

**Understanding the costs, benefits, mitigation potentials  
and ethical aspects of New Zealand's transport emissions  
reduction policies**

By

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## **Abstract**

Greenhouse gas emissions from New Zealand's road transport sector have been increasing rapidly since 1990. Between 1990 and 2017, New Zealand's gross greenhouse gas emissions increased by 23.1% while emissions from the road transport sector increased by 82%; rising to 15.9 MtCO<sub>2</sub>e in 2017 from about 8.8 MtCO<sub>2</sub>e in 1990. To reduce transport emissions, the government has undertaken various initiatives including electric vehicle support, introduction of an emissions trading scheme (ETS), promotion of biofuel and other alternative fuels, and announcement of a feebate scheme. However, even though some of these policies require time to take effect, it is evident from the increase in emissions that there has so far been little progress in terms of transport emissions reduction. This raises questions over the acceptability and effectiveness of the policies taken by the government.

Given the pressing need to reduce transport emissions globally and in New Zealand in particular, the present study initially investigates the major drivers of transport emissions from among a set of likely drivers, using a causality test. Because electric vehicles are widely seen as an obvious 'solution' within the sector, this study next examines the costs and mitigation potential of electric vehicles in the New Zealand context in order to understand the uncertainties, risks, barriers, costs, and policy gaps associated with their widespread adoption. Next, this study examines the scope for an increased carbon price signal to curb emissions growth. Finally, this study takes the view that technological and price instruments have to be seen within a wider range of possible transport policy measures, some of which may be complementary. The study therefore elicited the perspectives of a number of transport experts, and NGO and green energy activists. It ranked six mitigation policy pathways and 26 policy options on the basis of experts', and NGO and green energy activists' preferences.

Findings of this study include that poor vehicle fuel economy is the major driver of transport emissions in New Zealand. Policies such as a high minimum vehicle fuel economy standard and/or feebate scheme could effectively help New Zealand reduce its transport emissions significantly. Electric vehicles (EVs) are also found to be potentially very effective in reducing emissions as around 80-85% of New Zealand's electricity comes from renewable generation. Moreover, in terms of the ownership costs of using EVs, used EVs are now the most cost competitive among various vehicle types such as new EVs, used internal combustion engine vehicles (ICEVs) and new ICEVs. An increase in the carbon price to around NZD 235 per tonne of carbon dioxide (tCO<sub>2</sub>) is also likely to help the transport sector reduce its emissions

by 11% from the 1990 level and achieve the Paris target. However, according to experts', and NGO and green energy activists' preferences, EV support and an increased carbon price are not the most preferred emissions reduction options. Some experts, and NGO and green energy activists viewed EV subsidization, EV free parking and EV access to high occupancy lanes as unethical because EVs are mostly used by high-income people whereas low-income people often use bus or low-cost used cars. Likewise, some experts, and NGO and green energy activists did not prefer an increased carbon price because the impact of such a policy would be uneven, and low-income people would be hurt severely compared to high-income people. Results demonstrate that active and public transport support and travel demand management are the most preferred options. Since New Zealand roads are not wide enough to support a high level of individual car use both in the short and the long run, most experts, and NGO and green energy activists preferred active and public transport under current and future circumstances. Policies related to bio-fuel support were least preferred because most experts, and NGO and green energy activists think an increased production and use of biofuels is likely to replace existing forestry and farm activity and decrease food production and forestry. It is hoped that the findings of this study will help to better illuminate the difficult policy options facing policy makers and work to assist them in identifying the most acceptable policies and projects for investment.

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## **List of Abbreviations**

<b>ADF</b>	Augmented Dickey-Fuller
<b>AHP</b>	Analytic Hierarchy Process
<b>ASEAN</b>	Association of Southeast Asian Nations
<b>BEV</b>	Battery Electric Vehicle
<b>BRICS</b>	Brazil, Russia, India, China and South Africa
<b>BRT</b>	Bus Rapid Transit
<b>CAFÉ</b>	Corporate Average Fuel Economy
<b>CNG</b>	Compressed Natural Gas
<b>CO<sub>2</sub></b>	Carbon dioxide
<b>ECT</b>	Error Correction Term
<b>EECA</b>	Energy Efficiency and Conservation Authority
<b>ELECTRE</b>	Elimination and Choice Expressing Reality
<b>ERS</b>	Elliot, Rothenberg and Stock
<b>ETS</b>	Emissions Trading Scheme
<b>EU</b>	European Union
<b>EV</b>	Electric Vehicle
<b>EVP</b>	Electric Vehicle Programme
<b>FDI</b>	Foreign Direct Investment
<b>FGLS</b>	Feasible Generalised Least Square
<b>GDP</b>	Gross Domestic Product
<b>GHG</b>	Greenhouse Gas

<b>GMM</b>	Generalised Method of Moments
<b>GtCO<sub>2e</sub></b>	Giga-tonnes of Carbon dioxide equivalent
<b>HEV</b>	Hybrid Electric Vehicle
<b>ICAO</b>	International Civil Aviation Organisation
<b>ICEV</b>	Internal Combustion Engine Vehicle
<b>IMO</b>	International Maritime Organisation
<b>KPSS</b>	Kwiatkowski, Phillips, Schmidt and Shin
<b>LCC</b>	Life-cycle Costs
<b>LPG</b>	Liquefied Petroleum Gas
<b>MAC</b>	Marginal Abatement Cost
<b>MCA</b>	Multi-criteria Analysis
<b>MPP</b>	Mitigation Policy Pathway
<b>MtCO<sub>2</sub></b>	Million tonnes of CO <sub>2</sub>
<b>NDC</b>	Nationally Determined contribution
<b>NGO</b>	Non-government Organization
<b>NGP</b>	Ng-Perron
<b>NZD</b>	New Zealand Dollar
<b>NZTA</b>	New Zealand Transport Agency
<b>OECD</b>	Organisation for Economic Co-operation and Development
<b>OPEC</b>	Organization of the Petroleum Exporting Countries
<b>PCO</b>	Per-capita Cost of Ownership
<b>PCSE</b>	Panel-corrected Standard Errors

<b>PHEV</b>	Plug-in Hybrid Electric Vehicle
<b>PJ</b>	Petajoules
<b>PO</b>	Policy Options
<b>PP</b>	Phillips Perron
<b>PPP</b>	Purchasing Power Parity
<b>PROMETHEE</b>	Preference Ranking Organisation Method for Enrichment
<b>R&amp;D</b>	Research and Development
<b>RE</b>	Renewable Energy
<b>RRP</b>	Recommended Retail Price
<b>RUC</b>	Road User Charge
<b>SAVF</b>	Simple Aggregate Value Function
<b>SAW</b>	Simple Additive Weighting
<b>SCC</b>	Social Cost of Carbon
<b>TCO</b>	Total Cost of Ownership
<b>TDM</b>	Travel Demand Management
<b>TOPSIS</b>	Technique for Order of Preference by Similarity to Ideal Solution
<b>VECM</b>	Vector Error Correction Model
<b>VKT</b>	Vehicle Kilometres Travelled

## **Chapter 1: Introduction**

### **1.1 Background to the Study**

According to the World Economic Forum (2019), climate change is the greatest threat in today's world. The average number of annual deaths worldwide due to climate change is already around 150,000 (WHO, 2020). Between 1998 and 2017, the total number of deaths due to the direct effect of over 11,500 extreme climatic events was over 526,000 (Germanwatch, 2020). The economic losses due to these extreme weather events in this period were around USD 3.47 trillion (at PPP). Estimations project that climate change induced deaths and economic losses will increase in the future unless appropriate measures are taken to reduce greenhouse gas emissions from the atmosphere (WHO, 2020). Realising the importance of mitigating greenhouse gas (GHG) emissions, a global agreement on climate change, namely the 'Paris Agreement', was adopted in 2015 by 197 Parties under the United Nations Framework Convention on Climate Change (UNFCCC). According to the agreement, all parties will outline their targets and possible mitigation measures through nationally determined contributions (NDCs) to achieve the purpose of the agreement which is to keep the global temperature rise well below 2<sup>0</sup> Celsius and make an effort to limit the average temperature increase this century to 1.5<sup>0</sup> Celsius above the pre-industrial level (UNFCCC, 2019).

New Zealand signed the Paris Agreement on 22 April 2016 and ratified it on 4 October 2016 (Ministry for the Environment, 2020). Being a signatory party, New Zealand submitted its Nationally Determined Contribution (NDC) which sets out an aim to reduce its GHG emissions by 30% from the 2005 level by 2020 (Ministry for the Environment, 2018c). Since the New Zealand government is committed to becoming a global leader in climate change mitigation, it has introduced a Climate Change Response (Zero Carbon) Amendment Act and set a domestic target of achieving zero carbon by 2050 (Ministry for the Environment, 2019a). New Zealand's economic losses due to various extreme weather events has also played a role in setting a zero carbon target: New Zealand's annual climate change induced losses between 1998 and 2017 were USD 31.3.2 million (at PPP) (Germanwatch, 2020). To achieve the domestic as well as international targets, New Zealand's challenges are unique. For example, 80-85% of New Zealand's electricity already comes from renewables and there is limited scope for reducing further emissions from the electricity sector without increasing cost (Ministry of Business, Innovation & Employment, 2019). In addition, there is only a small number of important point

source emissions mainly in the manufacturing and industrial processes sectors, while most emissions are non-point source, especially in agriculture.

Emissions trends of New Zealand's major sources show that, between 1990 and 2017, emissions from the transport sector increased by 82% while emissions from the agriculture sector, the industrial processes sector, the manufacturing sector and the waste sector increased by 13.5%, 38.8%, 46.6% and 2%, respectively (Ministry for the Environment, 2019b). This indicates how fast transport emissions are growing in New Zealand and how important it is for the government to tackle transport emissions in order to achieve the Paris 2030 target as well as the 2050 target of net zero carbon emissions. Transport sector emissions are not only a major problem for New Zealand, but also for Australia and Europe. The transport sector is the fastest growing source of emissions in Australia and its transport emissions increased between 1990 and 2017 by 63% (Climate Council, 2018). Likewise, transport sector carbon dioxide (CO<sub>2</sub>) emissions in Europe have been found to be the greatest challenge in combating climate change. It is the *only* major sector in Europe that witnessed an increase in emissions between 1990 and 2014 (Climate Watch, 2019). Countries where transport sector emissions are not yet the major or fastest growing source of emissions are likely to face the transport emissions problem once they solve their problems with other emissions sources. This provides a strong justification for studying transport emissions issues.

Transport emissions mainly include emissions from domestic aviation, road transportation, railways and domestic navigation, and the percentage shares of emissions from these transport sub-sectors in New Zealand in 2017 were 6%, 91%, 1% and 2%, respectively. This indicates the road transport sector is by far the largest source of transport emissions and needs to be investigated systematically to achieve New Zealand's national and international emissions reduction targets. A systematic investigation of road transport emissions includes a comprehensive analysis of the drivers of road transport emissions, evaluation of existing mitigation measures including their challenges and opportunities, and understanding alternative measures through the lens of sustainability (**Figure 1**).

Literature shows the underlying drivers of New Zealand's ever-increasing road transport emissions are diverse. In New Zealand, urban population as well as travel demand are rapidly growing and urban areas are sprawling in nature (Ministry of Transport, 2014b). As a result, public transport infrastructure is often seem to be inadequate and cars are the main mode used to undertake trips (Holmes, Chapman, & Dodge, 2016). In addition, according to Hasan,



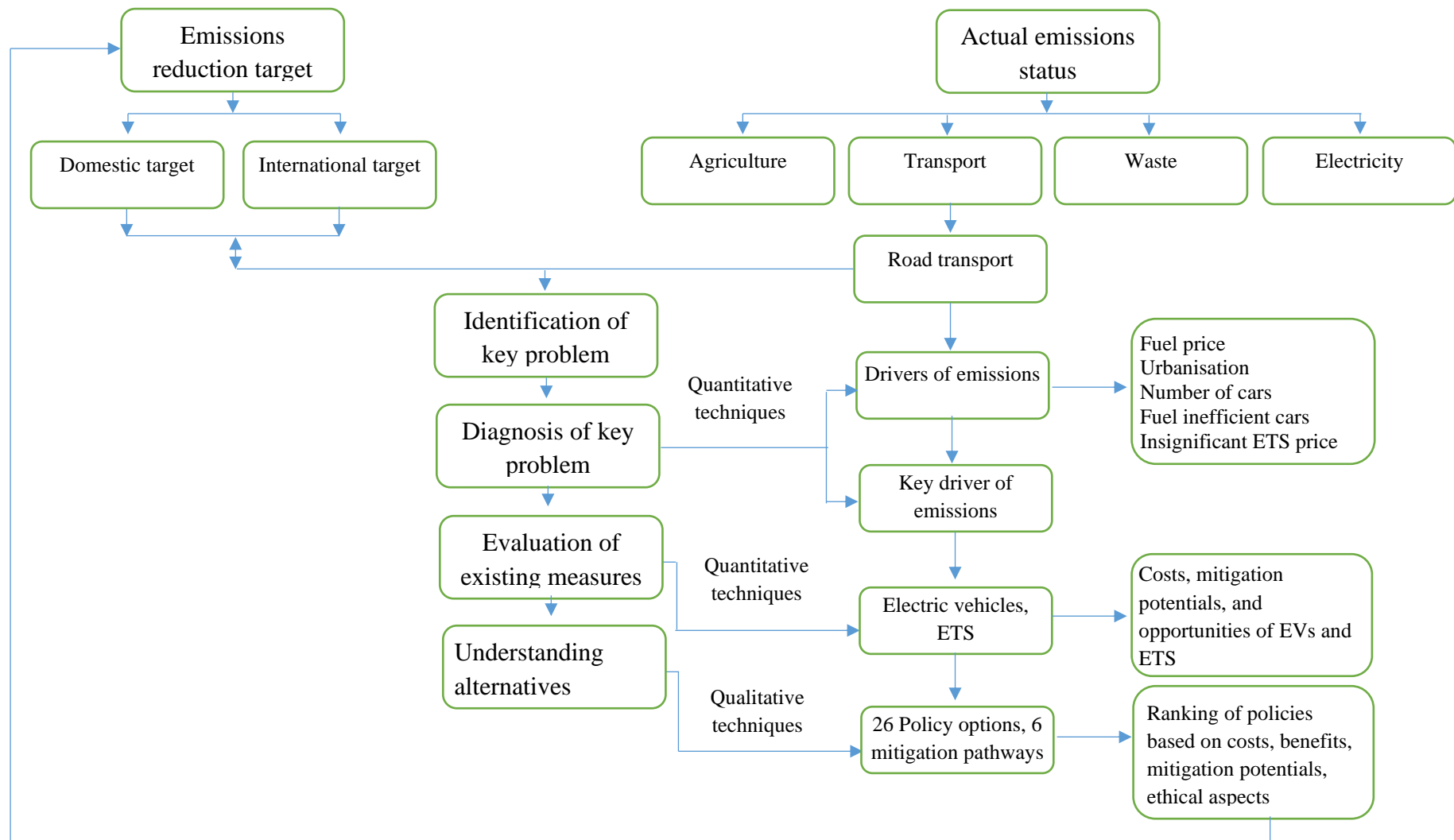
Frame, Chapman, and Archie (2019), New Zealand's vehicle fleet is one of the oldest among developed nations. The average age of a car in New Zealand in 2016 was 14.7 years while it was 10.1 years in Australia, 11.6 years in the USA and 10.7 years in the European Union (EU) countries. Partly because aged vehicles are less fuel-efficient, emissions from the road transport sector have been increasing (Hasan et al., 2019). Fuel price is another key factor that contributed to burgeoning road transport emissions in New Zealand (Hasan, Frame, Chapman, & Archie, 2020). Although the New Zealand Emissions Trading Scheme (NZ ETS) covers the transport sector, the increase in fuel price due to the NZ ETS is insignificant in changing people's travel behavior (Hasan et al., 2020; Leining, Kerr, & Bruce-Brand, 2020). In 2018, the average change in petrol price due to the NZ ETS was 5.8 NZ cents per litre (Carbon Tax Center, 2018) while the fluctuation of petrol prices over the past five years was around 40 NZ cents per litre (Ministry of Business, Innovation & Employment, 2018b). These various factors have been contributing to the rapid growth of road transport emissions and need to be addressed to achieve the Government's net-zero carbon emissions target by 2050.

Electric vehicles are undeniably important on the path to zero emissions (Hausfather, 2019; OECD, 2020). New Zealand's high share of renewables in the electricity generation mix (around 84% in 2018) could help the road transport sector do its part to achieve the net-zero carbon emissions (Hasan et al., 2020). In 2016, the Government announced the Electric Vehicles programme and aimed to increase the number of EVs to 64,000 by 2021. The programme activities include (i) the exemption of Road User Charge for EVs, (ii) coordination across government agencies and the private sector to ensure the bulk purchase of EVs, (iii) NZD 1 million per year for nationwide EV information campaigns and (iv) NZD 6 million per year to encourage innovation and EV uptake (Ministry of Transport, 2019c). However, the uptake of EVs so far has been insignificant. In 2018, the total number of light EVs in the light vehicle fleet was only 11,590 which was ~0.3% of the total light vehicle fleet (Ministry of Transport, 2019e). The high initial purchase price, unknown running and maintenance costs, and lack of New Zealand based studies on the challenges and opportunities of EVs were identified as some of the key barriers to uptake of EVs in New Zealand (Ministry for the Environment, 2018d).

Putting a price on carbon in the form of a tax or an ETS is another key instrument on the path to zero emissions (Carbon Market Solutions, 2015; Hasan et al., 2020). Researchers have suggested that an effective carbon price needs to be approximately equivalent to the social cost of carbon (SCC) to significantly reduce GHG emissions (Pezzey, 2019; Ricke, Drouet,

Caldeira, & Tavoni, 2018). But a major challenge associated with raising the carbon price to the equivalent of the social cost of carbon is its uneven economic burden it would place on different income groups (Rausch, Metcalf, & Reilly, 2011). However, there has been little investigation of cost burdens on various income groups in New Zealand. Therefore, the cost impact of a higher carbon price is unknown for New Zealand. In addition, the mitigation potential of a carbon price equivalent to the social cost of carbon has never been investigated. Until these effects are clearer, New Zealand cannot identify a suitable carbon price and utilise this strong mitigation measure in reducing its burgeoning transport emissions.

Other proven alternative options such as public and active transport, biofuels and hydrogen fuels, various travel demand management (TDM) measures and improved vehicle fuel economy standards have not been adequately investigated to understand their effectiveness and acceptability as transport carbon mitigation measures. Moreover, the best alternative options for transport emissions reduction among a set of alternatives has never been explored for New Zealand. Since resources are scarce, the identification of the best alternative measures is crucial. But the selection of alternatives needs to be based on a robust analysis where all sustainability aspects are considered, including economic, environmental and social aspects. Multi-criteria analysis (MCA) has been found to be a useful tool for identifying and comparing such alternatives (Hasan et al., 2020; Hickman, Saxena, Banister, & Ashiru, 2012; Sun, Zhang, Wang, Li, & Sheng, 2015). This study, therefore, aims to identify the costs, benefits, mitigation potentials and ethical aspects of various transport emissions reduction policies in New Zealand and compare them through adopting a multi-criteria analysis technique. As a background to this study, the major drivers and their roles behind the uncontrolled increasing trend of transport GHG emissions in New Zealand are identified. In addition, challenges and opportunities of the present policies regarding electric vehicle and ETS prices are investigated to understand their costs and emissions reduction potential in New Zealand context. It is expected that the findings of this study will help policy advisers understand the costs and emissions reduction potential of various transport policies, and assist them in identifying the most acceptable policies and projects for investment. As a result, New Zealand's burgeoning transport emissions could be reduced, contributing to the country's efforts to meet national and international emissions reduction targets.



**Figure 1: Conceptual framework of the study**

## **1.2 Research scope**

While investigating the drivers of transport emissions in New Zealand, this study avoided drivers that are less defined and difficult to quantify for a causality analysis. Therefore, New Zealand's urban form and migration policies are not investigated in this study despite their high long-term influence on transport emissions (Lee & Lee, 2014; OECD, 2020). In addition, the present study has focused on road transport emissions instead of total transport emissions because road transport accounts for over 90% of total transport emissions in New Zealand.

## **1.3 Research question**

What are the major drivers of transport sector emissions in New Zealand and which policy options are the most cost-beneficial and ethical, with high potential to reduce transport emissions?

## **1.4 Research aim**

The research initially aims to identify the major drivers of transport emissions in New Zealand so that policy makers and other stakeholders can gain a clearer and more up-to-date picture of the major sources of transport emissions. Next, this study explores the costs and mitigation potentials of the government's initiatives towards EVs and ETS prices so that the challenges and opportunities associated with these policy measures are better able to be understood by various stakeholders including policy makers, car manufacturers and customers. Finally, this study steps back in order to evaluate a wide range of transport emissions reduction policies based on stakeholders' views of their costs, benefits, mitigation potentials and ethical aspects so that appropriate policy options can be taken by the government to tackle burgeoning transport emissions.

## **Chapter 2: Literature Review**

This chapter provides an overview of the literature on the drivers and mitigation options for transport emissions globally and in New Zealand. Individual chapters below provide more detail on the specialised literature relating to the topics of those chapters.

This review starts with a wide look at the factors driving emissions, looking across countries, before moving to consider policy options for addressing emissions. In general, the study of policy options will tend to cover a smaller set of factors than the underlying drivers, partly because some options (e.g. some fuel taxes) may be ruled out politically by a number of countries. The studies that have examined the drivers of transport emissions in various countries are reviewed on the assumption that, although conditions vary across societies, the main conditions likely to influence transport emissions will tend to be broadly similar.

According to Pongthanaisawan and Sorapipatana (2013), vehicle fuel inefficiency is the key driver of road transport emissions in Thailand and they suggested that policies improve vehicle fuel efficiency and increase use of low-carbon fuel sources. Rahman, Khondaker, Hasan, and Reza (2017) researched drivers of transport emissions in Saudi Arabia and concluded that rapid growth of urban population, a large share of individual cars in the fleet, lack of public transport facilities, and low fossil fuel prices are contributing significantly to increased transport emissions. A study of 24 European countries showed that the increased use of non-renewable sources is the key factor in European levels of transport emissions (Marrero, 2010). Rasool, Zaidi, and Zafar (2019) studied the impacts of transport fuel intensity, fuel price, economic growth and population density on Pakistan's transport emissions, and found that low-carbon economic development and high fossil fuel prices could contribute significantly to reducing transport reduction in the long run. Santos (2017) also investigated the key determinants of transport emissions and suggested that high renewable energy costs and lack of legal emissions controls are the major obstacles for reducing transport sector emissions. Shahbaz, Khraief, and Jemaa (2015) studied the drivers of Tunisia's transport emissions and found that the increase of per capita road infrastructure (in metres) and low fuel prices drive increases in transport emissions. Using China's regional data, Zhang and Nian (2013) investigated the drivers of transport emissions and reported that economic growth, fuel price and population are the key determinants of transport emissions in China. Timilsina and Shrestha (2009) examined the transport emissions drivers of Asian countries and revealed that transport fuel intensity, economic growth and population growth are the main transport emissions drivers in Asia.

Unusually, Chandran and Tang (2013) investigated the role of foreign direct investment (FDI), as well as transport fuel intensity, economic growth, and population growth in relation to transport emissions in five ASEAN (Association of Southeast Asian Nations) countries, namely Malaysia, Philippines, Singapore, Thailand and Indonesia. Their research concluded that foreign direct investment contributed to reducing transport emissions while transport fuel intensity and economic growth contributed to the increase of transport emissions.

New Zealand-based literature on the drivers of transport emissions shows that low density urban development outside the city centre is one of the sources of road transport emissions (Adams & Chapman, 2016; Chapman, 2008). Residential areas are often separated from other types of land uses including offices, industries, recreational facilities, educational institutes and public places, which contribute to the demand for travel and thereby emissions (Adams & Chapman, 2016; Frumkin, 2016). The high share of used cars in the light vehicle fleet (around 45% in 2018), a non-stringent Vehicle Exhaust Emissions rule, and a low share of public transport trips in total urban trips were identified as some of the other drivers of road transport emissions in New Zealand (Hasan et al., 2019). Leining et al. (2020) and Hasan et al. (2020) pointed to the insignificant impact of the NZ ETS on fuel price changes as a driver of road transport emissions. As noted in the last chapter, although a number of studies have been carried out in New Zealand as well as worldwide to investigate the drivers of transport emissions, no systematic scientific study has been conducted so far to identify the key driver among the set of drivers. The identification of a key driver will help policy makers understand the root cause of the rise in transport emissions in New Zealand and help enable appropriate policy decisions to achieve the net-zero carbon emissions target.

To tackle the drivers of transport emissions and achieve the net-zero carbon emissions target, researchers have suggested a number of mitigation measures. According to Hasan and Chapman (2019), switching from a petrol car to an EV can reduce life cycle vehicle emissions in New Zealand by about 60%. Since New Zealand does not produce electric cars, there is an argument for only the user phase emissions to be considered, with no indirect effects being taken into account, the emissions reduction potential of EVs is around 90% (Hasan & Chapman, 2019). The Energy Efficiency and Conservation Authority (EECA) of New Zealand also estimated the emissions reduction potential of an EV compared to an ICEV across the life-time, and found that it is about 60% (EECA, 2015). The emissions reduction potential of an EV has also been studied in other countries. For example, Moro and Lonza (2018) compared the life-cycle emissions of an EV and an ICEV in the European Union countries and found that

EVs could help reduce GHG emissions by 60%. Qiao, Zhao, Liu, He, and Hao (2019), in a study on China, estimated that life-cycle emissions of an EV are 18% lower than its counterpart Internal Combustion Engine Vehicle (ICEV). The emissions reduction potential of an EV in China is lower than New Zealand and European countries because China has a high share (around 64%) of coal in its electricity mix (China Energy Group, 2016). In Brazil, the share of renewable energy in the electricity generation mix in 2018 was about 84% and a study by Falcão, Teixeira, and Sodré (2017) estimated that an EV emits 4.6 times less CO<sub>2</sub> across the lifetime than its diesel version.

Although EVs can reduce GHG emissions significantly in countries like New Zealand or Brazil where the share of renewable energy in the electricity-mix is higher, the high ownership costs of EVs often presents a major challenge for large-scale uptake of EVs. According to Falcão et al. (2017), the total ownership cost of an EV in Brazil is 2.5 times as high as its counterpart ICEV. Wu, Inderbitzin, and Bening (2015) estimated the ownership costs of various-sized EVs in Germany and compared them with their respective ICEV counterpart. The study showed that the costs of EVs are higher than the costs of their counterpart ICEVs. However, the study estimated that by 2027, on the basis of falling EV and battery prices, the ownership costs of an EV are likely to be equal or lower than that of the conventional vehicle. Unlike Falcão et al. (2017) and Wu et al. (2015), estimations of EV costs by Hagman, Ritzén, Stier, and Susilo (2016) and Palmer, Tate, Wadud, and Nellthorp (2018) indicate that EVs are cheaper than their counterpart ICEVs in Sweden, the United Kingdom, the USA and Japan. Although several studies conducted research on the ownership costs of EVs in various countries, a comprehensive cost analysis of an EV and its petrol equivalent for New Zealand across the lifetime is not yet available. Therefore, this study aims to fill the gap in the literature. Findings of this study may assist individuals and the government to understand the ownership costs and emissions reduction potential of EVs, and contribute to achieving the net-zero emissions target of the country through increasing the uptake of EVs.

A price on carbon equivalent to the social cost of carbon (SCC) would be another strong policy measure with the potential to contribute to achieving the national and international emissions targets of New Zealand (Leining et al., 2020). Literature shows that the social cost of carbon varies significantly depending on the damage estimation models used by economists and researchers (Hasan et al., 2020; Pezzey, 2019). The SCC values estimated by Ackerman and Stanton (2011) and Ricke et al. (2018) were very high, at NZD 770 for 2050 and NZD 610 for 2020 respectively. Researchers who estimated medium range values for the SCC include Stern

(2007), U.K. Department of Energy & Climate Change (2009), Hope (2013) and Stern and Stiglitz (2017). For 2030, their estimated SCC values ranged from NZD 100 to NZD 235 while the estimated range was between NZD 223 and NZD 326 for 2050. Some researchers made low estimations for SCC values. For example, Nordhaus (2017) estimated a SCC value of NZD 48 for 2015 and NZD 138 for 2050. Likewise, Greenstone and Cass (2016) estimated NZD 54 for 2015. In short, although a number of studies have estimated a range of SCC values which indicate a suitable level of carbon tax, the impact of an increased carbon price equivalent to a plausible SCC value on various income groups of New Zealand, and the emissions reduction potential of the increased carbon price, are unknown and warrant further investigation.

Besides EVs and an increased carbon price, there are other alternative transport emissions reduction measures, including active and public transport, travel demand management (TDM), cleaner emissions standard and biofuels and hydrogen fuels that have been investigated by researchers (Hasan et al., 2019; Rahman et al., 2017). Keall, Shaw, Chapman, and Howden-Chapman (2018) investigated the emissions reduction potential of cycling and walking in New Zealand, and found that increasing active travel would have an effect, but only a modest one, in terms of New Zealand transport emissions reduction. Chapman et al. (2018) and Mackenbach, Randal, Zhao, and Howden-Chapman (2016) emphasized a comprehensive set of measures targeting vehicle efficiency, cleaner fuel, and travel demand management (including public transport policies and land use planning) to reduce GHG emissions from New Zealand's transportation sector. Rahman et al. (2017) and Hasan and Chapman (2019) suggested the increasing use of vehicles powered by renewable or alternative energy sources because they can reduce by around 20-80% the life-cycle GHG emissions depending on the fossil fuel intensity of electricity generation. Yan, Inderwildi, King, and Boies (2013) proposed bioethanol as an alternative to fossil fuels because it is compatible with most spark-ignition vehicle engines, and the technology of producing this fuel is quite mature. As an alternative to conventional fossil fuels, bio-ethanol is the most produced and used alternative fuel in the road transportation sector across the world. Hydrogen fuel is another clean transportation fuel that can help reduce GHG emissions from the transportation sector significantly. However, there are challenges associated with the promotion of hydrogen fuel as an alternative transportation fuel. The cost of producing hydrogen fuel is much higher than the costs of the other conventional fuels because there is no naturally-occurring source of this gas (Rahman et al., 2017). In addition, there are some safety issues as hydrogen gas is more flammable than regular fuels.



Looking more widely, Javid, Nejat, and Hayhoe (2014) found that, among different road transportation emissions mitigation options such as switching to alternative fuels, vehicle efficiency, and transportation demand management (TDM), TDM has perhaps the highest impact in effectively reducing GHG emissions from the transportation sector. The success of travel demand reduction, especially automobile travel demand reduction, depends heavily on government transportation pricing policies and land use policies. The expansion of transit or other public transportation facilities along with distance-based car pricing are found to be effective policy options to reduce travel-induced GHG emissions. To reduce travel demand and shift road users from automobiles to public transportation, Rahman et al. (2017) suggested both pull and push strategies. Pull strategies attract the road users to use less or zero emitting transportation modes. Pull strategies suggested by Rahman et al. (2017) include (i) low cost public transportation facilities, (ii) an improved and integrated road network with better accessibility and mobility, (iii) improved pedestrian facilities, (iv) a dedicated lane for cycles and public transportation, and (v) improved telecommunication network facilities. Push strategies are defined by the same authors as strategies that discourage road users from using high emitting transportation modes. Push strategies proposed in their research include a carbon tax, road pricing on particular roads, fuel tax, parking charges, vehicle tax, congestion tax, restrictions on automobiles in certain roads or lanes over a certain period of time etc. According to Strompen, Litman, and Bongardt (2012), the success of these strategies largely depends on (i) collaboration among respective agencies, (ii) improvement in technological innovation, (iii) integration of such policies with long-term comprehensive strategies, and (iv) quality of implementation.

Although from the literature a wide range of mitigation options is evident, no systematic scientific study has been conducted so far to understand the ranking of these mitigation options. Each transport emissions reduction option has both limitations and advantages, which may be weighted differently by different observers depending on perceptions and ranking criteria (Hasan et al., 2020). Accordingly, the ranking of various mitigation options, considering both limitations and advantages, is of policy interest. As noted in Hasan et al. (2020), within an overall sustainability-oriented framework, the criteria for ranking transport emissions reduction measures should encompass economic, environmental and social aspects. Hasan et al. (2020) sought experts', and NGO and green energy activists' preferences to rank, in terms of costs, benefits, mitigation potentials and ethical aspects as major criteria, alternative transport emissions reduction measures. This study also aims to seek experts', and NGO and green

energy activists' preferences in filling the knowledge gaps in the literature in terms of the ranking of New Zealand's various transport emissions mitigation options.

## **Chapter 3: Methodology**

This chapter aims to provide an overview of the methodology adopted to investigate (i) the drivers of New Zealand's transport emissions, (ii) the costs and mitigation potential of the government's key transport emissions reduction initiatives (i.e. EVs and an increased ETS price), and (iii) the acceptability of various transport emissions reduction policies based on their costs, benefits (including co-benefits), emissions reduction potentials and ethical considerations. Individual chapters below provide more detail on the particular methodology relating to the topics of those chapters.

