (Lemon & Miller, 2013a).

Australia	Reduced luxury car tax for EV's (higher tax threshold); exemption from vehicle stamp duty (Australian capital territory); AUD\$100 reduction in annual registration fee (Victoria)
China	EV subsidies for 5 selected cities for private EV's up to USD\$7900 and for private PHEV's up to USD\$9500
New Zealand	Road user charges (RUC) waived on electric vehicles till 2020
United Kingdom	Plug-in car grant providing 25 percent off electric car price up to usd\$7800; plug-in van grant providing 20 percent off electric van price up to usd\$12500. Exemption from vehicle excise duty (assuming tailpipe emission below 100 g CO ₂ /km); exemption from company car tax for employees and employers. Exemption from van benefit charger for employees and employers. Exemption from fuel benefit charge Congestion charge waived for EV's Local exemption/charge reduction for parking
United States of America	Tax credits for EV purchase up to USD\$2500 - USD\$7500 based on battery capacity tax credits for EV conversion kits up to usd\$4000 Access to high occupancy vehicle lanes, priority parking and registration for specific states emission-based benefits for specific states Tax rebates and grants for specific states purchase incentives for specific states

5.3 Lithium Availability

Another factor affecting the uptake of EV's and PHEV's is the price of the battery replacement. As lithium is the major component of the battery, the price of lithium has also varied in recent years (Figure 5.2). The price may significantly increase if the demand increases in the future due to widespread uptake of electric cars. This depends on the number of PHEV's and EV's being manufactured in the future and, as anticipated by Engbu, that this demand may not be met (Egbue & Long, 2012).

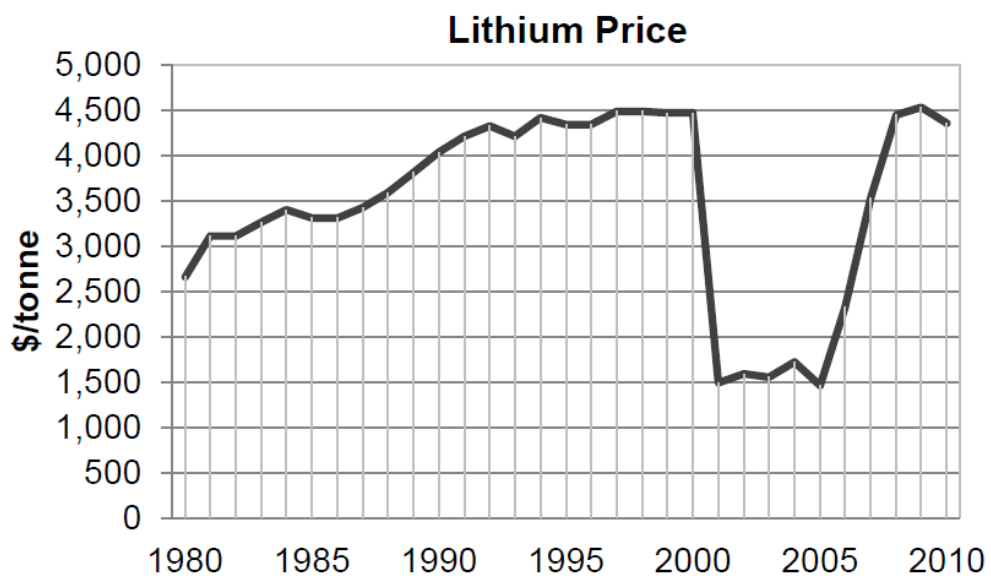


Figure 5.2: Evolution of lithium prices (Egbue & Long, 2012).

A range of estimated values has been reported for the amount of lithium contained in batteries for EV's and PHEV's varies depends on battery chemistry and the size of the battery. According to Kushnir and Sanden, there is a minimum amount of lithium required for a given battery capacity that is derived from the battery chemistry and cell voltage which can vary according to researchers (Kushnir & Sandén, 2012)

The estimate values range from as low as 2.7 to 7.7 kg of lithium per battery for EV's and 1.2 to 3.1 for PHEV's as shown in

Table 5.2. The amount of lithium used to make batteries for different model cars will vary according to their specification and intended market segment. Vehicles that travel more distance in electric mode will require a larger battery and, therefore, require more lithium.

Table 5.2: Estimation of needed lithium amounts for alternative vehicle batteries (Vikström *et al.*, 2013).

Reference's	Mass of Li (kg) per battery (EV's)	Mass of Li (kg) per battery (PHEV's)
Falås and Troeng	2.7–4.3	1.2–2.0
Gruber et al.	5.1–7.7	1.5–2.3
JOGMEC	2.8–5.7	1.4–3.1
Kushnir and Sandén	5.8	1.4
Average value	4.9	1.9

It is very difficult to predict the market for EV's and PHEV's. In this study, predictions from the International Energy Agency (IEA) shown in Table 5.3, are used to predict the amount of lithium that may be needed to cater for the demand of electric vehicles. Currently, there are about 180,000 electric vehicles world-wide that includes PHEV's and EV's (International Energy Agency, 2013). IEA predicts that by 2050 there will be about 106.4 million PHEV's and EVs on our roads. Based on this prediction, the amount of lithium needed to cater for the demand is calculated using equation 4.1.

$$\text{Amount of Lithium} = (N_{phev} \times Li_{needed}) + (N_{ev} \times Li_{needed}) \quad 4.1$$

Where *Amount of Lithium* is the lithium needed in to manufacture the vehicles in one year and N_{phev} is the number of PHEV's needed for that particular year, Li_{needed} is the amount of lithium needed to manufacture the batteries of the PHEV's in that year and N_{ev} is the number of EV's needed for that particular year, Li_{needed} is the amount of lithium needed to manufacture the batteries of the EV's in that year.

Table 5.3: Global Sales of PHEV's and EV's per year (International Energy Agency, 2011).

	2010	2015	2020	2025	2030	2035	2040	2045	2050
PHEV (millions)	0.0	0.7	4.9	13.1	24.6	35.6	47.7	56.3	59.7
EV (millions)	0.0	0.3	2.0	4.5	8.7	13.9	23.2	33.9	46.6
Total (millions)	0.0	1.1	6.9	17.7	33.3	49.5	70.9	90.2	106.4

Based on the average values of lithium needed to manufacture the batteries PHEV's and EV's the amount of lithium needed per year is calculated using the equation 4.1. Figure 5.3 shows that by 2050, about 250kt and 100kt of lithium will be needed to manufacture EV's and PHEV's in a year respectively.

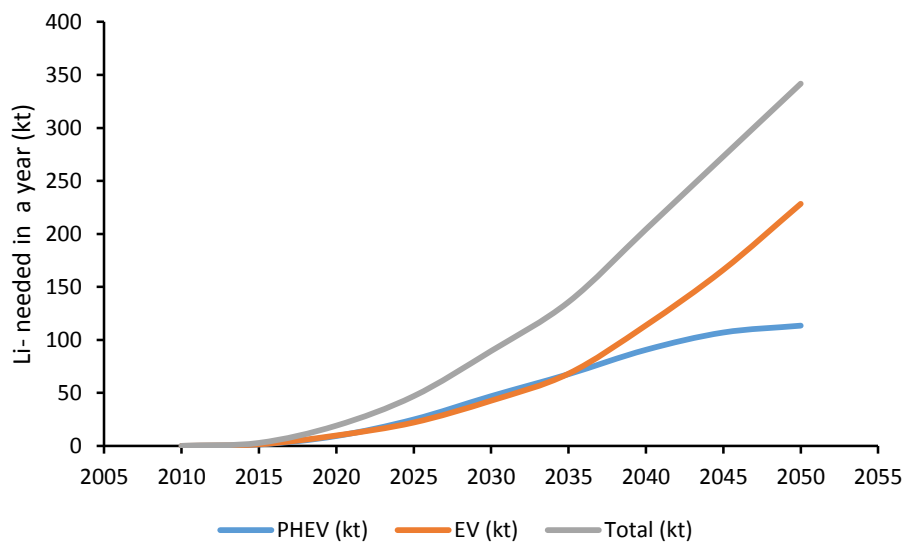


Figure 5.3: Annual amount of lithium used and predicted to be used in the manufacture of lithium-ion batteries for PHEVs and EV's from 2010 to 2050.

This value seems very high, as the current the production rate of lithium is about 40kt (U.S. Department of Interior, 2014; Vikström, *et al.*, 2013). Figure 5.4 shows that in 2050, the production of lithium will be between 75 and 200kt. Since the

demand to manufacture lithium-ion batteries for electric cars will be 250kt, and the supply will be about 200kt, current market price of lithium will increase significantly if the current trend continues.

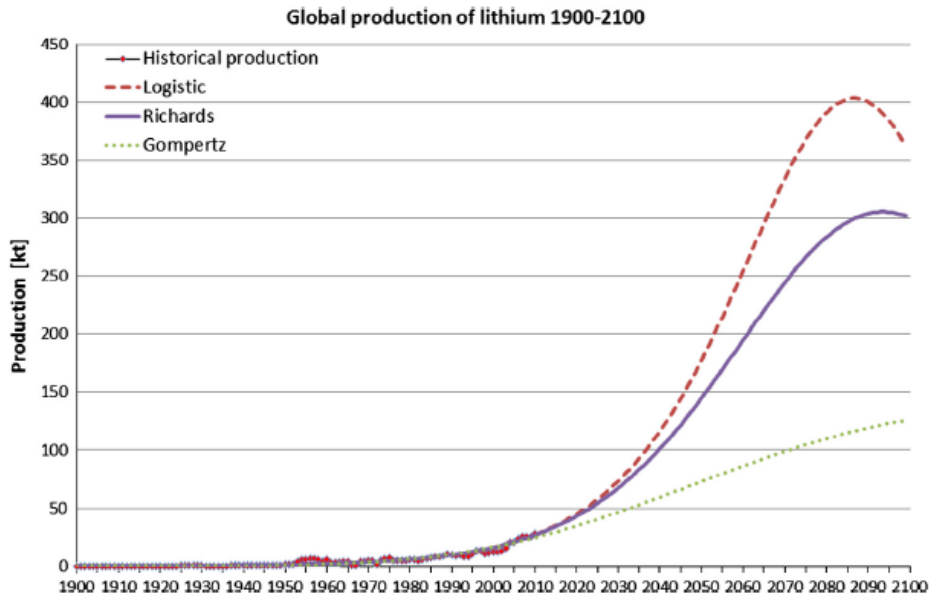


Figure 5.4: Global prediction of lithium production till 2100 based on high demand (Vikström, *et al.*, 2013).

The demand for lithium due to battery production for PHEV’s will be about 100 kt which may fall within the production rate as shown Figure 5.4. This may suggest that it will only be economically viable to mass produce PHEV’s as it needs less lithium compared to EV’s until alternative forms of lithium or another way to store energy is found.

Alternatively, it may also mean that in future as the demand for lithium increases, the prices of batteries and electric vehicles will go up. If this happens then it may not be within the budget of ordinary consumers and the popularity of electric vehicles will decrease. This may also mean that some of the battery parts need to be recycled to meet the demand as predicted by Goonan (Goonan, 2012; Vikström, *et al.*, 2013).

5.4 Increased electricity demand due to electric vehicles

New Zealand has a lot of natural resources from which energy can be harnessed for electricity. The major sources of renewable energies are hydro-power, geothermal, wind and bioenergy. Hydro dams generated about 57.1 percent of hydro-electricity last year compared to all other renewable energy sources as shown Figure 3.5.1. (Ministry of Business, 2015). The electricity sector has about eighty percent of renewable energy source, therefore, the electricity emissions factor (EEF) is lower compared to other nations (Internation Energy Agency, 2012).

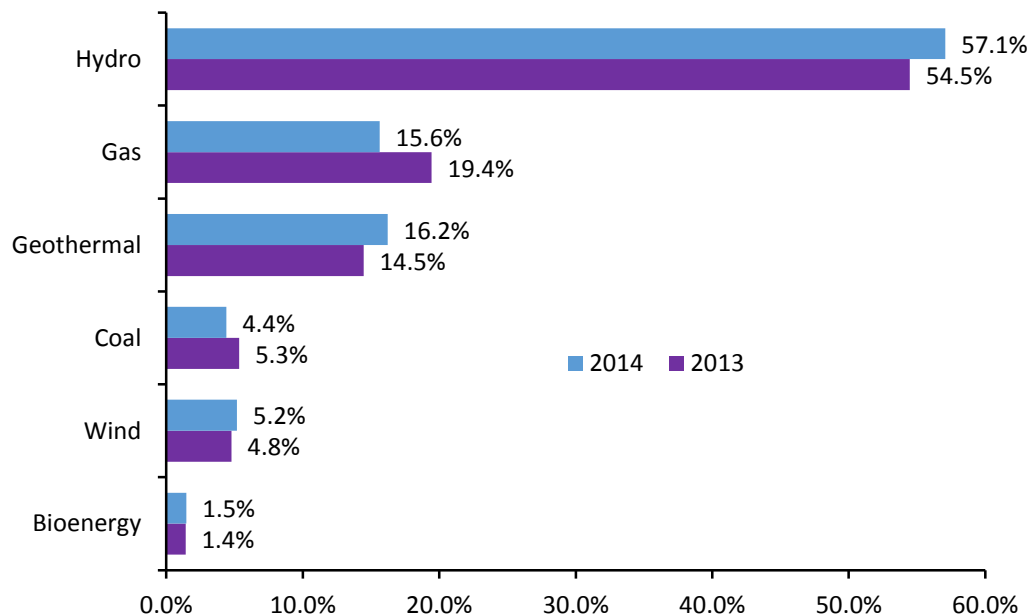


Figure 5.5: Electricity generation for different energy sources in New Zealand (Ministry of Business, 2015).

The consumption of electricity will increase if electric vehicles are introduced in the market. Electric vehicles use electricity to charge its battery. The amount of electricity it needs depends on the battery size and its charging efficiency. Lithium-ion batteries are mostly 99% efficient (Smith *et al.*, 2010). Equation 4.2 was used to calculate the total energy in New Zealand.

$$T.E = F + N \quad \text{Equation 4.2}$$

Where $T.E$ is the total energy that will be required in 2050 in Peta Joules (PJ) in a year for New Zealand and F is the predicted energy required in case of business as usual and N is the extra energy needed to charge the PHEV's and EV's. The average distance these cars will travel is 12,500km.

The impact on electricity sector due to the introduction of PHEV's or EV's is not significant as shown in Figure 5.6. This is based on the estimate that there will 1 million PHEV's and half a million EV's on New Zealand Roads by 2050. This is because the amount of energy required to charge the lithium-ion battery is not significant. A typical PHEV with a battery size of 4.4 kWh will use about 16 kJ of energy to get fully charged.

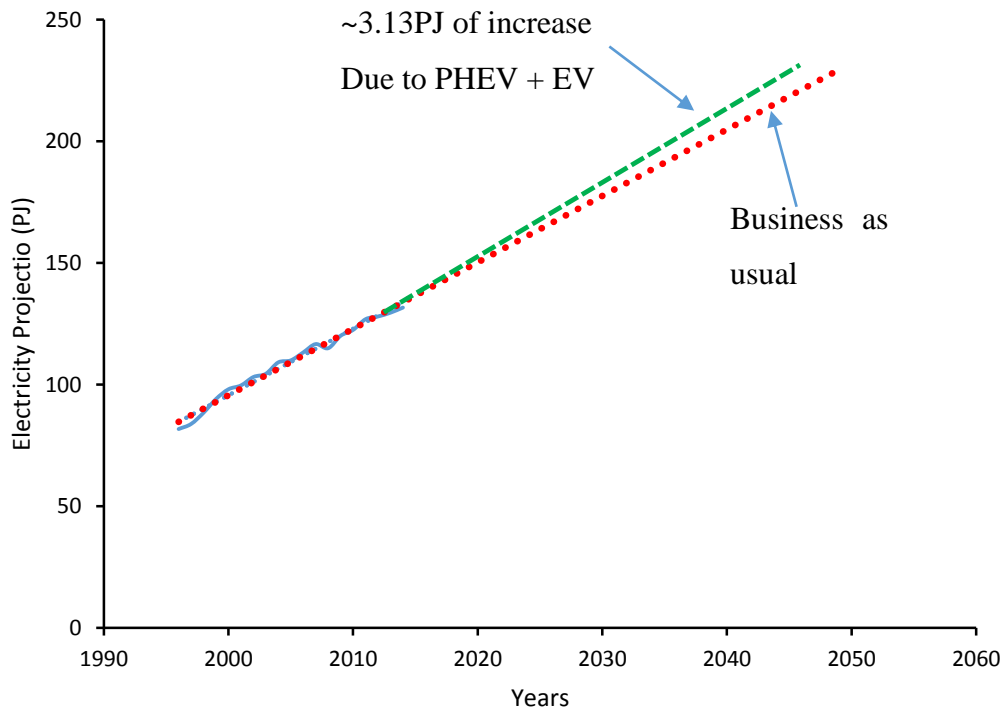


Figure 5.6: Projected electricity demand till 2050 based on different scenarios.