### **3.1 Drivers of road transport emissions**

To identify the key drivers of New Zealand's transport sector emissions, a set of drivers were first identified from diverse studies in a range of relevant areas including demographic factors (such as urbanisation rate), energy-related component (e.g. vehicle fuel efficiency), economic factors (GDP), transport factors (passenger vehicle numbers), and political or policy-related factors (e.g. increase of fuel price due to the ETS price). In identifying these drivers, three key features are considered: data availability, data type (i.e. time-series data) and perceived importance of a driver in influencing transport emissions. The historical emissions data are collected from the Ministry for the Environment (Ministry for the Environment, 2019b) while passenger vehicle numbers and vehicle fuel economy are collected from the Ministry of Transport (Ministry of Transport, 2019e). The data on urbanisation rate and GDP are taken from the The World Bank (2019) and fuel price data are collected from Ministry of Business, Innovation & Employment (2020).

A Vector Error Correction Model (VECM) was used to identify the key emissions drivers among these various drivers, and to investigate the short- and long-run causality among the drivers. A VECM model is used because it investigates all the interactions among the variables and provides an estimate of the impact of each variable on transport emissions (Arvin, Pradhan, & Norman, 2015). Three major steps were carried out to develop the VECM model: unit root tests, co-integration tests and Granger causality tests.

In order to test the unit root of all the time-series variables used in this study, both the Augmented Dickey-Fuller (ADF) and the Phillips Perron (PP) unit root tests were deployed. Since time-series data for some of the drivers such as passenger vehicle number and vehicle fuel efficiency were not available before 2000, this study used the ADF and the PP tests because

they are found to be suitable for small data sets (Bournakis, Papanastassiou, & Pitelis, 2019). Most importantly, the use of both the ADF and the PP test ensure a robust result as they help overcome each other's limitations. For instance, although the ADF test is widely used by researchers for its simplicity in construction and feasibility (Arltova & Fedorova, 2016), its ability to reject unit roots for variables is often considered to be limited (Azlina, Law, & Mustapha, 2014). In the second step of the VECM model development, this study employed the 'Johansen Co-integration Test' for examining the co-integrations among the various drivers (Johansen & Juselius, 1990). Trace statistics and Maximum Eigenvalue statistics were used to investigate the presence of co-integration among all drivers. Finally, the Granger causality test was carried out using a VECM framework to understand the short- and long-run causality among drivers (Engle & Granger, 1987). Wald F-statistics were used to investigate the short-run causalities while the t-statistics of the error correction terms (ECTs) were used to examine the long-run causalities among drivers (Enders, 2008).

After identifying the major drivers of New Zealand's road transport emissions from a set of drivers, potential mitigation measures were identified through a comprehensive review of the literature, which included scientific research articles, books, international organisations' reports, websites, online discussion forums etc.

The next step was to review New Zealand's recent transport policy documents to examine areas of potential policy action where there is evidently scope to accelerate or broaden emission reductions. Finally, policy recommendations were made based on the study findings with the aim of better illuminating which suitable policy options offer the most potential for rapid transport emissions reduction.

### **3.2 Costs and mitigation potential of EVs**

To estimate the costs and emissions reduction potentials of EVs, firstly, a baseline scenario is developed where the share of EVs and internal combustion engine vehicles (ICEVs) in the New Zealand passenger vehicle fleet, policy targets for EV uptake, life-time of vehicles and/or batteries, vehicle purchase costs, fuel costs, maintenance costs, average vehicle fuel economy and VKT were explored. The data on the share of EVs in the vehicle fleet is retrieved from New Zealand Vehicle Fleet Statistics (Ministry of Transport, 2019e). Policy targets for EV uptake are taken from the Ministry of Transport's website (Ministry of Transport, 2019b). Assumptions on the lifetime of vehicles and/or batteries are based on EECA's (Energy Efficiency and Conservation Authority) recent studies (Energy Efficiency and Conservation

Authority, 2017, 2018a). Vehicle purchase prices and maintenance costs are obtained from various sources (De Clerck et al., 2018; Energy Efficiency and Conservation Authority, 2018b; Harvey, 2018) while VKT and fuel economy data are retrieved from Ministry of Transport's website (Ministry of Transport, 2014b, 2018b). The data on fuel costs are taken from the Ministry of Business, Innovation & Employment (2020). The baseline scenario is developed for used EVs and ICEVs, as the share of *used* EVs and ICEVs in the New Zealand vehicle fleet is very large.

Next, the energy consumption and emissions from ICEVs were estimated following the 'Future demand model' developed by the Ministry of Transport (2014b). The 'future demand model' is considered because it is a comprehensive and robust New Zealand-based model that incorporated key drivers of VKT in its development including fuel price, urbanization, digital connectivity, population age structure, population growth, and fuel efficiency. Moreover, since the model was developed by the Ministry to explore a number of scenarios for future transport change in New Zealand, findings and results based on this particular model are expected to be influential in official circles.

Next, the ownership costs of EVs and ICEVs were calculated. To estimate the costs of using various vehicle types, cost components for both EVs and ICEVs were generated. Cost components include vehicle purchase cost, depreciation cost, fuel cost, repair and maintenance cost, government incentives, and resale values. Assumptions were also made while calculating ownership costs of EVs and ICEVs. For example, a 12-year vehicle ownership period is considered in this study. This is because most of the previous studies considered a similar vehicle ownership period (Vora et al., 2017; Weiss, Zerfass, & Helmers, 2019). In addition, in New Zealand, the manufacturer's warranty for an EV battery is up to 160,000 kilometres (Energy Efficiency and Conservation Authority, 2017). Since the annual VKT in 2018 in New Zealand is around 10,500 km (Energy Efficiency and Conservation Authority, 2018a) and the annual increase in VKT is estimated to be 1.2% (Ministry of Transport, 2014b), the life-time of an EV battery is about 12-13 years. This is another reason for considering a 12-year vehicle ownership period in this study.

To estimate the emissions reduction potential of EVs, annual emissions from EVs and ICEVs were calculated from an operational (or user) perspective instead of a life-cycle perspective

because New Zealand does not manufacture or recycle cars.<sup>1</sup> While calculating the annual emissions of EVs and ICEVs, three factors were considered: vehicle efficiency, fuel carbon intensity and annual distance travelled. Average vehicle efficiency of New Zealand's cars was taken from the New Zealand vehicle fleet statistics (Ministry of Transport, 2019e). The carbon intensity of passenger car fuel was estimated from government reports and scientific research articles. The upstream emissions from EVs, and the upstream and tailpipe emissions from ICEVs were calculated based on the emissions intensity of New Zealand's electricity and petrol, respectively. Since emissions from an ICEV or EV depend on vehicle kilometres travelled (VKT), the median projections of the 'Future demand model' developed by the Ministry of Transport (2014b) was used to estimate the future VKT and associated emissions. The median projection of the model is considered because the actual travel demand between 2014 and 2018 mostly matched with the median projection of the 'Future demand model'. Finally, the emissions reduction potential of EVs in New Zealand was calculated by comparing the per-kilometre emissions from an EV with those of an ICEV.

### **3.3 Costs and mitigation potential of an increased carbon price**

In order to estimate the cost of an increased carbon price in the transport sector of New Zealand, this study first collected New Zealanders' annual household expenditure data for domestic transport from Statistics New Zealand (2019). To investigate the cost burden of an increased carbon price on various income groups, New Zealand households were then divided into five income groups based on their annual average household incomes. They were categorised as low-income households (annual income below NZD 35,099), lower-middle income households (annual income NZD 35,100-NZD 60,599), middle income households (annual income NZD 60,600-91,099), higher middle income households (annual income NZD 91,100-NZD 133,699) and high-income households (annual income over NZD 133,700). Next, the social cost of carbon estimated by various researchers internationally were investigated through a comprehensive literature review. The first quartile, median and third quartile estimates of the social cost of carbon were derived as NZD 100, NZD 185 and NZD 235 respectively. The cost burdens on different income groups under the low (first quartile), medium (median) and high carbon (third quartile) price scenarios were developed to understand how domestic transport costs vary across various income groups with a change in carbon prices. To estimate carbon

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<sup>1</sup> Relevant emissions figures from a life-cycle perspective were however estimated for both New Zealand and Australian conditions, and a short article was published in The Conversation explaining these estimates: see Annex X1

price-induced cost-burdens, the price elasticity of travel demand is used instead of the price elasticity of fuel demand because the cost of transport does not only consist of fuel prices (Hasan et al., 2020).

In order to estimate the emissions reduction potential of different carbon price scenarios (low, medium and high carbon price), the price elasticity of transport fuel demand was used. An extensive literature review was carried out to identify estimates of the fuel price elasticity for the New Zealand transport sector. The outlier values of the price elasticity of fuel demand were disregarded in this study and changes in fuel consumption due to changes in fuel prices are estimated based on the first and third quartile estimates of price elasticities of transport energy demand i.e.  $-0.4$  and  $-0.7$  respectively. The reduction in transport energy consumption will proportionately reduce transport CO<sub>2</sub> emissions (Hasan et al., 2020). However, we acknowledge that any extrapolation of behaviour from an elasticity estimate will be limited in its application and accuracy. The further the price of carbon increases from NZD 100/tCO<sub>2</sub> towards NZD 235/tCO<sub>2</sub>, the less certain the projected change in fuel use will be. In the case of large percentage increases in fuel price, a range of behavioural factors will come into play, including the attractiveness of other modal choices such as electric vehicles, public transport, shared mobility, e-scooters, etc. The estimates of changes in fuel use should therefore be treated with caution and be seen as indicative only.

### **3.4 Acceptability of transport emissions reduction policies**

In the transport sector, decision making is quite complex as there are multiple goals that a government would like to reach (Beria, Maltese, & Mariotti, 2012), using a variety of policy measures. It is posited that consideration of trade-offs or complementarities among these goals is achieved by government through the inclusion of different experts, NGO and green energy activists and policy advisers in the decision making process providing insights in terms of cost effectiveness and social, environmental and economic benefits (Walker, 2000). MCA is often adopted by researchers to simulate or illuminate decision making problems in policy analysis (Baudry, Macharis, & Vallee, 2018; Dias, Antunes, Dantas, de Castro, & Zamboni, 2018; Soria-Lara & Banister, 2018; Vatn, 2005; Zaman, Brudermann, Kumar, & Islam, 2018). This study also applied an MCA of experts', and NGO and green energy activists' preferences to understand the acceptability of various transport emissions reduction policies. Four criteria were used in this study: costs, benefits (including co-benefits), mitigation potentials and ethical aspects. Hasan et al. (2020) also used four criteria in their study to understand carbon pricing

instruments. In this study, costs and benefits are used as economic indicators while mitigation potentials and ethical aspects are used as environmental and social indicators, respectively. Both costs and benefits are used to better understand the economic aspects including co-benefits. The use of two economic indicators but only one indicator for each environmental and social aspect would not have an effect in the analysis because all data is normalised and average values are taken into account.

To scope the MCA, a total of 26 possible transport emissions reduction policies were identified initially through a systemic review of literature which includes governmental reports and policy documents, scientific research articles, books, international organisational reports, websites, online discussion forums etc. Subsequently, policy options (POs) were categorised and pooled under six mitigation policy pathways (MPPs). Next, the preferences of 25 transport and environmental experts, and NGO and green energy activists from central and local governments, NGOs, green energy company, and academics were collected through face to face interviews or telephone calls. Among the 25 respondents, 20 were experts and 5 were NGO and green energy activists. Among the 20 experts, 5 were from the Ministry of Transport, 5 were from the Ministry for the Environment, 3 were from Wellington Regional Council, 2 were from Wellington City Councils, and the remaining 5 were independent researchers or academics. The experts, and NGO and green energy activists were identified using the snowball sampling technique where the initial respondents were identified through a peer review process (Christopoulos, 2009; Sun et al., 2015; Wasserman & Faust, 1994). Peers nominated a number of initial respondents from various organisations and institutions who enabled the desired number of respondents for this study to be achieved.

The six mitigation policy pathways and 26 policy options served as inputs for the MCA. To understand the hierarchy among the six MPPs and 26 policy options based on their costs, benefits (including co-benefits), mitigation potentials and ethical aspects, this study used the preferences of experts, and NGO and green energy activists. Preferences were taken through face-to-face interviews, except for one telephone interview. There were three main reasons for conducting face-to-face interviews for this study. Firstly, face-to-face interviews ensure higher response rates. Secondly, this study required respondents to answer a number of questions and face-to-face interviews are quick and take less time compared to other survey techniques. Thirdly, interpretation of some of the questions was required in this study (Fowler Jr, 2013). Respondents weighted the four criteria first using a scale of 0 to 9 where '0' indicates a least important criterion and '9' indicates a highly important criterion. Then, respondents rated 6



MPPs and 26 POs using a similar 9-point scale where ‘0’ indicates a weak and ineffective MPP or PO and ‘9’ indicates a strong and effective MPP or PO.

Experts’, and NGO and green energy activists’ responses were analysed using the Simple Additive Weighting (SAW) MCA approach. There were other techniques considered for processing and analysing preferences including the Analytic Hierarchy Process (AHP), Simple Aggregate Value Function (SAVF), Preference Ranking Organisation Method for Enrichment Evaluations (PROMETHEE), Elimination and Choice Expressing Reality (ELECTRE), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) etc. The SAW technique was chosen for this study because the technique is well-proven and easy to implement (Pires, Martinho, Rodrigues, & Gomes, 2019). The technique is also suitable for ranking a large number of alternatives. Since this study aimed to rank six MPPs and 26 POs, the SAW technique was found to be the most suitable to minimise the burden on the respondents. Even with the relatively streamlined SAW technique, it took around 50 minutes on average to complete an interview. Most importantly, the SAW technique is considered to be a compensatory method where every criterion has an important role in the decision making process (Gass & Harris, 1997).

## Chapter 4: New Zealand transport emissions drivers

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### Summary findings

The transport sector is the fastest growing greenhouse-gas-emitting sector in the world and it is also a major source of emissions in New Zealand. Greenhouse gas (GHG) emissions from road transport increased by 82% between 1990 and 2017. This increase in GHG emissions was the highest among the different energy sub-sectors of New Zealand. Increasing energy consumption and GHG emissions are due to the gradual increase in population, car-dependent low density development, lack of integrated public transport networks, inappropriate policy interventions and so on. These factors are making it difficult to reduce emissions from this sector. This chapter investigates (i) major drivers of transport sector emissions, including how drivers differ from those affecting other developed countries; (ii) a mitigation policy roadmap to achieve future emissions reduction targets; and (iii) mitigation policy initiatives by the government, and policy gaps. To identify the key drivers from a set of drivers, this chapter uses a Vector Error Correction Model (VECM). The Granger causality test reveals that the fuel economy of the New Zealand passenger vehicle fleet has a significant causal relationship with transport emissions. Introduction of a number of policies such as a feebate scheme and/or a high minimum fuel economy standard could effectively alter this causal relationship in the short term, along with other measures such as urban planning changes for medium-term impact. The findings of this chapter might help policy makers identify the most tractable factors driving transport emissions and alternative policy options suitable for emissions mitigation.

### 4.1 Introduction

Although the transport sector plays an important role in the growth of an economy and in the wellbeing of a society, it is the fastest growing emitting sector in the world and a major contributor of global greenhouse gas (GHG) emissions. Around 28% of global energy related carbon dioxide (CO<sub>2</sub>) emissions are emitted from the transport sector (Sims et al., 2014). Emissions from this sector more than doubled since 1970 and reached 7.0 Gigatonnes of carbon dioxide equivalent (GtCO<sub>2</sub>e) in 2010. Road transport was responsible for approximately 80% of this increase (Sims et al., 2014). Despite modest efforts by the global transport industries to make this sector energy and carbon efficient, the world has seen a continued growth in emissions in recent years. The seemingly inevitable increase in demand for travel with rising

incomes, slow deployment of new technologies, absence of stringent policy interventions, and a dearth of effective programmes to encourage behavioral change are some of the major challenges in reducing emissions from this sector.

Consistent with the global trend, New Zealand, a young island nation in the southwestern Pacific Ocean has also been experiencing a significant increase in transport sector emissions over the last two decades. Between 1990 and 2017, New Zealand's annual average increase in transport GHG emissions was around 2.3%, giving a total increase in emissions of 82% (Ministry for the Environment, 2018b). In this period, the increases of transport emissions in comparable countries ranged from 60.8% in Australia to 22.2% in the USA, 1.8% in the United Kingdom, and -12.9% in Sweden (OECD, 2019). The *road* transport sector is the major contributor of transport emissions in New Zealand: around 90.8% of the total transport emissions in 2017 were from this transport sub- sector. Moreover, this sub-sector expanded rapidly: its GHG emissions increased by 82% between 1990 and 2017 (Ministry for the Environment, 2018b). In 2017, emissions from the transport sector accounted for around 19.7% of the country's total GHG emissions (Ministry for the Environment, 2018b). Within the energy sector, transport has the largest share of emissions, followed by electricity/heat/energy and manufacturing/construction. In 2017, transport emissions were around 48.4% of total energy sector emissions, while electricity/heat/energy, and manufacturing/construction contributed around 12.2% and 18.4% of energy sector emissions, respectively (Ministry for the Environment, 2018b).

The trajectory of New Zealand's transport emissions indicates that the total emissions from this sector in 2030 are likely to be 60% above the 1990 emissions level (Shaw, Keall, Randal, & Howden-Chapman, 2017) or more. Major drivers responsible for the high GHG emissions trend in the transport sector in New Zealand are the rapid growth of population, dispersed suburban development, a sharp increase in the number of imported used cars, slow uptake of electric vehicles, a recent fall in fossil fuel prices between 2012 and 2017, and inappropriate policy interventions, including a lack of infrastructure development for public transport etc. The review of these drivers and the identification of any key driver from the set of drivers are crucial from a policy perspective to help policy makers identify the most tractable factors driving transport emissions. Moreover, this chapter performs some quantitative analyses for policies that utilizes the causal relationships between GHG emissions and their drivers. In addition, this chapter provides an emissions reduction roadmap, linking it to future emissions

reduction targets of the country so that policy makers understand the policy gaps and can decide on appropriate policy measures to achieve future targets.

The next section reviews the literature while section 4.3 presents the methodology. The 4.4 section reviews the drivers of New Zealand transport sector emissions and investigates how these drivers differ from those affecting other developed countries. The 4.5 section presents model results while the implications and a roadmap for emissions reduction are discussed in the 4.6 section. Transport emissions reduction initiatives by the government of New Zealand are explored in the 4.7 section, and the final section of this chapter identifies policy gaps related to key emission drivers and presents concluding remarks based on the findings of this chapter.

## **4.2 Literature review**

Many studies both in developed and in developing countries have identified the key drivers of transport emissions and possible mitigation options. The relative impact of different drivers on transport emissions has been explored in recent studies through analysis of factors such as urbanisation, fuel price, fuel efficiency, income, vehicle numbers, etc. A number of studies have used a multivariate causality framework to understand both the short- and the long-run relationships between transport emissions and various explanatory factors.

For example, Pongthanaisawan and Sorapipatana (2013) investigated transport sector emissions and energy consumption in Thailand, using an econometric model; they found that fuel efficiency improvement and fuel-switching are the most effective options for transport emissions reductions in the long- and short-run, respectively. Klier and Linn (2013) also used an econometric analysis to investigate the effect of fuel prices on new vehicle fuel economy in the USA and Western Europe. They found that the effect is much smaller for Europe than the USA. Marrero (2010) examined panel data from 24 countries in Europe between 1990 and 2006, and found that fuel mix and increased renewable energy use generated significant reduction in CO<sub>2</sub> emissions. A study in Brazil by De Freitas and Kaneko (2011) identified population and economic growth as the main drivers of CO<sub>2</sub> emissions. Another study in Malaysia investigated the role of GDP, population growth and energy consumption on CO<sub>2</sub> emissions and concluded that GDP and energy consumption have a long-run positive association with emissions. Therefore, the study suggested increasing the use of low-carbon technologies to reduce emissions (Begum, Sohag, Abdullah, & Jaafar, 2015). A recent study in 29 Chinese provinces showed that there is a mixed bi-directional causal relationship between the growth in GDP and carbon emissions, with the causality running from GDP growth to

emissions growth being positive, while the other way around is negative (Ahmad, Zhao, Irfan, & Mukeshimana, 2019). Another recent study in the USA revealed a unidirectional causal relationship between energy consumption and GHG emissions. The study proposed implementing a vehicle fuel economy standard to effectively regulate transport fuel demand and associated GHG emissions (Raza, Shah, & Sharif, 2019).

A number of other post-2010 studies have identified fuel consumption (or fuel efficiency) as one of the major factors in GHG emissions and proposed fuel efficiency as an appropriate instrument for emissions reduction (Akhmat, Zaman, Shukui, Irfan, & Khan, 2014; Alam et al., 2015; Arouri, Youssef, M'henni, & Rault, 2012; Asumadu-Sarkodie & Owusu, 2016; Ben Jebli & Hadhri, 2018; Boutabba, 2014; He, Xu, Shen, Long, & Chen, 2017; Lin & Xie, 2014; Rafindadi, Yusof, Zaman, Kyophilavong, & Akhmat, 2014; Shahbaz, Sbia, Hamdi, & Ozturk, 2014; Wang, Chen, & Kubota, 2016). Researchers who found GDP growth as one of the major drivers contributing to GHG emissions include Ahmad et al. (2019); Al-Mulali, Sheau-Ting, and Ozturk (2015); Al-Mulali, Weng-Wai, Sheau-Ting, and Mohammed (2015); Arvin et al. (2015); Asumadu-Sarkodie and Owusu (2016); Ben Jebli and Hadhri (2018); Chandran and Tang (2013); Hamit-Hagggar (2012); Lin and Xie (2014); Nasir and Rehman (2011); Ratanavaraha and Jomnonkwao (2015); Saboori and Sulaiman (2013); Sutthichaimethee and Ariyasajakorn (2018); Zhang and Da (2015) and so forth. Other factors affecting emissions found in empirical studies include urbanisation (Al-Mulali, Weng-Wai, et al., 2015; Arvin et al., 2015; He et al., 2017; Iwata, Okada, & Samreth, 2010; Lin & Xie, 2014; Martínez-Zarzoso & Maruotti, 2011; Shahbaz et al., 2014; Wang, Monzon, Di Ciommo, & Kaplan, 2014; Zhang, Liu, Zhang, & Tan, 2014), population (Ahmed & Long, 2012; Asumadu-Sarkodie & Owusu, 2016; Liddle, 2013; Noorpoor & Kudahi, 2015; Onafowora & Owoye, 2014; Ratanavaraha & Jomnonkwao, 2015; Sinha Babu & Datta, 2013), vehicle number (Liddle, 2012; Limanond, Jomnonkwao, & Srikaew, 2011; Ratanavaraha & Jomnonkwao, 2015; Raza et al., 2019) and fuel price (Liddle, 2012; Mustapa & Bekhet, 2016; Shahbaz et al., 2015; Sutthichaimethee & Ariyasajakorn, 2018).

The Granger causality test based on a vector error correction model (VECM) is a widely used method in empirical studies that analyse the relationship between carbon dioxide emissions and their key drivers. Dagher and Yacoubian (2012) investigated the relationship between GDP and energy consumption in Lebanon using a VECM based Granger causality test, and found a bi-directional causal relationship between them both in the short- and long-run. Another study by Saboori and Sulaiman (2013) used the same technique i.e. a VECM based Granger causality

test to understand the causal relationship among GDP, energy consumption and CO<sub>2</sub> emissions in five ASEAN countries: Singapore, Indonesia, Malaysia, Thailand, and the Philippines. The results showed a bi-directional causal relationship between CO<sub>2</sub> emissions and energy consumption in all countries. Interestingly, Liu and Bae (2018a) also used a Granger causality test based on VECM to examine urbanisation's effect on carbon dioxide emissions in China and concluded that there is no causal relationship between them. Other recent studies that have used a VECM based Granger causality test for their empirical research include Acaravci and Ozturk (2010); Akhmat et al. (2014); Ang (2007); Apergis and Payne (2010); Azlina et al. (2014); Boutabba (2014); Chandran Govindaraju and Tang (2013); Chandran and Tang (2013); Farhani, Chaibi, and Rault (2014); Halicioglu (2009); Jalil and Mahmud (2009); Lean and Smyth (2010); Pao and Tsai (2011); Shahbaz et al. (2014); Shahbaz, Solarin, Mahmood, and Arouri (2013); Tiwari, Shahbaz, and Adnan Hye (2013) and so forth. However, Appiah, Du, Yeboah, and Appiah (2019) used the feasible generalised least square (FGLS) and panel-corrected standard errors (PCSE) method to investigate the causal relationship between carbon emissions and its drivers such as population growth, economic development and non-renewable energy use for BRICS countries (Brazil, Russia, India, China and South Africa). The study found that all these factors have positive correlations with carbon emissions, which suggest an increase in the factors increases emissions. A recent study in 44 Sub-Saharan African countries employed a second-generation panel regression technique to investigate the effects of urbanisation on carbon dioxide emissions and revealed that urbanisation causes emissions and the relationship is statistically significant. The generalised method of moments (GMM) is another technique used by many researchers for empirical studies and some of these studies include Al-Mulali, Sheau-Ting, et al. (2015); Al-Mulali, Weng-Wai, et al. (2015); Alam et al. (2015); Du, Wei, and Cai (2012). The appropriate technique for the present empirical study was identified based on the results of the data stationarity test and the co-integration test, described in detail in the methodology section.

### **4.3 Methodology**

This chapter analyses New Zealand's transport sector emissions with an aim of identifying the key drivers of road transport emissions, current mitigation policies, the major policy gaps to deal with the key drivers of transport emissions. A cross-national comparative investigation is conducted to gain a deeper understanding of New Zealand's emission drivers and existing barriers in relation to reducing transport sector emissions. New Zealand's emission drivers and some mitigation policy measures are compared with those of Australia, the United Kingdom,

the United States of America, and Canada. In choosing these countries, priority was given to countries with similar institutional settings, value systems, language, lifestyles, energy behavioral patterns, and historical geo-political relations. However, countries like Sweden, Switzerland, Norway, Denmark, and France are also considered because all these countries have progressed significantly in reducing transport GHG emissions (Burck, Marten, Bals, & Höhne, 2018). The major steps of the methodology are as follows.

#### 4.3.1 Data and data source

Literatures from secondary sources are studied to identify the drivers of transport sector GHG emissions. Drivers of transport emissions are identified from diverse areas such as demography and urban economics (population change, urbanisation rate, and urban sprawl), energy (energy intensity, vehicle fuel efficiency, fuel consumption, and fuel-mix), socio-economic development (gross domestic product, passenger travel), transport factors (congestion, fleet composition, number of passenger vehicles, modal split, vehicle trips, public transport, and distance travelled), and politics and policies (fuel price that includes emissions trading scheme price, and vehicle efficiency/emissions standards). For the model development, one factor from each segment is chosen based on data type, data availability and perceived importance in driving transport emissions. This study requires time series variables for model development. Therefore, urbanisation rate (a demographic factor), passenger vehicle number (a transport factor), GDP per capita (a socio-economic factor), fuel efficiency (an energy-related factor), and fuel prices (a governmental policy factor) are chosen for this study.

The historical carbon emissions data from 1990 to 2016 are taken from the Ministry for the Environment's website (Ministry for the Environment, 2019b). The data on population, urbanisation rate, and gross domestic product (GDP) are drawn from the World Bank's website (The World Bank, 2019) and the data on energy use and fuel price are extracted from the Ministry of Business Innovation and Employment's website (Ministry of Business, Innovation & Employment, 2018a, 2018b). New Zealand's 'vehicle fleet statistics data' are used to explore the changes in vehicle fleet composition, vehicle numbers, annual travel (distance), and average vehicle age between 2000 and 2016 (Ministry of Transport, 2019e). The details of these variables are presented in **Table 1**.

**Table 1. Definition, measurement, period and source of variables**

Variable (Symbol)	Definition/description	Time period	Unit	Data source
Transport emissions (TE)	This includes GHG emissions from passenger land transport in New Zealand.	1990- 2016	million tonnes of carbon dioxide equivalent (MtCO <sub>2</sub> e)	New Zealand's GHG inventory (Ministry for the Environment, 2019b)
Passenger vehicle numbers (PV)	The annual total number of light passenger vehicles in the fleet	2000- 2016	millions	Vehicle fleet statistics (Ministry of Transport, 2019e)
Fuel price (P)	Real annual average petrol prices including the effect of the emissions trading scheme (ETS) on prices	1990- 2016	In constant 2017 New Zealand cents/litre	Energy prices (Ministry of Business, Innovation & Employment, 2018b)
Vehicle fuel economy (FE)	The total distance travelled by a light petrol vehicle, divided by the amount of petrol consumed	2000- 2016	Kilometre/litre (km/L)	Vehicle fleet statistics (Ministry of Transport, 2019e)
GDP per capita (GDP)	The gross domestic product (GDP), divided by the mid-year population.	1990- 2016	In constant 2010 US dollars	World development indicator (The World Bank, 2019)
Level of urbanisation (U)	Percentage of population living in urban areas (%)	1990- 2016	Percentage (%)	World development indicator (The World Bank, 2019)

#### 4.3.2 Model specification

This study proposes a multivariate regression model to identify the key drivers of transport emissions from a set of drivers and examines the empirical relationship between transport



emissions (TE) and its drivers i.e. passenger vehicle number (PV), fuel price (P), vehicle fuel economy (FE), GDP per capita (GDP), and level of urbanisation (U). The proposed model is as follows-

$$TE_t = \alpha + \beta_1 PV_t + \beta_2 P_t + \beta_3 FE_t + \beta_4 GDP_t + \beta_5 U_t + \varepsilon_t \quad (1)$$

Here  $TE_t$  is the amount of passenger transport emissions at time  $t$ ;  $\alpha$  is the intercept;  $\beta_1, \dots, \beta_5$  are the coefficients for the proposed explanatory variables and  $\varepsilon_t$  is the random error at time  $t$ .

Since this is a time-series analysis of the drivers of transport emissions, the proposed model (Equation 1) is converted to a logarithmic form for the purpose of examining the stationarity and differencing of data (Dogan & Turkekul, 2016; Gokmenoglu & Taspinar, 2018; Liu & Bae, 2018b; Ouyang & Lin, 2017; Wang & Lin, 2019; Wang et al., 2016). The logarithmic form of equation (1) is as follows-

$$\ln(TE_t) = \ln(\alpha) + \beta_1 \ln(PV_t) + \beta_2 \ln(P_t) + \beta_3 \ln(FE_t) + \beta_4 \ln(GDP_t) + \beta_5 \ln(U_t) + \ln(\varepsilon_t) \quad (2)$$

Equation (1) and (2) consider passenger transport emissions (TE) as the dependent variable and other variables such as passenger vehicle number, fuel price, vehicle fuel economy, GDP per capita and the level of urbanisation as independent variables. This study uses a Vector Error Correction Model (VECM) to examine the short-run and long-run causality between the dependent and independent variables. The advantage of using a VECM model is that it investigates all the interactions among the variables and provides an estimate of the impact of each variable on transport emissions (Arvin et al., 2015). There are three major steps for carrying out a time-series analysis (Azlina et al., 2014). The first step examines the presence of unit roots in the variables while the second step tests the existence of co-integration among the variables. Depending on the results of unit root and co-integration tests, the third step, the VECM, is developed. The preconditions for developing a VECM are (i) the presence of unit roots in the variables (i.e. variables must be non-stationary at the base level but stationary at the first difference) and (ii) variables are co-integrated (Engle & Granger, 1987). The VECM helps to infer the causal relationship among the drivers of transport emissions based on the Granger causality test.

The VECM model deployed for the Granger Causality Test is as follows-

$$X_t = \begin{pmatrix} D PV \\ \dots \\ D P \end{pmatrix} = \begin{pmatrix} \alpha 1 \\ \dots \\ \alpha 5 \end{pmatrix} + \begin{pmatrix} \beta 11(L) & \dots & \beta 15(L) \\ \dots & \dots & \dots \\ \beta 51(L) & \dots & \beta 55(L) \end{pmatrix} \begin{pmatrix} D PV \\ \dots \\ D P \end{pmatrix} + \begin{pmatrix} \gamma 1 Z1, t-1 \\ \dots \\ \gamma 5 Z5, t-1 \end{pmatrix} + \begin{pmatrix} \phi(L) & 0 & 0 \\ \dots & \phi(L) & \dots \\ 0 & \dots & \phi(L) \end{pmatrix} \begin{pmatrix} \varepsilon 1, t \\ \dots \\ \varepsilon 5, t \end{pmatrix} \quad (3)$$

Here,  $X_t$  is a (5x1) vector of the series (variables),  $\alpha$ 's are the vector constant terms,  $\beta$ 's are the coefficients,  $D$  represents the first difference of the time series data,  $\varepsilon_t$ 's are the error terms,  $Z_{t-1}$  are the error correction terms,  $\phi(L)$ 's are the lag operator, and  $\gamma$ 's are the coefficients of the error terms.

#### 4.3.3 Unit root and co-integration test

This study deploys the Augmented Dickey-Fuller (ADF) and the Phillips Perron (PP) unit root tests to examine the integration order and stationarity of the time-series variables because these tests have some advantages over other methods for this study (Cetin, Ecevit, & Yucel, 2018; Rauf et al., 2018). For testing unit roots, the ADF test is one of the most widely used reliable options due to its simplicity in construction and feasibility (Arltova & Fedorova, 2016). The main reason for using the ADF and PP test for testing unit roots in this study is that they are found to be the most suitable tests for small data sets (Arltova & Fedorova, 2016; Bournakis et al., 2019). Since the length of time series data in this study is very small i.e.  $n = 27$  (from 1990 to 2016), this study uses both the ADF and PP tests to test data stationarity. Other unit root tests such as the NGP (Ng-Perron) test, the KPSS (Kwiatkowski, Phillips, Schmidt and Shin) test, and the ADF-GLS test which is also known as the ERS (Elliot, Rothenberg and Stock) test are not used in this study because they are mostly suitable for large lengths of time series data ( $n = 50, 100$  or  $500$ ) and have a very limited ability to reject the null hypothesis of a unit root test under the small length of time series (Arltova & Fedorova, 2016). It is assumed that the combination of the ADF and PP tests provide a robust result because the ADF test often has a limited strength to reject a unit root (Azlina et al., 2014).