Although, the amount of electricity required on a yearly basis may not be significantly high, however, if all the PHEV's and EV's are charged during the peak hours of the day this may affect the peak hour loads (Kelly *et al.*, 2012) (Weiller, 2011). Equation 4.3 calculates the power required if the PHEV's and EV's are charged only during peak hours.

$$PD = D + D_{ev} \quad \text{Equation 4.3}$$

Where PD is the power required on the hourly basis (Transpower, 2015), D is the power demand of New Zealand and D_{ev} is the additional power required due to PHEV's and EV's. This prediction is based on Figure 3.18 that there will be about 50,000 EV's that will be available in New Zealand.

Typically the batteries of Toyota Prius take about 2 hours to charge (USA Toyota, 2014). If this is charged during the peak hours, then the typical power profile will be as shown in Figure 5.7.

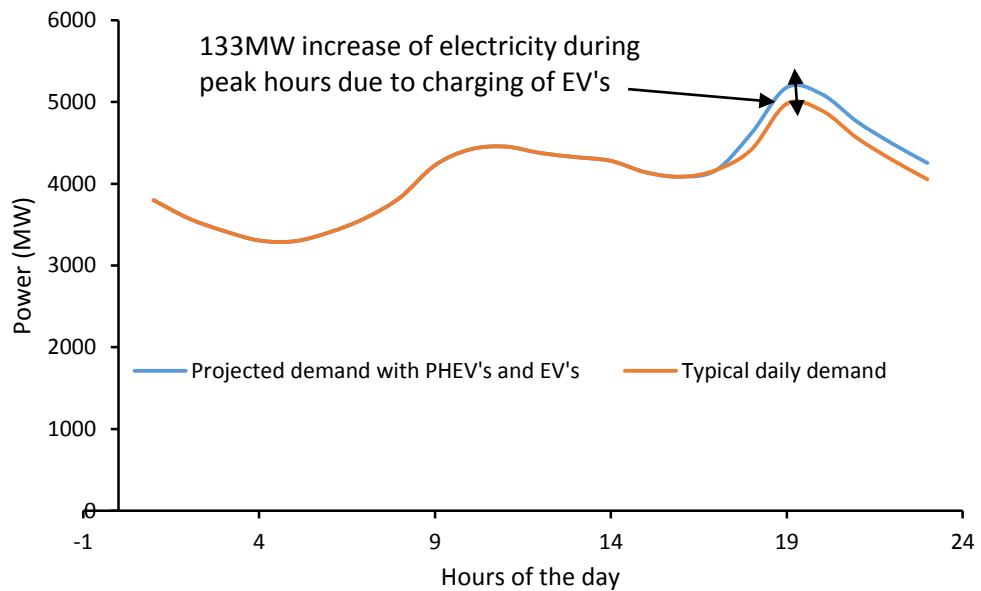


Figure 5.7: Power demand for a typical day.

The increase in 133MW of power due to EV's can be easily met by renewable energy sources since most of the renewable energy sources are not running on the full load as shown in Figure 5.8.

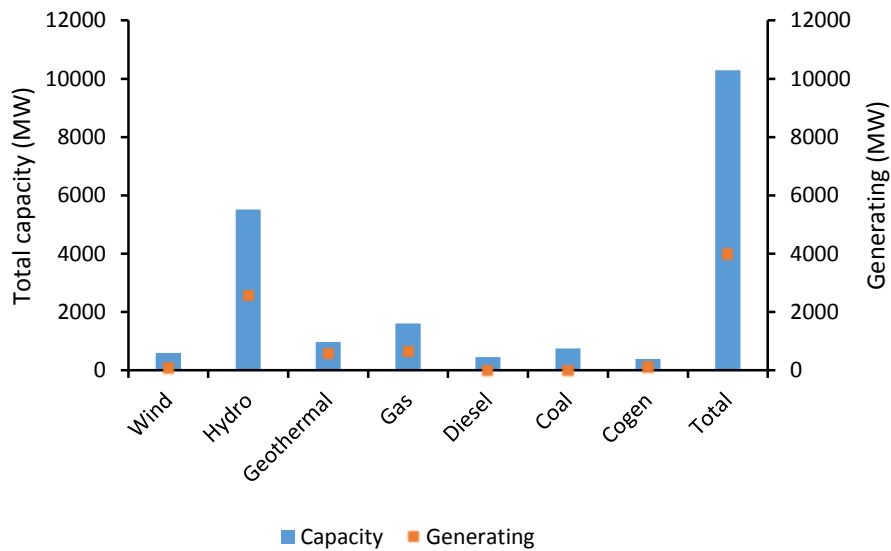


Figure 5.8: Typical day power generation from different energy sources.

5.5 Summary

The accelerated uptake of the PHEV's and EV's will depend on the different government incentives given to consumers as can be seen from the California case study. These incentives can be form of no road user charges, home charger, dedicated car lanes in busy cities subsidies etc.

In future, lithium availability could become a limiting factor to manufacture lithium-ion batteries. At the current production rate it will be very difficult to keep up with the demand. This might mean that the price of lithium-ion batteries will go up or more recycling of lithium related products will be needed.

The electricity demand in New Zealand will not significantly go up even though PHEV's and EV's are introduced. However, if all the vehicles are charged during the peak hour then the load will increased during that time. This extra demand electricity can be generated by renewable energy sources as currently our renewable energy sources are not operating at their peaks.

Chapter 6

Cycling

6.1 Introduction

Another way to reduce carbon dioxide from light passenger vehicles is to increase the amount of cycling. It is not a popular choice in New Zealand for a number of reasons such as safety, weather and infrastructure. One possible way to increase the amount of cycling in cities is to get more students to cycle to and from school. The trend to cycle to school has significantly decreased since 1989/90 as shown in the Figure 6.1. There can be a number of reasons for this, however, the main reasons may be the inexpensive cars available and the concern for safety issues regarding cycling. Parents are not prepared to take risks with their children and also there are so many regulations that make cycling unattractive to children e.g. wearing helmets.

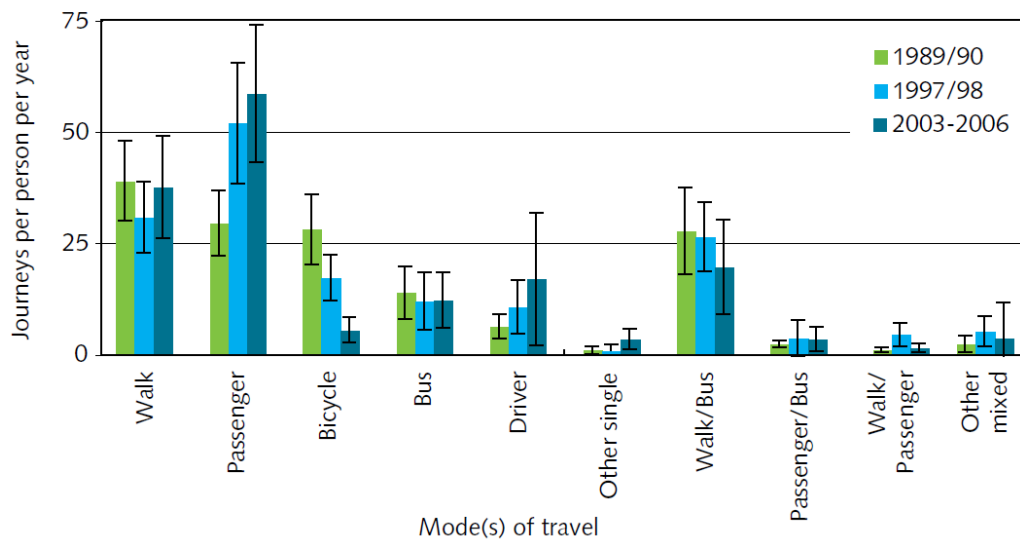


Figure 6.1: Mode of transport to School, between ages of 13 -17 (Ministry of Transport, 2008).

On average 250 people are either hospitalised or killed in New Zealand alone each year while cycling. This is a high number when compared to the size of population. As shown in Figure 5-2 these numbers are increasing which does not provide much incentive to people who want to cycle.

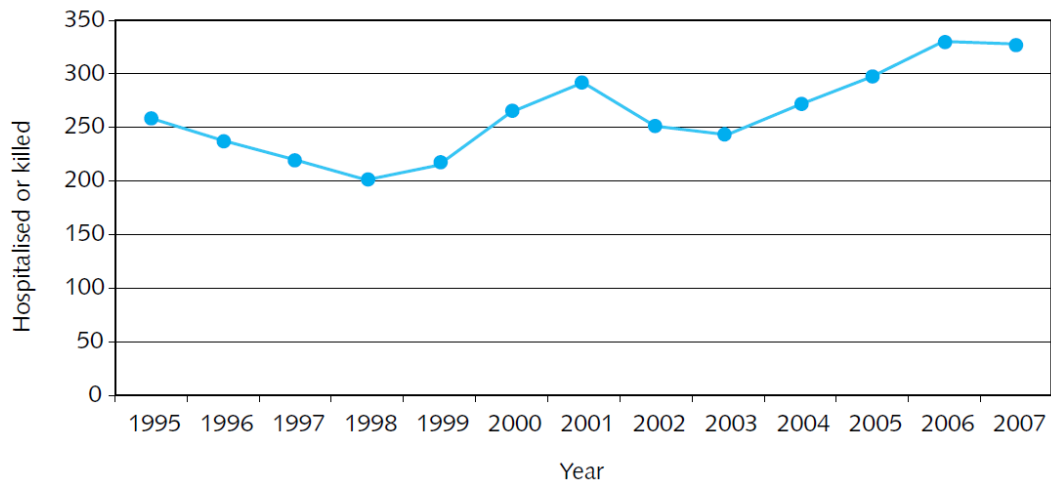


Figure 6.2: Number of people killed or hospitalised while cycling on New Zealand roads. (Ministry of Transport, 2008).

Some cities around the world have initiated programmes that encourage people to cycle such as Netherlands, Denmark and Sweden. In cities like Amsterdam about 70 percent of the journeys in the city is made on bike (BBC News, 2013). As shown in Figure 6.3 the roads are clearly marked and which encourages more people to cycle.



Figure 6.3: Road intersection in Amsterdam (BBC News, 2013).

Cycle ways around Hamilton city are disjointed (Figure 6.4), which makes it unsafe to travel. However, the council is investing \$3 million in next 2 years to build the cycle ways that connects south western suburbs to HGHS.

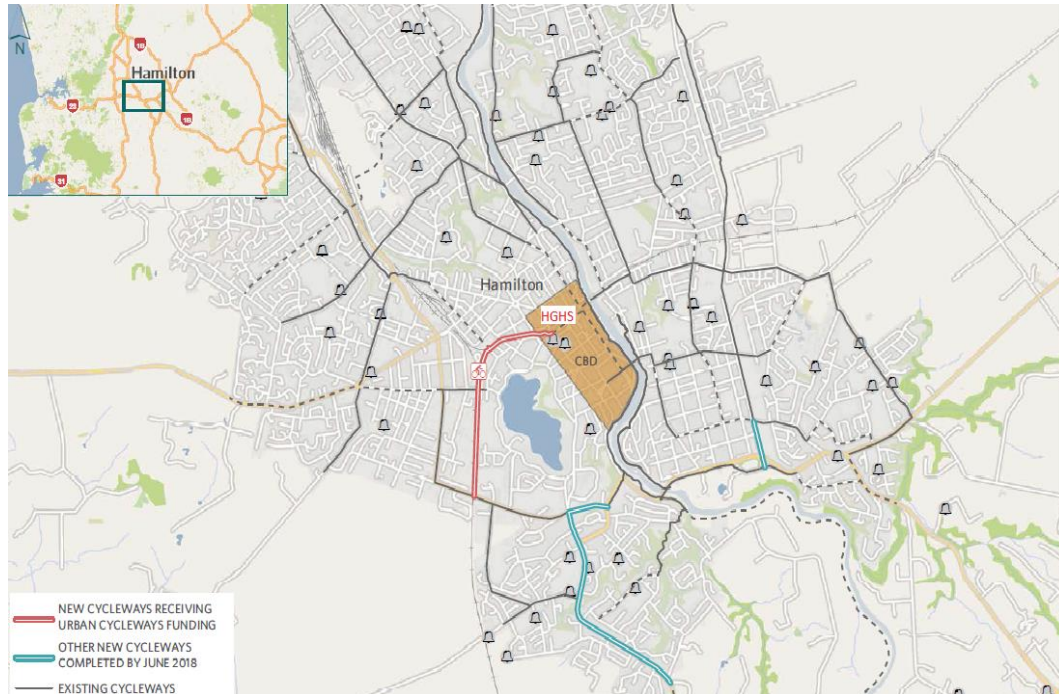


Figure 6.4 Cycle ways around Hamilton.

This chapter investigates the barriers and perceptions of Hamilton Girls' High School students toward cycling. It will further investigate the amount CO₂ is emitted by the students of HGHS and how much of this can be reduced if students are encouraged to cycle to school. Students were given questionnaires regarding cycling by means of a survey and interviews.

6.2 Methodology

A survey form containing the relevant questions regarding cycling were created in Google Document, which is an online survey tool. Students were able to type in their answers using their device and also able to find out the distance they are travelling to school by typing in their physical address on the google map. Their physical address was not recorded in the spreadsheet for privacy reasons.

Questions such as the transport method that is being used to travel to school, some of the barriers that discourages them from cycling, the type of vehicle used and its engine size were asked in the questionnaire (See Appendix 2). The size of the sample was 450 students and it covered years 9 to 13 students of Hamilton Girls' High School.

6.3 Results

6.3.1 Mode of Transport and distance travelled

Answers relating to mode of transport and distance travelled were analysed. Of the 450 participants who were surveyed about their modes of transport to school, 200 used cars or SUV's, 62 walked to school, 170 used buses and 1 used a bicycle to come to school. The total distance travelled by the students daily to and from school was 8666km and out of this 4360km was cars and SUV's, 204km was walking, 4092km was bus and 10km was cycling as shown in Figure 6.1.

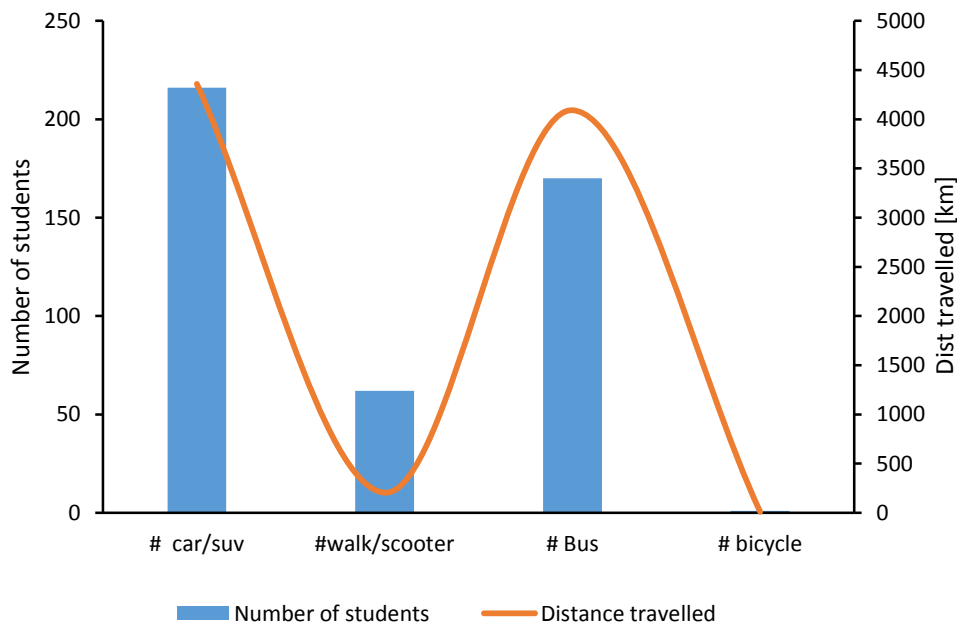


Figure 6.5: Modes of transport.

Of all the participants who walked to school were living in 5km radius as shown in Figure 6.6. Overall about 70 percentage of the students live with in a 10km zone. These are the potential students which can be encouraged to cycle to school.