After the establishment of the integration order of the time series variables, the next step of a multivariate time series regression analysis is the test of co-integration. Usually, variables that are non-stationary at levels ('order of integration'-1) and stationary at their linear combination (at first difference) are considered to be co-integrated (Arvin et al., 2015). The presence of any co-integration among two or more variables (series) is an indication of a long-run equilibrium relationship among the co-integrated variables (Engle & Granger, 1987; Granger, 1988). This

study employs the ‘Johansen Co-integration Test’ to examine the co-integration or long-run relationships among different drivers of transport emissions (Johansen & Juselius, 1990). Based on the ‘Trace statistics’ and ‘Maximum Eigenvalue statistics’, the presence of co-integration among the variables is identified.

#### 4.3.4 Granger causality test

To identify the key drivers of transport emissions from a set of drivers, this study performed the Granger Causality test using a VECM framework. This test indicates the causality direction and examines the significance of a variable to cause an event. The existence of co-integration among the variables necessitates the incorporation of an error-correction term (ECT) to the model to adjust the deviation from long-run equilibrium. The ECT of a variable indicates its adjustment speed to attain long-run equilibrium. In other words, it is the speed at which a proportion of disequilibrium is corrected from one period to the next period (Engle & Granger, 1987). The speed of adjustment depends on the coefficient value of ECT, its sign and the level of significance (Enders, 2008). If a variable has a large negative coefficient of ECT and the coefficient is significant, it suggests a speedy convergence from short-run to long-run, and illustrates a causal relationship with the dependent variable (Enders, 2008). On the other hand, a positive coefficient implies non-convergence in the long run (Enders, 2008). The incorporation of ECT into the model is important because it makes the model a vector error correction model (VECM). The F-statistic probability value is used to understand the significance of different variables to cause transport emissions in New Zealand.

#### **4.4 Major factors driving transport sector emissions**

With the increase in total population and especially urban populations, the demand for travel has increased in New Zealand. Accordingly, GHG emissions from the transport sector have also increased. Other factors such as the high share of cars in the vehicle fleet and therefore, large scale demand for carbon-intensive fossil fuels, the prevalence of low density urban sprawl, the decrease in carbon-intensive fuel prices in recent years, energy intensive travel behavior and life styles, lack of supporting transport sector policies, uncertainties with electric vehicles and hydrogen fuel, etc. also contribute significantly to transport sector emissions in New Zealand. These factors are examined in this section.

#### 4.4.1 Population and urbanisation

New Zealand population has continued to grow rapidly in the last quarter century. The total estimated population in New Zealand on 30 June 2016 was around 4.7 million. Between 1990 and 2016, the total population of New Zealand grew at an annual average rate of about 1.3% while the rates in Australia, Canada, the United States and the United Kingdom were around 1.3%, 1.0%, 1.0%, and 0.5% respectively (Stats NZ, 2018; The World Bank, 2019).

Rapid urbanisation can increase GHG gas emissions, but in New Zealand since urbanisation has slowed markedly since the 1970s, its contribution to the growth in emissions is likely modest. The highest rate of urbanisation was experienced in New Zealand between 1961 and 1971, and the annual average rate of increase in urban population was around 8% in that period (Gibson, 1973). However, the recent rate of urbanisation has been quite slow and in the last 12 years from 2005 to 2016, the increase in the urbanisation level was only 0.3% points (from 86.0% to 86.3%) (CIA, 2018).

#### 4.4.2 Sprawl development

Urban sprawl is often characterised as low density urban development outside the city centre. The dominant type of land use in this kind of urban form is residential, and residential communities are highly dependent on cars (Adams & Chapman, 2016). Since residential areas are separated from other types of land uses such as offices, retail stores, industries, recreational facilities and public places, this type of urban form generates more or longer trips compared to a compact mixed use development. Cars are used to accomplish most of those trips. This causes an increase in fossil fuel based GHG emissions (Frumkin, 2016; Holmes et al., 2016).

Although low-density leapfrog urban development is energy intensive and unfriendly to the environment and climate, this type of urban form is dominant in most of the cities of New Zealand. One of the major indicators of sprawl development in New Zealand cities is the decrease in (or no change in) population-weighted densities in a number of cities. Christchurch, Napier-Hastings, Dunedin, Rotorua, New Plymouth, Whangarei, Whanganui, and Gisborne all observed a decrease in population density between 2006 and 2013. Although the population-weighted density in Auckland, Wellington, Nelson and Hamilton increased between 2001 and 2013, their level of density is still low compared to that of other world cities. In 2013, the population weighted density of Auckland city was 43.1 people per hectare (ha). This is lower

than the population-weighted densities of Sydney and Melbourne in 2011, at around 76.3 people per ha and 45 people per ha, respectively (Nunns, 2014).

#### 4.4.3 Fleet composition

A preponderance of cars as the key mode of transport often leads to a range of transport related problems such as high per capita carbon emissions, congestion, parking, accidents and air pollution (Litman, 2009). Also, the cost of commuting in a car is relatively high compared to other transport modes. However, cars sometimes ensure better accessibility than other transport modes, once cities have become planned and developed around the car (Litman & Laube, 2002).

Most New Zealand cities are highly dependent on cars. Dispersed development and limited funding and development of alternative modes of transport are likely to have increased the use of cars in New Zealand. In 2016, the share of cars in the vehicle fleet was around 91.4%, with the share of light passenger vehicles and light commercial vehicles being around 77.9% and 13.5%, respectively. The share of other modes of transport such as motor cycles, trucks, buses, and others were 4.1%, 3.5%, 0.3%, and 0.7%, respectively (Ministry of Transport, 2019e). The total number of light vehicles per thousand population in New Zealand is the second highest in the world after the USA. In 2016, the number of light vehicles per 1000 population was around 773.7, having risen 17% from around 660.6 in 2001 (Land Transport Safety Authority, 2002; Ministry of Transport, 2019e).

#### 4.4.4 Vehicle fuel efficiency

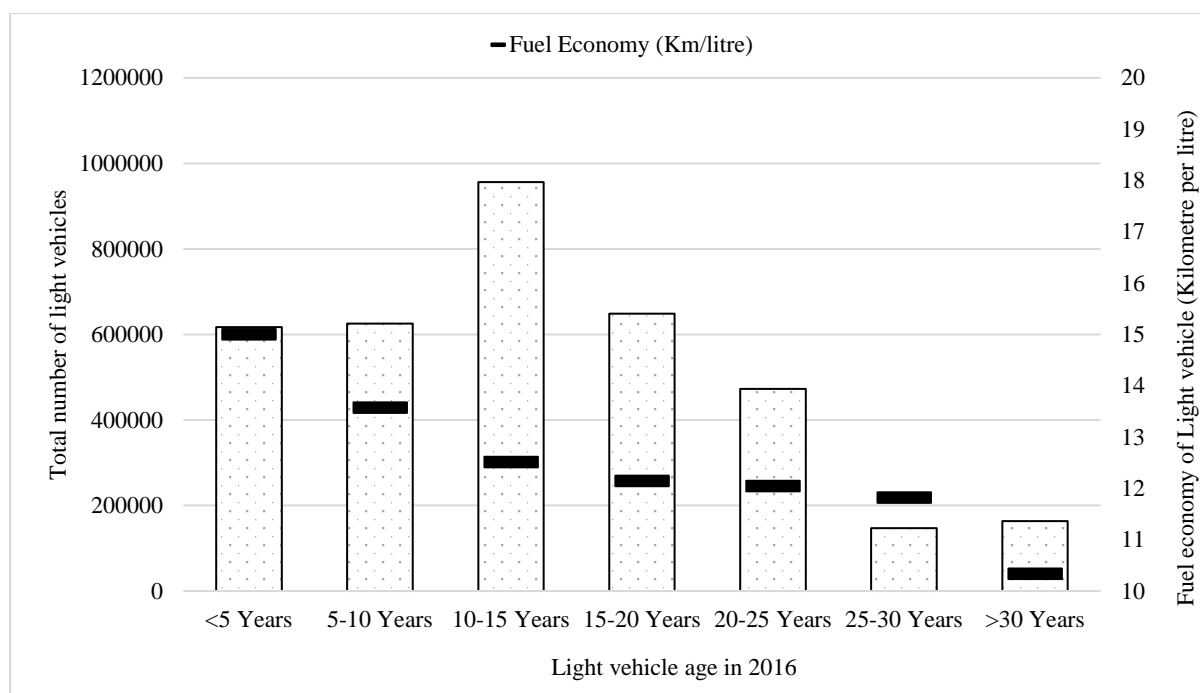
Vehicle emissions vary significantly based on the age of a vehicle. Research shows that vehicle age has a strong negative correlation with fuel economy and a positive correlation with transport emissions (European Environment Agency, 1999). Therefore, vehicle emissions standards are often set and imposed to control transport emissions from vehicles, especially old vehicles. The deterioration of vehicle fuel economy with age results in increasing emissions and affects the environment severely (Caserini, Pastorello, Gaifami, & Ntziachristos, 2013). According to the U.S. Bureau of Transportation Statistics (2017), the average fuel economy of a new light passenger vehicle of less than 5 years old is around 15 kilometres/litre while the average fuel economy of a vehicle of over 15 years old is around 12 km/litre. Since fuel economy and vehicle efficiency decline with the age of a vehicle, the proportion of used and

new vehicles in the vehicle fleet affects the transport sector emissions of a country significantly (Bastani, Hope, & Heywood, 2011).

The average age of the light vehicles on New Zealand's roads is one of the highest among developed countries. In 2002, the average age of New Zealand's light vehicles was about 12 years which increased to 14.1 years in 2016. Unlike New Zealand, the average age of the light vehicles in Australia was almost stable between 2010 and 2016. In this period, the average age of the light vehicles in Australia increased from 9.9 years to 10.1 years. Similarly, between 2002 and 2016, the average age of the light vehicles in the US increased from around 9.4 years to around 11.6 years. The EU car fleet observed a higher rate of increase in the light vehicle age compared to other developed nations and the average age of the light vehicles increased from 8.4 years in 2007 to 10.7 years in 2015 (Ministry of Transport, 2019e).

The 'Land Transport Rule: Vehicle Exhaust Emissions Amendment 2012' may be a key reason behind the increasing number of old light vehicles in New Zealand. This rule allowed all vehicles over 20 years old to drive on New Zealand roads without the vehicle emissions standard test and the metered emissions test (New Zealand Transport Agency, 2013). Conversely, in the UK, there are different test requirements for vehicles with different ages and an exemption from the metered emissions test is available only for those vehicles that were used on roads or manufactured before August 1, 1975. Likewise, Australia has different emissions standards for new and old vehicles and the vehicle emissions standard in Australia covers all light vehicles that were manufactured or used on roads after 1972 (Department of Infrastructure and Regional Development, 2018; Laurie Forestry, 2018).

The age structure of the cars in New Zealand shows that around 21.6% of the total light vehicles in New Zealand are over 20 years old (**Figure 2**). This means around one in five light vehicles is running on New Zealand's roads without any vehicle emissions standard test or meeting the metered emissions test. The highest proportion (26.3%) of the total light vehicles is between 10 and 15 years old, followed by 17.9% between 15 and 20 years old. The percentage of total light vehicles with an age of below 10 years old is around 34.2% (Ministry of Transport, 2019e).



**Figure 2. Ages of vehicles on New Zealand's road in 2016 (Ministry of Transport, 2019e; U.S. Bureau of Transportation Statistics, 2017)**

#### 4.4.5 Share of used vehicles in the fleet

The increasing use of used light vehicles for passenger travel and commercial purposes is often viewed as a major factor affecting GHG emissions from the transport sector because used vehicles are often less efficient in terms of fuel and emissions efficiency. Surprisingly, the shares of used vehicles and new vehicles are almost the same in New Zealand. In 2016, the shares of new light vehicles and used light vehicles were about 54% and about 46%, respectively. The total number of used light passenger vehicles increased from around 0.9 million in 2000 to around 1.6 million in 2016 (Ministry of Transport, 2019e). The annual average increase in the total number of used passenger light vehicles was around 3.8% and the annual average increase in the total number of used commercial light vehicles was around 0.3% in this period. These numbers reflect New Zealanders' preferences for new cars and new light commercial vehicles, over used vehicles.

#### 4.4.6 Fuel prices

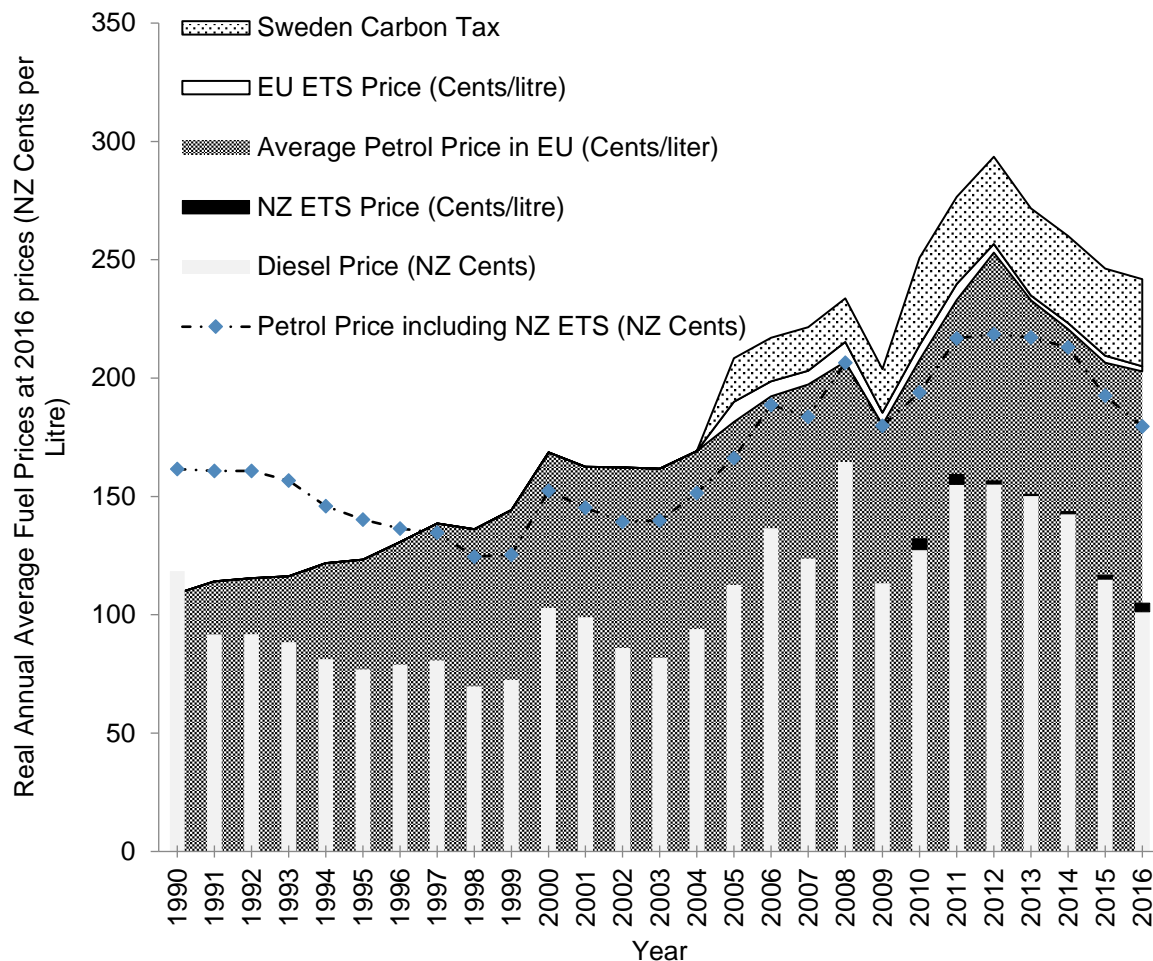
The prices of different fuels in New Zealand have experienced significant changes over the last 25 years. During the 1990s, both the diesel and petrol price fell gradually. Then, during the 2000s, fluctuations over both the petrol and diesel price were observed. Between 2011 and 2016, the price of diesel price as well as petrol decreased significantly. In this period, the diesel

price decreased from 155.2 New Zealand cents to 101.3 cents while the petrol price decreased from 216.8 cents to 179.6 cents (Ministry of Business, Innovation & Employment, 2018b).

Since fuel price plays an important role in the transport demand and transport emissions of a country, the imposition of a carbon tax or emissions price is often considered an effective tool for mitigating GHG emissions from this sector (Delsalle, 2012). With the aim of reducing GHG emissions from the transport sector, the Government of New Zealand incorporated the transport sector into the ETS in 2010 (Ministry of Transport, 2019b). According to the NZ ETS, transport sector fuel suppliers must surrender one New Zealand Unit (NZU), i.e. one emissions unit, for each tonne of CO<sub>2</sub>e emissions that the fuel generates. This increased the price of fuel in the transport sector. However, the change in fuel price due to the NZ ETS has been negligible. In 2018, the impact on the fuel price due to the NZ ETS was 4.6 NZ cents per litre (Ministry of Business, Innovation & Employment, 2018b). Like New Zealand's ETS, European nations also have a trading system, the European Union emissions trading system (EU ETS). Between 2010 and 2016, the average increase in fuel price in European nations due to EU ETS was almost four times higher than in New Zealand (Carbon Tax Center, 2018).

Countries like Sweden, Switzerland, Norway, Denmark, France, and many other developed nations have incorporated taxes along with the ETS price to shift people's behavior towards low-carbon transport solutions. **Figure 3** shows that Swedish road users are paying an additional 18.4 NZ cents per litre of fuel as carbon tax (Carbon Tax Center, 2018). This significant amount of tax is likely to have materially encouraged the Swedish people to use public transport rather than motorised private transport. The carbon tax in Sweden has been explored because Sweden leads the Climate Change Performance Index (CCPI) 2019 ranking for reducing GHG emissions significantly from different sectors (Germanwatch, 2019). Between 1990 and 2016, Sweden's emissions from the transport sector decreased by 11.6% (OECD, 2019) and Sweden's carbon tax played a key role in emissions reduction (Fouché, 2008; Shmelev & Speck, 2018). Compared to Sweden, New Zealanders pay only about one fifth as much per litre of fuel due to New Zealand's ETS. Considering this together with New Zealand's transport emissions growth, the study concludes that the price of the NZ ETS is insignificant in making any effective change in the mode-choice behavior or vehicle kilometres travelled by New Zealanders. Moreover, the public transport network of New Zealand is generally not comprehensive and sufficiently integrated to shift people's behavior towards alternative modes. Taking these factors together, it is not surprising that New Zealand has seen a significant increase in transport sector emissions since 1990.

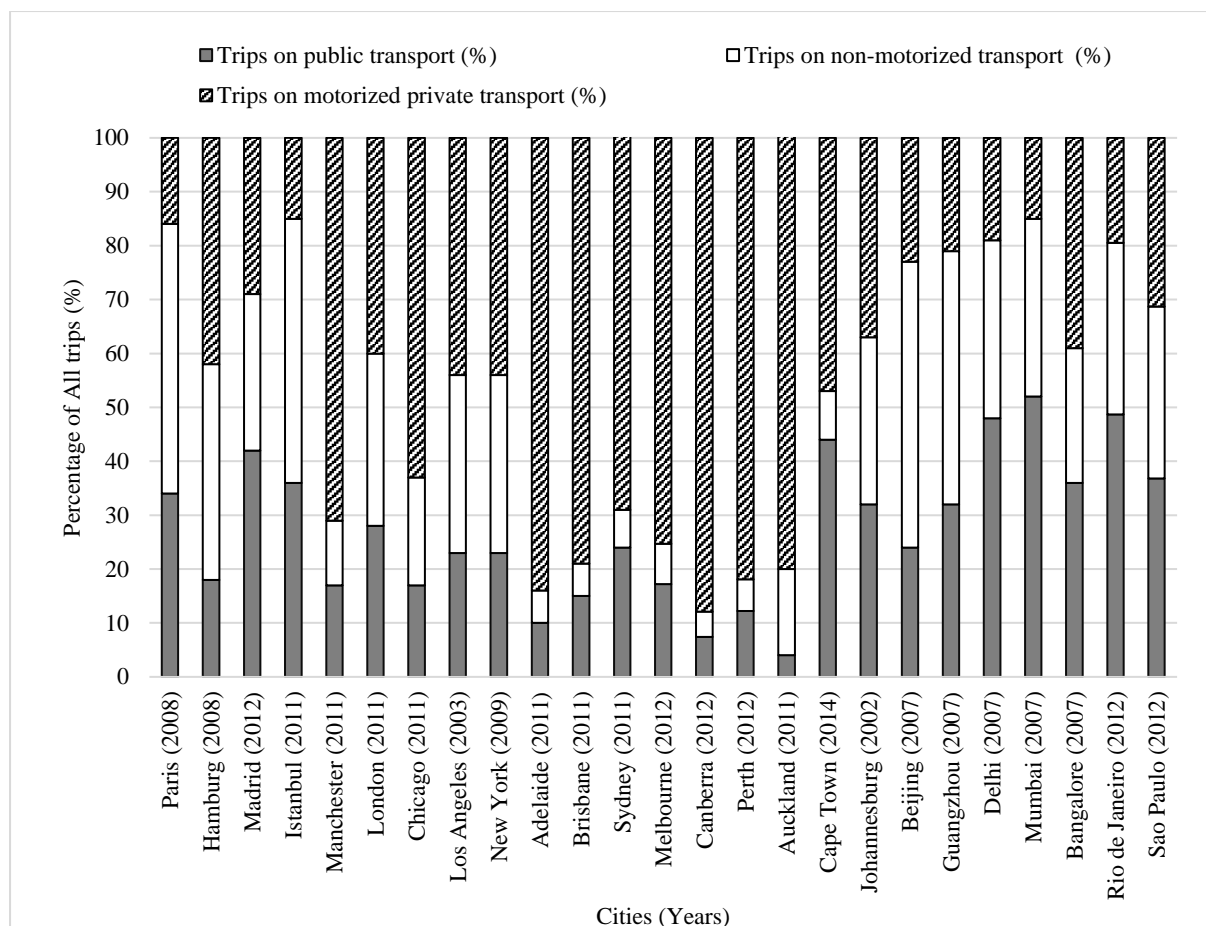




**Figure 3. Average Prices of different fuel types in New Zealand (Carbon Tax Center, 2018; CommTrade, 2018; Ministry of Business, Innovation & Employment, 2018b)**

#### 4.4.7 Modal split

The share of public transport trips in total transport trips in New Zealand is one of the lowest in the world. Only 4% of the total transport trips in Auckland are made on public transport modes (bus, rail, ferry) while around 81% and 16% of the total trips are made using motorised private transport and non-motorised transport, respectively (**Figure 4**). Among different world cities that have over a million population, Auckland's public transport trips share was one of the lowest at 4%, followed by Canberra (7.8%), Adelaide (10%), Perth (12.2%), Brisbane (15%), Chicago (17%), Manchester (17%) etc. Although the Auckland Plan proposed a series of public transport infrastructure projects to increase ridership, inadequate political support and the absence of a robust framework for funding those projects are some of the major challenges that remain to be surmounted (Imran & Pearce, 2015).



**Figure 4. Share of trips in different transport modes in world cities with over million (Global BRT Data, 2018)**

## 4.5 Model results

This section identifies the key drivers from the set of drivers using the Vector Error Correction Model (VECM). The results of this model are as follows-

### 4.5.1 Results of unit root test

The first step for developing a VECM model is to examine the existence of unit roots in the dataset. The ADF and the PP tests are the two unit root tests carried out to examine the stationarity of the time-series data. Two specifications, namely the ‘intercept’ and the ‘intercept and trend’ are considered in the tests. These results of both the tests under these two specifications are presented in **Table 2**. The results of both the tests indicate that all the variables are non-stationary in level (i.e. acceptance of null hypotheses: variables have unit roots) and stationary in first differences (i.e. rejection of null hypotheses: variables have no unit roots). Findings also suggest that the order of integration or the optimal lag length for all the variables is one.

**Table 2. Unit root test results**

	<b>Augmented Dickey–Fuller test statistics (Lag Length)</b>		<b>Phillips-Perron (Lag Length)</b>	
<b>At level</b>	Intercept	Intercept and Trend	Intercept	Intercept and Trend
TE	-0.2852 (0)	-0.3209 (0)	-0.2852 (1)	-0.3209 (1)
PV	-0.0849 (1)	-1.1069 (1)	-0.0393 (2)	-0.2499 (2)
P	-0.0167 (0)	-0.2228 (0)	-0.0167 (0)	-0.2228 (1)
FE	-0.2282 (0)	-0.3153 (0)	-0.2282 (1)	-0.3153 (2)
GDP	-0.0042 (0)	-0.1542 (0)	-0.0042 (2)	-0.1542 (1)
U	-0.0360 (0)	-0.1137 (1)	-0.0360 (3)	-0.1177 (4)
<b>At first difference</b>	Intercept	Intercept and Trend	Intercept	Intercept and Trend
TE	-0.5661 (0) *	-0.6134 (0) **	-0.5661 (5) *	-0.6134 (3) **
PV	-0.6863 (0) *	-2.3508 (1) *	-0.6863 (1) *	-0.7020 (1) *
P	-0.9756 (0) ***	-0.9837 (1) ***	-0.9756 (0) ***	-0.9837 (0) ***
FE	-1.0864 (0) ***	-1.1319 (0) **	-1.0864 (0) ***	-1.1319 (1) **
GDP	-0.9244 (0) ***	-1.7080 (1) ***	-0.9244 (2) ***	-0.9297 (1) ***
U	-0.6492 (0) ***	-0.6857 (0) ***	-0.6492 (1) ***	-0.6857 (2) ***

Note: Values in parenthesis are lag-lengths, and \*\*\*, \*\*, and \* indicate significance at 0.01, 0.05 and 0.1 levels, respectively.

#### 4.5.2 Results of co-integration tests

After unit root tests and the establishment of the order of integration, Johansen co-integration tests are carried out. The trace statistics and the maximum eigenvalue statistics are examined to identify the number of co-integrating relationships and built the co-integrating equation. The results presented in **Table 3** illustrate the presence of five co-integrating relationships among the variables.

**Table 3. Johansen co-integration test results**

Hypothesized number of co- integrating equation(s)	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$
Trace statistics	358.71***	174.75***	101.68***	59.71***	24.42***	0.001
Maximum Eigenvalue statistics	183.95***	73.08***	41.97***	35.29***	24.42***	0.001

Note: \*\*\*, \*\*, and \* indicate significance at 0.01, 0.05 and 0.1 levels, respectively.

#### 4.5.3 Results of long-run equilibrium relationship

Considering the existence of co-integrated variables, this study estimates the coefficient of each of the explanatory (independent) variables using the Ordinary Least Squares method. Transport emissions (TE) is considered as the dependent variable while passenger vehicle number (PV), fuel price (P), vehicle fuel economy (FE), GDP per capita (GDP), and level of urbanisation (U) are considered as the drivers or explanatory variables for TE. The long-run equilibrium relationship between the dependent and explanatory variables is presented in **Table 4**. Results show that passenger vehicle numbers and GDP per capita have positive relationships with transport emissions, while fuel price, fuel economy and level of urbanisation have negative relationships with transport emissions. All the relationships are consistent with the common assumptions because increase in passenger vehicle number and GDP per capita often increases transport emissions while increase in fuel price, fuel economy and the level of urbanisation reduces transport emissions. Among all the explanatory variables, the long-run elasticity between fuel economy and transport emissions is significant at the 10% level and the long-run

elasticity value is -1.38, meaning that a 1% increase in fuel economy is likely to decrease transport emissions by 1.38%.

**Table 4. Co-integrating equation in summarised form**

Dependent variable: TE

Explanatory variables	Coefficients	Standard Error	<i>t</i> -Statistics
Constant	-12.06	17.97	-0.67
PV	2.47E-06	7.1E-09	347.88
P	- 0.004	6.9E-05	-57.97
FE	- 1.38*	0.007	- 201.63
GDP	2.34E-05	4.3E-07	54.26
U	- 0.266	0.002	-125.8

Note: \*\*\*, \*\*, and \* indicate significance at 0.01, 0.05 and 0.1 levels, respectively.

#### 4.5.4 Granger tests of causality based on vector error correction model (VECM)

To understand the direction of a causal relationship and the significance of a variable to cause an event, the Granger causality test is carried out in the Vector Error Correction Model (VECM). The results are reported in **Table 5**. The short-run causality is performed using the Wald *F*-statistics of the VECM and the long-run causality is estimated based on the *t*-statistics of the error correction terms (ECTs). The results indicate that there is a one directional short-run causal relationship running (i) from fuel economy to transport emissions, and the result is significant at 0.05 level; (ii) from GDP per capita and transport emissions to fuel price, and the results are significant at 0.05 and 0.01 levels, respectively; (iii) from fuel price to fuel economy and the result is significant at 0.1 level; (iv) from fuel economy and fuel price to the level of urbanisation, and the results are significant at 0.01 and 0.1 levels. The results of the long-run causality test based on the *t*-statistics show that the coefficients of the error correction terms (ECTs) are significant in the transport emissions (TE) and fuel economy (FE) equations. In addition, a negative coefficient value of the ECT for fuel economy suggests a speedy convergence from short-run to long-run equilibrium (Enders, 2008). Therefore, the results illustrate that vehicle fuel economy is the key driver of New Zealand transport emissions both

in the short- and long-run, suggesting that any changes of fuel economy might cause a significant change in transport emissions. The difference in results between long-run Granger causality and long-run equilibrium could be due to a small number of observations ( $n=27$ ) and a few varied optimal lag lengths in unit root tests for some variables (Kripfganz & Schneider, 2016; Shrestha & Bhatta, 2018). One of the reasons for factors like passenger vehicle numbers, GDP per capita, fuel price, and urbanisation rate to be insignificant to drive GHG emissions could be the relatively small changes in values over the study period. An insignificant statistical relationship does not imply that there is no impact of those factors in influencing GHG emissions.

**Table 5. Results of Granger causality tests based on VECM**

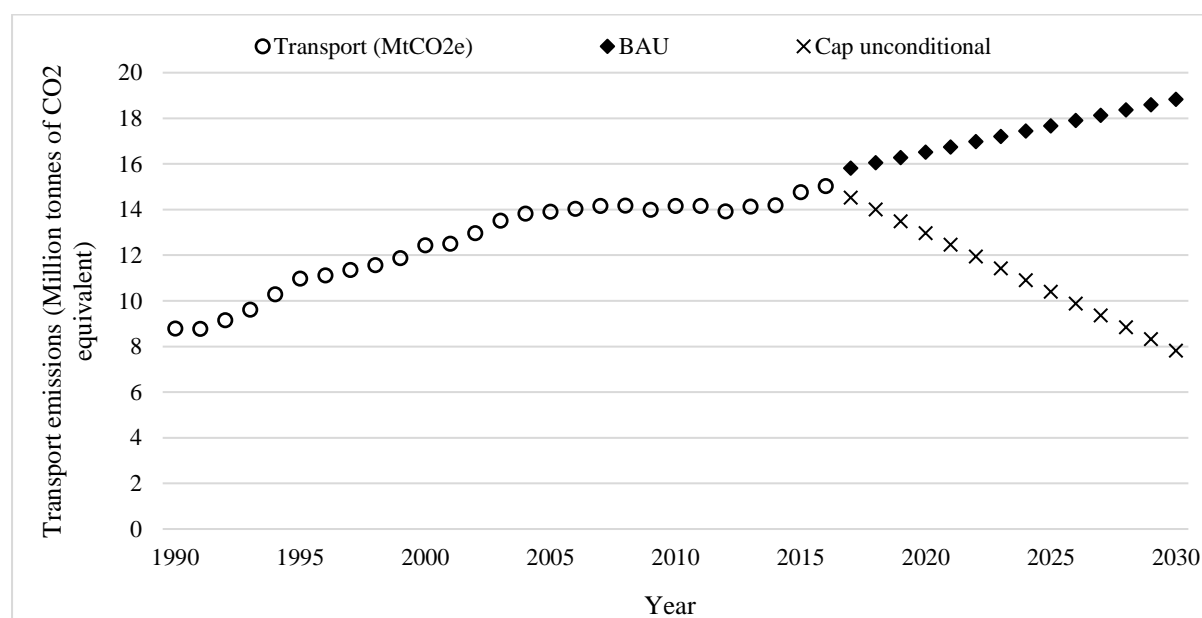
Short-run Granger causality $-F$ statistics							Long-run Granger causality- $t$ statistics
	Ln(TE)	Ln(PV)	Ln(P)	Ln(FE)	Ln(GDP)	Ln(U)	Error Correction Term (ECT)
Ln(TE)	-	0.689 (0.419)	1.177 (0.294)	7.531** (0.014)	0.473 (0.502)	2.482 (0.135)	2.232** (0.037)
Ln(PV)	1.926 (0.18)	-	0.43 (0.521)	2.750 (0.117)	0.003 (0.958)	0.128 (0.726)	0.828 (0.41)
Ln(P)	9.354*** (0.008)	2.081 (0.169)	-	0.861 (0.367)	4.639** (0.04)	0.118 (0.734)	-0.892 (0.383)
Ln(FE)	0.011 (0.918)	1.029 (0.326)	2.88* (0.1)	-	1.90 (0.187)	0.006 (0.938)	-1.784* (0.09)
Ln(GDP)	0.847 (0.371)	0.001 (0.993)	1.360 (0.254)	0.623 (.442)	-	1.665 (0.203)	1.173 (0.254)

Ln(U)	0.173	2.10	2.795*	10.94**	0.595	-	-0.381
	(0.683)	(0.167)	(0.10)	* (0.004)	(0.445)		(0.707)

Note: Values in parenthesis are p-values, and \*\*\*, \*\*, and \* indicate significance at 0.01, 0.05 and 0.1 levels, respectively.

#### 4.6 Implications for reducing transport emissions

Although New Zealand pledged in its Nationally Determined contribution (NDC) under the Paris agreement to reduce greenhouse gas (GHG) emissions by 11% by 2030 from the 1990 level, the country's transport sector emissions could increase by about 114% by 2030 from the 1990 level if left unaddressed (Ministry for the Environment, 2018c). In 1990, transport sector emissions were only 8.8 MtCO<sub>2e</sub>, and a reduction in sectoral emissions by 11% by 2030 from the 1990 level would require the sector to reduce its emissions to 7.8 MtCO<sub>2e</sub> (**Figure 5**). However, if the trend of transport emissions over the past 25 years continues, emissions from this sector might instead increase to 18.8 MtCO<sub>2e</sub> by 2030. This might require the transport sector to reduce its emissions by 48% by 2030 from the 2016 level.



**Figure 5. Emissions from the transport sector under business as usual (BAU) and NZ's unconditional emissions reduction target applied to transport (Ministry for the Environment, 2018c)**

Since this study finds a significant causal relationship between fuel efficiency and transport sector emissions, an improvement in vehicle fuel economy is expected to contribute to transport sector emissions reduction. Using a reference case, this study estimates the emissions reduction potentials of various fuel economy standards. The fuel economy and the fuel consumption data of light petrol vehicles for 2016 are considered as a reference case. Findings show that an increase in light petrol vehicle fuel economy by 5% from the reference case could reduce tailpipe emissions by around 4.8% while emissions reduction potentials for 10%, 15% and 20% improvement could be around 9.1%, 13% and 16.7%, respectively (**Table 6**). However, these emissions reductions are subject to rebound effects (i.e. driving more as fuel efficiency reduces costs per kilometre) that could potentially reduce their impact (Ministry of Transport, 2014b). Some of the policy interventions that might help improve light vehicle fuel economy include: announcing the cessation at some specified future date (e.g. 2035) of the import of diesel and petrol cars (Falk et al., 2018); setting a high minimum fuel economy standard to ensure the entry of only fuel-efficient cars from manufacturing countries (Ministry for the Environment, 2006); introducing a feebate scheme (Barton & Schütte, 2015; Rahman et al., 2017); introducing a vehicle age restriction (Ministry for the Environment, 2006); introducing a cleaner emission standard (Ministry for the Environment, 2006), etc.

**Table 6. Emissions reduction possibilities under different fuel economy standards for light petrol vehicles (author's calculation)**

Improvement in fuel economy	Average fuel economy standard (Km/L)	Consumption of petrol (million litres)	Total tailpipe emissions (MtCO <sub>2</sub> )	Emissions reduction from the reference case (assuming no rebound effects)
Reference case <sup>1</sup>	10.8	3143.7	7.23	-
5%	11.34	2994.0	6.89	4.8%
10%	11.88	2857.9	6.57	9.1%
15%	12.42	2733.7	6.29	13.0%
20%	12.96	2619.8	6.03	16.7%



<sup>1</sup> Reference case uses the 2016 data obtained from the Ministry of Transport (2019e)
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Findings from **Table 6** indicates that an improvement in fuel economy is very unlikely to be sufficient by itself to achieve a sectoral emissions reduction target in line with New Zealand's NDC (overall emissions reduction target under the Paris agreement), which implies a 48% reduction from the 2016 level by 2030. This requires a comprehensive policy package - a package of elements including improved vehicle efficiency, a carbon price (ETS or tax), expansion of public transport, expansion of alternative fuel sources, better planned urban development, increasing access, electric vehicles etc. It is worth noting that if in future New Zealand is obliged under the Paris agreement to ratchet up its commitments, as seems likely, then many of the policies considered below can be readily strengthened.

An outline of these policies and a roadmap to reduce transport emissions are as follows-

#### 4.6.1 Vehicle fuel efficiency

Improving vehicle fuel efficiency through effective policy measures is one of the key solutions to reduce transport sector emissions (Ratanavaraha & Jomnonkwao, 2015; Sims et al., 2016) because vehicle fuel efficiency has a direct causal relationship with emissions (Pongthanaisawan & Sorapipatana, 2013). The present study shows that a 5% increase in fuel efficiency could reduce transport emissions about 4.8% from the 2016 level (**Table 6**). Due to its large share of passenger cars (of which 45% are used cars), New Zealand's vehicle fuel efficiency is one of the lowest among developed countries, and therefore the energy intensity of passenger transport is one of the highest (International Energy Agency, 2018a; Ministry of Transport, 2019e). According to the International Energy Agency (2018a), the United States had the highest energy intensity of passenger transport which was around 2.4 Megajoules per passenger kilometre (MJ/pkm) followed by Australia (2 MJ/pkm), New Zealand (1.7 MJ/pkm), Canada (1.5 MJ/pkm), the Netherlands (1.6 MJ/pkm), Ireland (1.5 MJ/pkm), Switzerland (1.5 MJ/pkm), Germany (1.4 MJ/pkm), the United Kingdom (1.4 MJ/pkm), and France (1.3 MJ/pkm) (International Energy Agency, 2018a).

To improve passenger transport fuel efficiency or reduce energy intensity, different countries have set different improvement targets. For example, the Swedish government aims to achieve a fossil fuel free vehicle fleet by 2030 (Ministry of Environment, 2014; Swedish Institute, 2019). The government of Japan set a target of improving their vehicle fuel economy by 22.8%

between 1995 and 2010 (Ministry for the Environment, 2006), and offered a 60% discount on vehicle-purchase tax, 23% discount on vehicle-weight tax, and 82% discount on vehicle tax to promote lightweight passenger vehicles or ordinary passenger vehicles (Rahman et al., 2017). Likewise, according to the Ministry for the Environment (2006), the European Union's target was to make a 25% improvement in vehicle fuel economy between 1995 and 2008. In 2003, Australia also established a voluntary fuel economy target at the national level which is 6.8 Litre/100 kilometre. In the USA, the Corporate Average Fuel Economy (CAFE) standards have played a crucial role in improving vehicle fuel economy (Ministry for the Environment, 2006). To promote hybrid vehicles, all three levels of government in the USA, i.e. federal, state, and local government, waived sales tax on hybrid vehicles (Chavez-Baeza & Sheinbaum-Pardo, 2014). Also, some U.S. states and cities are providing access for hybrid vehicles to high occupancy lanes (Rahman et al., 2017). In China, vehicle purchase taxes on different green vehicles such as hybrid vehicles, fuel cell electric vehicles, battery driven electric vehicles, dimethyl-ether vehicles, and hydrogen engine vehicles are exempted by the government: these are around 10% of the sale prices of those vehicles (Yuan, Liu, & Zuo, 2015). Countries such as Lithuania and Canada have offered tax rebates, and income tax relief on the purchase of hybrid electric vehicles as a measure towards reducing GHG emissions from the transport sector (Yuan et al., 2015). Brand, Anable, and Tran (2013) found a feebate scheme (fee for high-emitting vehicles and rebate for low-emitting vehicles) is an effective instrument to accelerate low-carbon technology and reduce life-cycle emissions of a car in the United Kingdom. Setting a high minimum fuel economy standard and/or putting an age restriction on vehicles is proposed by the Ministry for the Environment (2006) to improve vehicle fuel economy in New Zealand.

#### 4.6.2 Public and active transport

Public and active transport are the two options that ensure better mobility of a large number of people with minimum transport emissions. They offer significant health co-benefits from reduced particulate matter and increased physical activity. Research shows that switching trips from car to foot travel by 5% annually could help to reduce 3 gigatonnes (Gt) of cumulative carbon dioxide (CO<sub>2</sub>) emissions globally by 2050. Similarly, an increase in urban cycling trip share from 5.5% to 7.5% could contribute to avoid 2.3 Gt of cumulative CO<sub>2</sub> by 2050 (Falk et al., 2018).

Different countries have invested in the infrastructure development of active and public transport. For example, the government of Sweden invested US\$182 million in 2015 under an 'Urban Environment Agreement' to support local and regional projects on public transport. The aim of the urban environment agreement was to encourage commuters towards public transport, pedestrian traffic, and bicycle riding (Raab, 2017; Romson, 2016). Portland in Oregon took a transit-oriented development approach to offer better public transport facilities to commuters. As a result, Portland residents are twice as likely to commute by mass transit than an average US resident (Falk et al., 2018). In order to promote cycling in the Netherlands, Denmark and Germany, these countries ensured extensive rights of way for cycling, offered ample space for bike parking, integrated cycling ways with mass transits and increased awareness (Pucher & Buehler, 2008). In England, the government introduced free bus services for older people in 2006; this has been contributing to an increasing rate of public transport use (Reinhard, Courtin, van Lenthe, & Avendano, 2018; Webb, Netuveli, & Millett, 2012).

#### 4.6.3 Carbon price

Putting a price on carbon is often considered an effective option for reducing transport emissions because it lowers the demand for high-emissions transport, and provides clean and sustainable solutions an opportunity to develop (Falk et al., 2018). As of 2018, 51 jurisdictions have implemented a carbon price initiative. Among them 25 jurisdictions have introduced an emissions trading scheme (ETS), and the other 26 jurisdictions initiated a carbon tax (The World Bank, 2018). Donovan et al. (2008) estimated that the average price elasticity of demand for transport fuel in 27 OECD countries is -0.7 which means a 10% increase in fuel price would reduce fuel consumption by 7.1%.

Sweden's carbon tax is found to be a long-standing and effective mitigation instrument. Sweden reduced transport emissions by 11.6% between 1990 and 2016 (OECD, 2019), with a main contributor being the introduction of carbon tax in 1991 (Fouché, 2008; Raab, 2017). Since introducing a new tax is always contentious, the government introduced tax reform alongside other key strategies. In the 1990/1991 tax reform, the labour tax was reduced and simplified, and the energy tax was cut by 50% (Fouché, 2008). Also, the government started supporting various investments in low-carbon alternative energy fuels, public transport, electric vehicles etc. (Swedish Institute, 2019). Before introducing a carbon tax, the government ensured that other feasible options such as bio-fuels, public transport, district heating systems etc. were widely available. Also, to accustom individuals and firms to the new tax, the tax rate

was kept low, initially at around 23 euro per tonne of CO<sub>2</sub> in 1991, rising slowly to around 119 euro per tonne of CO<sub>2</sub> in 2017 (The World Bank, 2018). Most importantly, a high level of environmental concern fostered the early green tax reform in Sweden (Hammar, Sterner, & Åkerfeldt, 2013). To avoid the distributional consequences of carbon tax hikes on low-income people, income tax rules were adjusted by the Swedish government (Hammar et al., 2013). Also, a two-level carbon tax system was designed to secure different sectors' competitiveness in the international market. Carbon tax for transport and heating fuels was much higher at the household level than the industrial level. In addition, all industries and installations that were covered by the EU ETS were exempted from the carbon tax. However, those industries and installations were subject to the payment of energy tax (International Energy Agency, 2019). Unlike in the UK and other nations, the tax on energy in Sweden is slightly higher for higher and middle income groups than low-income groups (Hammar et al., 2013).

Other countries also implemented a carbon price with an aim to reduce transport as well as overall emissions. India introduced a carbon tax in 2010 to fund future renewable projects in the country (Civil Engineer, 2018). South Africa started operating their carbon tax from 2019 to reduce emissions (Geroe, 2019). Denmark started its carbon tax in 2002 and offered a tax rebate for companies that signed a voluntary energy efficiency agreement (Geroe, 2019). The price on carbon is comparatively higher for countries that adopted a carbon tax than the countries with an ETS. For instance, in 2018, the carbon tax rates in Switzerland, Finland, Norway, and France were around USD101/tCO<sub>2</sub>e, USD77 /tCO<sub>2</sub>e, USD64/tCO<sub>2</sub>e, and USD55/tCO<sub>2</sub>e, respectively. In contrast, in this period, the ETS prices were USD16/tCO<sub>2</sub>e for the European Union ETS (EU ETS), USD15/tCO<sub>2</sub>e for New Zealand's ETS (NZ ETS), USD21/tCO<sub>2</sub>e for Korea, USD23/tCO<sub>2</sub>e for Alberta, and USD15/tCO<sub>2</sub>e for Quebec, Ontario and California. The ETS price in most developing countries is found to be less than USD10/tCO<sub>2</sub>e (Geroe, 2019; The World Bank, 2018). Revenue obtained from a price on carbon is used for (i) public transport development in Alberta (Tasker, 2016) (ii) transport fuel efficiency improvement in Denmark (Sumner, Bird, & Smith, 2009), (iii) income tax deductions for low and middle income people in Denmark, Finland and Switzerland (Geroe, 2019; Sumner et al., 2009), (iv) governmental expenditure in Norway (Sumner et al., 2009), and (v) education and other development projects in Chile (Gailbraith, 2014).

#### 4.6.4 Travel demand management

Travel demand management (TDM) generally aims to reduce the use of cars and increase public transport use (Gärling & Schuitema, 2007). Therefore, policy measures that help to reduce car use are often considered to be TDM approaches. In London, a reform of parking standards in 1996 to limit passenger car use increased public transport use by 18% while passenger kilometres travelled in public transport at the national level decreased 10% over twenty years (Andrea, Todd, & Gopinath, 2009). The TDM approaches of the University of New South Wales (UNSW) (e.g. managing crowds at public transport stations, and publishing a brochure to provide information about public transport schedules, routes, tickets, restricted parking and the health benefits of walking) reduced the number of passengers queuing by 50% and improved capacity, amenity and safety of the queue (Black, Mason, & Stanley, 1999). Aalborg in Denmark used telematics technology to provide priority access to buses at intersections (Andrea et al., 2009). As a result, the mobility, reliability, image and quality of bus services improved significantly. A congestion charge or tax is found to be another TDM approach that helps to reduce car use and increase public transport use. The introduction of a congestion charge in Stockholm in 2007 decreased car travel by 22% across the congestion charge zone and increased public transport travel by 4.5% (Andrea et al., 2009). Other countries and jurisdictions that introduced a congestion charge or tax as a TDM approach include London, Rome, Durham, Oslo, Bergen, Florence, Tromsø, Valletta, Kristiansand, Trondheim, Namsos, Stavanger, Tonsberg and Singapore (Andrea et al., 2009).

According to Falk et al. (2018), living close to workplaces can reduce passenger transport emissions by as much as 50% annually. Since TDM approaches reduce passenger car use and promote public transport use, measures related to TDM constitute an important option to reduce transport emissions. Apart from increasing the public and active transport trip share, TDM measures include: ensuring better accessibility through land-use planning to increase mixed use, higher density housing development along/near transport arteries; ensuring better integration among different modes to improve transport network efficiency; managing peak hour travel through providing alternative travel options to single occupant vehicles (e.g. car-pooling etc.); using telecommunication services as alternatives to travel (e.g. teleconferencing, teleshopping, distance learning etc.); and using advanced technology to manage waiting time at signals etc. It is clear that urban planning that reduces the need for carbon-intensive transportation in the medium to long-term -- such as compact, pedestrianised cities and

towns—plays an important role in limiting future emissions (Global Covenant of Mayors, 2018).

#### 4.6.5 Electric vehicles

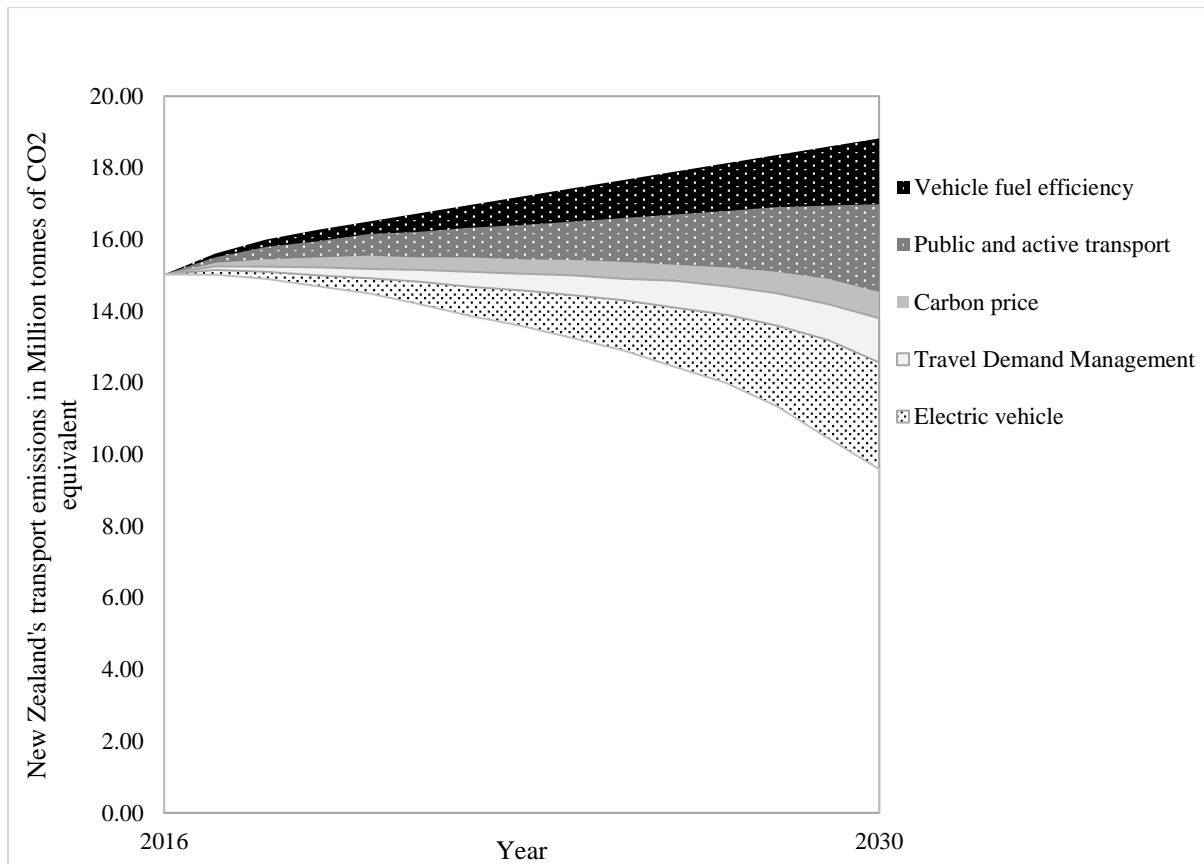
According to McKinsey & C40 Cities (2017), an increasing uptake of electric vehicles (EVs) could contribute to transport emissions reduction by 20 to 45%. EVs reduce dependency on the use of fossil fuels in the transport sector if the electricity is coming from renewable sources such as hydro, power, wind or solar (Tran, Banister, Bishop, & McCulloch, 2013). In recent years, EV car sales observed an increasing trend worldwide with a 57% increase between 2017 and 2018. The total number of passenger electric cars increased from around 2 million in 2016 to 3.1 million in 2017, while the number of electric buses and electric two-wheelers increased to 370,000 and 250 million respectively (International Energy Agency, 2018b). In 2017, among different developed countries, Norway had the highest market share of (new) electric cars (39.2%), followed by Sweden (6.3%), the Netherlands (2.7%), Finland (2.6%), China (2.2%), the United Kingdom (1.7%), France (1.7%), Germany (1.6%), Korea (1.3%), the United States (1.2%), Canada (1.1%) and New Zealand (1.1%). Australia's market share for electric cars in this period was 0.1% (International Energy Agency, 2018b).

Countries have set a variety of targets for EV uptake. For instance, the federal, provincial and territorial governments of Canada aim to develop a strategy to increase their EV sales by 30% by 2030 (Lopez-Behar et al., 2019). According to the International Energy Agency (2018b), China has adopted short-term, mid-term and long-term targets of increasing their new EV sales by 7-10%, 15-20% and 40-50%, by 2020, 2025 and 2030 respectively. The Netherlands, Ireland, Norway and Slovenia target to achieve 100% EV car sales by 2030 while the targets by India and Japan by this period are 30% and 20-30% respectively. The UK announced their target to reach 396,000 to 431,000 electric cars by 2030 while the targets set by Finland and New Zealand are to reach 250,000 by 2030 and 64,000 by 2021, respectively. Eight states of the United States namely New York, Massachusetts, California, Maryland, Connecticut, Oregon, Vermont and Rhode Island set a combined target of achieving 3.3 million EVs by 2025. California has also set an individual target of reaching 1.5 zero emissions vehicles (ZEVs) by 2025 and 5 million ZEVs by 2030 (International Energy Agency, 2018b).

The uptake of electric vehicles requires policy instruments such as subsidies, incentives, taxation incentives or regulations (Tran, Banister, Bishop, & McCulloch, 2012). Both supply and demand-focused policy are crucial. Supply-focused policies include a large variety of

models, continuous upgrade of EVs, deployment of research and development (R&D) funds to develop efficient EVs etc. (Ahman, 2006; van der Steen, Van Schelven, Kotter, van Twist, & van Deventer MPA, 2015), and demand-side policies include income tax deductions for EV purchase, exempting EVs from registration tax, access to high-occupancy lanes, low electricity prices, installation of EV charging infrastructure etc. (Lopez-Behar et al., 2019). Many regions, countries and States have deployed different policy instruments to promote the uptake of EVs. For example, Norway exempted vehicle tax and road user charges for EVs, and offered free parking in municipal parking spaces. The country also installed public charging facilities on main roads to support long-distance trips (EV Norway, 2018). According to Urban Access Regulations (2018), over 220 European cities have implemented low and/or zero emissions zones and EV lanes to increase the relative appeal of EVs. Some Canadian provinces such as Ontario, Quebec and British Columbia offer subsidies for EV purchase. For example, British Columbia gives a rebate of up to USD 5,000 to reduce new EV purchase costs. This province also charges USD 30/tCO<sub>2e</sub> on fossil fuels as a carbon tax, and offers low electricity rates to residential buildings to support home charging of EVs (Lopez-Behar et al., 2019). FleetCarma (2017) argues that these factors helped British Columbia to increase their EV sales by 49% between 2016 and 2017. To promote buying green cars, the government of Sweden also gave around US\$1120 rebate on the purchase of each car (Fouché, 2008).

**Figure 6** illustrates the relative contributions of different transport emissions reduction policy options to achieve a sectoral emissions reduction target in line with New Zealand's overall emissions reduction target under the Paris agreement (an 11% reduction from the 1990 emissions level or 48% emissions reduction from the 2016 level). The relative contributions of increased electric vehicle uptake and improved public and active transport services to achieve future emissions reduction targets are found to be higher in New Zealand due to supporting policy options by the government (Sims et al., 2016). Improved vehicle fuel economy is also significant in reducing future transport emissions (Falk et al., 2018; Sims et al., 2016). Putting a higher price on carbon and travel demand management (TDM) are some of the priority options that need policy support to contribute to New Zealand's future emissions reduction target.



**Figure 6. A roadmap to reduce New Zealand's transport emissions by 11% from the 1990 level by 2030 [author's generation based on Falk et al. (2018) and Sims et al. (2016)]**

#### **4.7 Mitigation policy initiatives for the New Zealand government**

To reduce GHG emissions from the transport sector, the government of New Zealand has outlined some key strategies in their recent draft 'Government policy statement on land transport'. These include: (i) investment in infrastructure development and services to support lower emission modes such as walking, cycling, electric cars, and public transport, (ii) integration between land use and transport system to improve accessibility and ensure efficient operation, (iii) encourage the use of bio-fuel on motorised vehicles, (iv) introduction of different road pricing mechanisms to change people's travel behavior and manage travel demand, and (v) exploration of the emission reduction potential of a cleaner vehicle fuel efficiency standard or a vehicle purchase feebate scheme (Ministry of Transport, 2018a).

The government has also taken a variety of direct and indirect policy initiatives. As already noted, the New Zealand Emissions Trading Scheme (NZ ETS) applies to the road transport sector (unlike, for example, the European ETS) with an aim of reducing GHG emissions from this sector, although its effect is small (Achtnicht et al., 2015). Other measures that are intended



to reduce transport emissions include: support for research into bio-fuels and other renewable energy, exemption of electric vehicles from road user charges to accelerate EV take-up, a fuel economy awareness programme for commercial fleet drivers, electrification of Auckland rail, labelling of vehicle fuel economy for cars at the point of sale, investment in public transport and national and urban cycle ways, subsidies for public transport etc. (Royal Society of New Zealand, 2016).

The government of New Zealand has exempted bioethanol from the excise tax which is mostly used to blend with petrol (Ministry of Transport, 2019b). To promote electric vehicles in New Zealand, the government announced the Electric Vehicle Programme (EVP) in 2016 and aims to bring around 64,000 electric vehicles onto roads by 2021. Under the EVP, the exemption from road user charges for light EVs has been extended until 2021; it is expected that this exemption will save around \$600 per vehicle annually. To deal with the issues related to charging EVs, the New Zealand Transport Agency (NZTA) is working with government agencies, power companies, motor industries, and technology providers to develop guidelines for public EV charging infrastructure. Since 85% of New Zealand houses have off-street parking facilities and the average daily distance travelled by car users is only 22 kilometres, EVs are in principle relatively well suited to New Zealand use, although some range and battery degradation anxiety remains (Smellie, 2018). The government has taken initiatives to change the Land Transport Act 1998 in order to allow EVs on transit lanes, priority bypass lanes, high occupancy vehicle lanes, and bus lanes. To encourage innovation in the development of low-emitting vehicles, a contestable fund of up to \$6 million per year was announced in 2017 and 15 innovative projects were approved in the first round so far (Ministry of Transport, 2019c).

To reduce the high level of dependency on fossil fuels in the transport sector, the government is investigating a variety of alternative transport fuel sources and technologies. Second-generation fuel sources such as biomass, landfill gas, and woody biomass are seen by some as potentially effective alternatives for fossil fuels in New Zealand, but generally for the heavy freight vehicle fleet rather than light vehicles (Scion, 2018). The fuel efficiency programme for heavy vehicles was launched by the Energy Efficiency and Conservation Authority (EECA) in 2012. This initiative is taken by the government to improve fuel efficiency and reduce emissions from this sector. A website is developed under this programme to help people compare vehicles' fuel efficiency at the time of purchase. This programme also provides short training courses to the transport industry professionals on how to improve vehicle fuel efficiency (Ministry of Transport, 2019b).

## 4.8 Policy gaps and conclusions

Findings suggest that vehicle fuel economy is the key driver of transport emissions in New Zealand and an improvement in light passenger vehicle fuel economy by 20% could reduce tailpipe emissions by around 16.7%. Light vehicles in New Zealand are relatively old (14.1 years) compared to other nations' light vehicles such as in the USA (11.6 years), Australia (10.1 years), and European nations (10.6 years) due to a large share of used vehicles (46% of the vehicle fleet) in the vehicle fleet. Since vehicle age has a strong negative correlation with vehicle fuel economy and the average age of light vehicles in New Zealand is increasing gradually, energy consumption-driven GHG emissions have increased consistently. Although the government has taken different policy initiatives including (i) increasing the uptake of electric vehicles, (ii) promoting alternative fuels, (iii) developing public and active transport infrastructure, and (iv) introducing the NZ ETS obligation for transport fuels, these policy initiatives have failed to materially impact light vehicle GHG emissions. At present, changes are being considered but no significant further policy has been proposed except a few awareness building activities and a recent feebate scheme to increase vehicle fuel economy. The introduction of a feebate scheme is often considered to be an effective option to improve vehicle fuel economy (Barton & Schütte, 2015; Rahman et al., 2017). Introducing a fee for low fuel efficient vehicles (high emitting vehicles) and rebate for highly fuel efficient vehicles (low emitting vehicles) is expected to encourage people to purchase fuel efficient vehicles. Another closely related feebate system could be imposing a tax for purchasing low fuel economy vehicles, with subsidies for purchasing high fuel economy vehicles. There are multiple countries in Europe as well as the USA which have benefited through this policy measure (Michaelis & Davidson, 1996; Rahman et al., 2017). Another effective policy option to improve vehicle fuel economy is to set a high minimum fuel economy standard and thus ensure the entry of only fuel-efficient vehicles from manufacturing countries. China introduced such a policy option in July 2005 and saved around 1.18 million tonnes of transport fuel by December 2006 which was around 11.5% of their total transport fuel consumption (Hu, Chang, Li, & Qin, 2010). Introducing a vehicle age restriction or a cleaner vehicle emission standard to exclude old-vehicle use could be another measure to improve vehicle fuel economy. They would be likely to push up some light vehicle prices, raising the price of transport for some low-income families. These impacts could be offset through the tax and benefit system. However, no such policy options are currently proposed by the government.

There are also policy gaps with regard to other drivers of transport emissions. Promotion of renewable energy in the transport sector is crucial (Lorenzi & Baptista, 2018). But while New Zealand already has a high renewables proportion in electricity generation, policies related to the development of alternative renewable fuel sources to meet the increasing energy demand for the New Zealand vehicle fleet are not adequate. No significant policy alternatives are in place to deal with increasing travel demand due to population growth and the pattern of dispersed urbanisation. It is true that the production of biofuel at commercial scale is still challenging and requires major efforts from global corporates and governments to develop advanced production methodologies (Kour et al., 2019). Similarly, the high cost of hydrogen fuel requires advanced technological development before it can be widely deployed as an alternative to fossil fuels. The promotion of these alternative renewable transport fuels requires appropriate policy interventions derived from scientific studies.

Policy targets for reducing automobile dependency and restricting vehicle age are also absent. Policy guidelines on how passenger trips could be shifted from automobile to public transport are not clear. In addition, despite having a high share of renewables in the power-generation mix, the costs and emissions reduction potential of EVs are unknown. This necessitates the investigation of the costs and emissions reduction potential of EVs along with the government's current EV policies and targets. The following chapter therefore looks into the economic and environmental aspects of EVs and compares them with that of internal combustion engine vehicles (ICEVs).

## Chapter 5: Costs and emissions reduction potential of electric cars

Some content related to the emissions reduction potential of EVs was published in *The Conversation* and can be found here: <https://theconversation.com/climate-explained-the-environmental-footprint-of-electric-versus-fossil-cars-124762>. In addition, the contents of this chapter are revised based on the suggestions of three anonymous reviewers who recommended publication after revisions at *Transportation Research Part D: Transport and Environment*. The article is likely to be available online in August 2020.

### Summary Findings

In New Zealand, the emissions reduction potential of electric vehicles (EVs) as substitutes for ICEVs is not clear. Most importantly, despite a large share of used vehicles in the New Zealand vehicle fleet (around 45% in 2017), no study has been conducted so far to calculate the per-kilometre cost of ownership (PCO) for used vehicles. Therefore, this chapter attempts to identify the PCO of a new and a used light EV over a 12-year period in New Zealand and compares this with the PCO of a new and used light ICEV. In addition, the emissions reduction potential of EVs at the user level is investigated. Findings of this chapter are that the PCO for a used EV is the lowest (25.5 NZ cents) followed by the PCO of a used ICEV (31.5 cents), a new ICEV (36.9 cents) and a new EV (47.5 cents). Most importantly, replacing a light ICEV by a light EV can reduce GHG emissions at the user level (ignoring manufacturing and recycling phases) by 90%. If the additional phases are taken into account, the reduction would be around 60%. Therefore, a 45% share (say) of EVs in the light vehicle fleet by 2030 would help this sector play a significant part in achieving New Zealand's emissions reduction target under the Paris agreement. The findings of this chapter have significant policy implications for New Zealand and other countries especially the Central and South American countries that have high renewable shares in their electricity mix and are considering rapid emissions reduction through electric vehicle support.