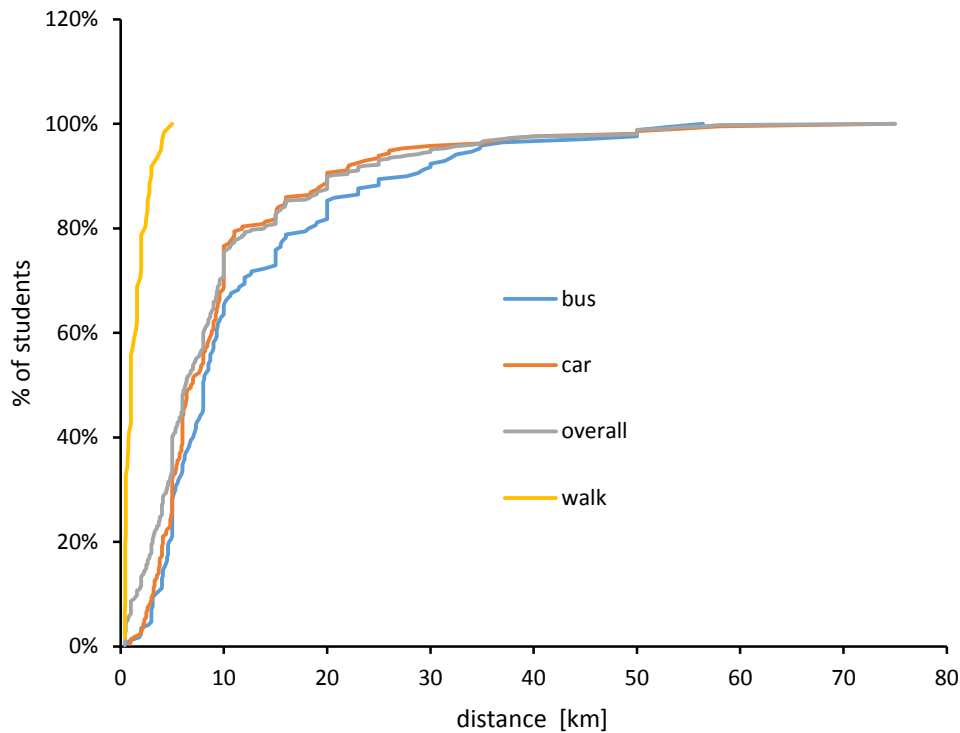


Figure 6.6: Distance profile of students coming to school.

6.3.2 Barriers to Cycling

Students were asked questions regarding some of the obstacles they face in order to cycle to school. The options were given to them in terms of a check box on a google docs. They can choose multiple options from the checkbox. The reasons given by students for not cycling to school is shown in Figure 6.7. The main reason given by students for not cycling to school was the distance followed by safety for the whole cohort. Majority of students perceived that they are living far away from the school, however, which is not true as shown in Figure 6.6. This may suggest that students perceive 10km as a long distance. Safety was the second biggest hindrance for them not to cycle to school. Weather and no place to leave the bicycle at school were also a concern for them.

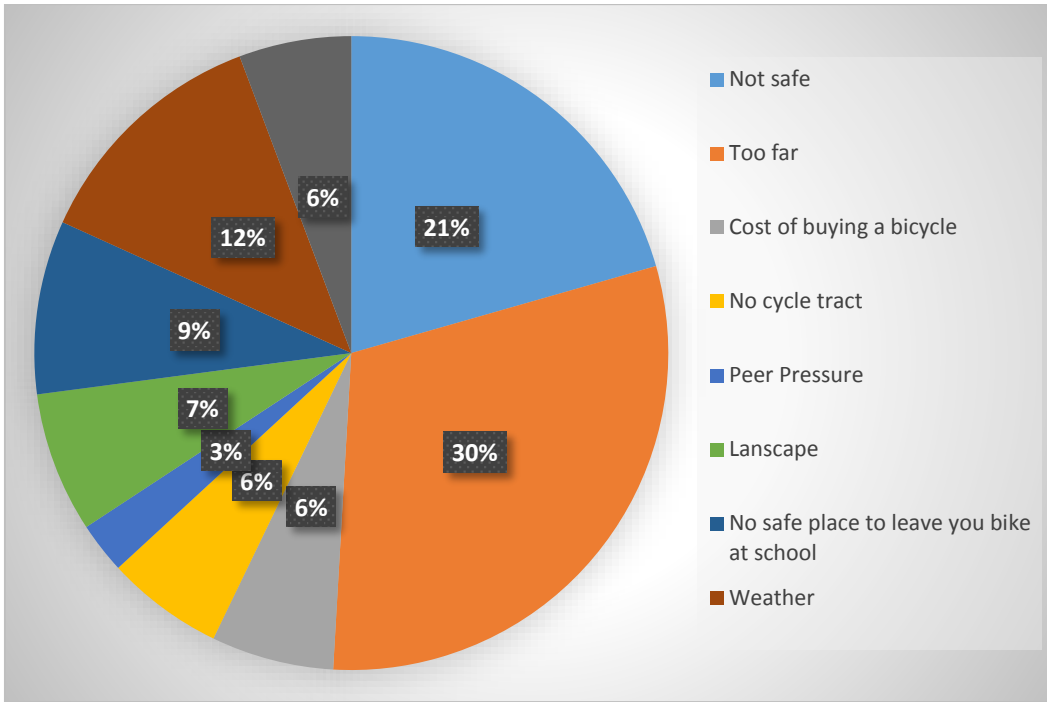


Figure 6.7: Reasons for not cycling to school for the whole cohort.

Students come from various suburbs around Hamilton. Some places the cycle tracks are not connected at various places along the path. This makes it very difficult to cycle along these roads.

6.3.3 Students keen to cycle

According to the survey about 18 percent of the students are living in the 10 km zone and are willing to cycle to school. Main reason for them not to cycle to school is safety as shown in Figure 6.8. They fear that if they cycle to school they might end up in an accident. There are hidden bends along the way and some place the cycle tracks are not complete in Hamilton. Some parents also fear the safety of their child if they cycle to school (Burdett, 2014).

Some perceive that distance and no place to put the bike at school is a problem. Schools should look at their policies regarding the bike storage and create a safe place where students can store their bike. Some students who were interviewed said Student A: “I don’t bike to school because of the school uniform. Principal also does not allow us to come to school in another uniform and there is no place to shower in school in the morning even if I cycle to school.” Student B: I will get

sweaty and stinky and there is no place to shower. As students have mentioned there is no place in school to have a shower and there is a school policy that students must come to school in uniform is reason for not cycling to school. School should align their policy to encourage students to cycle to school. Small things like making a safe place to store the bike at school, promoting cycling as being the fashion to be fit and healthy or making students aware of the environmental effects will make a difference.

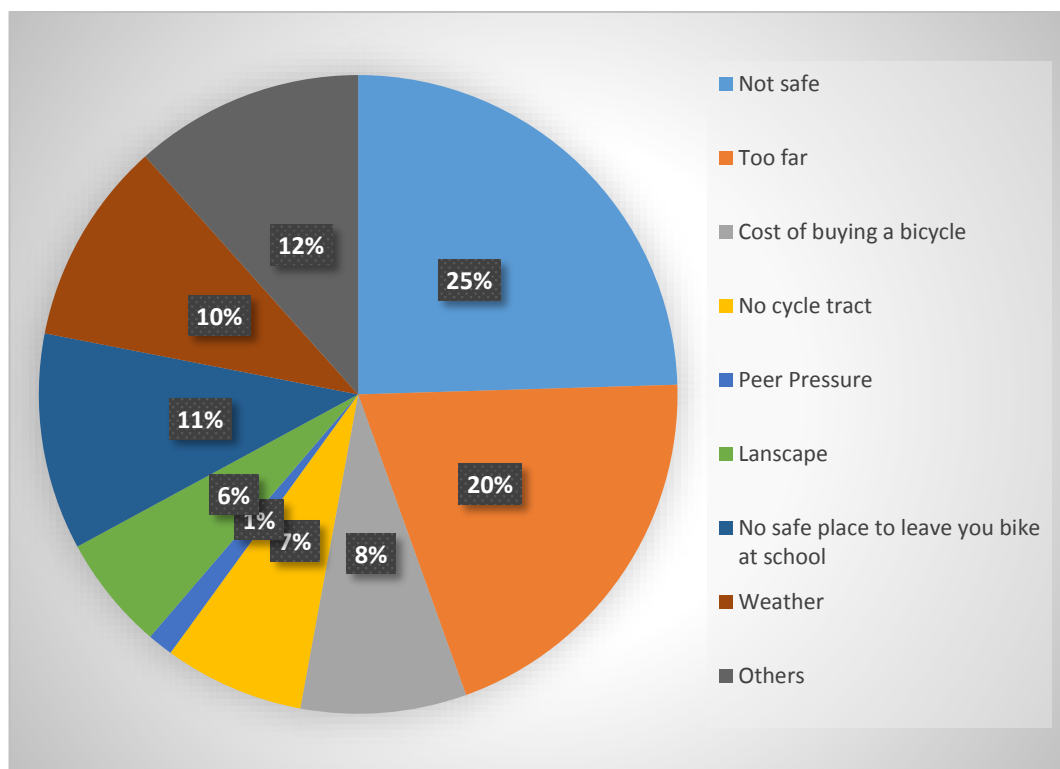


Figure 6.8: Barriers to cycling for keen cyclists.

About 20 percent of the students believe that distance is a barrier for them cycling to school. As seen from Figure 6.9, about 80 percent of the students live in the 10 km radius, however, some may be hostel students who live 40 to 50 km away. It shows that students perceive 10km as a very long distance to cycle.

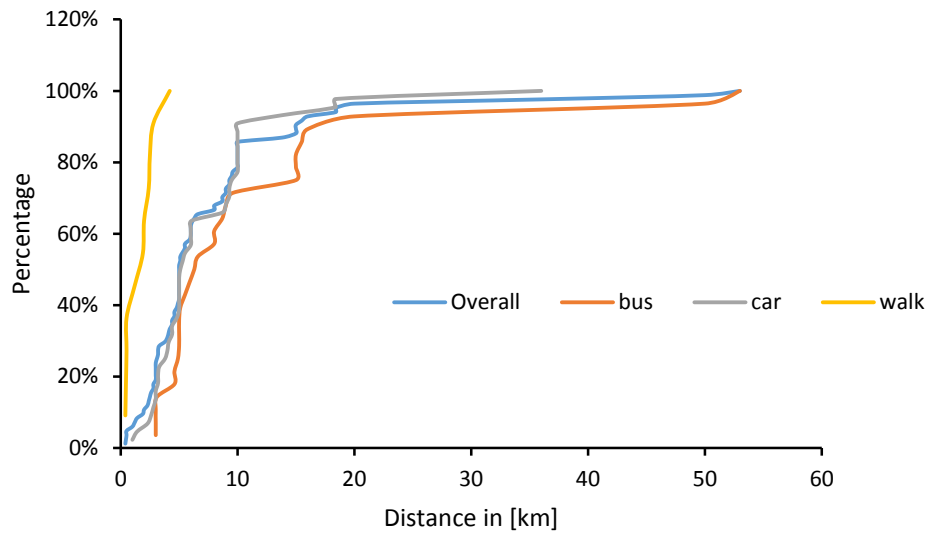


Figure 6.9: Distance profile of students who are keen to cycle.

6.3.4 Collision points near HGHS

Currently students cycling to school face a collision points when the cycle to school. At the junction near Ruakiwi road and Tainui Road (Figure 6.10) the road about is very dangerous for the cyclist to cross.

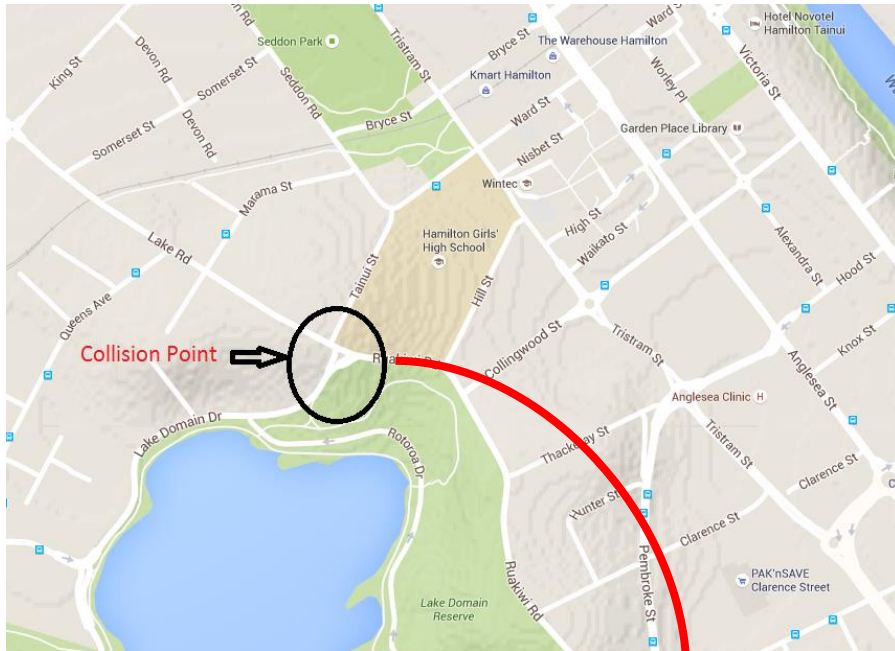


Figure 6.10: Junction near HGHS.

6.4 Possible CO₂ Reduction from Cycling to HGHS

Carbon dioxide emission reduction is one of the many benefits from cycling.

Equation 6.1 shows how much carbon dioxide can be reduced if students cycle to school.

Overall equation 6.1

$$CO_2 = \Sigma car + \Sigma bus$$

$$\Sigma car = Dist + Ef car$$

$$\Sigma bus = \frac{Dist \times Ef bus}{\eta bus}$$

Where Σcar is the total carbon dioxide emission by car, Σbus is the total carbon dioxide emission by bus, $Dist$ is the total distance travelled by a student, $Ef car$ is the carbon dioxide emitted by the car to travel 1 km [g/km], $Ef bus$ is the carbon dioxide emissions factor of the bus per km [g/km] and ηbus number of students travelling on the bus.

Those students who were traveling by cars or SUVs were asked about the fuel type of the vehicle and to estimate the engine size. This information was then used to calculate the carbon dioxide emitted during their trip to school as shown in Table 6.1. For the students who travelled by bus, it was assumed that the capacity was 60 and it was full and carbon dioxide emission of the bus was 814g/km.

The amount of carbon dioxide emitted by different kinds of vehicles varied from model to model and there was no direct relationship between the engine size and the carbon dioxide emission as it depends on many factors such as driver behaviour, landscape, weather etc. The average value of carbon dioxide emissions were considered for different engine sizes as shown in Figure 6.11. This information was then used to determine the carbon dioxide emissions of the vehicles used by the students to commute to school.

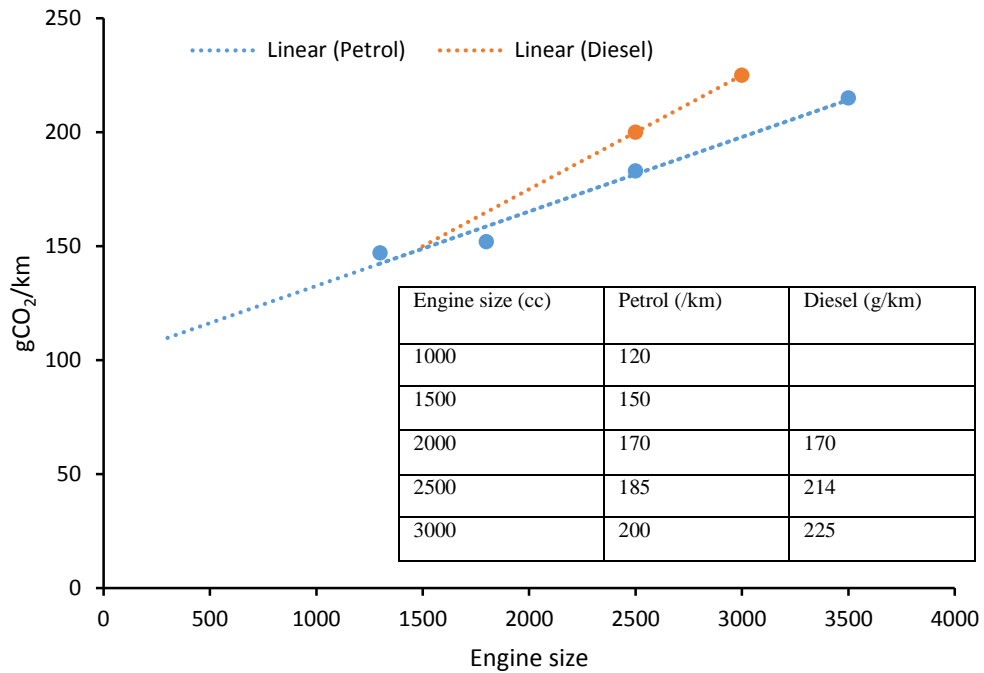


Figure 6.11: Engine size and carbon dioxide emission.

The results show (Table 6.1) those commuting by bus have the lowest carbon dioxide emission per student compared to the other modes. However, students who come to school on a diesel car or SUV' emits the largest amount of carbon dioxide.

Table 6.1: CO₂ emissions from different modes.

Vehicle type	CO ₂ emission (kg) per day at HGHS	Average CO ₂ (kg) per student per day at HGHS
Petrol car/suv	532	3.04
Diesel car/suv	149	4.40
Bus	552	0.32
Total	738	1.64

At Hamilton Girls High School, there are 1664 students, and on average the daily carbon dioxide emission based on the above value will be about 2735.39kg and 519.72 tonnes in a year. However, this is not possible as not all the students are keen to cycle to school.

6.4.1 Reduction of CO₂ from keen cyclers

Based on the survey results from the students who are keen to cycle to school, they emit on average 1.06 kg of CO₂ in a day. If the safety which is the number one concern for the students to cycle to school is improved then the students who are willing to cycle to school may do so. Based on the above figure (1.06 kg) which means that about 0.318 tonnes per day 60 tonnes in a year of carbon dioxide can be saved respectively.

6.4.2 Reduction of CO₂ for the Hamilton City

There are about 55 primary and secondary schools (Ministry of Education, 2015b) inside the Hamilton City boundary and a student population of 29,020, of which 12,258 are secondary school students (Ministry of Education, 2015a). About 20,000 students who are in years 6 to 14. If students are encouraged to cycle to school then the carbon footprint will go down for the city. Currently, about 9716 tonnes of CO₂ are emitted in the Hamilton city due to light vehicle as shown in Table 6.2. This is calculated using equation 5.2

$$\text{Amount of } CO_2 = N_{\text{dwell}} \times N_{\text{car}} \times Av_{CO_2} \times Av_{\text{dist/yr}} \text{ Equation 5.2}$$

Where *Amount of CO₂* is the carbon dioxide emitted in Hamilton city due to light vehicles, N_{dwell} is the number of house hold in Hamilton city, N_{car} is the number of car per dwelling in Hamilton city, Av_{CO_2} is the average carbon dioxide emitted by the cars, $Av_{\text{dist/yr}}$ is the average distance travelled by the cars in a year. On average the amount of car dioxide emission come to be 91,768 tonnes/yr.

Table 6.2: Total CO₂ emission by light vehicle in Hamilton City (Hamilton City Council, 2015).

Number of dwelling in Hamilton city	50820	
Number of cars per dwelling	1.2	
Number of car	60984	
Average distance travelled by a car in NZ	8360	km
Average CO ₂ emitted by cars in NZ	0.18	kg/km
Total CO ₂ emission	91768.72	tonnes/year

Figure 6.12 shows the percentage reduction of CO₂ from light vehicles if students at intermediate and high schools are encouraged to cycle to school in Hamilton city area. It shows that up to 6 percent of Cities CO₂ emission can be reduced just by students cycling to school.

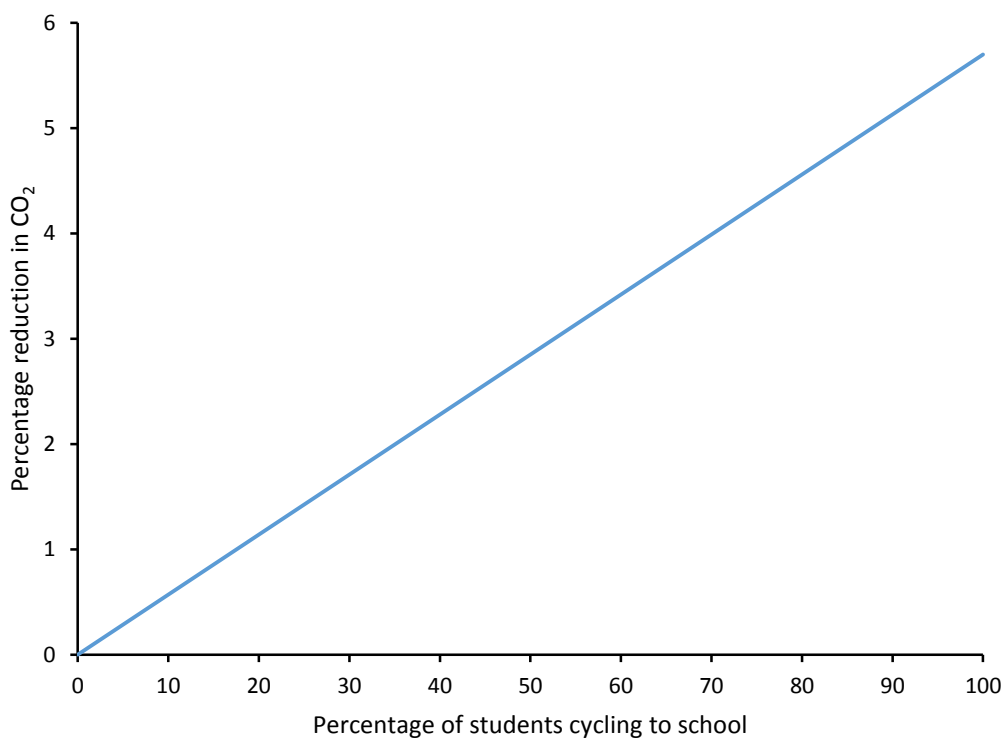


Figure 6.12: Overall reduction of CO₂ if students cycle to school in Hamilton.

To increase the number of students that cycle to school, council should invest in the infrastructure which encourage this. Most of the schools on the Eastern side of Hamilton are very close together as shown in Figure 6.13. It also shows around

Hamilton Boys High school there are 6 schools present which can be a potential target for the council to invest some money in cycle ways. A common cycle way linking these schools will be a better idea compared to disjointed cycle ways. This will make the cycle way much safer and will encourage more students to cycle to school.

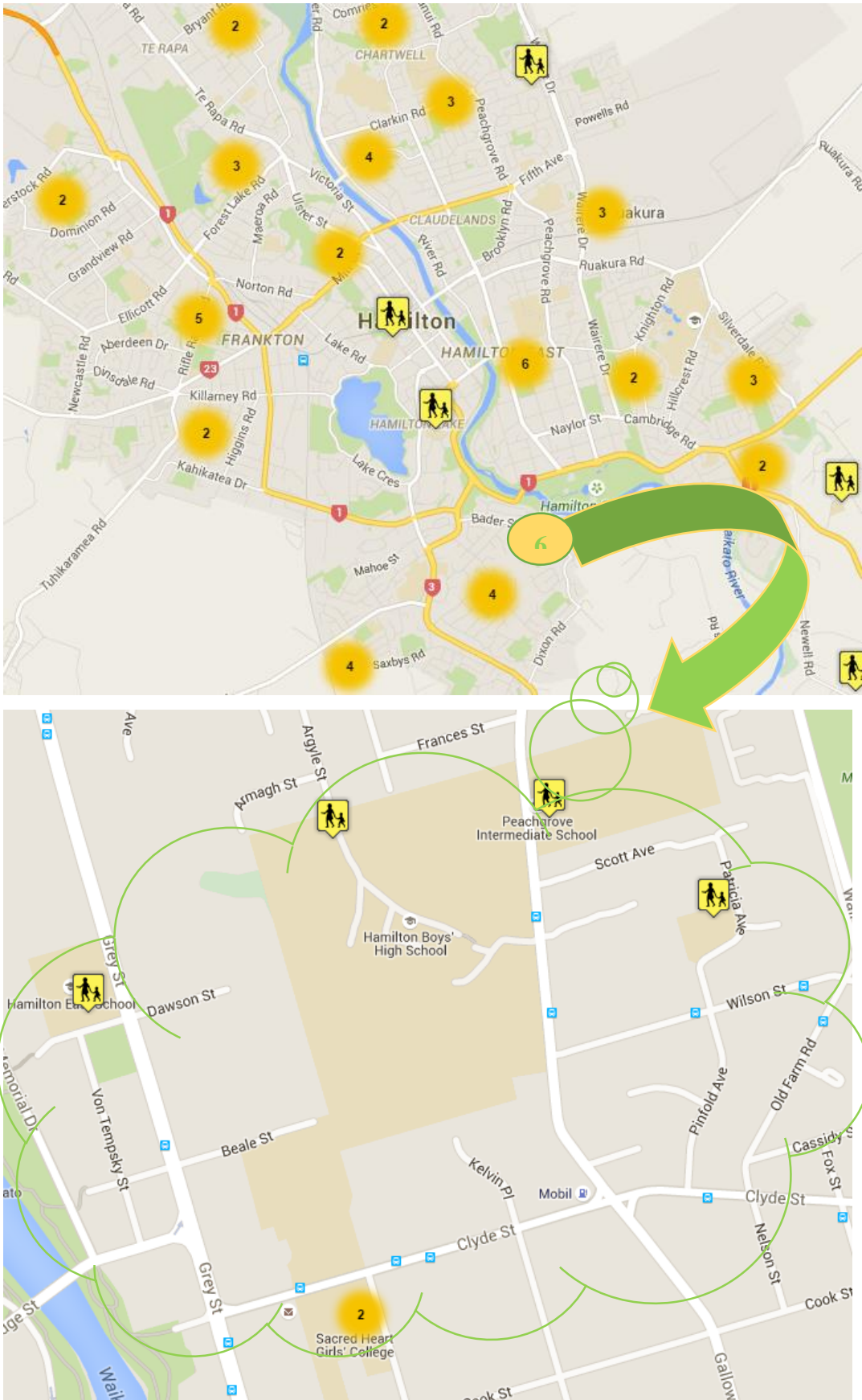


Figure 6.13: Locations of schools in Hamilton City.

6.5 Summary

Promoting cycling at Hamilton Girls High School can reduce carbon dioxide emissions from light passenger vehicles in Hamilton city area. This reduction will increase, if more and more schools come on board and promote cycling. However, there are some challenge to increase the number of student cyclers at Hamilton Girls High School. There are number of barriers which prohibit students from cycling to school such as safety, school uniform, bike storage at school, disjointed cycle ways, whether, distance, cost of buying the cycle, landscape and peers pressure. There are certain elements which cannot be eliminated, however, it can be minimised.

Safety concerns can be minimised if council invests some money to join the current cycle ways. Schools should make a place for students to store bike and allow them to come to school in mufti. There should be some dedicated changing room and showers for the students who chose to cycle to school. Cycling should be promoted as the healthy choice. These are small changes that can promote cycling in Hamilton.

Chapter 7

Conclusion and Recommendations

Carbon dioxide emissions can be reduced in New Zealand by electrification of all rail and partial electrification of light passenger vehicles through plug-in hybrid and electric vehicle technologies. New Zealand's electricity is supplied by a high proportion of hydro and geothermal renewable generation, which in turn can help lower emissions from the transport sector when effectively integrated. With an uptake of 40% for all light passenger vehicles, buses and light commercial vehicles, hybrid engine technology is estimated to reduce liquid fuel use by 77 PJ in 2050 compared to using current transport technologies. In 2050 total transport energy use as a combination of liquid fuels and electricity is calculated to be 220 PJ. To reach the goal of reducing carbon emissions to 1990 levels in 2050, 47 PJ of biofuels is needed together with 174 PJ of conventional liquid fuels from oil.

Since New Zealand is a small country and most cars imported are second hand vehicles it will take some time for the electric vehicles to capture a major share in the market. It is predicted that by 2035 there will be about 160,000 PHEV' and EV's in New Zealand. This will mean that there will be a 6 percent reduction of CO₂ emissions from light passenger vehicles. However, this market share can be accelerated if there are government incentives such as home charger, tax rebates, car pool lanes, subsidies and no road user charges are given to consumers hence CO₂ emission reduction will increase.

As PHEV's and EV' increase in numbers the electricity usage for the country will go up, as they use external energy sources to charge their batteries. Based on the current battery efficiency and the types of vehicles analysed, this increase will not be high as it does not need much electricity to charge a battery.

Total ownership cost of PHEV's and EV's depend on capital cost and the life expectancy of batteries, and for PHEV's it also depends on the fuel mix. As the life expectancy of the battery life increases the cost of these vehicles decreases.

Lithium availability can affect the price of lithium-ion batteries. With the current projections done by International energy agency for PHEV's and EV's will be difficult to keep up with the demand with the predicted production rate. This may mean that the price of lithium-ion batteries will go up or an alternative form will be found.

Another way CO₂ emissions can be reduced is by encouraging more students to cycle to school. At Hamilton Girls High School the students face a number of barriers that discourage them to cycle to school such as safety, school uniform, bike storage at school, disjointed cycle ways, whether, distance, cost of buying the cycle, landscape and peer pressure. Some of these barriers can be minimised in order to encourage more students to cycle to school. About 20 percent of students at HGHS keen to cycle to school are living less than 10 km radius from the school. If the barriers are reduced and these students cycle to HGHS then there will a reduction of 60 tonnes of CO₂ emissions from light passenger vehicles in Hamilton City. However, if most students in the city area living within the 10 km radius are encouraged to cycle to school then there can be a reduction of about 6 percent CO₂ emissions from the light passenger vehicle in Hamilton City area. Apart from CO₂ emission reduction there will be other benefits such as less traffic congestion on our roads and students will be healthier.

New Zealand can reduce its CO₂ emissions footprint from vehicles by introducing a combination of initiatives such as fuel mix, electrification of vehicles and promoting cycling as a healthier choice.

7.1 Recommendation

A comprehensive survey can be carried out to gauge the public opinions regarding PHEV's and EV's. Based on a survey, a policy document can be compiled that will encourage more people to buy PHEV's and EV's.

Design a system that can replace our parking meters that also has charging facility for PHEV's and EV's.

References

- Armand, M., & Tarascon, J. M. (2008). Building better batteries. *Nature*, 451(7179), 652-657.
- BBC News. (2013). *Why is Cycling so Popular in the Netherlands?* Retrieved 15 June, 2015, from <http://www.bbc.com/news/magazine-23587916>
- Burdett, B. (2014). *Hamilton City Cycling Survey*. Hamilton, New Zealand, Hamilton City Council. 64p. Retrieved October 2015, from <http://www.hamilton.govt.nz/our-services/transport/movingaround/Documents/12545%20Hamilton%20Cycling%20Survey%20summary%20report140724.pdf>.
- Cluzel, C., & Douglas, C. (2012). *Cost and Performance of EV Batteries*. Final report for the Committee on Climate Change. Cambridge, U.K., Element Energy Limited. 91p. Retrieved 24 April 2015, from http://www.element-energy.co.uk/wordpress/wp-content/uploads/2012/06/CCC-battery-cost_-Element-Energy-report_March2012_Finalbis.pdf.
- Crilly, D., & Zhelev, T. (2008). Emissions targeting and planning: An application of CO₂ emissions pinch analysis (CEPA) to the Irish electricity generation sector. *Energy*, 33(10), 1498–1507.
- Daimler AG. (2013). *Environmental Certificate Mercedes-Benz S-Class*. Stuttgart, Germany, Mercedes-Benz. 58p. Retrieved October 2015, from https://www.daimler.com/Projects/c2c/channel/documents/2373360_Environmental_Certificate_Mercedes_Benz_S_Class.pdf.
- Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy Policy*, 37(3), 972-983.
- Dunn, J. B., Gaines, L., Sullivan, J., & Wang, M. Q. (2012). Impact of recycling on cradle-to-gate energy consumption and greenhouse gas emissions of automotive lithium-ion batteries. *Environmental Science and Technology*, 46(22), 12704-12710.
- Egbue, O., & Long, S. (2012). Critical issues in the supply chain of lithium for electric vehicle batteries. *Engineering Management Journal*, 24(3), 52-62.