### 5.1 Introduction

New Zealand has made a strong commitment to achieving net zero CO<sub>2</sub> emissions by 2050 (Ministry of Foreign Affairs and Trade, 2018), but the challenges it faces are unusual: limited remaining scope for further reducing carbon emissions in electricity, as renewables already account for the bulk of supply, a small number of important point source emissions, and an unusually elderly vehicle fleet. Because of the relatively small industrial sector and the high renewable electricity fraction (similar to Brazil's at 84% in 2018), some of the areas of current mitigation focus in other developed countries are less prominent in New Zealand. The transport

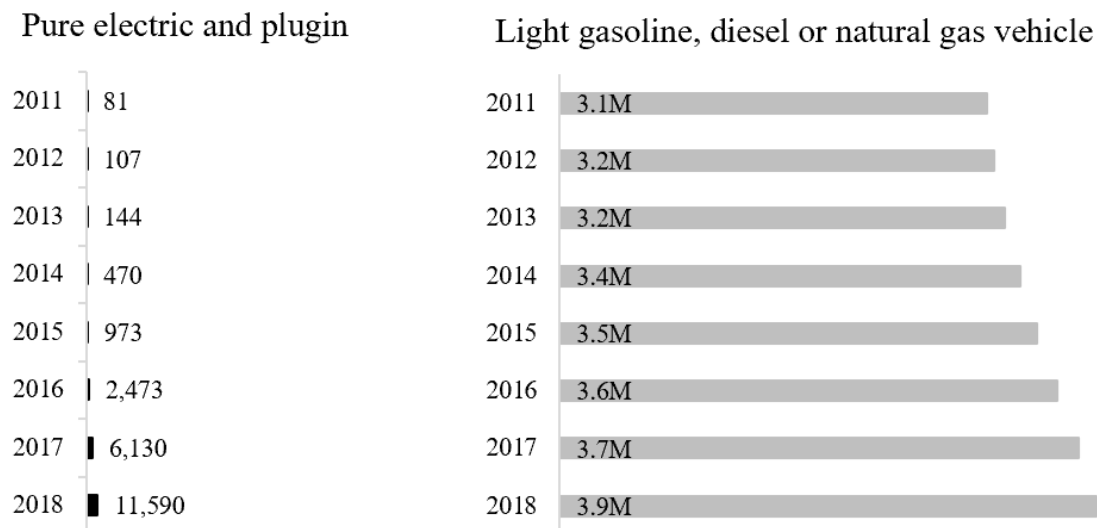
sector, on the other hand, is a central area of concern: rapidly growing, and driven by the oldest vehicle fleet in the OECD. The average age of a car in New Zealand in 2016 was 14.1 years while it was 10.1 years in Australia, 10.7 years in the European Union countries and 11.6 years in the USA (Hasan et al., 2019).

New Zealand's gross greenhouse gas (GHG) emissions grew 23.1% between 1990 and 2017. Much of this growth was due to a rapid increase in emissions from the road transport sector. GHG emissions from road transport increased by 82%; rising to 15.9 MtCO<sub>2e</sub> in 2017 from about 8.8 MtCO<sub>2e</sub> in 1990. This increase in emissions was the largest of any sector (Ministry for the Environment, 2019b). The large share of light internal combustion engine vehicles (ICEVs) in New Zealand's vehicle fleet is considered a major driver of the country's transport emissions. In 2017, the vehicle ownership rate per 1000 population was around 792.5 and the share of light ICEVs in the vehicle fleet was around 91.4%. The shares of petrol vehicles, diesel vehicles and pure electric vehicles (EVs) in the light vehicle fleet were around 80.0%, 17.7% and 0.11%, respectively (Ministry of Transport, 2019e). Emissions from the light vehicle fleet in 2017 were 10.6 MtCO<sub>2e</sub>, which were 66% of the total road transport emissions.

The ongoing rise of emissions from the transport sector is not consistent with New Zealand's commitments under the Paris agreement. New Zealand's main climate policy tool is the multisector emissions trading scheme (ETS), which aims to put a consistent price on carbon (Ministry for the Environment, 2018a). However, at around NZ\$25 (€15 or US\$16.8) per tonne, this amounts to around 5.8 NZ cents per litre of petrol at the pump (Carbon Tax Center, 2018). New Zealand's petrol price has fluctuated by around 40c per litre over the past five years (Ministry of Business, Innovation & Employment, 2018b). The ETS price on petrol (and diesel) is therefore small compared to commodity price variability, and as such it cannot, on its own, be expected to do much to change behaviour.

To help reduce transport emissions, the government introduced an EV programme in 2016, aiming to bring around 64,000 EVs onto roads by 2021 (Ministry of Transport, 2019c). The government recently proposed a feebate scheme, namely 'clean car discount' to promote EVs and efficient cars (Ministry of Transport, 2019d). At time of writing, this feebate scheme was due to come into force from 2021. Under the feebate scheme, no or less emitting vehicles (i.e. EVs or new ICEVs) will receive a rebate of up to NZD 8,000, while high emitting vehicles (old ICEVs) will be charged a maximum NZD 3,000 (Ministry of Transport, 2019d). The government is also reviewing the current NZ ETS price to make it effective. Despite various

policies, the uptake of light EVs is so far insignificant compared to the growing demand for regular vehicles (ICEVs). The total number of light EVs in the fleet in 2018 was only 11,590 compared to a total light vehicle stock of 3.9 million, around 0.3% (**Figure 7**).



**Figure 7. Comparison of light electric vehicle and regular vehicle fleets in New Zealand (Ministry of Transport, 2018b)**

Costs, uncertainties, and risks associated with the purchase and use of light EVs are likely to be the major factors responsible for the insignificant uptake of light EVs in New Zealand. Some of the challenges include (i) the high initial purchase price of light EVs, (ii) insufficient public EV charging infrastructures, (iii) lack of financial incentives for light EV purchase, (iv) the ineffectiveness of the New Zealand Emissions trading Scheme (NZ ETS) and (v) flexible emissions standard for fossil-fuelled cars. Moreover, the costs and mitigation potential of using light EVs in New Zealand as substitutes for fossil-fuelled cars are not clear to policy makers, vehicle manufacturers/importers, and consumers.

This chapter aims to compare the per-kilometre cost of ownership (PCO) for new and used light EVs with costs for new and used light ICEVs. This is an important and unstudied question in the context of New Zealand's vehicle fleet, which is characterised by a large share of used vehicles, many of which are retained for a long time by their owners. The recently proposed feebate scheme and its impact on the PCOs for light EVs and light ICEVs are investigated to provide an up-to-date cost analysis. The emissions reduction potential of light EVs is also assessed in relation to uncertainties, risks, other barriers than upfront costs, and policy gaps. This chapter, in short, aims to provide key information on the costs and emissions reduction potential of light EVs in New Zealand. It is expected that findings of this chapter will have

potential policy implications for both developed and developing countries. In Europe, between 1990 and 2014, the transport sector is the only sector that observed an increase in greenhouse emissions (World Resource Institute, 2019) and findings of this chapter will help policy advisers understand the costs and mitigation potentials of light EVs and support them in making informed policy decisions. Since Brazil and other Central and South American countries have high shares of renewables in their electricity mix like New Zealand (BP, 2019) and EV uptakes are increasing in these Latin American countries due to stringent emissions and pollution control policies (Jackson, 2019), the method and findings are expected to have significant reference value for them.

## **5.2 Literature review**

Various studies has been carried out to assess the life-cycle ownership costs of alternative vehicle technologies such as pure electric cars (Palmer et al., 2018; Weiss et al., 2019), commercial EVs (Falcão et al., 2017), electric buses (Li, Jin, & Xiong, 2017), plug-in hybrid trucks (Vora et al., 2017) and pure automated vehicles (Wadud, 2017). With advancement in technologies, the ownership cost of alternative cars has been changing significantly. Since the calculation of vehicle ownership costs becomes outdated relatively quickly, this section investigates post-2010 studies focusing mainly on pure (battery) electric cars and ICEVs.

Palmer et al. (2018) examined the changes in total costs of ownership (TCO) of a mid-sized battery electric vehicle (BEV), a plug-in hybrid electric vehicle (PHEV), a hybrid electric vehicle (HEV) and a conventional ICEV between 1997 and 2015 in the UK, the USA and Japan. The calculation of TCO combined the initial purchase price and all operating expenses including vehicle depreciation, maintenance inclusive of testing fee, insurance fee, and fuel prices between 1995 and 2015. Findings show that in all the three countries, the BEVs (and the HEVs) have observed a greater reduction in TCOs than ICEVs during the study period. Another study by Falcão et al. (2017) compared the TCOs and carbon dioxide emissions between an BEV minibus and its diesel-powered conventional (ICEV) version. Study results show that the total cost of ownership (TCO) of an electric minibus is around 2.5 times higher than its diesel-powered cousin. However, in terms of emissions reduction, an electric minibus emits 4.6 times less carbon dioxide than its diesel version. For an electric minibus, the costs of vehicle purchase and battery are nearly  $\frac{3}{4}$  of the ownership cost, and payback occurs only after 13 years of operation.

Wu et al. (2015) estimated the TCOs of small, medium and large BEVs in Germany and compared them with respective ICEV classes. The study shows that the cost efficiency of a small sized EV is higher (better) than medium or large sized EVs. With an increase in driving distances, the cost efficiency of an EV also increases. Within 10 years, on the basis of falling EV prices, the TCO of an EV is expected to be equal or lower to that of the conventional vehicle. Hagman et al. (2016) investigated the TCOs of four vehicle-fuel types in Sweden, namely Volvo V40 D3 (diesel ICEV), Volvo V40 T4 (petrol ICEV), Toyota Prius (HEV) and BMW i3 (BEV). The study assumed a three year ownership period for all vehicles and estimated the lowest TCO for the BMW i3 (€18,922) followed by Volvo V40 D3 (€19 927), Toyota Prius and (€21 070), and Volvo V40 T4 (€21 158). Free parking and charging facilities in some local municipalities, a €4,202 cash premium for vehicles that emit less than 50 gCO<sub>2</sub> per kilometre, and low maintenance and repair costs due to the small number of moving parts are some of the factors that contributed to the lowest TCO for the BEV despite a high purchase (and/or depreciation) price (Hagman et al., 2016). The advantage of the BEV would have been greater over a longer evaluation period.

Other researchers have also estimated vehicle ownership costs for different countries using different techniques. For example, Gilmore and Patwardhan (2016) evaluated the full costs including private and social cost for different vehicle fuel-types in India; and Diao, Sun, Yuan, Li, and Zheng (2016) examined the life-cycle costs (LCCs) for EVs and conventional vehicles in China. Neither study is closely applicable to the New Zealand situation – as, for example, Indian electricity is substantially coal generated, whereas in New Zealand it is ~85% renewable.

The next section draws on this and other literature to consider the most appropriate methods for the present study's purpose of estimating the PCO for different vehicle types (new EV, used EV, new ICEV, and used ICEV) and hence the relative cost competitiveness of different vehicle types in New Zealand.

## **5.3 Methodology**

### **5.3.1 Methodology for estimating future emissions and energy consumption**

The estimation of future energy consumption and emissions from passenger vehicles is conventionally based on the estimation of future changes in vehicle fuel efficiency and VKT in New Zealand. However, as the 'Future demand' review showed (Ministry of Transport, 2014b), projections of VKT growth in the past have often been way off-target. Here, six major



drivers of changes in passenger travel in New Zealand are identified and expected changes between 2018 and 2030 are taken from the literature (Ministry of Transport, 2014b). The six major drivers of changes in VKT considered in this study are fuel price, urbanisation, digital connectivity, population age structure, population growth, and fuel efficiency. Then the effects of such changes on projected passenger travel are quantified to develop a baseline projection of VKT. Alternative scenarios are developed based on underlying drivers, and forecasts out to 2030 are made. Finally, the estimated passenger VKT is used to calculate future energy consumption and carbon dioxide emissions resulting from passenger travel. This is a consciously conservative approach which sets aside any changes to mode shares due to factors such as increased vehicle sharing in cities, or any penetration of autonomous vehicles around 2030 – such changes are not unlikely, but simply beyond the scope of this chapter.

### 5.3.2 Methodology for calculating the PCO for new and used light EVs and ICEVs

To calculate the costs of new and used light EVs and ICEVs, baseline scenarios for both light EVs and ICEVs are developed. Baseline scenarios include information on both light EVs and ICEVs regarding their present market shares, policy targets for EV uptake and emissions mitigation, life-time of vehicles and/or batteries, costs, present available technologies and likely technological changes. Cost components for new and used light EVs and ICEVs are identified and associated with the baseline scenarios. These components include vehicle purchase price, vehicle depreciation cost, fuel cost, repair and maintenance costs, and resale values. A 12-year ownership period is considered in this study because most of the previous studies considered a similar vehicle ownership period (Please see Table 1). In addition, in New Zealand, the manufacturer's warranty for an EV battery is up to 160,000 kilometres (Energy Efficiency and Conservation Authority, 2017). Since the annual VKT in 2018 in New Zealand was 10,500 km (Energy Efficiency and Conservation Authority, 2018a) and the annual increase in VKT is estimated to be 1.2% (Ministry of Transport, 2014b), the life-time of an EV battery is about 12-13 years. This is another reason for considering a 12-year vehicle ownership period in this study. Assumptions on vehicle cost components and other key parameters are presented in Table 7.

**Table 7. Assumptions on vehicle cost components and other key parameters (author's estimates where other sources not indicated; all data as at 2018 except as indicated)**

<b>Cost components /parameters</b>	<b>Data Source</b>	<b>Assumptions</b>	<b>Notes</b>
Vehicle purchase cost	Manufacturer's recommended retail price (RRP) (Energy Efficiency and Conservation Authority, 2018b)	NZD 31,000 for the new Toyota Corolla; NZD 57,000 for the Nissan Leaf (2019 model); NZD 8,450 for the eight-year old used Toyota Corolla, and NZD 15,530 for the eight-year old used Nissan Leaf (2012 model)	In 2017, around 80% of the newly registered internal combustion engine (ICE) cars were Japanese cars, and Toyota Corolla was the best-selling small car; Up to October 2018, the share of Nissan Leafs in the EV fleet was 52% (Ministry of Transport, 2018b). The average age of newly imported used cars in New Zealand is 8 years.
Depreciation cost	Various (Chatterton, Anable, Cairns, & Wilson, 2018; Palmer et al., 2018)	Vehicle depreciation rate: 15% per year	Although the vehicle depreciation rate is considered the same for light ICEVs and EVs, depreciation cost will be higher for light EVs than ICEVs due to a higher initial purchase price for light EVs.
Fuel cost	Government reports and websites (Ministry of Business, Innovation & Employment, 2018b)	Petrol retail price- NZD 2.20 per litre including GST and the NZ ETS price; Domestic electricity price- NZD 0.3 per kWh. Real annual average increases in petrol and electricity prices are 1.4% and 1.1%	A NZ ETS price of NZD 25 per ton of CO <sub>2</sub> emissions increased the petrol price by 5.8 NZ cents; about 85% of New Zealand's electricity is generated from renewable sources; the change in electricity

<b>Cost components /parameters</b>	<b>Data Source</b>	<b>Assumptions</b>	<b>Notes</b>
		respectively (national average of last ten years).	prices due to the NZ ETS is 0.9 NZ cents.
Repair and maintenance costs	Various (De Clerck et al., 2018; Energy Efficiency and Conservation Authority, 2018b; Harvey, 2018)	NZD 0.04 per km for a new Toyota Corolla; NZD 0.08 per km for a used Toyota Corolla; NZD 0.03 per km for a new Nissan Leaf; and NZD 0.06 per km for a used Nissan Leaf	Various estimates (De Clerck et al., 2018; Harvey, 2018; Weldon, Morrissey, & O'Mahony, 2018) suggest the repair and maintenance costs of light EVs are less than similar ICEVs by around 35%, 25% and 18% respectively. This study assumed that repair and maintenance costs of light EVs are 25% less than that of ICEVs.
Fuel economy	Government reports and websites (Energy Efficiency and Conservation Authority, 2018b; Energy Efficiency and Renewable Energy, 2018; Ministry of Transport, 2018b; U.S. Bureau of	6.4 litre/100 kilometres for a new Toyota Corolla; 9.1 litre/100 kilometres for a used Toyota Corolla; 4.0 km/kWh for a new Nissan Leaf; and 4.0 km/kWh for a used Nissan Leaf.	Mean fuel economy ratings reported by the New Zealand Ministry of Transport and the U.S. Office of Energy Efficiency and Renewable Energy are considered for the used ICEV and EV respectively.

<b>Cost components /parameters</b>	<b>Data Source</b>	<b>Assumptions</b>	<b>Notes</b>
	Transportation Statistics, 2018)		
Incentives	New Zealand Government policy documents (Ministry of Transport, 2019c)	An incentive of NZD 600 / year per vehicle for light EVs	An exemption from road user charge (RUC) for light EVs is expected to contribute to this saving. This incentive does not include the proposed feebate scheme
Annual vehicle kilometres travelled (VKT)	Government reports and websites (Energy Efficiency and Conservation Authority, 2018a; Ministry of Transport, 2014a)	Annual VKT: 10,500 km; an annual average increase in passenger VKT is 1.2% (Ministry of Transport estimates)	Average daily passenger car travel is reported as below 30 km by the Energy Efficiency and Conservation Authority of New Zealand
Resale value	Various (Chatterton et al., 2018; Palmer et al., 2018)	Mean 12-year resale values at 2030 in real New Zealand dollars; NZD 4,400 for the new Toyota Corolla; NZD 1,100 for the used Toyota Corolla; NZD 8,100 for the new Nissan Leaf; and NZD 2,000 for the used Nissan Leaf	A depreciation rate of 15% per year is considered to estimate the resale value of the cars.
Discount rate	Government reports and	6% per year	The default Treasury discount rate as well as the

<b>Cost components /parameters</b>	<b>Data Source</b>	<b>Assumptions</b>	<b>Notes</b>
	websites (The Treasury, 2018)		discount rate for road and other transport projects is 6% per year

### 5.3.3 Methodology for calculating the emissions reduction potential of an EV

This chapter calculates the emissions reduction potential of an EV from a user perspective instead of a life-cycle perspective because New Zealand does not manufacture or recycle cars. However, the chapter explores the emissions from battery manufacturing and recycling (life-cycle analysis of emissions) to make the study useful for the broader community. To measure the emissions reduction potential of light EVs, annual emissions from an EV and ICEV are initially determined. Annual emissions from an EV and ICEV are determined using (i) vehicle efficiency, (ii) fuel carbon intensity and (iii) annual distance travelled (Pike, 2012). The details of these factors are as follows.

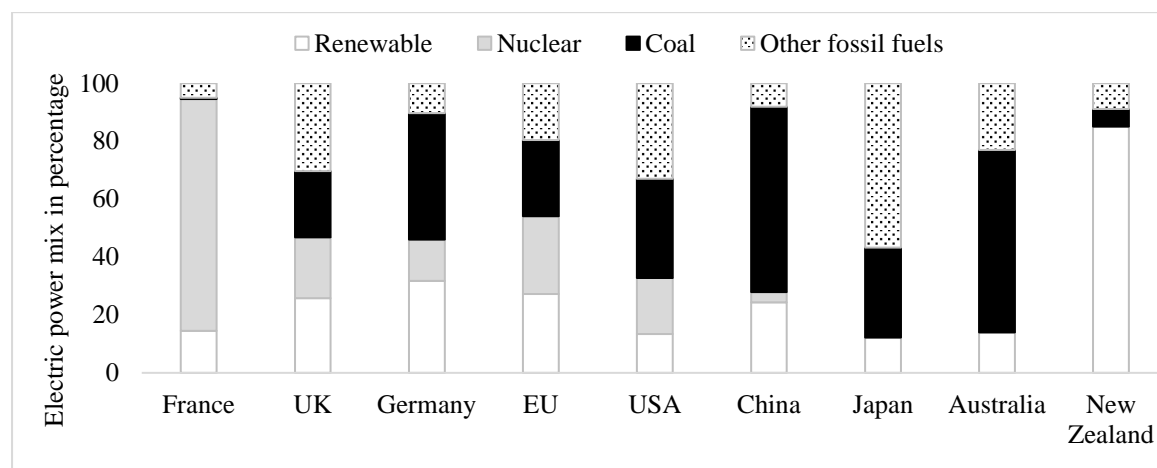
#### 3.3.1. Vehicle efficiency

Vehicle efficiency clearly plays a crucial role in the calculation of upstream and/or tailpipe emissions from vehicles. Efficiency varies significantly depending on vehicle cabin climatic condition (in hot/cold weather), driving behaviour (speed and acceleration), congestion conditions, vehicle age, fuel type, vehicle type etc. (Sperling and Gordon, 2010; United Nations, 2011). To compare vehicle efficiencies between an EV and an ICEV, the five-cycle test of the US Environmental Protection Agency (EPA) is used, where typical congestion, vehicle cabin climatic condition and driving behaviour parameters are used.

#### 3.3.2. Carbon intensity of vehicle fuel

The carbon intensities of different fuels (including electricity) vary. For instance, the mean lifecycle emissions intensity of coal is around 888 tonnes of carbon dioxide equivalent per gigawatt-hour (tCO<sub>2e</sub>/GWh) while the emissions intensity of hydro-electricity is only 26 tCO<sub>2e</sub>/GWh (World Nuclear Association, 2011). The total emissions of a light EV largely depend on this fuel carbon-intensity as EVs do not have any tailpipe emissions. The mix in electricity production mode of a country determines the upstream emissions of an EV.

Countries like Australia, China, Germany and USA have relatively high shares of coal-generated electricity and thereby the upstream emissions from EVs are relatively high in these countries. On the other side, France and New Zealand have high shares of low-carbon electricity generation sources such as nuclear or renewable energy sources (**Figure 8**). Therefore, the upstream emissions from EVs are relatively low in these two countries (China Energy Group, 2016; Department of Industry, Innovation and Science, 2016; European Environment Agency, 2016; Ministry of Business, Innovation & Employment, 2018a; Ministry of Economy, Trade and Industry, 2016).



**Figure 8. Energy sources for electricity generation in different countries in 2016**

In this chapter, fuel carbon intensity is determined, on a ‘well to tank’ basis. The average emissions intensity of electricity generation is measured taking into account transmission and distribution losses. ‘Well to tank’ GHG emissions due to petroleum production, refining and transport are measured to estimate the emissions saving associated with light EVs. Electric vehicle driving range data and annual VKT data are used to calculate annual electricity consumption and upstream emissions of light EVs. For internal combustion engine vehicles, VKT data are used to calculate both tailpipe and upstream emissions.

### 3.3.3. Total distance travelled

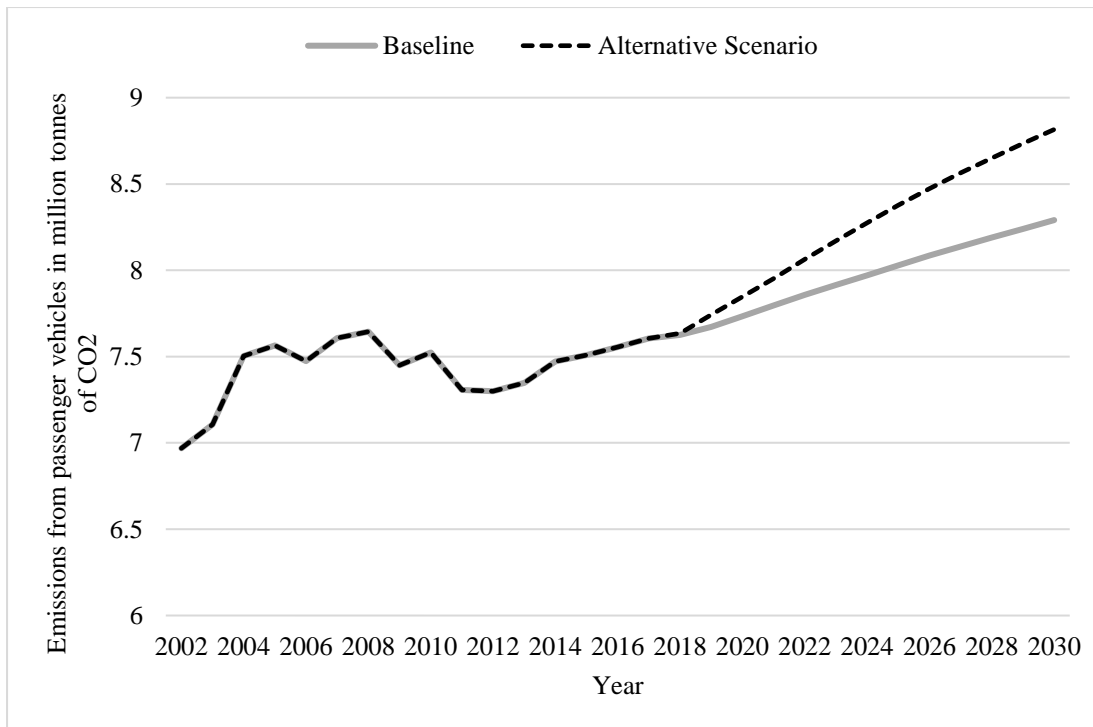
Vehicle fuel consumption and associated emissions depend on VKT. This chapter uses the forecasts of the (Ministry of Transport, 2014b) to estimate passenger VKT in New Zealand. For EVs, annual electricity consumption is measured by multiplying annual VKT (km) by vehicle energy efficiency (kWh/km). Similarly, for an ICEV, annual fuel consumption is derived by multiplying annual VKT (km) with vehicle fuel efficiency (Litre/km).

## 5.4 Results and discussions

### 5.4.1 Energy consumption and GHG emissions

The total amount of energy consumed by passenger road transport in New Zealand has been following a fluctuating but increasing trend over the last one and half decades. In 2002, energy consumption from passenger transport was only 2.3 million tonnes of oil equivalent (Mtoe) which increased to 2.5 Mtoe in 2017. The annual average rate of increase in energy consumption in this period was around 0.6 percent. The forecast values of energy consumption obtained by the future travel demand modelling of the Ministry of Transport also show an increasing trend. The Ministry of Transport's method forecast the energy consumption as 2.9 Mtoe for the year 2030, an increase of 1.2% per year over 2018-2030.

Similar to the energy consumption trend, GHG emissions from passenger transport have been experiencing an increasing trend over the past 15 years. Between 2002 and 2015, GHG emissions increased from around 7.0 million metric tonnes of carbon dioxide equivalent (MtCO<sub>2e</sub>) to around 7.6 MtCO<sub>2e</sub>. The forecast GHG emissions generated by the future travel demand modelling of the Ministry of Transport for the year 2030 is 8.8 MtCO<sub>2e</sub> which is 26% higher than the 2002 emissions level (**Figure 9**). This chapter uses this as a working estimate, despite reservations the study has about its credibility post-Paris and more particularly since the IPCC report on Global Warming of 1.5 °C was published in October 2018 (IPCC, 2018).



**Figure 9. Estimated carbon dioxide emissions from New Zealand passenger vehicles (adapted from (Ministry of Transport, 2014b))**

#### 5.4.2 Per-kilometre cost for new and used light EVs, and ICEVs

Costs associated with new and used light EVs, and ICEVs include the purchase price of the vehicle and battery, cost of electricity and fuel, cost of repair and maintenance, and costs associated with governmental disincentives on certain vehicle types. The details of these cost components for different types of vehicles are as follows-

##### 4.2.1. Vehicle purchase cost

Based on the year of manufacture, year of use, weight of the vehicle, and the manufacturer, the purchase price of vehicles vary significantly. However, based on the manufacturer's recommended retail price (RRP), the purchasing price of a new Nissan Leaf, a new Toyota Corolla, a used Nissan Leaf and a used Toyota Corolla is assumed to be NZD 57,000, NZD 31,000, NZD 15,530 and NZD 8,450 respectively (Energy Efficiency and Conservation Authority, 2018b). These price assumptions are found compatible with other research as well (Clover, 2013; Drive electric, 2018; Shafiei, Leaver, & Davidsdottir, 2017).

##### 4.2.2. Vehicle depreciation cost

Despite the assumption of a flat depreciation rate of 15% per year, the depreciation cost of a new Nissan Leaf is very high due to its high initial purchase price. The per-kilometre



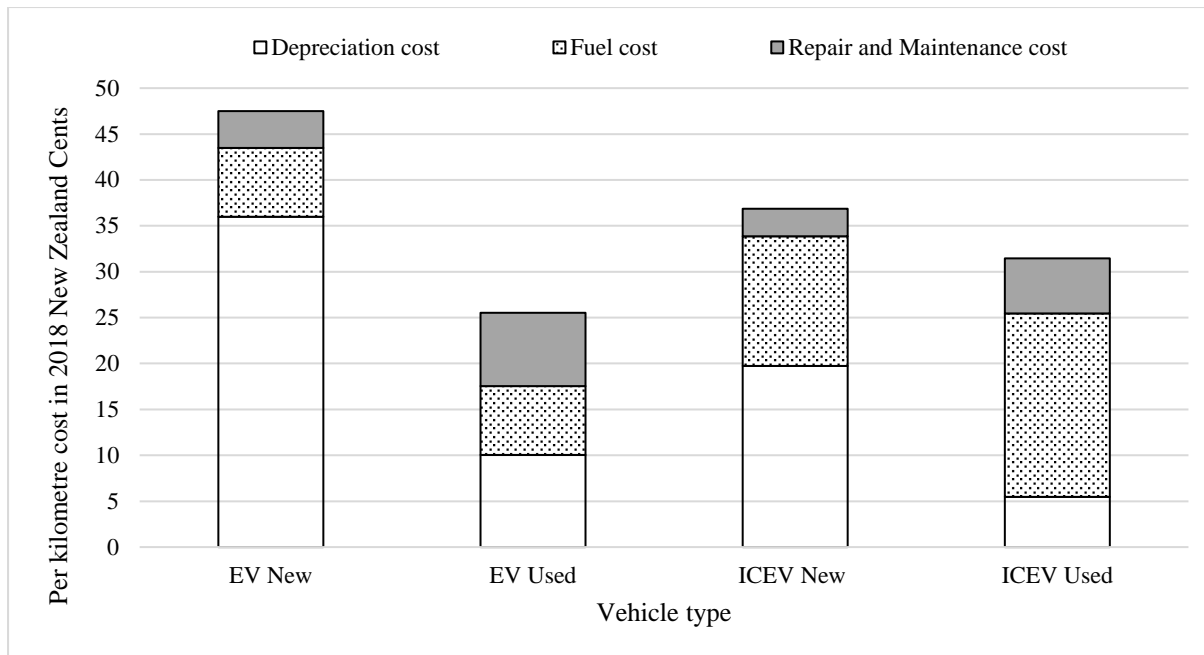
depreciation cost of a New Nissan Leaf over a 12 years period is around 36 New Zealand (NZ) cents while the costs of depreciation for new Toyota Corolla, used Nissan Leaf and used Toyota Corolla are 19.8 cents/km, 10 cents/km, and 5.5 cents/km respectively (**Figure 10**).

#### 4.2.3. Fuel cost

The total cost of fuel varies significantly with vehicle fuel efficiency, vehicle distance travelled, vehicle weight, and electricity or petrol price (Shafiei et al., 2017). New vehicles are relatively more fuel efficient than used vehicles. In this study, fuel efficiency of a new Nissan Leaf (2019 model), a new Toyota Corolla, a used Nissan Leaf (2012 model) and a used Toyota Corolla are assumed to be 4.0 km/kWh, 6.4 litre/100 kilometres, 4.0 km/kWh, and 9.1 litre/100 kilometres respectively. As a result, a retail petrol price of NZD 2.2 per litre and a domestic electricity price of NZD 0.3 per kWh incur a cost of 7.5 cents/km for a new and used Nissan leaf, 14.1 cents/km for a new Toyota Corolla, and 20.0 cents/km for a used Toyota Corolla (**Figure 10**).

#### 4.2.4. Repair and maintenance cost

The total cost of maintaining a light EV is higher than the cost of maintaining a light ICEV if the battery replacement cost is included under the repair and maintenance category. Without the battery replacement cost, the repair and maintenance cost of a light EV is lower as the total number of ‘moving parts’ in an EV is very small. A recent decrease in battery prices has made EVs more cost competitive. The use of zinc-air batteries instead of lithium-ion batteries should help to keep the battery price below NZD 150 per kWh (Hanley, 2018) while the price of a lithium-ion battery in 2010 was around NZD 1500 per kWh (Union of Concerned Scientists, 2018). In this study, the battery replacement cost of EV is considered under the repair and maintenance cost and accordingly the repair and maintenance costs of a new Nissan Leaf, a new Toyota Corolla, a used Nissan Leaf and a used Toyota Corolla are found to be 4.0 NZ cents/km, 3.0 cents, 8.0 cents, and 6.0 cents respectively (**Figure 10**).



**Figure 10. Per kilometre cost of ownership (PCO) for different types of vehicle in New Zealand (author's calculations)**

From **Figure 10**, it is evident that the PCO for a new light EV is the highest (47.5 cents) followed by a new light ICEV (36.9 cents), a used light ICEV (31.5 cents) and a used light EV (25.5 cents). PCOs estimated in this study are lower than the PCO estimated by the AA Motoring (2018). The average cost estimated by AA Motoring (2018) for a small petrol and a diesel car is 54.8 cents/km. There could be a number of factors behind the differences. Since AA Motoring (2018) considered diesel vehicles in their study, they considered road user charge (NZ\$ 600/year) while this study does not. Most importantly, this study considered a resale value of cars after 12 years while AA Motoring (2018) did not consider vehicle resale values. In addition, the depreciation rate assumed in the AA Motoring (2018) is higher than the depreciation rate used in this study. Unlike the study of AA Motoring (2018), the total cost of ownership for a used Nissan Leaf calculated by the EECA (2020) is 28 cents/km, which is very similar to this study (i.e. 25.5 cents/km). The difference in PCO could be due to the non-inclusion of the resale value in the EECA (2020) study.

The results obtained from this study is to some extent consistent to other total cost of ownership (TCO)-related international studies. For example, Lévy, Drossinos, and Thiel (2017) found that the TCOs of big EVs are lower than counterpart ICEVs in the United Kingdom and Norway. Similar results were found by Wu et al. (2015) where they claimed that the TCOs of EVs become lower than ICEVs after 12 years of ownership (i.e. by 2025) in Germany. However, according to van Velzen, Annema, van de Kaa, and van Wee (2019), the TCOs of

EVs will not be cost competitive to their counterpart ICEVs unless there is a tax policy in place to increase the TCOs of ICEVs. Similarly, van Vliet, Brouwer, Kuramochi, van den Broek, and Faaij (2011) found that the TCO of an EV is uncompetitive to its counterpart regular car by more than 800 euro per year. Nemry and Brons (2010) claimed that even if the high initial purchase price of EVs were spread over their lifetimes, EVs would not be very attractive in the European Union countries.