- Gerrard, J., & Kandlikar, M. (2007). Is European end-of-life vehicle legislation living up to expectations? Assessing the impact of the ELV Directive on 'green' innovation and vehicle recovery. *Journal of Cleaner Production*, 15(1), 17-27.
- Goonan, T. G. (2012). *Lithium Use in Batteries*. Circular 1371. Reston, VA, U.S. Department of the Interior. 14p. Retrieved October 2015, from http://pubs.usgs.gov/circ/1371/pdf/circ1371_508.pdf.
- Hamilton City Council. (2015). *QuickStats about Hamilton City*. Retrieved 13 July, 2015, from http://www.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx?request_value=13702&tabname=&sc_device=pdf
- Hawkins, T. R., Singh, B., Majeau-Bettez, G., & Strømman, A. H. (2013). Comparative environmental life cycle assessment of conventional and electric vehicles. *Journal of Industrial Ecology*, 17(1), 53-64.
- Hondo, H. (2005). Life cycle GHG emission analysis of power generation systems: Japanese case. *Energy*, 30(11–12), 2042-2056.
- Husain, I. (2011). *Electric and Hybrid Vehicles: Design Fundamentals* (2nd ed.). Boca Raton, FL: CRC Press.
- International Energy Agency. (2012). *Electricity Emissions Factor*. Retrieved 25 April, 2015, from http://data.iea.org/ieastore/product.asp?dept_id=101&pf_id=305
- International Energy Agency. (2013). *Global EV Outlook: Understanding the Electric Vehicle Landscape to 2020*. Clean Energy Ministerial. 40p. Retrieved October 2015, from http://www.iea.org/publications/globalevoutlook_2013.pdf.
- International Energy Agency. (2011). *Technology Roadmap: Electric and Plug-in Hybrid Electric Vehicles (EV/PHEV)*. Paris, France, OECD. 47p. Retrieved 8 October 2015, from <http://www.iea.org/publications/freepublications/publication/technology-roadmap-electric-and-plug-in-hybrid-electric-vehicles-evphev.html>.
- IPCC. (2015). *Climate Change 2014: Synthesis Report*. Geneva, Switzerland, Intergovernmental Panel on Climate Change. 151p. Retrieved October 2015, from http://epic.awi.de/37530/1/IPCC_AR5_SYR_Final.pdf.
- Jack, M., & Hall, P. (2009). *Bioenergy Options for New Zealand: Analysis of large-scale bioenergy from forestry*, Scion, Rotorua, NZ.

- Kane, M. (2014). *Study: State Incentives Drive Electric Vehicle Sales*. Retrieved 5 November 2015, from <http://insideevs.com/study-state-incentives-drive-electric-vehicle-sales/>
- Kelly, J. C., MacDonald, J. S., & Keoleian, G. A. (2012). Time-dependent plug-in hybrid electric vehicle charging based on national driving patterns and demographics. *Applied Energy*, *94*, 395-405.
- Kuschel, G., Metcalfe, J., Wilton, E., Guria, J., Hales, S., Rolfe, K., & Woodward, A. (2012). *Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report*. Prepared for Health Research Council of New Zealand, Ministry of Transport, Ministry for the Environment and New Zealand Transport Agency. Auckland, New Zealand. 44p. Retrieved October 2015, from http://www.hapinz.org.nz/HAPINZ%20Update_Vol%201%20Summary%20Report.pdf.
- Kushnir, D., & Sandén, B. A. (2012). The time dimension and lithium resource constraints for electric vehicles. *Resources Policy*, *37*(1), 93-103.
- Lallanila, M. (2015). *What is the Greenhouse Effect?* Retrieved 5 November 2015, from <http://www.livescience.com/37743-greenhouse-effect.html>
- Lemon, S., & Miller, A. (2013a). *Electric Vehicles in New Zealand: From Passenger to Driver?* Christchurch, New Zealand, University of Canterbury. 31p. Retrieved October 2015, from <http://www.epecentre.ac.nz/docs/media/Electric%20Vehicles%20in%20New%20Zealand%20White%20Paper-r10.pdf>.
- Lemon, S., & Miller, A. (2013b). *Electric Vehicles in New Zealand: Technologically Challenged?* Paper presented at the EEA Conference & Exhibition 2013, 19 - 21 June, Auckland, New Zealand, retrieved from <http://www.epecentre.ac.nz/docs/media/Electric%20Vehicles%20in%20New%20Zealand%20-%20Technologically%20Challenged.pdf>
- Ma, H., Balthasar, F., Tait, N., Riera-Palou, X., & Harrison, A. (2012). A new comparison between the life cycle greenhouse gas emissions of battery electric vehicles and internal combustion vehicles. *Energy Policy*, *44*, 160-173.
- Marano, V., Onori, S., Guezennec, Y., Rizzoni, G., & Madella, N. (2009). Lithium-ion batteries life estimation for plug-in hybrid electric vehicles. In *2009 IEEE Vehicle Power and Propulsion Conference Proceedings* (pp. 536-543). Piscataway, NJ: IEEE.

- McManus, M. C. (2012). Environmental consequences of the use of batteries in low carbon systems: The impact of battery production. *Applied Energy*, 93, 288-295.
- Miller, J. F. (2011). Analysis of current and projected battery manufacturing costs for electric, hybrid, and plug-in hybrid electric vehicles. *World Electric Vehicle Journal*, 4(1), 347-350.
- Ministry of Business, Innovation and Employment,. (2015). *Electricity Graph and Data Tables*. Retrieved 24 April, 2015, from <http://www.med.govt.nz/sectors-industries/energy/energy-modelling/data/electricity>
- Ministry of Education. (2015a). *Education Counts*. Retrieved 10 July, 2015, from <http://www.educationcounts.govt.nz/statistics/schooling/student-numbers/6028>
- Ministry of Education. (2015b). *Schools*. Retrieved 10 July, 2015, from <https://www.tki.org.nz/Schools?schoolSearch=true&location=Hamilton%20City>
- Ministry of Transport. (2008). *Raising the Profile of Walking and Cycling in New Zealand: A Guide for Decision-Makers*. Wellington, New Zealand. 42p. Retrieved October 2015, from <http://www.transport.govt.nz/assets/Import/Documents/RaisingtheProfileWalkingCyclinginNZ.pdf>.
- Ministry of Transport. (2014). *Data and Spreadsheets - Household Travel Survey (2003-2014)*. Retrieved 13 April, 2014, from <http://www.transport.govt.nz/research/travelsurvey/data-and-spreadsheets-household-travel-survey/>
- Ministry of Transport. (2015). *New Zealand Vehicle Fleet Statistics*. Retrieved 21 March, 2015, from <http://www.transport.govt.nz/research/newzealandvehiclefleetstatistics/>
- Ministry of Transport, NZ,. (2013). *New Zealand Vehicle Fleet Statistics*. Retrieved October, 2013, from <http://www.transport.govt.nz/research/newzealandvehiclefleetstatistics/>
- New Zealand Holden. (2014). *Holden Volt*. Retrieved 1 May, 2014, from <http://www.holden.co.nz/cars/volt/range>

- New Zealand Toyota. (2014a). *Corolla Hatch Specifications GLX*. Retrieved 1 May, 2014, from <http://www.toyota.co.nz/our-range/corolla/corolla-hatch/specifications/glx/>
- New Zealand Toyota. (2014b). *Toyota Prius Hybrid*. Retrieved 1 May, 2014, from <http://www.toyota.co.nz/our-range/prius/prius/specifications/fwd/>
- Nissan New Zealand*. (2015). Retrieved October, 2015, from <http://www.nissan.co.nz/>
- Ooi, R. E. H., Foo, D. C. Y., Tan, R. R., Ng, D. K. S., & Smith, R. (2013). Carbon constrained energy planning (CCEP) for sustainable power generation sector with automated targeting model. *Industrial and Engineering Chemistry Research*, 52(29), 9889–9896.
- Owens, J. W. (1997). Life-cycle assessment: Constraints on moving from inventory to impact assessment. *Journal of Industrial Ecology*, 1(1), 37-49.
- Scrosati, B., & Garche, J. (2010). Lithium batteries: Status, prospects and future. *Journal of Power Sources*, 195(9), 2419-2430.
- Smith, A. J., Burns, J. C., Trussler, S., & Dahn, J. R. (2010). Precision measurements of the coulombic efficiency of lithium-ion batteries and of electrode materials for lithium-ion batteries. *Journal of The Electrochemical Society*, 157(2), A196-A202.
- Sullivan, J. L., & Gaines, L. (2012). Status of life cycle inventories for batteries. *Energy Conversion and Management*, 58, 134-148.
- Transport, M. o. (2013). *Annual Fleet Statistics 2014*. New Zealand.
- Transpower. (2015). *Transpower System Operator*. Retrieved October, 2015, from <https://www.systemoperator.co.nz/system-operations/published-data/load-graphs>
- U.S. Department of Energy. (2014). *Fuel Economy*. Retrieved 21 July, 2014, from <http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=34516&id=33900&#tab2>
- U.S. Department of Interior. (2014). *Lithium: Statistics and Information*. Retrieved 13 June, 2014, from <http://minerals.usgs.gov/minerals/pubs/commodity/lithium/>
- US Department of Energy, Transportation Energy Data Book*. (2013). Retrieved May 22, 2014, from <http://cta.ornl.gov/data/index.shtml>

- USA Toyota. (2014). *Prius Plug-in Hybrid*. Retrieved 1 May, 2014, from <http://www.toyota.com/prius-plug-in/#!/Welcome>
- USEP. (2015). *Global Greenhouse Gas Emissions Data*. Retrieved 6 August, 2015, from <http://www.epa.gov/climatechange/ghgemissions/global.html>
- Väyrynen, A., & Salminen, J. (2012). Lithium ion battery production. *The Journal of Chemical Thermodynamics*, *46*, 80-85.
- Vikström, H., Davidsson, S., & Höök, M. (2013). Lithium availability and future production outlooks. *Applied Energy*, *110*, 252-266.
- Walmsley, M. R. W., Walmsley, T. G., Atkins, M. J., Kamp, P. J. J., & Neale, J. R. (2014). Minimising carbon emissions and energy expended for electricity generation in New Zealand through to 2050. *Applied Energy*, *135*, 656–665.
- Weiller, C. (2011). Plug-in hybrid electric vehicle impacts on hourly electricity demand in the United States. *Energy Policy*, *39*(6), 3766-3778.
- Zackrisson, M., Avellan, L., & Orlenius, J. (2010). Life cycle assessment of lithium-ion batteries for plug-in hybrid electric vehicles - Critical issues. *Journal of Cleaner Production*, *18*(15), 1519-1529.
- Zhang, L., Brown, T., & Samuelson, G. S. (2011). Fuel reduction and electricity consumption impact of different charging scenarios for plug-in hybrid electric vehicles. *Journal of Power Sources*, *196*(15), 6559-6566.
- Zhang, S. S., Jow, T. R., Amine, K., & Henriksen, G. L. (2002). LiPF₆-EC-EMC electrolyte for Li-ion battery. *Journal of Power Sources*, *107*(1), 18-23.

Appendices

Appendix 1: Energy Paper

ARTICLE IN PRESS

Energy xxx (2015) 1–8



Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy



Carbon Emissions Pinch Analysis for emissions reductions in the New Zealand transport sector through to 2050

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ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form
22 April 2015
Accepted 25 April 2015
Available online xxx

Keywords:
Carbon Emissions Pinch Analysis
Energy planning
Transport energy sector

ABSTRACT

The CEPA (Carbon Emissions Pinch Analysis) method for energy planning has been modified for improved application to large transport systems. The modified method is applied to investigate the feasibility of NZ (New Zealand) reaching a 1990 emission levels for transport by 2050. The transportation sector has been traditionally a difficult area to transition to high levels of renewable energy because of the strong dependency on fossil fuels. For New Zealand, possible steps for low carbon emissions from transport are: (1) electrification of all rail, (2) wide-spread adoption of energy efficient vehicle technologies, (3) partial electrification of light passenger vehicles through plug-in hybrid and electric vehicle technologies, and (4), introduction of liquid fuels from biomass as an alternative to liquid fuels from petroleum.

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1. Introduction

Replacement of traditional oil and natural gas based transport fuels with alternatives that are both technically and economically viable and environmentally, socially and politically sustainable is a significant global issue. As transport energy demand rises, especially in developing countries, and as oil and gas reserves become increasingly difficult to find and exploit, energy companies and nations will be driven to convert unconventional energy resources, like tar sands, shale oil, agricultural crops and silviculture forests, into replacement fuels. Increased motivation to address the transporters' fuel challenge is derived from the need to lower environmentally harmful emissions, such as carbon and the like emissions, and to reduce air pollution in many of the world's major cities. However converting unconventional energy resources into transport fuels, even after considerable research effort, remains a technical challenge and struggles to economically compete with oil-derived liquid fuels.

Careful energy sector planning using engineering analysis tools, such as CEPA (Carbon Emissions Pinch Analysis) [1] and EROI (Energy Return on Investment) analysis [2], is therefore needed to ensure that the inevitable transition to a low fossil fuel transport

energy sector occurs in a way that minimises the increase in cost and energy expended from the economy to meet the desired demand within the nation's carbon emissions targets. EROI is essentially the ratio of the amount of useful energy produced for society to the amount of energy that has to be expended to obtain the useful energy in the first place. Effective production of energy with high EROI values is crucial to economic growth, industrial manufacturing, employment and the general economic well-being of citizens [3]. CEPA, on the other hand, quantifies the environmental impact in terms of emissions of using energy. CEPA is a graphical method for showing how much carbon emissions are contributed from each part of an energy sector (e.g. electricity, transport) and exploring possible pathways for modifying the energy system to meet fixed emissions targets.

NZ (New Zealand) is well endowed with natural energy resources. Renewable resources such as hydro (58%), geothermal (13%), wind (4%) and biomass (<1%) accounted for 77% of electricity generation in 2011 [2]. Coal, natural gas and biomass are used for process heat and the remaining power generation demand. Imported crude oil accounts for 33.8% of NZ's primary energy needs and 99.8% of NZ's transport fuel needs [4]. NZ has a current population of 4.4 million that is anticipated to reach 5.8 million about 2050 [5]. There is strong political will within NZ for continued growth in the renewable generation sector as a strategy for reducing NZ greenhouse gas (GHG) emissions. Numerous studies

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<http://dx.doi.org/10.1016/j.energy.2015.04.069>
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Please cite this article in press as: Walmsley MRW, et al., Carbon Emissions Pinch Analysis for emissions reductions in the New Zealand transport sector through to 2050, Energy (2015), <http://dx.doi.org/10.1016/j.energy.2015.04.069>

have been commissioned by the NZ government into alternate transport fuel options for NZ in the biofuels areas [6].

There are also many other studies that are specific to other countries that are in a similar energy and resource position as NZ that may be considered when exploring solutions for NZ. For example, Mathiesen et al. [7] conclude that Denmark should use their abundant renewable electricity generation potential to directly power as much of the future transport fleet as possible. Other transport operations such as aeroplanes and ships that cannot be electrified are anticipated to use liquid fuels from biomass. As a result, they are exploring ways to increase the carbon yield of liquid fuels from biomass through the direct or indirect integration of renewable electricity in the conversion process. These ideas may have merit for countries that have the natural resources to produce large quantities of renewable electricity at reasonably high EROI ratios. Maintaining high EROI levels for transport energy will help minimise the economic and environmental effects of transitioning from fossil fuels to other energy alternatives.

The aim of this paper is to apply a modified CEPA method to explore how NZ can meet its future transport demand in 2050 while reducing the associated carbon emissions to 1990 levels. Various methods for reducing emissions are investigated including production of biofuels, electrification of the transport fleet using renewable resources, and increases in combustion engine efficiency through hybrid systems. For example, we are attempting to define such items as how much biofuels NZ needs to produce, not how much biofuels NZ can produce. There will continue to be technical and economic challenges facing the quantum of biofuels NZ requires by 2050 to help achieve 1990 levels of emissions. As a result, this paper extends the CEPA for analysis of transport sectors where the transport demand can be divided into distinct classes. CEPA has been chiefly applied to electricity sectors in NZ [8] and Ireland [9] and extended to include carbon capture and storage (CCS) [10].

2. A modified Carbon Emissions Pinch Analysis framework for transport sectors

CEPA was first developed by Tan, Foo, and co-workers [1], and is based on the application of traditional Pinch Analysis techniques beyond Total Site Analysis for large industrial sites to broader macro-scale applications such as regional and national electricity generation sectors [9]. Sectorial and regional studies have been conducted for power systems emissions constraint planning [11] with CCS [10] including retrofitting [12] and for multi-period scenarios [13] and variable CO₂ sources and CO₂ sinks [14]. In the New Zealand context, CEPA has been applied to the national electricity sector [8] to show how increased electricity demand in 2050 can be met and the generation mix optimised for minimum energy cost [2]. However, the method has not been applied to the transport sector as far as the authors are aware and some degree of modification to the standard method is required to extend CEPA to analysis of a transport system.

In this work the CEPA method is modified for extended application to transport sectors. An underlying tool of CEPA is the construction of composite curves together with identification of the pinch, which is often caused by an emissions target that is lower than the current emissions level. The y-axis of the composite curve graph is carbon emissions equivalent in kt CO₂-e and the x-axis is the useful transport output in Mt-km, where the tonnes represent people or freight depending on the purpose of the transport operation. The demand curve represents the transport's primary purposes (e.g. freight or passenger), mode (e.g. marine, air, rail) and class (e.g. buses, ships, trains, light passenger vehicles, etc.). The supply curve captures the fuels sources (e.g. petrol, diesel,

electricity, compressed natural gas, etc.) used in the various transport operations, which are stacked beginning with the fuel with the lowest transport fuel emissions factor (ϵ_{TF}) and so on to the one with the highest. The transport fuel emissions factor can be determined by

$$\epsilon_{TF} = \frac{\epsilon_F}{\phi_w \eta_T} \quad (1)$$

where ϵ_F is fuel emissions factor in kt CO₂-e/MJ, ϕ_w is the ratio of useful transport weight to gross vehicle weight in Mt/Mt_{gross} and η_T is the gross transport output efficiency in (Mt_{gross}-km)/MJ. ϵ_F is dependent on the fuel and is not affected by the transport method. ϕ_w is a function of the transport method and its fill-rate. η_T mainly relates to the engine efficiency and its aero- and/or hydro-dynamics.