## **5.5 Sensitivity Analysis**

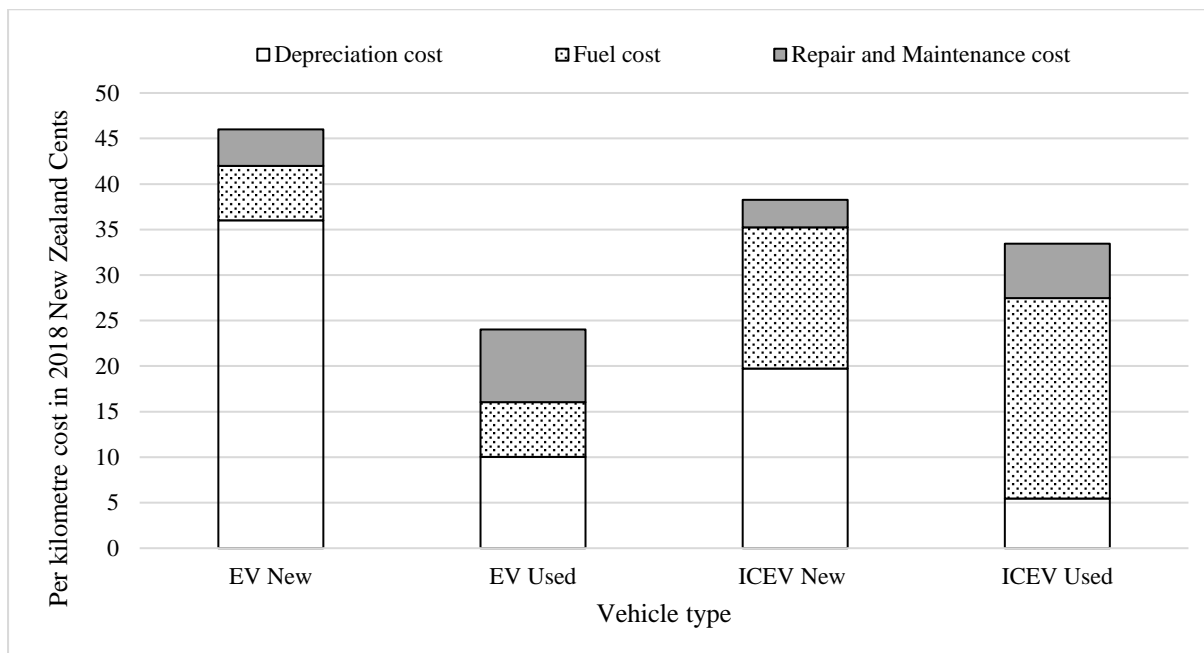
The last section explained the per kilometre ownership cost for different types of vehicles based on a baseline scenario. This section performs some sensitivity analyses to examine how the per-kilometre ownership cost (PCO) changes depending on the changes to fuel price, depreciation rate, discount rate and VKT.

### **5.5.1 Fuel prices**

In the baseline scenario, it was assumed that changes in fuel prices would continue the past decadal trends, which were 1.4% per year increase for petrol and 1.1% for electricity. Here, this chapter examines how the PCOs for different types of vehicles change under favourable price assumptions. There are a few studies that calculated the electricity cost for EV charging using average residential power prices (Breetz & Salon, 2018; Prud'homme & Koning, 2012) whereas some studies considered discounted off-peak power prices assuming that EV owners have access to home charging during the low-cost off-peak period (Center for Sustainable Energy, 2013, 2016). One study assumed that free or discounted charging at off-peak hours might reduce fuel cost for EVs by 50% (Breetz & Salon, 2018). This is optimistic in the New Zealand context, but recharging 'at work' at zero price is likely to be fairly widely available. Mercury, a power company in New Zealand offers a 20% discount on electricity uses everyday from 9 pm to 7 am (Mercury, 2019). Therefore, this scenario assumes EVs' relative electricity costs to be at a 20% discount on retail prices.

For ICEVs, the petrol price has not changed much over the past decade. The contribution of the ETS price (NZD 25 per tCO<sub>2</sub>e) to the present petrol price increase is only 5.8 cents per litre while the average social cost of carbon is estimated around 35 cents per litre (using an estimate of a social cost of carbon of NZD 150 per tCO<sub>2</sub>e). In July 2018, a regional fuel tax of 11.5 cents per litre was introduced for Auckland to fund some regional transport projects; this is about 5% of the current fuel price. Considering these, this scenario assumes a 10% increase in petrol price between 2018 and 2030 and determines the ICEVs' relative fuel costs on this basis.

A 10% increase in petrol price would increase the fuel cost per kilometre for a new and used Toyota Corolla by 1.4 cents and 2 cents, respectively. On the other hand, a decrease in electricity costs by 20% would reduce fuel costs per kilometer for new and used light EVs by 1.5 cents each. As a result, the PCO of new and used Leafs would decrease to 46 cents/km and 24 cents/km, respectively, while the PCO of new and used Corollas would increase to 38.3 and 33.5 cents/km, respectively (**Figure 11**). We found no relative change among different types of vehicles due to fuel price changes.

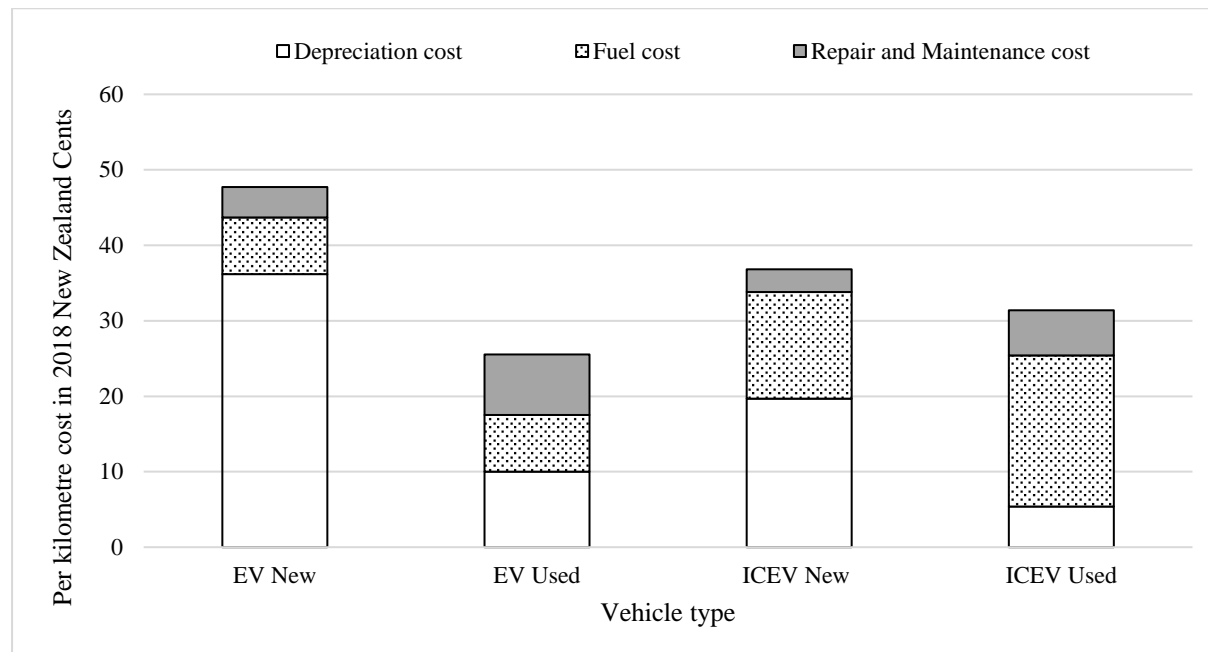


**Figure 11. Sensitivity analysis assuming an increase in petrol price by 10% and a decrease in electricity costs by 20% (author's calculations)**

### 5.5.2 Discount rates

We used the New Zealand Treasury discount rate of 6% for transport and public sector projects (The Treasury, 2018) for the baseline scenario analysis. However, to understand the sensitivity to the discount rate of relative ownership costs, this study considered a 4% discount rate. Wu et al. (2015) and Hagman et al. (2016) used a similar discount rate in their studies while Palmer et al. (2018) used a discount rate of 3.5%. We found no relative change among different types of vehicles due to this lower discount rate. Similar to the baseline scenario, for a 4% discount rate, the new Nissan Leaf (2019 model) has the highest PCO followed by the new Corolla, the used Corolla and the used Leaf (**Figure 12**). However, the cost gap between the new Leaf and the used Corolla increases with a lower discount rate. Changes in discount rates typically affect the fuel price and vehicle resale price. A higher discount rate (the base case) reduces the value

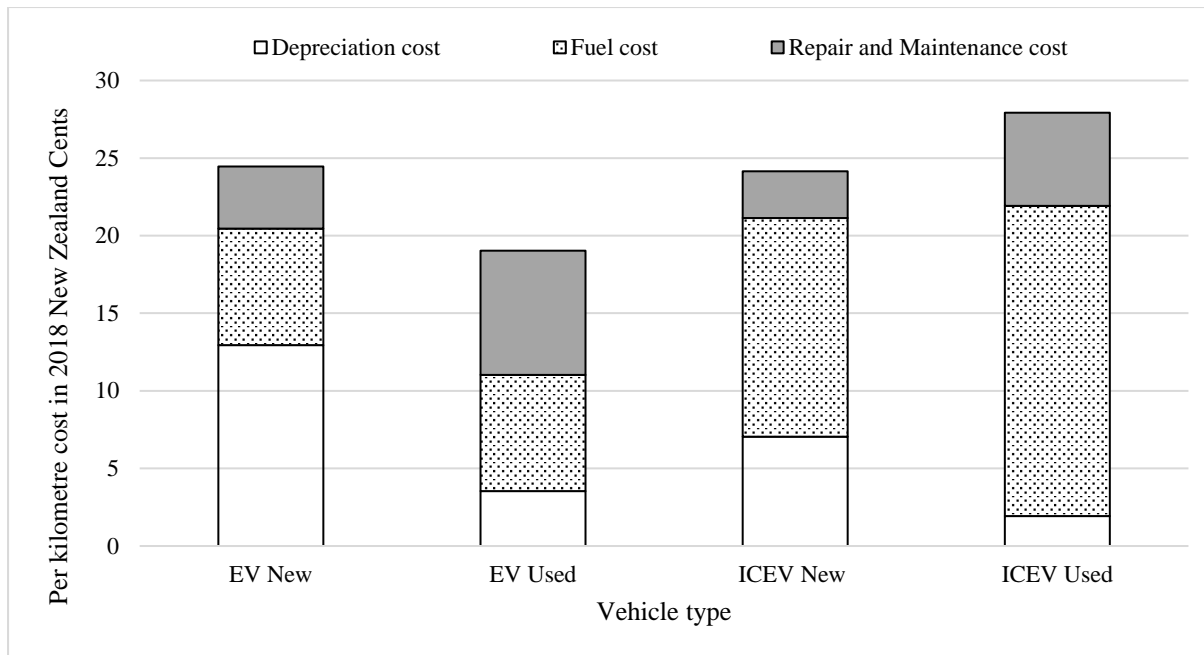
of the fuel savings that accumulate over time and reduces the attraction of new vehicles relative to used vehicles. Also, a high discount ‘hurts’ a new vehicle more than a used vehicle because the loss in resale value of a new vehicle is greater after discounting than for a used vehicle (Breetz & Salon, 2018).



**Figure 12. Sensitivity analysis: PCOs for a lower discount rate (4%) for the 2018-2030 period (author’s calculations)**

### 5.5.3 Depreciation

Changes in the depreciation rate plays a crucial role in the relative cost scenario of different types of vehicle as it affects the resale value significantly. Different studies adopt different depreciation rates in estimating the costs of ownership for different vehicles. The baseline scenario analysis used a vehicle depreciation rate of 15%. However, a sensitivity test can show a break-even point where the PCO of a new Leaf equals the PCO of a new Corolla. The result shows that a depreciation rate of about 3% achieves such a break-even point. At 3% depreciation rate the PCOs for the new Leaf and the new Corolla decrease by 23 cents/km and 12.7 cents/km respectively while the PCO for the used Leaf and the used Corolla decreases by only 6.5 cents/km and 3.5 cents/km respectively (**Figure 13**).



**Figure 13. Sensitivity analysis: PCOs for an annual vehicle depreciation rate of 18% between 2018 and 2030 (author's calculations)**

### 5.6 Scenario under proposed feebate scheme

In July 2019, the government of New Zealand announced a feebate scheme for new and used vehicles namely a 'Clean Car Discount' which is expected to be introduced from 2021 (Ministry of Transport, 2019d). Vehicles that are three years old or less are identified as new vehicles while vehicles over three years old are categorised as used vehicles. The proposed scheme aims to achieve an emissions target of 161 grams of carbon dioxide per kilometre ( $\text{gCO}_2/\text{km}$ ) for the national fleet in 2022. The emissions target will be updated every year, and the target for the national fleet for 2025 is proposed to be 105  $\text{gCO}_2/\text{km}$ . Any vehicle emitting above 161  $\text{gCO}_2/\text{km}$  in 2022 will pay a fee while vehicles emitting below 161  $\text{gCO}_2/\text{km}$  will receive a rebate. Fees and rebates largely depend on vehicle weights and vehicle types (electric, hybrid, ICEV etc.).

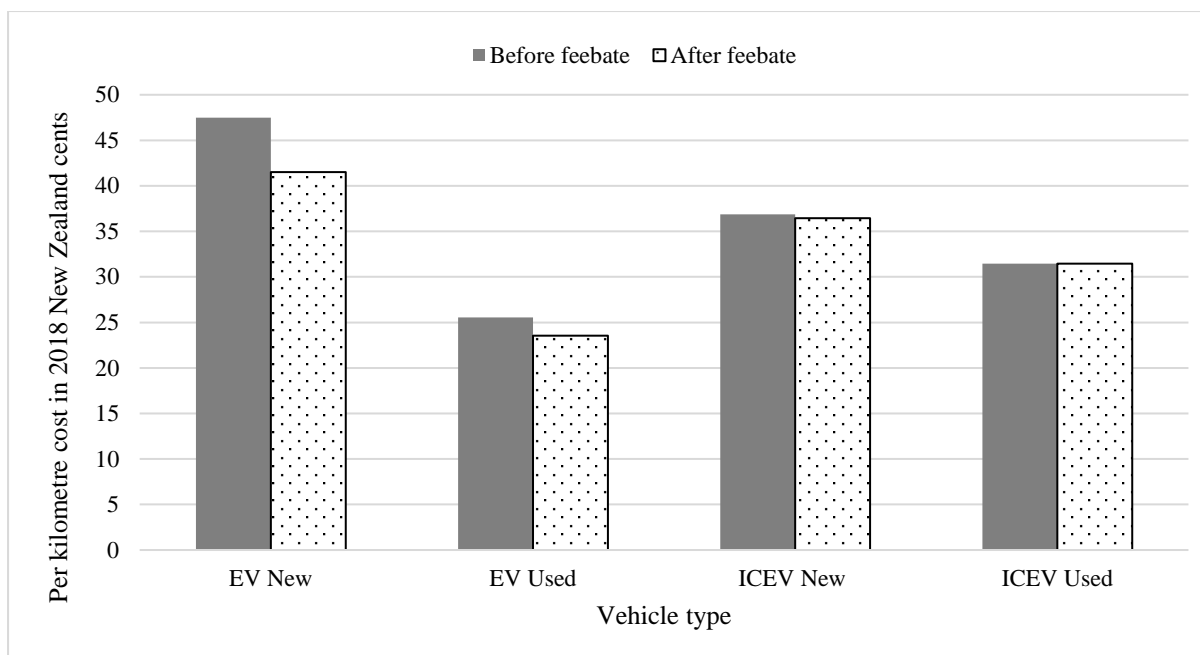
This analysis focuses on the PCOs of using a new and used Toyota Corolla, comparing them with the PCOs for a new and used Nissan Leaf. The feebate scheme is expected to increase the PCO for high emitting vehicles (i.e. ICEVs) and reduce the PCO for low or no-emitting vehicles (i.e. EVs). Exactly how much the PCO for light EVs will fall and for light ICEVs will rise depends on the details of the scheme which remain to be finalised, but estimates are made below based on details currently available (see Table 8). The proposed fees and rebates for different vehicles are presented in the discussion paper (Ministry of Transport, 2019d). The

study has made an assumption about the rebate for the new Nissan Leaf, because this information is not presented in the discussion paper. The assumption is based on the expected emissions from the vehicle and respective rebate. For instance, the rate for the new Toyota Prius Prime is assumed to provide a reasonable rebate estimate for a new Nissan Leaf car. The details of the fees and rebates for different vehicles are presented in Table 8.

**Table 8. Proposed feebate scheme for new and used light EVs and ICEVs (Ministry of Transport, 2019d)**

Fee/rebate	New Toyota Corolla	Used Toyota Corolla	New Nissan Leaf	Used Nissan Leaf
Total fee or rebate	NZD 600 (rebate)	0	NZD 8,000 (rebate)	NZD 2,600 (rebate)
Fee or rebate per kilometre*	0.4 cents/km (rebate)	0	6.0 cents/km (rebate)	2.0 cents/km (rebate)
*assumes annual VKT in 2018 is 10,500 kilometres, annual increase in VKT is 1.2%, and vehicle ownership period is 12 years				

The impact of the proposed feebate scheme on the PCO for light EVs will be significant as the rebate rate is significant for such vehicles. The rebate that will be received by a new Toyota Corolla (ICEV) is smaller at NZD 600. Under an annual increase of VKT of 1.2% between 2019 and 2030, the rebates per kilometre for use of the new and used Nissan Leafs are estimated at 6.0 cents and 2.0 cents respectively, while rebates per kilometre for the use of the new Toyota Corolla would be 0.4 cents. As a result, the PCO for the new Toyota Corolla, and new and used Nissan Leaf would fall to 36.5 cents, 41.5 cents and 23.5 cents respectively (**Figure 14**).



**Figure 14. PCOs for new and used light EVs and ICEVs over a 12-year period, showing impact of the proposed feebate (author’s calculation)**

### 5.7 Emissions reduction potential of EV

The emissions reduction potential of light EVs is analysed at both a micro-level (emissions reduction through replacing a light ICEV by a light EV) and a macro-level (emissions reduction from New Zealand transport sector). The detailed analysis is as follows.

This study calculates the emissions reduction potential of a light EV from a user perspective instead of a life-cycle perspective because New Zealand does not manufacture or recycle cars. However, we explore the emissions from battery manufacturing and recycling (life-cycle analysis of emissions) to make the study useful for the broader community. To measure the emissions reduction potential of light EVs, annual emissions from a light EV and ICEV are initially determined. Annual emissions from a light EV and ICEV are determined using the life cycle emission model of Elliot, McLaren, and Sims (2018). **Figure 15** shows the major stages of the life cycle emissions of light EVs and ICEVs.

Here, emissions from the manufacturing stage include the total emissions from the mining of ore, transformation of materials, manufacturing of vehicle parts and assembly of vehicle parts (Hasan & Chapman, 2019). Emissions due to the transportation of a light EV or ICEV from the manufacturing country to New Zealand are taken from literature (Elliot et al., 2018). Emissions from the use phase are calculated based on three factors: vehicle efficiency, fuel carbon intensity and annual distance travelled. Emissions from a light EV and ICEV in the



recycling stage include emissions associated with vehicle dismantling, battery recycling, vehicle recycling and the recovery of materials (Hasan & Chapman, 2019).

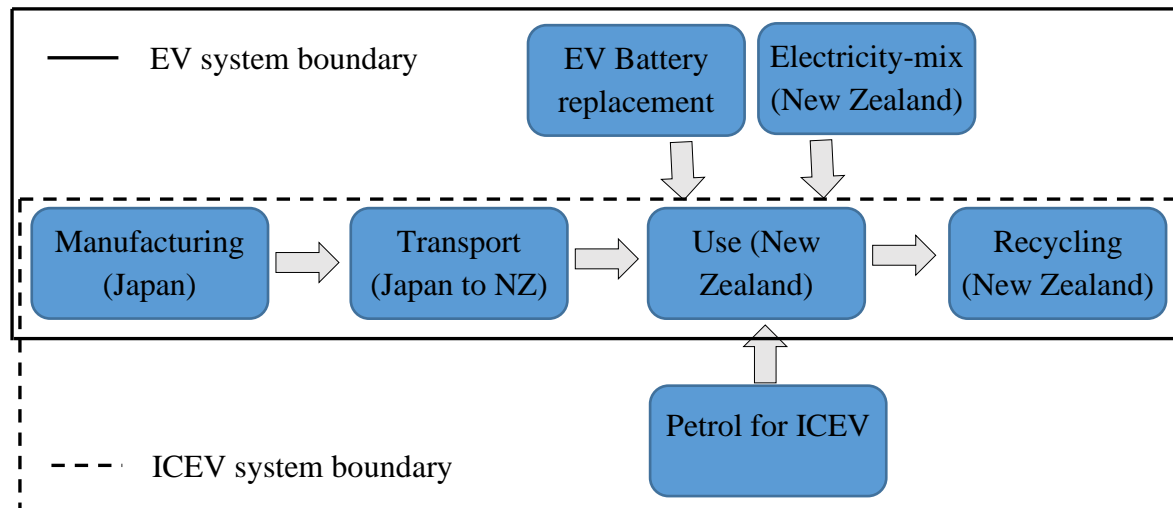


Figure 15. Stages of life cycle emissions of light EVs and ICEVs (source: adapted from Elliot et al. (2018))

Table 9 presents the life cycle emissions of a light ICEV and EV in different stages. From Table 9, it is evident that although the emissions reduction potential of light EVs at user level is quite significant (around 90%), emissions due to vehicle manufacturing (including battery for light EVs) and recycling are higher for EVs than ICEVs. Emissions from vehicle transport from Japan to New Zealand are the same for light EVs and ICEVs as the origin and destination are the same for both of these cars. According to Elliot et al. (2018), vehicles are mostly transported in a container ship fuelled by heavy fuel oil and emissions in this stage are 1% of its Global Warming Potential (GWP). Therefore, emissions due to vehicle transport are estimated to be 2.3 gCO<sub>2</sub>/km for both a light EV and a light ICEV.

Qiao et al. (2019) compared emissions between a light ICEV and a light EV in China at the other three stages (i.e. manufacturing, use, and recycling) and found higher GHG emissions for light EVs than ICEVs at the manufacturing and recycling phases. The difference in emissions was mostly due to the additional emissions in battery manufacturing and recycling. In 2015, per kilometre emissions from light EV battery manufacturing and recycling were around 23.5 gCO<sub>2</sub> and 5.1 gCO<sub>2</sub> respectively. However, Qiao et al. (2019) assume an improvement in battery technology, and expect emissions from light EV battery manufacturing and recycling to be around 22 gCO<sub>2</sub>/km and 4.9 gCO<sub>2</sub>/km respectively in 2020. Adding in emissions due to

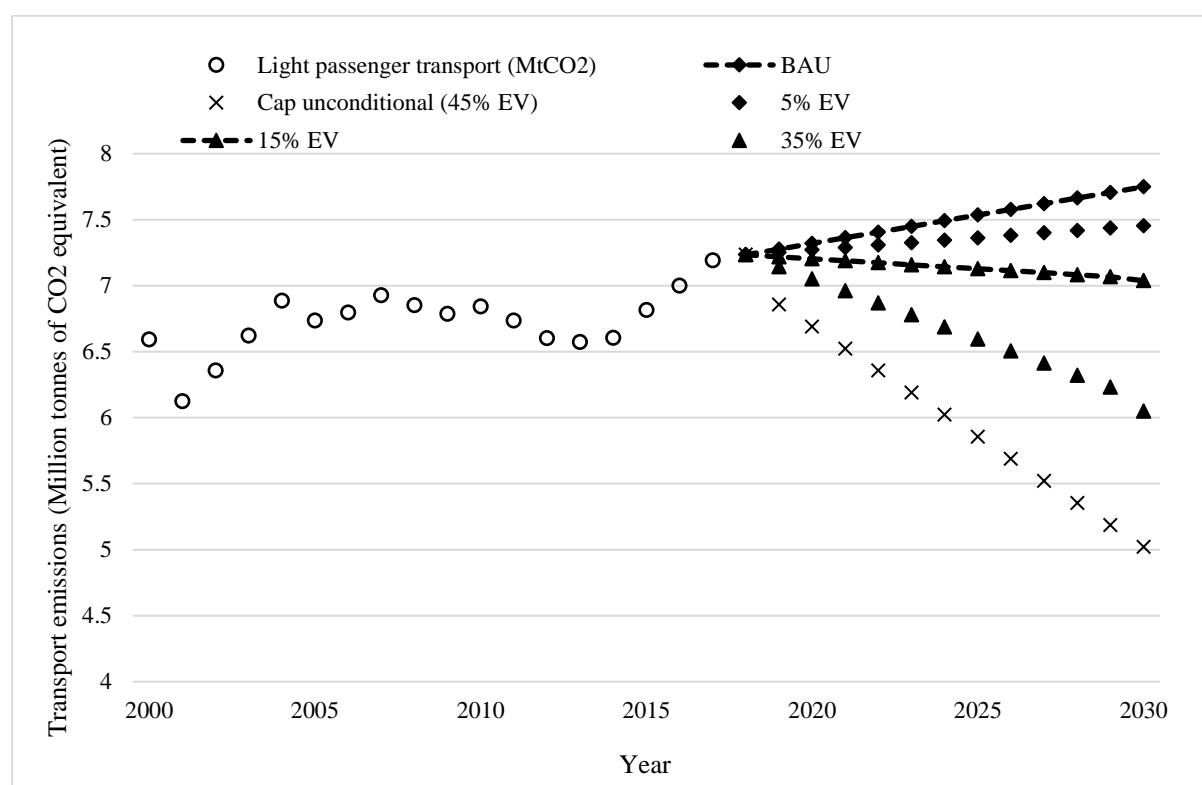
battery manufacturing and recycling reduces the overall emissions reduction potential of light EVs. The total life-cycle emissions of light ICEVs and EVs were 344.4 gCO<sub>2</sub>/km and 141.6 gCO<sub>2</sub>/km respectively, while the emissions due to vehicle operation (use) alone were 251.0 gCO<sub>2</sub>/km and 25.0 gCO<sub>2</sub>/km respectively (Table 9.). This indicates a life cycle emissions reduction potential of 59% for light EVs, as opposed to 90% when *excluding* manufacturing and recycling emissions. Likewise, the Energy Efficiency and Conservation Authority (EECA) of New Zealand found that, across the lifetime, the emissions reduction potential of a light EV compared to a light ICEV is around 60% (EECA, 2015). A similar result was found for European Union (EU) countries: Moro and Lonza (2018) used a well-to-wheels methodology to compare the life-cycle emissions of a light EV with a light ICEV, and concluded that in the EU, using a light EV saves 60% of GHG emissions.

**Table 9. Life cycle emissions of light ICEVs and EVs in different phases (adapted from Qiao et al. (2019) and Elliot et al. (2018))**

Phase	Processes	GHG emissions* (gCO <sub>2</sub> /km)	
		ICEV	EV
Manufacturing	Ore mining	77.9	96.4
	Material transformation		
	Component manufacturing		
	Vehicle assembly		
Transport	From Japan to New Zealand	2.3	2.3
Use	Vehicle driving	251	25
Recycling	Dismantling	13.2	17.9
	Vehicle recycling		
	Battery recycling (for EV)		
Total life-cycle emissions		344.4	141.6
*assumes annual VKT in 2018 is 10,500 kilometres, annual increase in VKT is 1.2%, and vehicle ownership/life is 12 years or 150,000 km, whichever comes first			

Under the Paris agreement in 2015, New Zealand committed to reduce its emissions by 11% from the 1990 emissions level by 2030. However, in **Figure 16**, the emissions trajectory of New Zealand's light passenger transport shows that emissions from this sector are likely to reach 7.7 MtCO<sub>2</sub> in 2030, which will be around 38% above the 1990 level. If the light passenger transport sector plays its part to achieve the unconditional emissions reduction target under the Paris agreement, emissions from this sector need to be kept to 5.0 MtCO<sub>2</sub> by 2030. An increased uptake of light electric vehicle could contribute significantly to achieving that target. Analysis reveals that replacing a Toyota Corolla by a Nissan Leaf could reduce 226 gCO<sub>2</sub> in per kilometre travel, which is around 90% of the total emissions per kilometre of travel by a

Toyota Corolla. Therefore, a 5% share of electric vehicle in the light-passenger vehicle fleet by 2030 is expected to reduce GHG emissions by 0.4 MtCO<sub>2</sub>. Likewise, 15%, 35% and 45% shares for light electric vehicles by 2030 are anticipated to reduce emissions by 0.7 MtCO<sub>2</sub>, 1.7 MtCO<sub>2</sub> and 2.7 MtCO<sub>2</sub> respectively (**Figure 16**). Most importantly, a light electric vehicle share of 45% will help this sector play its part to achieve the unconditional emissions reduction target for 2030 of the government under the Paris agreement.



**Figure 16. Emissions reduction potential at user level under different light EV uptake scenario (Author's calculations)**

### 5.8 Co-benefits of using an electric vehicle

The transport sector is one of the fastest growing economic sectors in the world. Use of fossil fuel in the transport fleet is a growing concern worldwide due to its contribution to climate change, congestion, and pollution of the environment. Moreover, the increasing consumption of fossil fuel in this sector risks the energy security of a country (Foley, Tyther, Calnan, & Gallachóir, 2013). Switching to EVs will therefore create co-benefits. Investment in EV will generate new employment in the transport sector. Local investments in EV components such as public charging infrastructure development, power plants, batteries etc. will create new jobs in this sector, some overseas, but many in New Zealand. However, there will also be job losses in the ICEV maintenance sector. The biggest benefit is likely to be reduction in air pollution.

Alternative vehicles like EVs help ensure cleaner air by reducing different types of pollutants such as particles, sulphur dioxide, nitrogen oxides and other toxic compounds. Overall, there are substantial health benefits of introducing EVs in the transport sector.

## **5.9 Major barriers and uncertainty to increase the uptake of electric vehicles**

The uncertainties and major barriers to the uptake of EVs in New Zealand are diverse. These barriers and limitations are explained under four major categories in this section. These categories include barriers related to (i) Price gaps and vehicle design, (ii) fuel infrastructure, (iii) safety aspects, and (iv) policy gaps.

### **5.9.1 Price gaps and vehicle design**

The initial price of EVs is higher than that of ICEVs. Since the ICEV is manufactured at large scale across the world, the price of an ICEV is relatively low. To date, the production scale of the EV is much small and the price is higher. However, the price of the EV including the battery has been falling recently due to technological advancement and governmental policy measures (Cano et al., 2018). As a result, the initial purchase price gap between an EV and an ICEV is narrowing. The driving range of the electric car is another major issue as most recent EVs are still short-range. Again, this barrier is diminishing as ranges improve. Although it is expected to be less problematic to maintain an EV as the number of ‘moving parts’ in an EV is very small, the maintenance practice of an EV is relatively new while the driving and maintenance practice of an ICEV is well established.

### **5.9.2 Fuel/charging infrastructure**

The required domestic infrastructure to recharge an EV is a socket to plug in the EV. Therefore, it is relatively cheap and easy to extend EV refuelling infrastructure. A study shows that the availability of public charging infrastructure increases the uptake of electric vehicles (Egnér & Trosvik, 2018). Beside traditional road-side fuel stations, charging facilities can be built at parking lots and other public places. The time required for charging an EV is higher than for an ICEV, which is another challenge to increase the uptake of EVs. Installation of fast charging facilities and on board range extenders are some possible alternatives to reduce EV charging time.

### **5.9.3 Policy gaps**

To increase the uptake of light EVs, the initial price of light EVs would need to be more competitive with light ICEVs. Exemption from vehicle tax, other fiscal incentives, free parking

facilities, and introduction of a quota system for specific types of electric cars are some of the effective ‘pull’ policy options for large scale uptake of light EVs. Findings from a recent study show that for every USD 1,000 tax rebate or credit, the average sales of EVs increase by 2.6% (Jenn, Springel, & Gopal, 2018). However, some of these options have significant disadvantages e.g. free parking, which would distort urban land use. ‘Push’ policy options such as an effective (higher price) New Zealand Emissions trading Scheme (NZ ETS) or other form of carbon price, a stringent fuel economy standard, and cleaner emissions standard could also play a role in light EV take-up in New Zealand.

Examples of different policy options already implemented in various countries across the world to increase the uptake of EVs are as follows- (i) income tax deduction or credit for EV purchase in Austria, the Netherlands, Belgium, Israel and the United States; (ii) rebate or grants on EV purchase or lease in Sweden, Spain, the United Kingdom, the United States, Canada and China; (iii) fee-bate scheme (fee for high-emitting vehicles and rebate for low-emitting vehicles) in Sweden, France, Belgium, Spain, Austria, Ireland, Luxembourg, Estonia, Singapore, Japan, China and New Zealand (in the consultation phase); (iv) tax reduction or exemption on vehicle registration or purchase in Sweden, Belgium, Denmark, the Netherlands, Norway, Portugal, Finland, Romania, the United Kingdom, the United States, Costa Rica, Japan, Singapore, Malaysia, India and Israel; (v) reduction in or exemption from annual road tax or tonnage tax in Sweden, Norway, Austria, Denmark, Germany, Switzerland, Greece, Portugal, the United Kingdom, Ireland, Italy, Czech Republic, Latvia, the United States, India, Japan, Australia, and New Zealand; (vi) free or discounted battery charging facility in Norway, the Netherlands, and the United States; (vii) access to high occupancy lanes or bus lanes in Norway, the Netherlands, Portugal, the United States, Canada and Korea; (viii) reduction in or exemption from parking charges in public parking spaces in Norway, France, the Netherlands, Denmark, Portugal, the United Kingdom; (ix) preferences in public procurement in Sweden, France, Belgium, Italy, Portugal, Bulgaria, the United Kingdom, Estonia, the United States, Japan, and Korea; (x) income tax rebate, credit or grant for private charging infrastructure in Denmark, Belgium, the United States and Canada (Metcalf & Kuschel, 2015).