A generic example of a transport system is presented in Fig. 1 to demonstrate how the CEPA method may be modified for transport systems. Fig. 1A is the conventional CEPA style plot that presents the overall fuel supply and transport demand with an associated emissions of 1000 kt CO₂-e. The solid black line is the average ϵ_{TF} for the entire system and called the overall Transport Emissions Factor (TEF). The new emissions target represents a 20% reduction goal of transport emissions. The point where the dotted diagonal line, which is based on the emissions target, intersects the fuel supply curve is the pinch point.

When considering how to achieve the emissions target, the overall CEPA graph lacks sufficient detail about transport modes and classes to base decisions of where emissions reduction efforts are best focused. The overall transport demand can be broken-down into the individual transport classes with as shown in Fig. 1B. Combinations of transport classes and fuels that contribute a high proportion of the total emissions can now be identified and emissions reductions methods considered. Two options for emissions reduction are presented in Fig. 1C and D. The first option targets improving transport fuel efficiency of class B with fuel C. An example of this option is increasing public transport fill-rates by encouraging their use through measures such as increasing Government subsidies or, in the long-term, market driven increases in petrol prices. The second option switches some of fuel C for A within class B. An example of this can be electrification of the rail network, where electricity is generated using a high proportion of renewables (e.g. hydro). There are many other situational options for reducing emissions such as switching transport classes, which also can be considered.

It is also useful to plot the transport data on an emission versus fuel use in P] to understand the impact various emissions reduction options have on total fuel use.

3. Transport efficiencies and fuel emissions factors

There are a wide variety of transport modes (e.g. marine, air, road, and rail) and many classes of vehicles or vessels within these modes. For example, within the road transport mode there are light trucks, heavy trucks, and light commercial vehicles. Within these classes, there are further subclasses of specific vehicle or vessel makes and models made to common specification and/or performance.

At the vehicle class level, transport fuel use, emissions and useful transport output can be calculated with a reasonable degree of accuracy using the numerous data available from government agencies. This study uses transport data published by the NZ Ministry of Transport [15] and the Ministry of Business, Innovation and Employment [5] and literature values of average transport fuel efficiencies in passenger-km/L and t-km/L [16], which are

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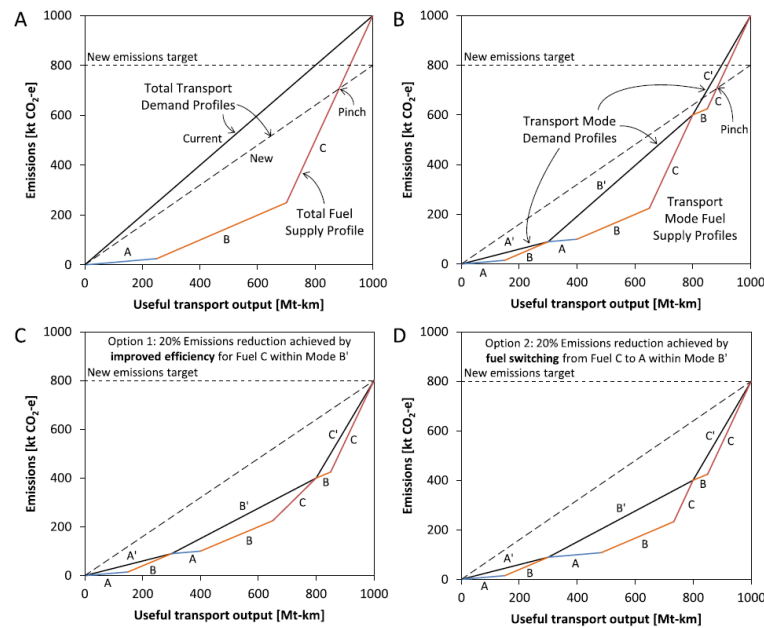


Fig. 1. Methods for reducing emissions of a generic transport sector. (A) Total transport demand and fuel supply curves; (B) supply and demand profiles divided by transport classes; and (C and D) two options for reducing emission.

compared in Fig. 2A for passenger transport and Fig. 2B for freight transport. A log scale has been used to enable presentation of a wide range of transport modes on a single graph. Public transport methods like ferry, bus and rail potentially have good efficiencies provided passenger fill rates are high. Fill-rates for NZ's public transport are low likely due to the comparatively low population density of NZ cities. Freight transport exhibits similar trends (Fig. 2B) with ship and rail being the most efficient methods, followed by heavy and light truck, and air. LCV (Light Commercial Vehicles) is less energy efficient transport mode but most convenient.

Transport class emission factors used in this study were calculated based on data from NZ's Ministry of Business, Innovation and Employment energy data set [5] and are presented in Table 1. Useful transport output for passengers has been calculated by assuming passengers have an average mass of 75 kg.

4. New Zealand transport sector fuel and emissions growth projections

The NZ transport sector has experienced significant growth in fuel demand from 1974 to 2008 as illustrated in Fig. 3. Petrol and diesel fuels dominate the growth in fuel use, followed by aviation fuels. Fuel oil declined in the 1980s and again increased in the 1990s. Responses to global recessions, oil price hikes and/or periods of economic restructuring are also evident in the fuel use data. As global oil prices rose in the late 1970s, economies like NZ were forced to spend more on foreign imported oil, which affected their balance of trade, which in turn forced other changes on the economy. The economic restructuring that took place in NZ in the 1980s was in many ways precipitated by the oil crisis of 1979.

The large increase in diesel fuel use and to a lesser extent petrol fuel use, as is seen in Fig. 3, is related to the large increase in LPVs (light passenger vehicle) and LCVs (light commercial vehicle) that occurred during the 1990s and beyond when import regulations were relaxed in the early 1990s, along with road freight transport rules. Light vehicle numbers soared, especially diesel powered vehicles, and imported second-hand vans and trucks increased the overall freight transport supply at the expense of any growth in rail (Fig. 4A).

The contribution of each transport mode to fuel use and emissions from 1990 to 2012 is illustrated in Fig. 4. As discussed previously, road transport has dominated the growth in both fuel use and emissions. International air and international marine have also risen most likely as a result of global tourism increases. Domestic air, domestic marine and rail, have experienced only small increases. Significantly, about half of the international transport emissions are not formally included in NZ's emissions for this study. Only trips that fuel and begin in NZ, e.g. departing international flight, are counted.

Since 2005 annual growth has slowed with negative growth in 2009 after the start of the global recession in 2008. Growth rates are expected to return to traditional levels from 2013 due to a rising population with continued reliance on fossil fuels for transport (Fig. 5). The current population of 4.4 million is rising because of positive net migration and a higher than replacement birth rate of 2.1 [17]. It is projected by Statistics NZ, the country's population is most likely to peak between 6 and 7 million after 2050. The increase in population will put pressure on energy, land and water resources.

For this study we have taken a conservative 'business-as-usual' approach and assumed passenger and freight transport demand

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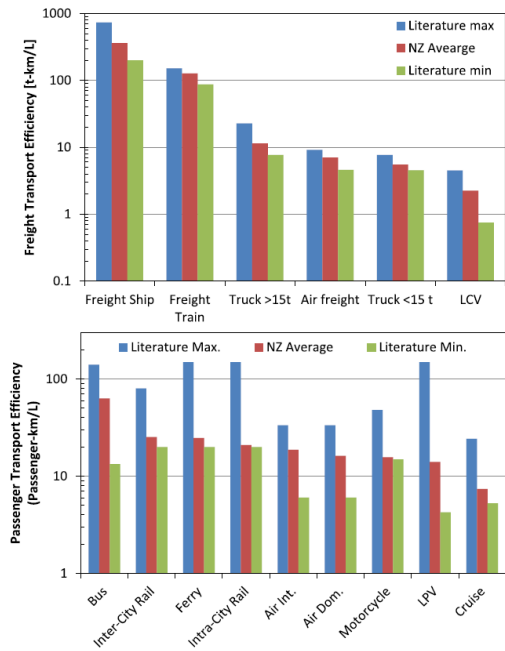


Fig. 2. Freight (top) and passenger (bottom) transport efficiency by transport mode and class for NZ transport [5,15] compared to literature values [16].

will increase proportional with population through to 2050. This gives 2050 targets for CEPA of 107 G(passenger)-km for passenger transport demand and 126 Gt-km for freight transport demand, which equates to approximately 326 PJ of fuel use. Beyond population, transport demand is also closely tied to national and global economic states and the oil price, both of which have seen dramatic fluctuations over the past decade. Between the 1990 and 2005 transport demand per capita in terms of both freight and passenger

Table 1
Transport fuel emissions factors for fossil fuel energy supply.

Type	Class	ϵ_{FT} [t CO ₂ -e/Gt-km]
<i>Freight transport</i>		
Marine	Cargo ships domestic	9
Marine	Cargo ships international	11
Rail	Freight	18
Road	Truck B (>15 t)	200
Air	Freight	372
Road	Truck A (<15 t)	414
Road	Light commercial vehicles (LCV)	1013
<i>Passenger transport</i>		
Marine	Ferry	21
Marine	Cruise ships international	137
Marine	Cruise ships domestic	137
Road	Bus	452
Rail	Commuter inter-city	902
Air	International (passenger + cargo)	936
Air	Domestic (passenger + cargo)	1327
Rail	Commuter intra-city	1361
Road	Motor cycle	1950
Road	Light passenger vehicles (LPV)	2177

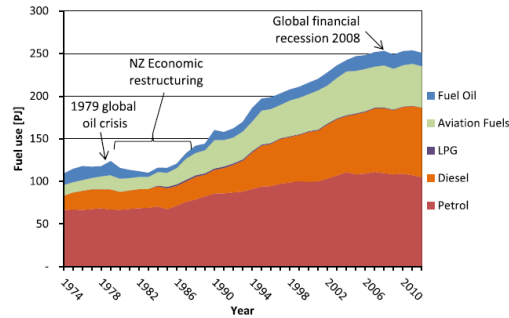


Fig. 3. Transport fuel growth in NZ by fuel type from 1974 to 2013. Data taken from the NZ Ministry of Transport [15].

transport increased by 29% and 25% respectively. From 2005 to 2012 the global financial crisis hit reducing freight and passenger transport demands per capita by 13% and 5% respectively. The future projections of transport demand have therefore a significant degree of uncertainty because of the several forces that come into play that influence total transport demand.

5. Results and discussion for New Zealand transport case study

5.1. Carbon Emissions Pinch Analysis for the New Zealand transport sector in 2012

Using the CEPA composite curve method the freight and passenger transport demands in NZ for the year 2012 are illustrated in Fig. 6. The fuel supply composite curve has not been included in Fig. 6 because it cannot clearly be distinguished from the demand curve, which is due to all current transport fuels being derived from crude oil with very similar EFs (Emissions Factor) within each vehicle class. Fig. 6 shows passenger transport contributes 12% of the useful transport output but is responsible for 71% of transport emissions. The total freight transport demand and emissions for NZ in 2012 were 95.9 Mt-km and 5.0 Mt CO₂-e respectively (TEF = 0.052 Mt CO₂-e/Mt-km). The total passenger transport demand and emissions for NZ were 13.1 Gt-km and 12.4 Mt CO₂-e respectively (TEF = 0.944 Mt CO₂-e/Mt-km). In both cases the amount powered from renewable fuels was negligible.

EFs vary depending on the freight or passenger load factor, engine technology and tare weight differences rather than fuel differences. Marine transport is clearly very efficient at transporting both freight and people with marine vessels having the lowest emission factors in both demand classes. Freight rail is equally a low emissions transport method and road freight methods are the highest. It is important to note that although road freight methods have the highest emissions factors, they have additional cost benefits of being flexible giving point-to-point delivery with minimal handling stages.

With passenger transport, LPV (Light Passenger Vehicles) stands out as generating 65% of passenger transport emissions, while delivering only 28% of the useful transport output. High EFs for rail and bus are principally caused by low participation rates as a result of high LPV use, and as a result the useful transport output from these classes is relatively small. Air transport, including domestic and international travel, contributes 27% of passenger transport emissions and provides 25% of the useful transport output.

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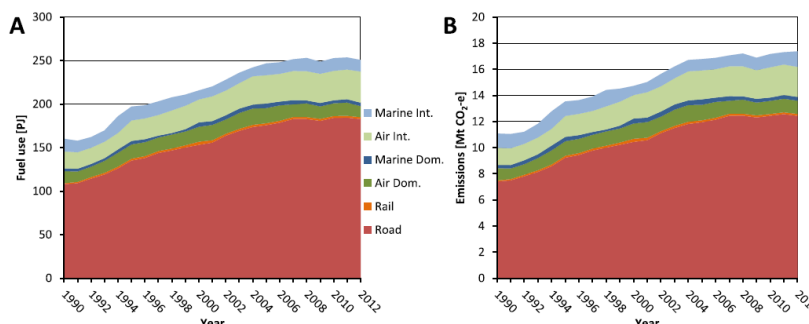


Fig. 4. Transport fuel (A) and emissions (B) in NZ growth by transport mode from 1990 to 2012. Data taken from the NZ Ministry of Transport [15].

5.2. Approaches to reducing CO₂-e emissions in transport energy sectors

5.2.1. Renewable liquid fuel production

Globally liquid fuels for transport vehicles are nearly exclusive refined from crude oil. This refining process and the eventually fuel combustion emits a substantial amount of emissions. Producing drop-in liquid biofuels from sustainably grown biomass resources can begin to replace oil based fuels in the future when oil reserves are sufficiently low and the price of oil high enough for the economics of biofuel production to be economic. In 2009 Jack and Hall [18] reported a detailed analysis of the potential biofuel production in NZ showing where and how much new afforestation may occur. Their results indicate that with the use of an additional 1.8 million hectares of low productivity land, currently returning less than NZ\$200/(ha y) mainly for sheep and beef farming, to produce woody biomass at a similar return rate, NZ could produce up to 232 PJ or 7.0 billion litres of petrol equivalent biofuel and could be economically competitive with conventional liquid fuels at an oil price of around US\$200 per barrel. Most biofuel conversion technologies are currently in the pre-commercialisation stage and, therefore, the efficiency of biofuel production and its cost competitiveness and rate of return for land use is likely to improve in the future.

5.2.2. Improved vehicle transport fuel efficiency

In the last decade the fuel efficiency of LPVs, LCVs and buses has been significantly improved by hybrid engine technology. HVs (hybrid vehicles) intelligently use a battery and electric motor in conjunction with a combustion engine to achieve high fuel efficiency. Based on data from the NZ Ministry of Transport [15], an estimate of 40% reduction in fuel use can be obtained when switching from a normal combustion engine vehicle to a hybrid vehicle for the same total distance travelled under normal use. With rising fuel prices, it is anticipated that at least half of the LPVs, LCVs and Buses will contain some form of hybrid engine by 2050.

5.2.3. Increased integration of electricity in transport vehicles

Integration of electricity into the transport sector has traditionally focused on the electrification of rail. New Zealand has some opportunities to convert fossil fuel driven rail to electric rail and for purposes of this study it is assumed that by 2050 conversion has taken place. Beyond electrification of rail, there is growing popularity around the future adoption of EV (electric vehicles). Some organisations [19] and politicians [20] have campaigned on the misleading notion that EVs have zero emissions. In this section it is shown the actual emissions from an EV over its life are dependent on the weight of the car and battery, and the overall GEF (Grid

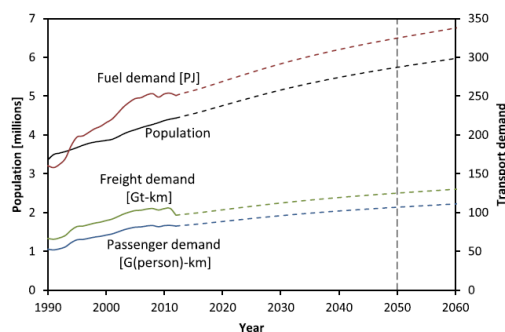


Fig. 5. Projected population and transport demand growth in NZ to 2050 for business as usual.

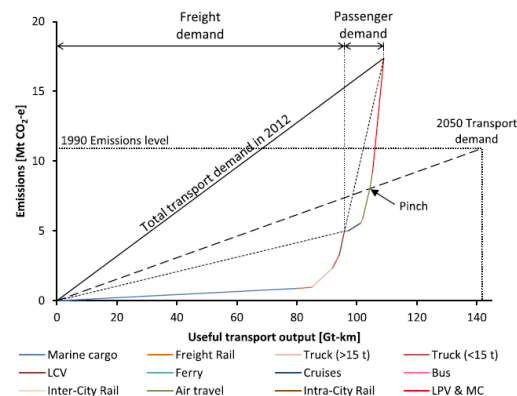


Fig. 6. Combined emissions composite curve for freight and passenger transport demand by transport purpose and class in New Zealand for 2012 and the target for 2050.