Some of these policies presented above are not appropriate for New Zealand, while some policies have not yet been adequately considered by the New Zealand government. For example, New Zealand roads are not wide enough to allow EVs to use high occupancy lanes or bus lanes, especially as EV number grow, slowing buses. On the other hand, the proposed feebate scheme could be designed with an aim to strongly support the 2050 net zero emissions

target of the government (Ministry of Foreign Affairs and Trade, 2018). The cost burden on various income groups due to a feebate scheme could be investigated as well. Although a higher carbon price in the form of an increased NZ ETS price is proposed by Hasan et al. (2020) to promote EVs in New Zealand, such policy options have not been adequately considered by the New Zealand government. Hasan et al. (2020) estimate that an increase of ETS price to NZD 235/tCO<sub>2</sub> could reduce transport emissions by about 44% from the 2016 level by 2030, which is broadly equivalent to the Paris target. This study notes that the revenue generated through an increased carbon price could be utilised to build EV infrastructures and fund EV purchase. It could also be used to assist a 'just transition'. Besides such policies, building public awareness to change people's perceptions would also be helpful for increasing EV uptake. Uncertainties and risks associated with EV driving range, charging infrastructure, safety, policy intentions, and permanence of policies could be clarified for the public in the light of advances and up to date research initiatives.

#### 5.9.4 Safety

There is no difference in the road safety regulations applying to an EV or ICEV. However, the use of a lithium-ion battery in EVs create a safety issue as it has a tendency to catch fire (Chen, Xiong, Lu, & Li, 2018). To address this issue Tesla, Nissan, Volvo, Ford and other electric car manufacturers have installed some precautionary devices such as circuit and fuse breaker, radiator-chilled coolant etc. A zinc-air battery is another low cost safe option because zinc is less toxic in nature (Hanley, 2018; Linden & Reddy, 2002).

### 5.10 Conclusions and policy implications

A key finding from this chapter is that in New Zealand, light used EVs offer financial gains over ICEVs and this edge is likely to increase over time. The PCO for a used light EV is the lowest across the vehicle types examined in this study. Although the initial purchase price and the battery replacement price of a new light EV are much higher than costs of a new and used light ICEV, the PCO for a new light EV is competitive with a new light ICEV under the proposed feebate scheme (clean car discount). The proposed 'Clean Car Discount', from 2021, would reduce the PCO for a new Toyota Corolla, and new and used Nissan Leaf by 0.4 cents, 6 cents and 2 cents respectively. While it remains true that on the present (baseline) scenario, the PCO for new light EVs is higher than for new and used light ICEVs, lower-income households would be advantaged by switching to a used light EV.

This chapter also underlines that there is substantial potential to reduce GHG emissions from the New Zealand transport sector through increasing the uptake of light EVs. New Zealand has a high share of renewable energy in its power-generation mix and thereby EV upstream emissions are low. The GHG emissions from a light EV in New Zealand are measured as around 25g per kilometre (25gCO<sub>2</sub>e/km). In contrast, the per kilometre emissions in the Japanese, American, and European contexts for petrol-powered cars are measured as considerably higher. Findings show that light EVs in New Zealand have the potential to reduce New Zealand's carbon emissions by 226 gCO<sub>2</sub>e per kilometre of travel. This indicates that replacing a regular car with a light EV can reduce emissions by around 90% (in terms of the use phase). A 45% share of electric vehicle in the total light passenger vehicle fleet will help to achieve a sector emissions reduction target of 11% from the 1990 emissions level by 2030 (the unconditional emissions reduction target under the Paris agreement) which is assumed to apply to New Zealand's transport emissions.

Despite being competitive with light ICEVs and having high emissions reduction potential at user level, the uptake of light EVs in New Zealand has so far been slow. This is mainly due to the high initial purchase price and negative perceptions of the public about EV use. This study found that the uncertainties and barriers associated with EVs could be addressed through appropriate policies. There are policy gaps that need to be addressed if an increase in the uptake of light EVs in New Zealand is to be assured. The recently proposed feebate scheme would help fill an important policy gap identified by the New Zealand Ministry of Transport, which noted that the country is one of only three developed countries that has no effective incentives or regulation to ensure the import of efficient fuel cars into the country (Ministry of Transport, 2019d).

Besides the feebate scheme, introduction of an increased carbon price could also play a crucial role in increasing light EV uptake. The introduction of a carbon price and/or carbon tax has successfully reduced GHG emissions from the transport sector in many countries such as Sweden, Norway, Denmark, Switzerland etc. However, no feasibility study on the introduction of a carbon tax rather than the ETS, or on top of the ETS in New Zealand, has so far been carried out. This necessitates a feasibility study on a higher carbon price and its impact on emissions reduction. Most importantly, while considering the introduction of a carbon tax or an increased ETS price, the cost burdens of the price increase on low-income people need to be evaluated. Therefore, the next chapter, investigates the costs and emissions reduction potential of an increased carbon price.

## **Chapter 6: Cost burdens and mitigation potential of a higher carbon price**

The contents of this entire chapter are published in **Climate Policy** and can be found here: <https://doi.org/10.1080/14693062.2020.1750334>

### **Summary findings**

In this chapter, we investigate the scope for a targeted price signal to curb emissions growth and help deliver on the country's Paris Agreement pledges. Cost burdens on various income groups are investigated. We estimated the social cost of carbon and the price elasticity of demand for fuel to understand the mitigation potential of a higher carbon price. The findings are that with a price elasticity of demand for transport fuel of around -0.7, a carbon price between NZD 100 (USD 65) per tonne of carbon dioxide (tCO<sub>2</sub>) and NZD 235/tCO<sub>2</sub> could reduce transport emissions by between 33% and 44% in 2030, respectively, from the 2016 level. The (uncompensated) cost burdens on low income households due to a hypothetical price of NZD 100/t CO<sub>2</sub> (lower price case) and NZD 235/tCO<sub>2</sub> (higher price case) are estimated to be around NZD 531/year and NZD 670/year per household respectively. These findings have potential policy implications for New Zealand as it develops its mitigation efforts, and may provide reference values for other countries considering faster mitigation.

### **6.1 Introduction**

Globally, greenhouse gas (GHG) emissions from the transport sector have experienced unprecedented growth over the past two and half decades (Campbell, Zhang, Yan, Lu, & Streets, 2018). Over the same period, New Zealand's transport sector also experienced a rapid increase in total GHG emissions, almost all of which are carbon dioxide. Between 1990 and 2016, carbon emissions from domestic road transport in New Zealand increased around 92% – the highest across all energy and non-energy sectors (Ministry for the Environment, 2018b). Total annual emissions from New Zealand's domestic road transport in 1990 were around 8.0 MtCO<sub>2e</sub>, increasing to 13.6 MtCO<sub>2e</sub> in 2016 (Ministry for the Environment, 2018b). Under the Paris agreement, New Zealand pledged an unconditional target – a Nationally Determined Contribution (NDC) – to reduce its gross emissions by 11% from the 1990 level (i.e. 30% below its 2005 level) by 2030 (Ministry for the Environment, 2018c). If the domestic road transport sector aims to play a proportional part, it needs to reduce its emissions to 7.1 MtCO<sub>2e</sub> by 2030. This requires reducing domestic road transport emissions by about 48% from the 2016 level by 2030, a demanding task.



Increasing population numbers, urban sprawl, cheap prices of second-hand fossil-fuelled cars, no vehicle emissions standards, and a weak climate policy signal from the New Zealand Emissions Trading Scheme (NZ ETS) have increased car dependency and fossil fuel consumption, and thereby carbon emissions (Chapman, Howden-Chapman, Whitwell, & Thomas, 2017). To mitigate climate change by reducing GHGs, different countries and regions have adopted a variety of market and non-market based climate-related policies. Among these, introduction of a carbon price has been found to be an effective market-based tool across the world (Calderón et al., 2016; Dulal, Dulal, & Yadav, 2015; Pereira, Pereira, & Rodrigues, 2016; Zhang & Zhang, 2018). Over the last decade, the world experienced a growing interest in carbon pricing (The World Bank, 2018). As of 2019, 57 carbon pricing schemes (28 ETSs and 29 carbon taxes) are implemented and scheduled across the world. ETSs are applied on regional, national and sub-national levels while carbon taxes are mainly implemented at a national level (World Bank Group, 2019). Besides governments and regional authorities, over 500 global private companies have employed an internal carbon price, considered while making decisions on technologies and strategies. (Ecofys, 2018). As a result, about 20% of global GHG emissions are now covered by pricing in one form or another (emissions trading schemes or carbon taxes) and this coverage is expected to reach 25% by 2020 (Ecofys, 2018; World Bank Group, 2019).

New Zealand opted for an Emissions Trading Scheme (ETS) in 2008 to help reduce its GHG emissions in line with international pledges. But this carbon pricing scheme has had very little impact in achieving the government's emissions reduction targets due to its settings and a weak and variable price signal (Chapman et al., 2017; Ministry for the Environment, 2014). Since around 99.5% of the fuel consumed in the road transport sector comes from fossil fuel sources, putting a high price on carbon to better reflect the global social cost of carbon (i.e. the estimated global damage caused by a tonne of carbon dioxide) is expected to bring significant change in people's fuel use and various transport-related behaviours, and contribute to transport emissions reduction.

A social and political consideration in raising a carbon price is its uneven economic burden on different income groups. Surprisingly, there has been no serious investigation of cost burdens due to carbon prices on different income groups in New Zealand. The mitigation potential of an increased carbon price in New Zealand is also unknown. Most importantly, the choice of a suitable carbon price instrument based on the social, economic and political context of New Zealand has been little explored (Bertram & Terry, 2010; Chapman, 2015; Inderberg, Bailey,

& Harmer, 2017). This chapter aims to address these gaps by using two different methodologies. The social cost of carbon (SCC) is the fundamental input which, in conjunction with the price elasticities of fuel demand and travel demand, is used to estimate the mitigation potential and cost burdens of an increased carbon price. Views on the relative advantages and disadvantages of an increased ETS price and a carbon tax are sought through a multi-criteria analysis (MCA) technique where criteria used include costs, benefits, mitigation potentials and ethical aspects.

The contributions of this chapter are potentially threefold. First, having estimated the cost burdens of low and high carbon prices on New Zealand households, we compare these to price impacts seen in New Zealand in the past. Second, we estimate the impact of low and high carbon prices on New Zealand's transport emissions reduction. Third, we explore the relative merits of an increased ETS price and a carbon tax 'in the round' – i.e. considering cost, benefit, mitigation potential and ethical considerations.

## **6.2 Literature review**

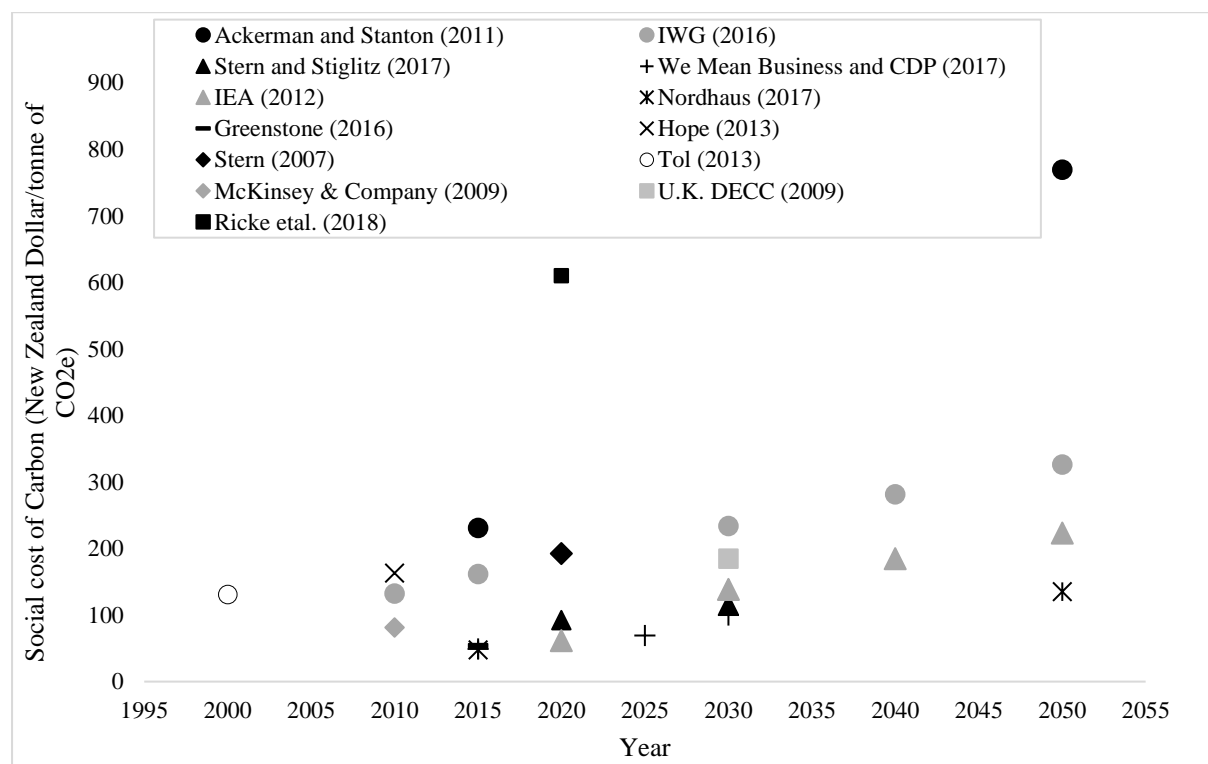
In this section, firstly, the literature on the social cost of carbon for New Zealand and other countries is explored. Next, research on fuel price elasticities as well as ETSs and carbon taxes is reviewed. Finally, a short review of MCA is presented.

### **6.2.1 Social cost of carbon**

The global social cost of carbon (SCC) usually refers to the (global) damage value of emitting one tonne of carbon dioxide into the atmosphere (Environmental Defense Fund, 2019). Due to differences among damage estimation models, the estimation of the SCC varies significantly and often receives strong criticism by economists and researchers (Pezzey, 2019). Ricke et al. (2018) estimated the median global SCC value as NZD 610 for 2020 while a recent estimate from Pindyck (2019) found a range of SCC values between approximately NZD 115 and NZD 295 for 2066. **Figure 17** shows a range of year-wise estimates based on previous literature and identifies that the SCC in 2050 varies from about NZD 770 (Ackerman & Stanton, 2011) to about NZD 135 (Nordhaus, 2017). Except for estimates by Ackerman and Stanton (2011) for 2050 and Ricke et al. (2018) for 2020, other estimates of SCC do not vary much (Greenstone & Cass, 2016; Stern, 2007; Tol, 2013). The SCC in 2030 is estimated between NZD 235 and NZD 100 (IEA, 2012; Stern & Stiglitz, 2017; U.K. Department of Energy & Climate Change, 2009; WE Mean Business and CDP, 2017) while the SCC values for 2010 range from NZD 165 to NZD 82 (Hope, 2013; Interagency Working Group on Social Cost of Carbon, 2016;

McKinsey and Company, 2009). From this research, it is evident that a median estimate of the social cost of carbon in 2030 would be about NZD 185, with minimum and maximum estimates of about 100 NZD and NZD 235 respectively. Therefore, this study takes NZD 100 as a low estimate of social cost and NZD 235 as a high estimate for 2030. By taking a lower bound that is far higher than the observed economy-wide price on carbon in any country, the study assumes that climate policy will ramp up significantly in the next decade. It is possible, of course, that this will not happen; but the purpose of the chapter is to investigate response under stronger climate policy, rather than the consequences of failure or a continuation of tepid policy.

The damages caused by a tonne of carbon exceed the marginal abatement cost (MAC) of carbon while rates of abatement remain low. As abatement increases, the costs of reducing emissions will generally rise and the damage costs of emissions at the margin may fall. Thus, the SCC figure represents a guide for an appropriate price (incentive for abatement) of carbon. Note that estimates for future years are higher, as damages from emissions are expected to rise over time. Using the SCC estimates above (NZD 100 and 235) as an indicator of what level the price of carbon would be set at if it better reflected social damages, this study estimates corresponding cost burdens and mitigation scenarios below.



**Figure 17. Estimates of social cost of carbon by different researchers (source: various)**

### 6.2.2 Price elasticity of demand for fuel and travel

The (own-) price elasticity of demand is an important parameter that indicates the change in demand for a product with a change in its price (Liang, 2012). The degree of change in demand due to a price change varies from product to product and depends largely on the availability of alternatives and the time period (short- and long-run) (Denson, 2019). According to Espey (1998), short-run responses of fuel demand to a price change could occur within a month, while the long-run effects could be observed within a quarter of a year or more. However, a New Zealand based study by Kennedy and Wallis (2007) on transport fuel price elasticities considered 0-1 year as a short-run period and over three years as a long-run period.

Transport fuel is often considered a highly price-elastic product especially following the development of renewable energy technologies. Researchers have estimated a variety of values for the price elasticity of transport fuel demand. A study of 27 OECD countries in the 2000s estimated that the price elasticity of transport fuel demand averaged -0.71 (Donovan et al., 2008). This indicates that an increase in fuel price by 10% would reduce the consumption of fuel by 7.1%. Graham and Glaister (2004) studied 113 cases across the world (both developed and developing countries) and reported that the average price elasticity of long-run transport fuel demand is -0.77. Based on a survey of 46 estimates, Goodwin, Dargay, and Hanly (2004) found that the mean estimated value of the price elasticity of long-run fuel consumption in the United Kingdom is -0.64. Another cross-national study by Graham and Glaister (2002) estimated a range between -0.6 and -0.8 for the long-run price elasticity of petrol consumption. Brons, Nijkamp, Pels, and Rietveld (2008) carried out a meta-analysis to estimate the price elasticity of petrol consumption and concluded that the long run elasticity is around -0.84. However, some studies including some New Zealand based studies observed low price elasticities of fuel consumption. Kennedy and Wallis (2007) estimated the price elasticity of petrol consumption for New Zealand in the short and long run as -0.14 ( $\pm 0.07$ ) and -0.19 ( $\pm 0.1$ ), respectively. Similarly, a recent study in Sweden found a short-run price elasticity of demand for petrol of -0.12 (Huse, 2018). Santos (2013) found that petrol demand in Brazil has a short-run price elasticity of -0.399, which is close to the estimates of Burnquist and Bacchi (2002) and Schünemann (2007) who estimated short-run price elasticities as -0.319 and -0.488 respectively. The low estimates of price elasticity in New Zealand could be due to the limited alternative transport options at the time in provincial and rural towns of New Zealand.

However, despite a low price elasticity estimate by Kennedy and Wallis (2007), the present study uses a range of price elasticities of transport energy demand, between -0.4 and -0.7, to

estimate the sensitivity of changes in fuel consumption in New Zealand with price, and thereby the sensitivity of emissions reduction to carbon price. This is due to the fact that in recent days most New Zealanders live in medium to large cities, and the use of alternatives to cars is gradually increasing (Chapman et al., 2017). We place more weight on the higher (absolute) elasticity value of 0.7 as it implicitly makes better allowance for a variety of behavioural adjustments over time.

With regard to the price elasticity of travel demand, it is found that travel demand is less elastic with respect to fuel price changes than is fuel demand (Odeck & Johansen, 2016). Odeck and Johansen (2016) estimated the price elasticity of travel demand in the short and long run as -0.11 and -0.24, respectively while their estimates for fuel demand were -0.26 and 0.36, respectively. In a recent study, Sheng and Sharp (2019) estimated the price elasticity of passenger travel demand in the short-run as -0.11. Fridstrøm and Alfsen (2014) studied the price elasticity of road transport demand using Norwegian data and found that the short-run fuel price elasticities ranged from -0.08 to -0.18 and the long-run elasticities lay between -0.17 and -0.27. In the present study we concluded that using a fuel price elasticity of travel demand of -0.2 is reasonable in estimating the cost burden on different income groups.

There are two main ways of introducing a carbon-pricing instrument: emissions trading schemes (ETSs) and carbon taxes (Wang-Helmreich & Kreibich, 2019). An ETS sets an overall emissions cap (declining over time) for emissions sources and allows emitters to trade for allocated emissions permits. The price of each emissions unit depends on the emissions reduction ambition of the jurisdiction (i.e. emissions cap) and the abatement costs of the emitting entities. In contrast, trading is not involved in a carbon tax and the tax rate per unit emissions is often determined based on economic, social, ethical and political considerations (Wang-Helmreich & Kreibich, 2019). An extensive literature has explored the design options and benefits of adopting a carbon tax (Jin, Shi, Emrouznejad, & Yang, 2018; Kuo, Hong, & Lin, 2016; Stram, 2014; Zhang, Wang, Liang, & Chen, 2016) and an ETS (Partnership for Market Readiness, 2016; Rosendahl & Strand, 2015; Trotignon, 2012; Yu & Xu, 2017). A carbon tax is more transparent, including more revenue raised, has arguably greater potential for raising revenue, but may be harder to adjust; whereas an ETS offers increased scope to the business sector for strategic behaviour.

Although some research has explored the practical aspects of both instruments (Dong et al., 2017; Haites, 2018), a comparative study of perceptions of both instruments based on multiple

criteria such as cost, benefit, mitigation potential and ethical considerations is not available, to the author's knowledge, for any country or jurisdiction. This study examines the ETS and tax alternatives using an MCA approach and explores their relative advantages and disadvantages of the two instruments.

### **6.3 Methodology**

The SCC is central to the methodological approach because it the most widely used method for estimating a scientifically based carbon price and its use helps to shed light on the cost burdens and mitigation potential of an increased carbon price (Boyce, 2018; Floros & Vlachou, 2005; Marron & Toder, 2014). In this study, estimates of SCC are combined with the price elasticity of travel demand (vehicle kilometres travelled) and households' travel demand (consumption) to estimate the cost burdens on different income groups (Boyce, 2018; Marron & Toder, 2014; Wang & Chen, 2014). To estimate the emissions reduction potential of an increased carbon price, the price elasticity of fuel demand is used in conjunction with the SCC (Boyce, 2018; Floros & Vlachou, 2005). Since the relative advantages and disadvantages of an ETS and a carbon tax need to be investigated in terms of various aspects including costs, benefits, mitigation potentials and ethical aspects, an MCA technique is adopted in this study. The methodologies are discussed in detail below.

#### **6.3.1 Calculating cost burden by income group**

This study uses five different income groups based on their annual average household incomes derived from Statistics New Zealand's Household Expenditure and Income Survey 2016. Households that earn below NZD 35,099 annually are considered low-income households while households earning over NZD 133,700 annually are considered high-income households. The three middle quintiles are lower-middle, middle and higher middle, with annual household income ranges in NZD of 35,100-60,599, 60,600-91,099, and 91,100-133,699, respectively. To calculate carbon price-induced cost burdens on different income groups, this study uses 2016 annual household expenditure data for domestic transport from Statistics New Zealand under four categories, namely spending on petrol car, passenger transport, domestic air transport and other private transport services (Statistics New Zealand, 2019). The prices of carbon used are based on the figures derived above: the carbon price under a low-price scenario is assumed to be NZD 100/tCO<sub>2</sub>, and NZD 235/tCO<sub>2</sub> under a high-price scenario. The emissions of CO<sub>2</sub> per litre of different types of fuel are taken from the technical literature and the percentage increases in fuel price per unit under low and high-price scenarios are calculated.

It is assumed that the increases in fuel prices per litre will reduce travel demand in accordance with the fuel price elasticities, and will increase the overall domestic transport expenditures of different income groups.

#### 6.3.2 Measuring emissions reduction potential

The price elasticities of demand for transport fuel are used here to estimate the emissions reduction effects of a carbon price. As noted above, this study disregards the outlier values of price elasticity of demand for transport fuel and considers the price elasticities of transport energy demand at -0.4 and -0.7 to examine the sensitivity of spending on fuel consumption, placing greater weight on the -0.7 value. Reductions in fuel consumption due to a carbon price induced fuel price rise are estimated using price elasticity values. The reduction in transport energy consumption will proportionately reduce transport CO<sub>2</sub> emissions.

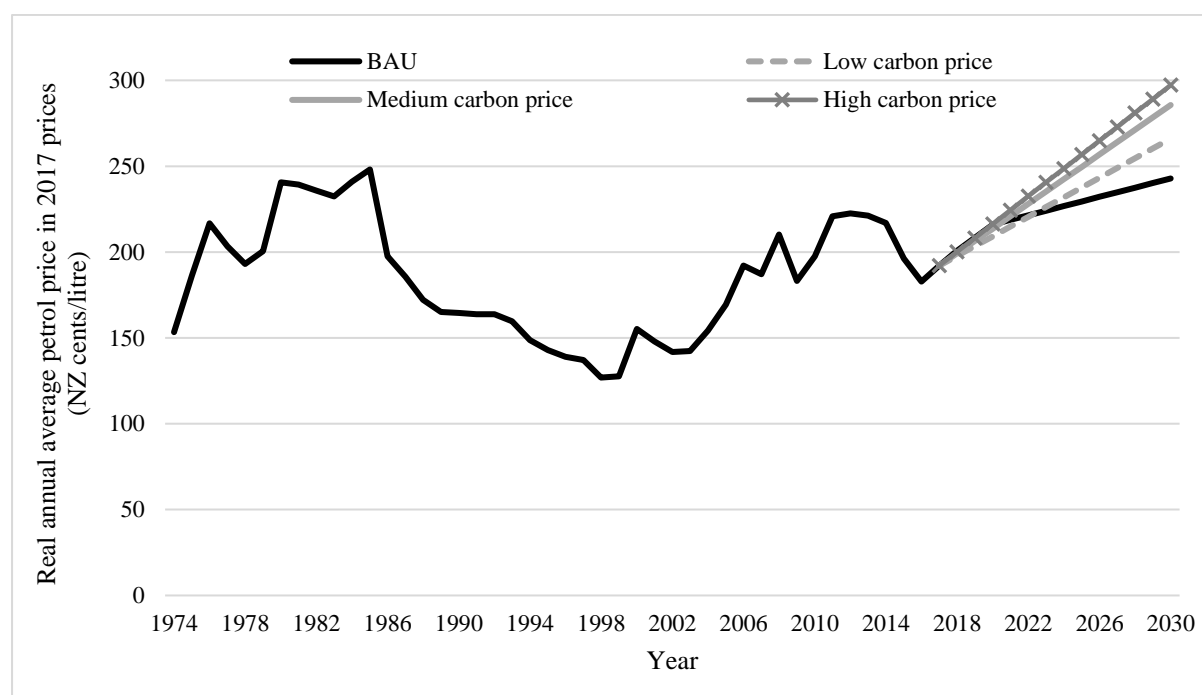
### 6.4 Results and discussions

#### 6.4.1 Fuel price scenario under different carbon prices

Introducing a carbon price of NZD 100 (low carbon price), NZD 185 (medium carbon price) and NZD 235 dollar (high carbon price) in 2030 is expected to increase the real price of petrol by NZ cents 23.1, NZ cents 42.8 and NZ cents 54.3, respectively from the business as usual price of petrol price in 2030 (**Figure 18**). The historic petrol prices in real 2017 NZ dollar terms between 1974 and 2017 show that the price of petrol reached its peak in 1985 at NZ cents 248.1. For comparison, in the low carbon price scenario the real price of petrol in 2030 is expected to be NZ cents 266. The real prices of petrol in 2017 NZ dollars for a medium carbon price and a high carbon price are expected to be NZ cents 285.6 and NZ cents 297.2, respectively.

Older New Zealanders have witnessed petrol prices on a par with those the study expects from the imposition of an appropriate carbon price. Two shocks hit New Zealand in the 1970s: one was the global shock accompanying the formation of the Organization of the Petroleum Exporting Countries (OPEC) oil cartel; the second, unique shock was the loss of New Zealand's favourable export relationship with the United Kingdom (New Zealand History, 2018). Both of these were major challenges for the New Zealand economy, which the Muldoon Government attempted to ride out by borrowing (Evans, Grimes, Wilkinson, & Teece, 1996). When, inevitably, the bill came due, New Zealand was ill-equipped to deal with it: the final days of the Muldoon administration saw a macroeconomic crisis as Muldoon tried to avoid the inevitable devaluation of the currency (Dalziel, 2002). When the incoming Lange Government

floated the exchange rate, the result was a strong devaluation (Evans et al., 1996). This combination of factors led to a period of very high real petrol prices in New Zealand in the early 1980s (**Figure 18**). Since the real price of petrol under different carbon price scenarios would be about the same in real terms as the prices in the early 1980s, an increase in petrol price equivalent to the mid-range carbon price (NZD 100/tCO<sub>2</sub> - NZD 235/tCO<sub>2</sub>) is not likely to affect the economy significantly more than the specific price did in the late 1970s and early 1980s.



**Figure 18. Real annual average prices of petrol, 1974 - 2030, in 2017 prices (Ministry of Business, Innovation & Employment, 2018b) compared with projected carbon prices (author's generation)**

#### 6.4.2 Cost burdens on different income groups

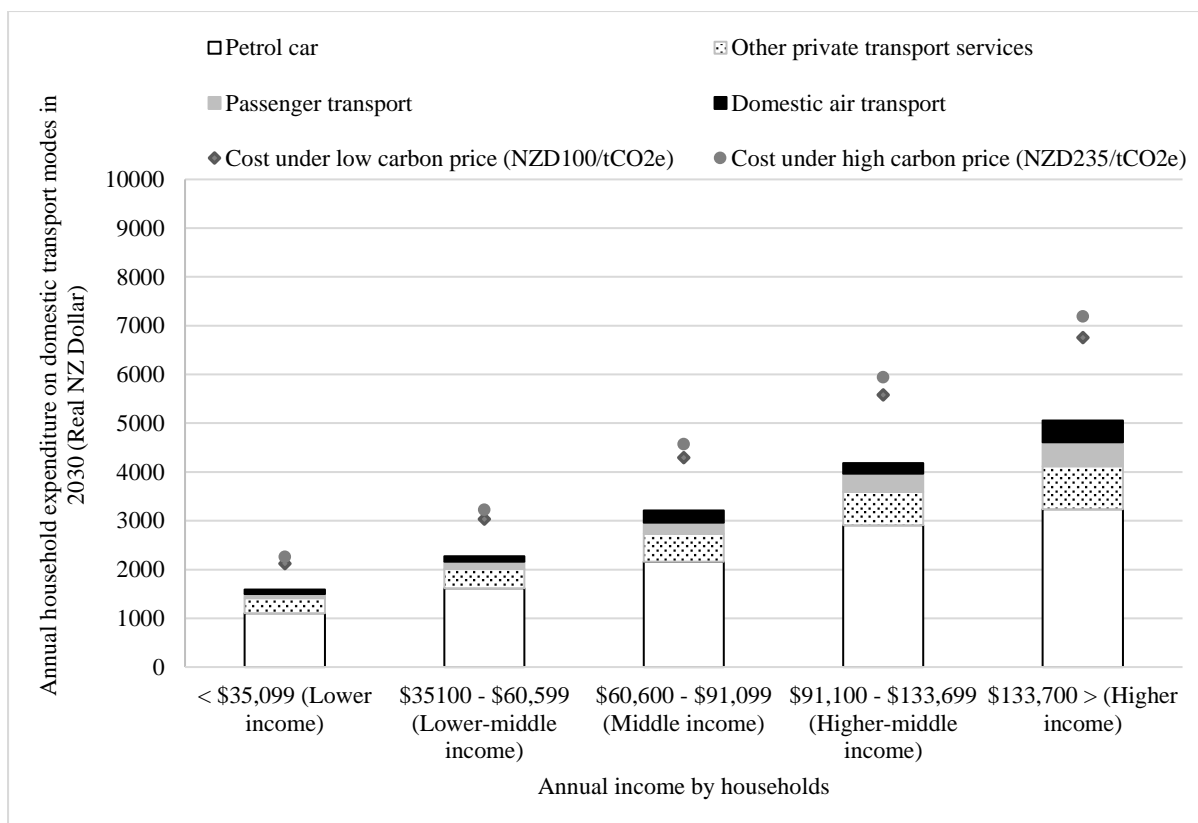
The increase in fuel prices due to a carbon price will increase household expenditure on domestic transport costs. Carbon price induced annual cost-burdens on different income groups will depend on their annual domestic transport expenditure. The household expenditures on domestic transport in New Zealand are categorised under four expenditure types by Statistics New Zealand. These are expenditures on (i) petrol/diesel car transport, (ii) passenger transport (including bus and train transport), (iii) domestic air transport and (iv) other private transport services (such as taxis). **Figure 19** shows that annual household expenditures on domestic transport increases with annual household incomes. The annual average expenditure on domestic transport for low-income households (annual average income below NZD 35,000) is



around NZD 1,590 while the average expenditure for the highest income households (annual average income over NZD 133,700) is around NZD 5,060.