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Table 2
Estimated emission factors for three light passenger vehicles.

	Embedded car emissions ^a [kt CO ₂ -e]	Embedded battery emissions ^b [kt CO ₂ -e]	Fuel consumption [L/km]	Operating emissions factor ^c [kt CO ₂ -e/100 km]	Life cycle emissions factor [kt CO ₂ -e/100 km]	Operating & battery emissions factor [kt CO ₂ -e/100 km]
ICE (internal combustion engine)	7500	–	0.072 L/km	17.57	21.32	17.57
P-HV (plug-in hybrid vehicle)	7500	1800	0.0214 L/km 0.20 kWh/km	5.74	10.39	6.64
EV (electric vehicle)	7800	8100	0.24 kWh/km	1.16	9.11	5.36

^a Based on 5 kg CO₂-e/kg_{car}.

^b Based on 15 kg CO₂-e/kg_{bat}.

^c Based on NZ 2050 GEF 0.049 kg CO₂-e/kWh, 50% EV mode for P-HV, Petrol EF 2.44 kg CO₂-e/L.

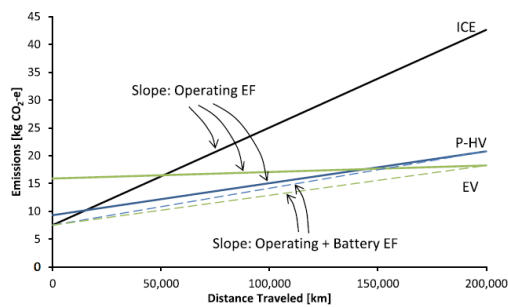


Fig. 7. Emissions for LPVs based on the 2050 estimated electricity GEF for NZ (0.049 kg CO₂-e/kWh).

Emissions Factor) for electricity production in a given country. Where it means that additional coal will be burned to supply electricity to an EV, the overall emissions will be greater than the typical petrol engine car.

It is important when considering alternate LPVs that the life-cycle GHG emissions are included, especially for EVs where increased emissions occur with the manufacture and replacement of the batteries. As the range of the vehicle in electric mode increases the mass of the battery must become greater. There is a large variation in the reported GHG emissions of battery manufacture from 6 kg CO₂-e/kg_{bat} [21] to 22 kg CO₂-e/kg_{bat} [22]. The variation is due in part to the different assumptions and system boundaries used in the LCA (Life Cycle Analysis) studies. A value of 15 kg CO₂-e/kg_{bat} has been used in this study. The GHG emissions associated with the production of the car is assumed to be 5 kg CO₂-e/kg_{car} and is within the range of 4–6.5 kg CO₂-e/kg_{car} reported in the literature [23]. The extra battery emissions will normally be attributed to the country that makes the batteries, but in this analysis these emissions have been included as an operating and battery emissions factor (Table 2).

The emissions as a function of distance for ICE (Internal Combustion Engine) vehicles, P-HV (plug-in hybrids vehicles), and EV (Electric Vehicles) are presented in Fig. 7 based on the 2050 GEF of

0.049 kt CO₂-e/GWh_e [2]. The various EFs used to construct Fig. 7 are given in Table 2. The slopes of the solid lines represent the operating EF for each vehicle type. The dashed lines in the figure represent the operating and amortised battery emissions for P-HV and EV, and is used to determine the actual GHG reductions possible by switching from ICE to P-HV and EV. The total reduction in GHG emissions over the total life of the vehicle is 49% and 43% for P-HV and EV respectively. The EV has greater final overall emissions than the P-HV due to the significant increase in the emissions associated with the manufacture and replacement of the batteries. The overall lifecycle contribution of the fuel decreases as vehicles become more electrified. The fuel contribution for the ICE is 82%, while the P-HV and EV have fuel contributions of 55% and 13% respectively.

The slope of the EV line in Fig. 7 is derived from the GEF for electricity production. As the GEF increases, the slope of the EV (and P-HV) line also increases. For countries where the GEF is greater than 0.566 kt CO₂-e/GWh_e, the adoption of EVs is counter-productive in terms of reducing overall emissions. At present New Zealand has a GEF for electricity of 0.129 kt CO₂-e/GWh_e, Australia has a GEF of 0.811 kt CO₂-e/GWh_e, and the USA has a GEF of 0.530 kt CO₂-e/GWh_e [2]. Converting significant proportions of the electricity grids in Australia and the USA to renewables (e.g. wind and solar) and/or low carbon emitting fuels and generation technologies (e.g. nuclear power plant and coal power plant with CCS) are needed before EVs present themselves as a viable solution to reducing carbon emissions.

5.2.4. Government policy and intervention

Governments play a critical role in setting policies that encourage the use of more efficient transport methods. New Zealand can learn from methods being employed in other countries as a guide to what implemented government policies are effective for driving good behaviour and lowering transport emissions. For example, many highways in the USA and other countries have car-pool lanes dedicated to high occupancy vehicles (usually two or more people in a vehicle), which aims to increase the fill rate of on-road LPVs. Dedicated bus lanes in inner cities and/or adjacent to highways are also common in major cities as a way to improve the travel time on public buses, which also leads to increased fill rates. In Hasselt, Belgium the city council decided to abolish bus fares in 1997 [24]. This resulted in the number of travellers on buses

Table 3
Options for NZ to meet 1990 emissions level in 2050. Energy units PJ use a thermal basis.

	P-HV and EV fuel savings	Fuel replaced by electrification	Oil and gas fuels	F-T coal	Biofuels needed
Scenario A	77 PJ	49 PJ (5.4 TWh _e)	155 PJ	–	47 PJ
Scenario B	77 PJ	49 PJ (5.4 TWh _e)	–	–	169 PJ
Scenario C	–	26 PJ (2.9 TWh _e)	–	31 PJ	106 PJ

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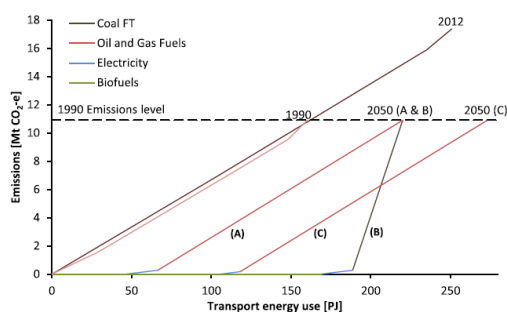


Fig. 8. Emissions – transport energy use composite curves to meet 2050 over all transport demand for a 1990 emissions target.

increasing from 350,000 in 1997 to 4,600,000 in 2007. In 2013, the city revisited the policy and under the weight of an on-going financial recession reverted to charging adults (19 + years) €0.60 per trip. Establishing safe cycle ways is another approach targeted towards reducing the number of single passenger cars on the road. California introduced an effective financial incentive programme to encourage the uptake of P-HVs.

5.3. Transport planning for New Zealand through to 2050 with reduced carbon emissions

Three scenarios are illustrated in Table 3 and Fig. 8 for achieving transport emissions reduction to 1990 levels by 2050 using the CEPA graphical method. A variety of transport fuel mixes are possible for reaching the demand and emissions target.

In Scenarios A and B, it is assumed 40% of the LPV, LCV and bus fleets will be hybrid vehicles, which improves the overall energy efficiency of these classes and results in a fuel savings 77 PJ. Scenarios A and B also assume P-HVs and, to a lesser extent, EVs in the LPV class (~40%) will enable replacement of 46 PJ of liquid fuels with 18 PJ (5.1 TWh) of electricity use. Freight and city rail is also electrified replacing a thermal fuel need of 2.9 PJ with 1 PJ (0.3 TWh) of electricity use. An increase in demand of 5.4 TWh is

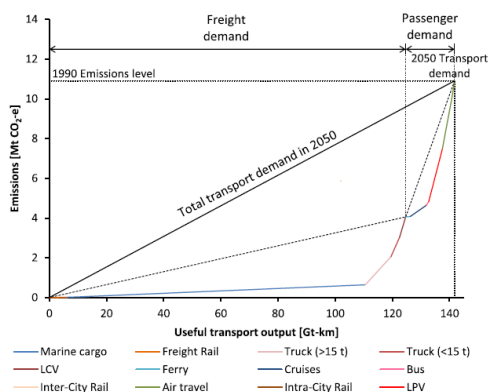


Fig. 9. Combined emissions composite curve for freight and passenger transport supply and demand in New Zealand for 2050 Scenario A, i.e. minimum biofuels production.

equivalent to 7.3% of estimates of the NZ electricity grid (75 TWh) in 2050 [2]. The 2050 electricity demand projection from Walmsley et al. [2] of 75 TWh assumed an uptake of electric powered vehicles of 6.5 TWh, which is close to the estimate in this work. The remainder of the transport demand for Scenarios A is met using oil derived fuels of 155 PJ and the minimum amount of biofuels of 47 PJ that is required to keep within the emissions target based on 1990 levels. In Scenario B, the remainder of the transport demand is met using Fischer–Tropsch (FT) liquid fuels from coal (31 PJ) and biofuels (169 PJ) while keeping under the emissions target. Scenario C is the same as A with the exception of assuming a 20% uptake of HVs, P-HVs, and EVs in the LPV, LCV and bus fleets, which means the energy savings is half the amount that was originally quantified. The lower uptake of energy efficiency technologies means an additional 53 PJ of input energy is needed in Scenario C compared to the first two scenarios (Fig. 8). As a result, the minimum required biofuel production to keep within the emissions target is 106 PJ.

The anticipated transport supply and demand profiles for freight and passenger transport from Scenario A in 2050 are plotted in Fig. 9. Where a transport mode and class requires a liquid fuel, a blended fuel is assumed and its emissions are determined using a weighted emissions factor (53.5 kt CO₂-e/PJ) for renewable biofuel (zero emissions) and liquid fuel from oil (69.3 kt CO₂-e/PJ). LPVs benefit significantly from increased overall efficiency from the uptake of hybrid systems and from the integration of electricity as a main power source.

The presented scenarios assume that existing transport modes continue to be used in a similar manner and similar amount per capita as in 2012. Further emissions reduction can be achieved with further transport class switching; for example, more freight by rail and marine rather than truck and LCV and more public transport by light rail and bus, especially in NZ's largest cities, i.e. Auckland, Wellington, Christchurch and Hamilton. The challenge of meeting the 1990 emissions level in 2050 critically depends on the uptake of energy efficient vehicles and production of biofuels. This needs to be done with the minimum amount of extra energy being expended by the economy to ensure that the transition to a new fuel source does not reduce NZ's economic competitiveness.

6. Conclusion

Freight and passenger transport demand in New Zealand is anticipated to increase by 30% from 2012 to 2050 due to population growth. An important element of reducing carbon emissions attributed to transport in New Zealand is electrification of all rail and partial electrification of light passenger vehicles through plug-in hybrid and electric vehicle technologies to the degree of 5.4 TWh, which replaces the equivalent of 49 PJ of conventional liquid fuels. New Zealand's electricity is supplied by a high proportion of hydro and geothermal renewable generation, which in turn can help lower emissions from the transport sector when effectively integrated. With an uptake of 40% for all light passenger vehicles, buses and light commercial vehicles, hybrid engine technology is estimated to reduce liquid fuel use by 77 PJ in 2050 compared to using current transport technologies. In 2050 total transport energy use as a combination of liquid fuels and electricity is calculated to be 220 PJ. To reach the goal of reducing carbon emissions to 1990 levels in 2050, 47 PJ of biofuels is needed together with 174 PJ of conventional liquid fuels from oil.

References

- [1] Tan RR, Foo DCY. Pinch analysis approach to carbon-constrained energy sector planning. *Energy* 2007;32:1422–9. <http://dx.doi.org/10.1016/j.energy.2006.09.018>.

Please cite this article in press as: Walmsley MRW, et al., Carbon Emissions Pinch Analysis for emissions reductions in the New Zealand transport sector through to 2050, *Energy* (2015), <http://dx.doi.org/10.1016/j.energy.2015.04.069>

- [2] Walmsley MRW, Walmsley TG, Atkins MJ, Kamp PJJ, Neale JR. Minimising carbon emissions and energy expended for electricity generation in New Zealand through to 2050. *Appl Energy* 2014;135:656–65. <http://dx.doi.org/10.1016/j.apenergy.2014.04.048>.
- [3] Hall CAS, Balogh S, Murphy DJR. What is the minimum EROI that a sustainable society must have? *Energies* 2009;2:25–47. <http://dx.doi.org/10.3390/en20100025>.
- [4] MBIE. Energy balances. *Minist. Bus. Innov. Employ.*; 2012. <http://www.med.govt.nz/sectors-industries/energy/energy-modelling/data/energy-balances> [accessed 22.05.14].
- [5] Statistics NZ. New Zealand's growing population. *NZ Off Yearb* 2012 2013. http://www.stats.govt.nz/browse_for_stats/snapshots-of-nz/yearbook/people/population/7-million.aspx [accessed 22.05.14].
- [6] Taylor M. Alternative liquid fuels: global availability, economics and environmental impacts. Auckland, New Zealand: EME Consulting; 2007. <http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/technical-papers/alternative-liquid-fuels.pdf> [accessed 22.05.14].
- [7] Mathiesen BV, Lund H, Connolly D, Østergaard PA, Möller B. The design of smart energy systems for 100% renewable energy and transport solutions. [http://vbn.aau.dk/en/publications/the-design-of-smart-energy-systems-for-100-renewable-energy-and-transport-solutions\(5d61152c-f511-48eb-bc0f-a490275fba9c\).html](http://vbn.aau.dk/en/publications/the-design-of-smart-energy-systems-for-100-renewable-energy-and-transport-solutions(5d61152c-f511-48eb-bc0f-a490275fba9c).html); 2013 [accessed 04.12.14].
- [8] Atkins MJ, Morrison AS, Walmsley MRW. Carbon emissions pinch analysis (CEPA) for emissions reduction in the New Zealand electricity sector. *Appl Energy* 2010;87:982–7. <http://dx.doi.org/10.1016/j.apenergy.2009.09.002>.
- [9] Crilly D, Zhelev T. Emissions targeting and planning: an application of CO₂ emissions pinch analysis (CEPA) to the Irish electricity generation sector. *Energy* 2008;1498–507. <http://dx.doi.org/10.1016/j.energy.2008.05.015>.
- [10] Ooi REH, Foo DCY, Tan RR, Ng DKS, Smith R. Carbon constrained energy planning (CCEP) for sustainable power generation sector with automated targeting model. *Ind Eng Chem Res* 2013;52:9889–96. <http://dx.doi.org/10.1021/ie4005018>.
- [11] Priya GSK, Bandyopadhyay S. Emission constrained power system planning: a pinch analysis based study of Indian electricity sector. *Clean Technol Environ Policy* 2013;15:771–82. <http://dx.doi.org/10.1007/s10098-012-0541-y>.
- [12] Priya GSK, Bandyopadhyay S, Tan RR. Power system planning with emission constraints: effects of CCS retrofitting. *Process Saf Environ Prot* 2014;92:447–55. <http://dx.doi.org/10.1016/j.psep.2014.02.010>.
- [13] Ooi REH, Foo DCY, Tan RR. Targeting for carbon sequestration retrofit planning in the power generation sector for multi-period problems. *Appl Energy* 2014;113:477–87. <http://dx.doi.org/10.1016/j.apenergy.2013.07.047>.
- [14] Lee J-Y, Tan RR, Chen C-L. A unified model for the deployment of carbon capture and storage. *Appl Energy* 2014;121:140–8. <http://dx.doi.org/10.1016/j.apenergy.2014.01.080>.
- [15] Ministry of Transport. New Zealand vehicle fleet statistics. *NZ Veh Fleet Stat* 2014. <http://www.transport.govt.nz/research/newzealandvehiclefleetstatistics/> [accessed 22.05.14].
- [16] US Department of Energy. Transportation energy data book. 2013. <http://cta.ornl.gov/data/index.shtml> [accessed 22.05.14].
- [17] Statistics NZ. National population projections: 2011(base) – 2061. *Stat NZ* 2012. http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/NationalPopulationProjections_HOTP2011/Commentary.aspx [accessed 10.12.13].
- [18] Jack M, Hall P. Bioenergy options for New Zealand: analysis of large-scale bioenergy from forestry. Rotorua, New Zealand: Scion; 2009.
- [19] Emissions Free Cars. All the benefits of electric vehicles. *Emiss. Free Cars*; 2014. <http://emissionsfreecars.com/> [accessed 22.05.14].
- [20] Clegern D. Governors announce bold initiative to put 3.3 million zero-emission vehicles on the road by 2025. *Calif. Environmental Prot. Agency*; 2013. <http://www.arb.ca.gov/newsrel/newsrelease.php?id=520> [accessed 22.05.14].
- [21] Notter DA, Gauch M, Widmer R, Wäger P, Stamp A, Zah R, et al. Contribution of Li-ion batteries to the environmental impact of electric vehicles. *Environ Sci Technol* 2010;44:6550–6. <http://dx.doi.org/10.1021/es903729a>.
- [22] Majeau-Bettez G, Hawkins TR, Strømman AH. Life cycle environmental assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles. *Environ Sci Technol* 2011;45:4548–54. <http://dx.doi.org/10.1021/es103607c>.
- [23] Hawkins TR, Singh B, Majeau-Bettez G, Strømman AH. Comparative environmental life cycle assessment of conventional and electric vehicles. *J Ind Ecol* 2013;17:53–64. <http://dx.doi.org/10.1111/j.1530-9290.2012.00532.x>.
- [24] Eltis. Hasselt cancels free public transport after 16 years (Belgium). *Eltis*; 2013. http://www.eltis.org/index.php?id1=5&id=60&news_id=4183 [accessed 22.05.14].

Please cite this article in press as: Walmsley MRW, et al., Carbon Emissions Pinch Analysis for emissions reductions in the New Zealand transport sector through to 2050, *Energy* (2015), <http://dx.doi.org/10.1016/j.energy.2015.04.069>

Appendix 2: PHEV and EV Technical Specifications

Toyota Corolla

COROLLA SEDAN SPECIFICATIONS

	COROLLA GX SEDAN	COROLLA GX SEDAN	COROLLA GLX SEDAN	COROLLA ZR SEDAN
	MANUAL	CVT	CVT	CVT
MECHANICAL SPECIFICATIONS	1.8L, 4 cylinder, in-line, 16 valve Double Over Head Cam (DOHC) with Dual Variable Valve Timing-intelligent (VVT-i). Maximum power 103kW at 6400rpm. Maximum torque 173Nm at 4000rpm			
	Fuel type - 91 octane or higher is recommended. Tank capacity is 55L			
	Drive type - Front wheel drive			
	Fuel economy - Combined ECE101/01			
	CO ₂ emissions - Combined ADR81/02			
	Transmission - 6-speed manual			
	Transmission - Continuously Variable Transmission (CVT) with 7-speed sport sequential manual mode, uphill and downhill shift control and flex lock-up control			
DIMENSIONS	Overall length (mm)	4620	4620	4620
	Overall width/height (mm)	1776/1460	1776/1460	1776/1460
	Wheelbase (mm)	2700	2700	2700
	Gross vehicle weight (kg)	1705	1735	1740
	Kerb weight (kg)	1250	1280	1285
	Towing capacity - unbraked/braked (kg)	450/1300	450/1300	450/1300
				Paddle shifters

Toyota Prius Hybrid

Prius SPECIFICATIONS

	Base	i-Tech
MECHANICAL SPECIFICATIONS	Engine Description - Petrol	
	1.8 Litre, 4 cylinder, In-line type, 16 Valve Double Overhead Camshaft (DOHC) with Dual Variable Valve Timing with intelligence (VVT-i).	
	Engine Description - Hybrid	
	Nickel Metal-Hydride (Ni-MH) Battery, Permanent Magnet Synchronous A/C Motor	
	Maximum power	
	73kW at 5200 rpm	
	Maximum torque	
	142Nm at 4000rpm	
	Fuel type	
	95 octane or higher	
	Fuel economy - ADR 81/02 (Combined cycle)	
3.9L/100km		
CO ₂ emissions - ADR 81/02 (Combined cycle)		
89g/km		
Exhaust emission standard		
Euro 4		
Transmission (EV mode, Eco/Normal/Power modes)		
Electronic Continuously Variable Transmission (ECVT)		
Drive modes		
EV, Eco, Normal and Power drive modes		

Toyota Prius Plug-In Hybrid

Specifications

MECHANICAL AND PERFORMANCE	PRIUS PLUG-IN HYBRID/PRIUS PLUG-IN HYBRID ADVANCED
Hybrid System Net Power	134 hp (100 kW)
ENGINE	
Hybrid engine	1.8-Liter Aluminum 4-Cylinder DOHC 16-Valve Variable Valve Timing with intelligence (VVT-i), EV ⁴ /ECO/POWER Modes; 98 hp @ 5200 rpm (73 kW @ 5200 rpm); 105 lb.-ft. @ 4000 rpm (142 N•m @ 4000 rpm)
Compression ratio	13.0:1
Induction system	Sequential multi-point EFI with Electronic Throttle Control System with intelligence (ETCS-i)
Emission rating	TZEV (Transitional Zero Emission Vehicle) or Tier 2/Bin 3 ²
ELECTRIC MOTOR	
Motor type	Permanent magnet AC synchronous motor
Power output	80 hp (60 kW)
Torque	153 lb.-ft. (207 N•m)
Voltage	650V maximum
TRACTION BATTERY	
Type	Lithium-ion
TRANSMISSION	
Type	Electronically controlled Continuously Variable Transmission (ECVT)
DRIVETRAIN	
Type	Front-Wheel Drive
SUSPENSION	
Type	Independent MacPherson strut front suspension with stabilizer bar; torsion beam rear suspension
STEERING	
Type	Electric Power Steering (EPS); power-assisted rack-and-pinion
Turning circle diameter, curb to curb (ft.)	34.2
BRAKES	
Type	Power-assisted ventilated front disc brakes; solid rear disc with integrated regenerative braking and Star Safety System™
EXTERIOR DIMENSIONS (in.)	
Overall height/width/length	58.7/68.7/176.4
Wheelbase	106.3
Track (front/rear)	60.0/59.8
Ground clearance	5.3
Coefficient of drag (Cd)	0.25
INTERIOR DIMENSIONS (front/rear) (in.)	
Head room	38.6/37.6
Shoulder room	54.9/53.1
Hip room	52.7/51.2
Leg room	42.5/36.0
WEIGHTS AND CAPACITIES	
Curb Weight (lb.)	3194/3216
Seating capacity	5
Passenger volume (cu. ft.)	93.7
Cargo volume ⁸ (cu. ft.)	21.6
Battery capacity (kWh)	4.4
Battery weight (lb.)	176.0
Fuel tank (gal.)	10.6
TIRES	
Size	P195/65R15
MPG/OTHER	
Mileage estimates (EPA-rated MPGe/hybrid mode mpg)	95/50 ⁸
EPA-rated driving range	11 mi ^{5,9}
Charging time (120V ⁹ /240V ¹⁰)	-3 hrs./-1.5 hrs.

Nissan Leaf – EV

NEW LEAF

MODEL		80kW AC Electric Motor
Body type		5 door hatchback
Available grades		Visia, Acenta, Tekna
Seating capacity	persons	5
ENGINE		
Engine code		EM57
Elec. Motor type		AC synchronous
Max. engine power 1)	kW(PS)/min-1	80(109)/3008-10000rpm
Max. torque 1)	Nm/min-1	254.7(0-3008)rpm
max RPM		10,500
Energy type		Electricity
BATTERY		
Type		Laminated lithium ion
Voltage	V	360
Capacity	kWh	24kWh, 48modules
Number of cells		192
CHARGER		
On-board charger		3.6kW, 6.6kW(option)
Rapid Charging Capability		50
Charging cable		6m long - 3.0kg
DRIVE TRAIN		
Clutch type (AT)		Automatic
Transmission code		RE1F61B
Gear ratio		Single Speed Gear Reduction
Final drive ratio (AT)		8.1938
Driven wheels		Front
CHASSIS		
Suspension front		Independent Mac Pherson strut
rear		Torsion beam axle
Steering		Electric power assisted
Braking system		CLZ31VE 283 x 28t
		AD11VE+ DS17 292x16t
Stability control system (option)		ESP (Standard)
Wheel size (option)		6.5J 16 O/S/40 / 6.5J 17 O/S/45
Tyre size (option)		205/55R16 / 215/50R17
Tyre Make and model		

1) In accordance with 1999/99/EC.

2) Figures in accordance with EC Directive. Kerb weight condition is without driver and including coolant, oils, fuel, spare wheel and tools. Pay load will be reduced depending on the options and/or accessories installed.

3) In accordance with UN/ECE Regulation 101

4) Figures shown are with driver + 4 passengers and luggages and max. kerb weight.

NEW LEAF

		80kW AC Electric Motor
LEAF		
Body type		5 door hatchback
Available grades		Visia, Acenta, Tekna
WEIGHTS & DIMENSIONS		
Kerb weight min./max. 2) Visia Grade	kg	1474/1503
Kerb weight min./max. 2) Acenta Grade	kg	1493/1519
Kerb weight min./max. 2) Tekna Grade	kg	1512/1541
Gross Vehicle Weight	kg	1,945
Max. pay load 2)	kg	395
Max axle load FR 2)	kg	1,030
Max axle load RR 2)	kg	960
Overall length	mm	4445
Overall width	mm	1770
Width, door mirror to door mirror	mm	1967
Overall height	mm	1545 / 1550
Wheelbase	mm	2700
FR Overhang	mm	952
RR Overhang	mm	788
Track front	mm	1540 / 1530
Track rear	mm	1535 / 1525
Min. Ground clearance	mm	100 / 108 (rear tyre deflector)
Turning radius	m	5.2 / 5.4
Towing capacity	kg	N/A
Roof load capacity	kg	N/A
Luggage capacity (VDA)	L	370 (std) / 365 (bose)
Luggage capacity (until roof)	L	911.6 (Lugg Floor to Head Liner)
max. with folded seats (VDA)	L	720L (to top of seats)
Cd		0.291 (16") / 0.289 (17")
PERFORMANCE		
Electricity consumption 3)	Wh/km	150
Autonomy (NEDC) 3)	km/miles	199 / 124
CO2 mass emission (Combined)	g/km	0
Max. speed	mph	16inch 87 mph 17inch 89 mph
Acceleration (0 - 62 mph)	sec	11.5
Min. turning circle (kerb to kerb)	m	16inch 10.4 17inch 10.8

1) In accordance with 1999/99/EC.

2) Figures in accordance with EC Directive. Kerb weight condition is without driver and including coolant, oils, fuel, spare wheel and tools. Pay load will be reduced depending on the options and/or accessories installed.

3) In accordance with UN/ECE Regulation 101

4) Figures shown are with driver + 4 passengers and luggages and max. kerb weight.

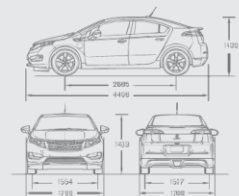
Holden Volt

Technical specifications

Overview	
Body style/driveline	five-door hatchback long range electric vehicle
Battery system	
Type	rechargeable energy storage system comprising multiple linked modules
Size/case	5.5-foot-long I-shaped, glass-filled polyester structural composite with aluminium thermal radiation shield and steel
Mass (kg)	198.1
Battery chemistry	lithium-ion
Thermal system	liquid active thermal control
Cells	288 prismatic
Energy	16.5 kWh
Electric drive	
Type	electric, two-wheel, front-drive
Motors (two)	drive motor, 11 kW; generator motor, 55kW
Transaxle	Voltec electric drive system
Power (kW)	111
Torque (Nm)	370 @ 250–2800rpm
Engine	
Type	1.4L DOHC I-4
Cylinder head material	cast aluminium
Valve train	overhead camshafts; four valves per cylinder, continuously variable intake and exhaust cam phaser
Ignition system	individual coil-on-plug – cassette type
Fuel delivery	sequential multi-port fuel injectors with electronic throttle control
Compression ratio	10.5:1
Output (kW @ rpm)	63 @ 4800
Emissions controls	close-coupled catalytic converters; 58x ignition system; returnless fuel rail; fast light-off O ₂ sensor
Fuel type	95 RON premium fuel
Charging times	
240 V 6A (normal power point)	under 10 hours (actual charge times may vary)
240 V 10A (normal power point)	under 6 hours (actual charge times may vary)
240 V 15A (charge spot)	under 4 hours (actual charge times may vary)
Performance	
EV range (urban)	up to 87km based on ADR 81/02
EV/extended range	over 600km including EV on fully charged battery and full tank of fuel
Chassis/Suspension	
Front	independent MacPherson strut-type with side-loaded strut modules, specially tuned coil springs, direct-acting hollow stabiliser bar, hydraulic ride bushings
Rear	specially adapted compound crank (torsion beam) with double-walled, U-shaped profile at the rear; specifically tuned coil springs; hydraulic bushings
Steering type	rack-mounted electric power steering with ZF steering gear
Turning circle, kerb-to-kerb (m)	11
Brakes	
Type	power four-wheel vented disc with ABS; electro-hydraulic; fully regenerative to maximise energy capture; dynamic rear brake proportioning
Wheels/Tyres	
Wheel size and type	17" x 7" 215/55 R17 lightweight, five-spoke painted aluminium alloy
Capacities	
Kerb weight (kg)	1721
Fuel tank (L)	35.2
Coefficient of drag (Cd)	0.28

Vehicle dimensions

Exterior (mm)	
Wheelbase	2985
Overall length	4498
Overall width	1788
Track width front	1554
Track width rear	1577
Height	1439
Front overhang	993
Rear overhang	820
Interior (mm)	
Seating capacity (front/rear)	2 front/2 rear
Headroom (front/rear)	960/916
Shoulder room (front/rear)	1436/1360
Hip room (front/rear)	1366/1301
Leg room (front/rear)	1068/866
Cargo volume (L)	300.2



Appendix 3: Transportation Survey

Transportation Survey

As part of my study at Waikato University, I am doing a survey regarding transportation around Hamilton City.

* Required

1. Which suburb do you live in?

Tick the closest suburb if you are not sure
Mark only one oval.

- Beerescourt
- Badder
- claudelands
- Chedworth
- Dinsdale
- Deanwell
- Enderly
- Frankton
- Fairfield
- Fairview
- Forestlake
- Flagstaff
- Grandview Heights
- Glenview
- Hamilton East
- Hamilton Central
- Hamilton Lake
- Huntington
- Hillcrest
- Melville
- Maeroa
- Nawton
- Pukete
- Qeenwood
- Rototuna
- Saint Andrews
- Silverdale
- Riverlea
- Rototuna North
- Temple View
- Te Rapa Park
- Whitiara
- Not listed
- Hostel

2. **What is the approximate distance you travel to school ? ***

You can get the distance (km) by clicking on this link and typing your home address.
<http://goo.gl/6Z1cyf>

3. **What is your mode of transport? ***

You use this mode of transport more often.
Mark only one oval.

- Car *After the last question in this section, skip to question 7.*
- Bus *After the last question in this section, skip to question 13.*
- Bicycle *After the last question in this section, skip to question 9.*
- Walk *After the last question in this section, skip to question 10.*
- Van/SUVs *After the last question in this section, skip to question 7.*
- Scooter *After the last question in this section, stop filling out this form.*

4. **If you are given a choice to cycle to school, would you take that option. ***

Mark only one oval.

- Yes
- No

5. **What is stopping you from cycling to school?**

(You can choose more than one answer)

Check all that apply.

- Not safe
- Too far away
- Cost to buying a bicycle
- There is no cycle track to school where I live
- Peer pressure
- Landscape (The cycle way is too hilly)
- No safe place to leave your bike at school
- Weather
- Other:

6. **How many vehicles do you have at your place? ***

(This only includes cars, vans, SUVs, and other vehicles you use for transportation.
Mark only one oval.

- 1
- 2
- 3
- 4
- 5
- more that 5

Stop filling out this form.

Vehicle type

7. **Answer these questions only if you know the answers.**

Is the vehicle you are using to travel to school uses diesel or petrol
Mark only one oval.

- Diesel
- Petrol

8. **Approximately what is the engine size of the vehicle you are using to come to school?**

Mark only one oval.

- 1000cc (1litre engine)
- 1500cc (1.5 litres engine)
- 2000cc (2 litres engine)
- 2500cc (2.5 litres engine)
- 3000cc (3.5 litres engine)
- Other:

Stop filling out this form.

Bicycle

9. **Why do you cycle to school?**

Check all that apply.

- I am living near to school.
- I have a cycle tract that goes past my house to school.
- Its safe
- Other:

Stop filling out this form.

Walking

10. Do you have footpaths to walk to school?

Mark only one oval.

Yes

No

11. Do you feel safe while walking to and from school

Mark only one oval.

Yes

No

12. What can the council do to make walking more safer?

Check all that apply.

More police on the roads

Good footpaths

Other:

Stop filling out this form.

Bus

13. Why do you take bus to school?

Check all that apply.

Its cheap


No one to drop me to the school

Bus is readily available in my area

Peer pressure

Other:

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