Annual household expenditure on car transport is the highest for all income groups and the lowest expenditure type is domestic air transport. Low-income households (earning below NZD 35,000) spend around 70% (NZD 1,105) of their domestic transport expenditure on car use while the highest income group (households with an annual average earning of over NZD 133,000) spend a marginally lower proportion, 64% (NZD 3,240), of their domestic transport expenditure on car use. For low-income households, expenditures on passenger transport, domestic air transport and other private transport services are around 5.2%, 5.7% and 19.5% respectively. For the highest income group, these expenditures are 9.8%, 8.8%, and 17.3% respectively.

Cost burdens on different income households due to different carbon price options (low and high carbon prices) depend on the price elasticity of travel demand and are proportionately related to their domestic transport expenditures. Study findings suggest that cost burdens due to low and high carbon prices vary between around NZD 531 and NZD 2,133 annually. For lower income households, a carbon price of NZD 100/tCO<sub>2</sub> and a fuel price elasticity of travel demand of -0.2 are expected to increase their annual domestic transport cost from around NZD 1590 to NZD 2,121. The increase of domestic transport expenditures due to a carbon price of NZD 100/tCO<sub>2</sub> on lower-middle income, middle income, higher-middle income and higher income households are around NZD 761, NZD 1,078, NZD 1,402 and NZD 1,697 respectively. The cost-burdens on different income groups due to a high carbon price of NZD 235/tCO<sub>2</sub> in 2030 are expected to be around NZD 670, NZD 958, NZD 1,356, NZD 1,764, and NZD 2,133 respectively (**Figure 19**).



**Figure 19. Increase in domestic transport expenditure of different income groups in 2030 due to a high and a low carbon price (Statistics New Zealand, 2019)**

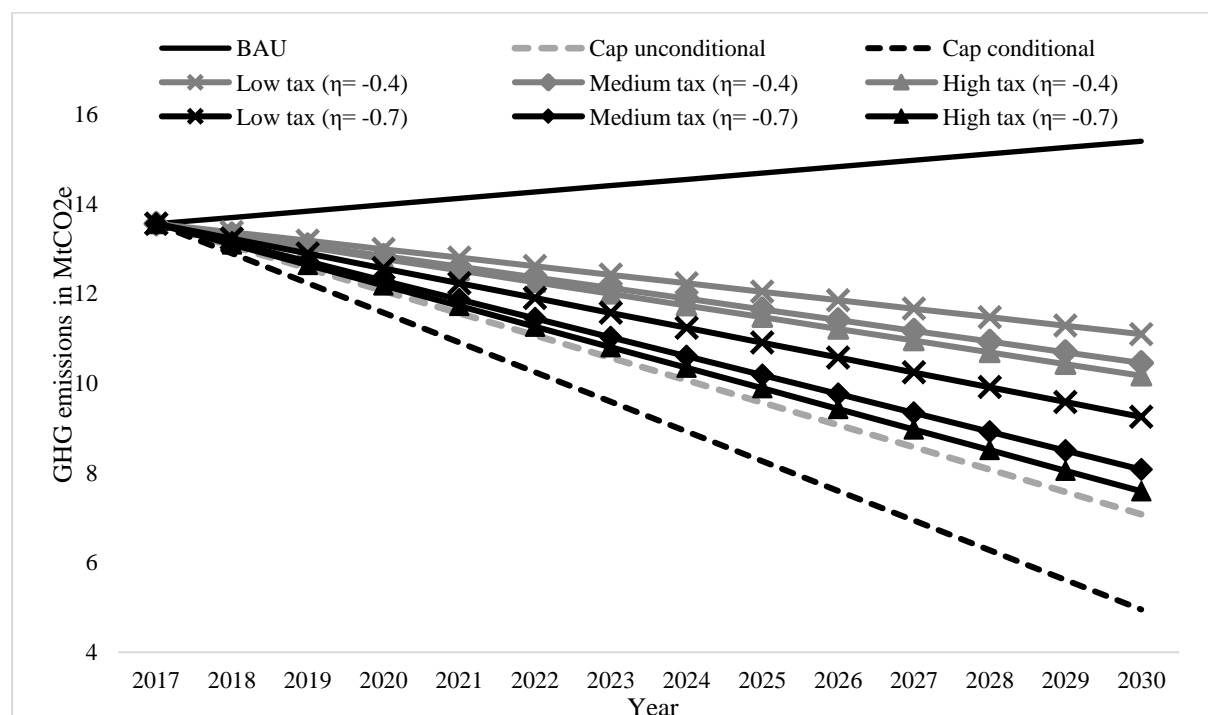
#### 6.4.3 Mitigation potential

The emissions reduction potential of an increased carbon price depends on the price elasticity of demand for fuel value ( $\eta$ ). The price elasticity values estimated in this study are (-) 0.4 and (-)0.7. A price elasticity value of -0.7 indicates that an increase in fuel price by 10% will reduce fuel consumption as well as emissions by 7%. Emissions reduction potentials of different carbon prices are estimated using both price elasticity values. In 2016, emissions from domestic road transport in New Zealand were around 13.6 MtCO<sub>2</sub> compared with around 10.7 MtCO<sub>2</sub> in 2001 (Ministry for the Environment, 2018b). If this growth trend continued, emissions from this transport sub-sector would reach around 15.4 MtCO<sub>2</sub> in 2030.

Estimates using a price elasticity of (-) 0.4 and a carbon price of NZD 100/tCO<sub>2</sub> are that emissions from domestic road transport will reduce to 11.0 MtCO<sub>2</sub> in 2030 (**Figure 20**). The annual average rate of decline in emissions over 2017-2030 would be around 1.6%. The average rate of decline over this period under the same price elasticity value but a higher price of carbon (NZD 235/ tCO<sub>2</sub>) would be 2.2% per year, with emissions in 2030 around 10.2 MtCO<sub>2</sub>. The emissions reduction potential with a higher price elasticity value is higher. With a price elasticity of -0.7 and a carbon price of NZD 100/tCO<sub>2</sub>, emissions would reach 9.0 MtCO<sub>2</sub>

in 2030 (an annual average rate of decline of 3.1%). The most rapid emissions reduction scenario would be for a price elasticity value of -0.7 and a carbon price of NZD 235/tCO<sub>2</sub>. Expected emissions from domestic transport in 2030 under this scenario would be around 7.6 MtCO<sub>2</sub> (44%) and the average rate of decline between 2017 and 2030 would be about 4.4% per year.

Interestingly, emissions in 2030 under a price elasticity value of (-) 0.7 and a carbon price of NZD 235/tCO<sub>2</sub> would almost meet the unconditional target of the New Zealand government under the Paris agreement. New Zealand aims to reduce its GHG emissions by 11% from the 1990 level or 25% from the 2005 level by 2030 without any condition (Ministry for the Environment, 2019a). This indicates that introducing a high carbon tax of NZD 235/tCO<sub>2</sub> and ensuring an increased number of alternative modes and transport fuels (to increase price responsiveness) could help the transport sector to play its part in achieving New Zealand's emissions target under the Paris agreement.



**Figure 20. Road transport emissions under different carbon price scenarios (Author's calculation)**

## 6.5 Conclusions and policy implications

Putting a high price on carbon is often viewed as regressive. The relative cost-burden on lower income groups can be significantly higher than on higher income groups. Although Creedy and Sleeman (2006) in a New Zealand study found that the distributive effect of a (proposed)

carbon tax was ‘not unambiguous’ (cited in NZPC, 2018, p. 291), the distributive effects of a high carbon price will no doubt need to be addressed. There are also possible issues related to the loss of international market competitiveness and certain types of jobs, which could impact differentially on different social groups. These are important considerations that warrant policy attention.

It is clear that a considerably higher carbon price on transport fuel would have a significant impact in reducing transport emissions. With a price elasticity of demand for transport fuel of -0.7, a carbon price of NZD 235/tCO<sub>2</sub> could reduce transport emissions by around 44% in 2030 from the 2016 level and could help this sector to play its part in achieving New Zealand’s unconditional target of emissions reduction under the Paris agreement.

This implies a fuel price comparable to prices in the early 1980s. Importantly, the petrol tax revenue in the late 1970s and early 1980s was spent on energy projects and heavy industries by Robert Muldoon’s National government instead of investments in public transport, demand management, and/or low-carbon alternative infrastructures (Challies & Murray, 2008). A more holistic approach to deploying the revenues from high fuel prices could help New Zealand build a climate-responsible economy and reduce further the emissions from different sectors. It might be argued that the increase in fuel price in the late 1970s and early 1980s was temporary and thus ‘discounted’, while today a high price would be seen as likely to stay longer and the effect on the economy might be greater. The effect depends on long-run elasticities and behavioural responses, both of which are highly uncertain on the timescale of several decades. Nevertheless, it is likely that the expected durability of the price increase would ensure more sustained emissions reductions and could help the price-responsive parts of the economy to become more efficient over time. It could also provide a very strong signal to investors to invest in renewable energy and energy efficient technologies and stimulate innovation towards cleaner production methods.

Finally, it is important to handle the transition period from a low carbon price to a high carbon price carefully. Strong political commitments and partnership between public and private are important to address the issues of the transition period. An increased carbon price in the form of a tax might allow the government to compensate low-income households and affected companies, reduce other taxes and help to invest in renewable energy sources, public transport infrastructures, etc. The administrative cost of an increased carbon price would be negligible as it can be implemented using existing systems. But the key is to move in a structured, organized and fair way without further delay. Individual actions are also important such as

choosing energy-efficient transport modes or engaging politically to encourage political leaders to act in a climate friendly way. Findings of this study have policy implications for New Zealand and other countries or states similar to New Zealand because it provides evidence that, despite having automobile dependent low-density development patterns and low fuel prices, achieving an emissions reduction target in the relatively difficult transport sector would be possible with a carbon price that is within the realm of relatively recent economic experience.

Although EVs and an increased price on carbon price are the two key instruments on the pathway to zero emissions for New Zealand, their acceptability to experts, and NGO and green energy activists in relation to other alternative measures including active and public transport, TDM, biofuels and clean emissions standards is unknown. Ranking all road transport emissions reduction measures based on a similar set of criteria will help policy advisers understand the most acceptable transport emissions reduction policies for New Zealand and their relative advantages or challenges. The findings are also likely to ensure an effective utilisation of New Zealand's available resources to mitigate New Zealand's burgeoning transport emissions and achieve their national and international emissions reduction targets. Therefore, the next chapter aims to investigate the acceptability and effectiveness of various transport emissions reduction policies using multiple criteria analysis (MCA).

## **Chapter 7: Multi-criteria analysis of transport emissions reduction policies**

The contents of this chapter are revised based on the suggestions of three anonymous reviewers who recommended publication after minor revisions at Renewable & Sustainable Energy Reviews. The article is likely to be available online in August 2020.

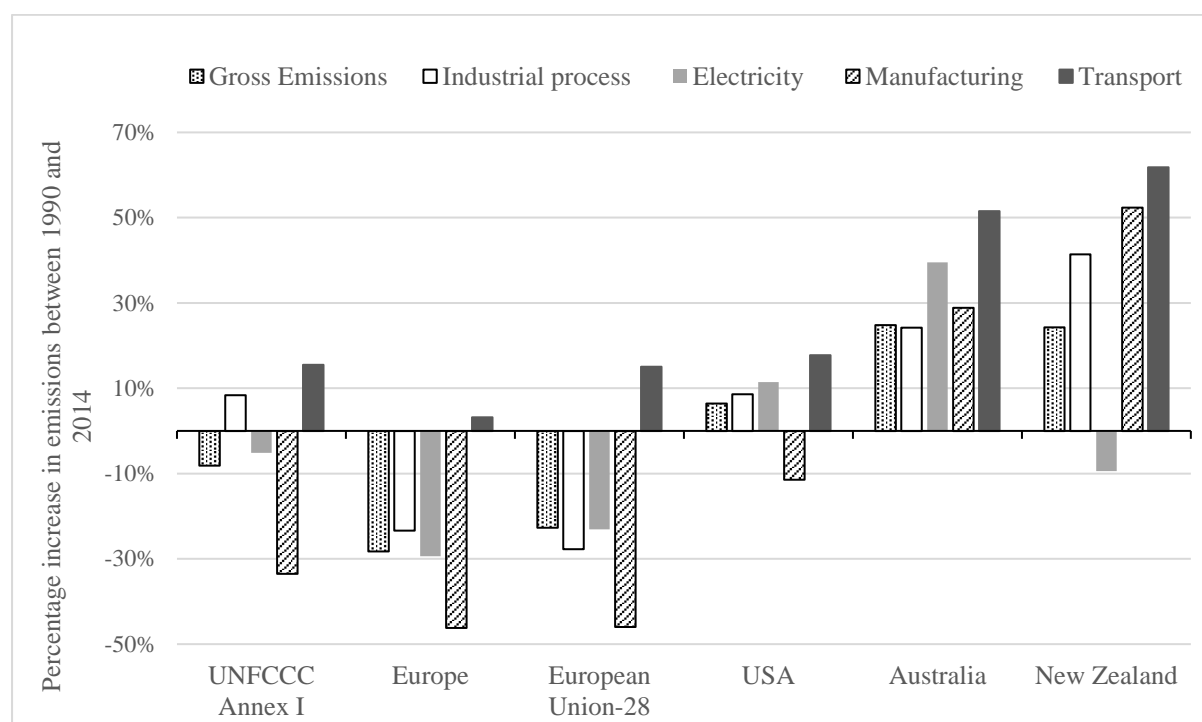
### **Summary findings**

Greenhouse gas emissions from the transport sector of New Zealand have increased rapidly over the last two and half decades despite various policy initiatives by the government. This raises questions over the acceptability and effectiveness of various policies to reduce greenhouse gas emissions from this sector. This chapter therefore investigates the mitigation potential of various transport policies while considering their costs, benefits and ethical aspects. A multi-criteria analysis technique is adopted to understand how experts, and NGO and green energy activists (including policy advisers) perceive the costs, benefits, emissions reduction potentials and ethical priorities of New Zealand's transport policies. A total of 26 policy options are identified, and they are categorised under six mitigation policy pathways. The perspectives of experts and NGO, and green energy activists are sought and aggregated using the Simple Additive Weighting (SAW) technique to compare and evaluate the mitigation policy pathways and policy options. Results demonstrate that increasing active and public transport investment is the most acceptable option followed by travel demand management, a carbon price, electric vehicle support, and support for fuel-efficient vehicles and biofuels. However, in terms of emissions reduction potential, ceasing the import of petrol and diesel cars into New Zealand by 2030 is found to be the strongest policy option. It is expected that the findings of this chapter will help illuminate the costs, benefits, mitigation potential and ethical aspects of various transport emissions reduction measures and assist policy advisers in identifying the most attractive policies and projects for investment.

### **7.1 Introduction**

The seemingly inexorable growth in private vehicle travel and associated emissions is one of the major challenges in reducing global greenhouse gas emissions (Gössling & Cohen, 2014). The total number of passenger cars in the world could double from 1.1 billion in 2017 to 3 billion in 2050 (International Energy Agency, 2018c). However, under the high ambition scenario of the International Transport Forum (ITF), the total number of passenger cars would be 2.4 billion in 2050 i.e. 20% less to the current scenario (International Transport Forum, 2019). Both sets of projections would increase transport's share in global emissions which was

23% in 2010 (Sims et al., 2014; Soto, Cantillo, & Arellana, 2018). Most importantly, transportation has been the fastest growing source of emissions in the developed countries (**Figure 21**). In Europe, the transport sector is the only sector that experienced a rise in emissions between 1990 and 2014 (Climate Watch, 2019; Tagliapietra & Zachmann, 2018). Whether this increase soon ceases (as in the ITF's high ambition scenario) remains to be seen.



**Figure 21. Percentage increase in greenhouse gas emissions from different source-categories in developed countries between 1990 and 2014 (Climate Watch, 2019; Department for the Environment and Energy, 2016; Environmental Protection Agency, 2018)**

Among New Zealand's energy sectors, the transport sector produces the greatest GHG emissions. In 2016, emissions from this sector accounted for around 48.0% of energy sector emissions and around 19.1% of total New Zealand GHG emissions. Most importantly, this is the only energy sector that has generated an essentially continuous increase in emissions since 1990. The emissions from this sector increased by an average of 2.1% per year from 8.8 MtCO<sub>2</sub>e in 1990 to 15.0 MtCO<sub>2</sub>e in 2016, suggesting that there were strong underlying drivers at work (Ministry for the Environment, 2019b).

The government of New Zealand has proposed a number of policy options to tackle the increasing rate of transport emissions. Electric vehicle support, subsidised public transport, promotion of biofuels production and use, a feasibility study of a cleaner fuel standard and a car use awareness program to improve vehicle fuel efficiency are some of the major policy

recommendations proposed by the government (Hasan et al., 2019). However, the costs, benefits, mitigation potential and ethical aspects of these policies have not so far been explored to help select the best policy options for transport sector emissions reduction in New Zealand. Therefore, this chapter investigates various transport emission reduction policies against four criteria: costs, benefits, mitigation potential and ethical considerations. The findings of this chapter may help policy advisers understand various policy options in terms of the key policy criteria of costs, benefits, mitigation potential and ethical aspects, and assist them in identifying the most attractive projects for investment.

The following section reviews the literature in this topic and the 7.3 section presents the methodology used in this study. Results are discussed in section 7.4 while a sensitivity analysis is performed in section 7.5. The 7.6 section presents the discussion and the final section concludes with a general summary and policy implications.

## **7.2 Literature review**

This section discusses the literature on multi-criteria approaches and transport emissions reduction measures.

### **7.2.1 Multi-criteria approaches**

Multi-criteria analysis (MCA) approaches have been successfully used to make or advise on decisions in the transport sector for a long period of time (Gerçek, Karpak, & Kılınçaslan, 2004; Soria-Lara & Banister, 2018; Wang et al., 2014). MCA approaches have the advantage of considering a range of factors in addition to monetised benefits and costs; this is helpful where decision makers wish to take a variety of non-quantified factors into account in policy decisions. Nogués and González-González (2014) used a multi-criteria model to rank highway projects in Spain to assess their impacts on population, environment, economy, mobility and territory. Criteria used in this study were efficiency, and intraregional and interregional cohesion. Sun et al. (2015) applied a multi-actor, multi-criteria analysis to evaluate low-carbon transport policies in China where preferences of different stakeholders such as government authorities, infrastructure suppliers and operators, end users, academics, and planning and technology experts were sought. Findings suggested that managing traffic demand, subsidizing public transport and energy saving measures, and building public transport infrastructures were widely supported by stakeholders. The measures proposed to manage traffic demand included flexible work hours, and passes at the surface level through the central urban area. Zubaryeva, Thiel, Zaccarelli, Barbone, and Mercier (2012) investigated the leading markets in Europe for



electric vehicles using a spatial multi-criteria assessment technique and found that London, Berlin, Madrid and Rome would observe high electric vehicle sales in 2030 under a moderate as well as an accelerated technological advancement scenario.

To identify the most cost competitive and eco-friendly transport technologies in the European Union (EU), Streimikiene, Baležentis, and Baležentienė (2013) used a multi-criteria framework to assess a number of transport technologies, namely (i) transport fuels (hydrogen, electricity, compressed natural gas, liquefied petroleum gas and biofuels) and (ii) vehicle technologies (battery-electric, hybrid-electric and fuel cell-electric). The findings of a holistic analysis of both cost and emissions components were that battery electric vehicles powered by renewable energies are a preferred transport technology compared to other options. A similar study was conducted by Sehatpour, Kazemi, and Sehatpour (2017) in Iran using a multi-criteria approach to assess eight alternative fuels for light duty-vehicles: diesel, biogas, biodiesel, hydrogen, liquefied petroleum gas (LPG), compressed natural gas (CNG), E85 (blending ethanol with petrol) and M85 (blending methanol with petrol). Four criteria were used in this study including cost, technical factors, social factors and policy support. Findings indicate that LPG and CNG were the best alternative fuels among both renewable and non-renewable sources while biogas ranked highest among the renewable alternatives. Alsabbagh, Siu, Guehnemann, and Barrett (2017) assessed different measures for road transport sector emissions reduction in Bahrain using a multi-criteria analysis. Public transport, fuel economy standards, low-carbon cars and carbon pricing were among measures evaluated based on economic, environmental, social, political, weather, land availability and fuel availability criteria. Survey results from policymakers, experts and the public indicated that an improved fuel economy standard was the top ranked measure for road transport emissions reduction. Javid et al. (2014) ranked different road transport emissions reduction strategies in two US cities namely Lubbock, Texas (small city) and Dallas, Texas (metropolitan city) using a multi-criteria method. Mitigation strategies were grouped into three categories: a reduce strategy (reduce average vehicle fleet age), an avoid strategy (avoid physical travel to reduce annual vehicle kilometre travelled), and a replace strategy (replace regular cars by plug-in hybrid electric vehicles). Four criteria were used in the assessment: air pollution, natural environment impact, traffic congestion and cost of investment (no benefits included). Preferences for reduce, avoid and replace strategies were 40%, 36% and 24%, respectively. MCA approaches were also used in a number of studies to assess airport expansion plans (Vreeker, Nijkamp, & Ter Welle, 2002), alternative renewable energy options (Rojas-Zerpa & Yusta, 2015; Seddiki &

Bennadji, 2019; Troldborg, Heslop, & Hough, 2014), carbon pricing mechanisms (Venmans, 2012) and energy vulnerability (Marz, 2018).

### 7.2.2 A scan of transport sector carbon mitigation approaches

Putting aside the techniques involved, it is important to appreciate the range of policy measures considered in the literature on transport sector carbon mitigation. Researchers have studied a wide array of mitigation options to reduce emissions from the sector. Talbi (2017) found that improvement in energy efficiency would be important to reduce transport emissions in Tunisia. As a mitigation option, the author proposed an increase in fuel price to reflect environmental externalities. In addition, the development of an electricity-powered public transport system, increased uptake of electric vehicles, large-scale consumption of bio-fuels, and travel demand management (TDM) through urban planning and route optimisation were proposed as means to reduce transport emissions. The study by Javid et al. (2014) mentioned above emphasized TDM over other mitigation options such as switching to alternative fuels or vehicle efficiency due to its large impact in reducing GHG emissions from the transport sector effectively. The expansion of transit or other public transport facilities along with distance-based car use pricing were also found to be effective policy options to reduce travel-induced GHG emissions by a number of researchers (Pablo-Romero, Pozo-Barajas, & Sánchez-Braza, 2015; Rahman et al., 2017). Hasan et al. (2019) focused on reducing vehicle energy intensity, concluding that vehicle fuel efficiency improvement may be the most effective measure to reduce transport emissions in New Zealand.

Switching from private vehicles to public transport was also found to be effective in reducing carbon emissions, and citizen awareness plays a crucial role in promoting the use of public transport and low-emitting alternatives in Europe (Pablo-Romero et al., 2015). The development or improvement of bikeways and walkways is another effective measure to reduce GHG emissions (Chapman et al., 2018; Rodier, Lee, Haydu, & Linesch, 2014). To reduce travel demand and shift road users from private vehicle to public transport, both pull and push strategies and programmes are found to be useful. Pull strategies attract road users to use less or zero emitting transport modes. Examples of such strategies are (i) low cost public transport facilities, (ii) an improved and integrated road network with better accessibility and mobility, (iii) improved pedestrian facilities, (iv) dedicated lanes for cycles and public transport, and (v) improved telecommunication network facilities. Push strategies discourage road users from using high emitting transport modes. Examples include a carbon tax, road pricing on particular roads, higher fuel tax, parking charges, vehicle tax, congestion tax, restrictions on automobiles

in certain roads or lanes over a certain period of time etc. The success of these strategies largely depends on (i) collaboration among respective agencies, (ii) improvement in technological innovation, (iii) integration of such policies with a long-term comprehensive strategy, and (iv) quality of implementation (Rahman et al., 2017; Strompen et al., 2012; Zannat, Akhter, Hasan, & Mitra, 2013)

Lin and Xie (2014) emphasized an improved energy consumption structure (i.e. promote low-carbon alternatives to oil products) to reduce China's transport emissions. Large scale production and use of bio-fuels were found to contribute to reducing GHG emissions in the long run (Bae & Kim, 2017). Yan et al. (2013) also proposed bioethanol as an alternative to fossil fuels because it is compatible with most internal combustion engine vehicle (ICEV) engines and the technology for producing this fuel is quite mature. As an alternative to conventional fossil fuels, bio-ethanol is the most widely produced and used alternative fuel in the road transport sector across the world (Yan et al., 2013), but can have negative side-effects in its production (Mohanty & Swain, 2019). Hydrogen fuel is another clean transport fuel that can help reduce GHG emissions from the transport sector significantly (Salvi, Subramanian, & Panwar, 2013). However, there are challenges associated with the promotion of hydrogen fuel as an alternative transport fuel: its production is more costly than other conventional fuels because there is no naturally occurring source of this gas (Rahman et al., 2017; Salvi et al., 2013) and methods such as manufacturing from natural gas or reforming methanol involve use of fossil fuels. In addition, there are some safety issues as hydrogen gas is more flammable than regular fuels, and the infrastructure for hydrogen distribution is costly to install. Advanced research on hydrogen fuel might help overcome those limitations and increase its use in heavy transport vehicles such as trolley bus or heavy duty trucks (Rahman et al., 2017; Salvi et al., 2013).

Within a voluntary action paradigm, people's lifestyles, personal choices, and perceptions of particular modes affect their mode choice decisions. Therefore, awareness programmes focusing on the negative impacts of car use and the potential for healthier mode choices can bring long-term benefit in transport sector emissions reduction (Pablo-Romero et al., 2015; Rahman et al., 2017). Besides user behavior change, technological improvement in road design, traffic management, and roadway construction are found to be useful in reducing GHG emissions from the road transport sector. According to Rahman et al. (2017), road characteristics such as sight distance, quality of pavement, curvature, road signals per kilometre, coordination among traffic signals, number of traffic lanes and road shoulder

facilities have an influence on fuel consumption, and consequently on GHG emissions. Traffic congestion and signaling systems at intersections reduce travel speed and increase travel time and fuel consumption. Therefore, road design with minimum road intersections (or signal system) and better coordination of signaling system at the intersections can effectively reduce energy consumption related GHG emissions. However, such considerations need to be balanced by considerations of safety and urban amenity, and the tendency of faster travel to encourage individual vehicle use, negating fuel savings.

Options that governments have tended to favour include alternative fuels, ensuring vehicle efficiency, and managing travel demand. For example, the Japanese government offered a 60% discount on vehicle-purchase tax, a 23% discount on vehicle-weight tax, and an 82% discount on vehicle tax to promote lightweight passenger vehicles or ordinary passenger vehicles (Rahman et al., 2017). In the US, all three levels of government, i.e. federal, state, and local, have waived sales taxes on electric and hybrid vehicles (Chavez-Baeza & Sheinbaum-Pardo, 2014). Also, some U.S. states and cities provide access for electric and hybrid vehicles to high occupancy vehicle lanes (Wee, Coffman, & Croix, 2019). In China, purchase taxes on various green vehicles such as hybrid vehicles, fuel cell electric vehicles, battery electric vehicles, dimethyl-ether vehicles, and hydrogen vehicles are tax-exempted by the government: taxes would otherwise be around 10% of the sale prices of those vehicles (Yuan et al., 2015). Countries such as Lithuania and Canada have offered tax rebates and income tax relief on the purchase of hybrid and electric vehicles as a measure towards reducing GHG emissions from the transport sector (Yuan et al., 2015). However, promoting electric vehicles (EVs) in countries where electricity is generated from high carbon intensive fuels such as coal, heavy oil, or lignite might be counterproductive (Hawkins, Singh, Majeau-Bettez, & Strømman, 2013). By contrast, countries like New Zealand where around 85% of electricity is generated from various renewable sources are better placed for promoting, developing and investing in EVs, including electric bikes and buses (Ministry of Business, Innovation and Employment, 2018). Since the private sector is profit-oriented and less motivated by environmental concerns, government support and collaborations among the government, vehicle manufacturers, and alternative fuel producers can be important for promoting low emitting vehicles or fuels and reducing GHG emissions from the road transport sector.

### 7.3 Methodology

The evaluation of transport emissions reduction policies by undertaking an MCA is found to be an appropriate approach for this study for four possible reasons. Firstly, this technique has been found to be a successful way to undertake complex transport-related decision making where a variety of criteria can be constructed (Gerçek et al., 2004; Soria-Lara & Banister, 2018; Wang et al., 2014). Secondly, MCA is suitable where it is desirable that a number of sustainability dimensions such as economic, social and environmental impacts of a proposed policy option, in the short or long run, are considered in the ranking of policy options (Hickman et al., 2012; Soria-Lara & Banister, 2018). Thirdly, MCA offers a simple and flexible evaluation framework where a wide range of stakeholders can be incorporated in the evaluation process (Vermote, Macharis, Boeykens, Schoolmeester, & Putman, 2014; Zubaryeva et al., 2012). Finally, MCA allows stakeholders to participate actively in the decision making process and share their insights on different policy options (Bertolini, 2007; Soria-Lara & Banister, 2018). MCA also has some disadvantages but they are not so fatal. For instances, MCA typically includes non-quantified variables; some consider that this lack of quantification is a disadvantage. However, it can be argued that omitting non-quantified variables would create a greater problem by biasing results. In addition, MCA can sometimes place a large burden of computation and comparison on respondents. However, studies can be designed to limit this burden, e.g. by grouping evaluations or adopting simple techniques such as SAW etc.

The steps used in this study are as follows-

#### 7.3.1 Defining alternatives

A total of 26 possible transport sector emissions reduction measures were identified through a systematic review of literature. Subsequently, policy options were categorised and pooled under six mitigation policy pathways (MPPs). The categorisation of 26 policy options and the identification of MPPs was based on a number of recent studies including a Royal Society policy document (Sims et al., 2016), scientific research findings (Hasan et al., 2019), and work by credible international organisations, such as the Stockholm Resilience Centre (Falk et al., 2018). The categorisation and description of policy options are presented below in table 10.

**Table 10. Mitigation Policy Pathways (MPPs) and Policy Options (POs) for transport sector emissions reduction**

<b>Mitigation Policy Pathway (MPP)</b>	<b>Policy Option</b>	<b>Definition/Description of policy options</b>
1. Switching from fossil-fuelled vehicles to low or zero emission vehicles	PO 1. EV road user charge exemption	Exempting electric vehicles (EVs) from road user charges
	PO 2. Feebate scheme	Introducing a feebate scheme (fee for high-emitting vehicles and rebate for low-emitting vehicles)
	PO 3. Income tax deduction for EV purchase	An income tax deduction for EV purchase
	PO 4. Income tax deduction for EV registration tax	An income tax deduction for EV registration tax
	PO 5. Subsidisation of EV re-charging facilities	Subsidisation of EV re-charging facilities
	PO 6. EV access on high occupancy lanes	Allowing EV access to high occupancy lanes on motorways
	PO 7. EV parking charge exemption	Exempting EVs from parking charges in certain public parking spaces
	PO 8. Subsidising electric bikes or buses	Subsidizing electric bikes or buses
	PO 9. Ceasing the import of regular cars	Ceasing the import of petrol and diesel cars into New Zealand by, say, 2030.
	PO 10. Car free zone in major city area	Excluding petrol and diesel vehicles from a major area of a city by, say, 2030.
2. Putting a high price on carbon	PO 11. Increase ETS price	Increasing the present ETS price to between NZ\$ 100 and NZ\$175 (2030 estimates) to better reflect the social cost of carbon while offsetting the regressive effects of a higher carbon price through reducing income tax for

<b>Mitigation Policy Pathway (MPP)</b>	<b>Policy Option</b>	<b>Definition/Description of policy options</b>
		low-income earners or lowering public transport costs
	PO 12. Impose carbon tax on top of ETS	Putting a transport carbon tax between NZ\$ 100 and NZ\$175 (2030 estimates) on top of the ETS price to better reflect the social cost of carbon while offsetting the regressive effects of a higher carbon price through reducing income tax for low-income earners or lowering public transport costs
3. Increasing active and public transport trip share and reducing trip demand	PO 13. Investment in active and public transport	Investing in active and public transport, e.g. infrastructures such as pedestrian ways, cycle lanes, rail infrastructure etc.
	PO 14. Reduce public transport fares	Reducing the cost of public transport use
	PO 15. Better accessibility through urban planning	Ensuring better accessibility through land-use planning to increase mixed use, higher density housing development along/near transport arteries
4. Promoting alternative renewable fuel sources	PO 16. Exemption of bio-fuel excise tax	Exempting excise tax on bio-fuels
	PO 17. Subsidizing bio-fuel production and use	Subsidising the production and use of bio-fuels, hydrogen, etc.
	PO 18. Awareness to promote low-carbon fuel	Promoting alternative fuel use through awareness building and information dissemination
	PO 19. Subsidies for low-carbon infrastructure	Grants or tax-rebates for alternative transport fuel infrastructure development

<b>Mitigation Policy Pathway (MPP)</b>	<b>Policy Option</b>	<b>Definition/Description of policy options</b>
5. Increasing vehicle fuel economy	PO 20. High fuel economy standard	Setting a high minimum fuel economy standard to ensure the entry of only fuel-efficient cars from manufacturing countries
	PO 21. Cleaner emissions standard	Introducing an age restriction or a cleaner emission standard to exclude old-car use
	PO 22. Education on fuel-efficient driving	Educating consumers in fuel-efficient driving
6. Managing traffic and travel demand	PO 23. Manage waiting time at signals	Using advanced technology to manage waiting time at signals
	PO 24. Better integration among modes	Ensuring better integration among different modes to improve transport network efficiency
	PO 25. Car-pooling at peak hours	Managing peak hour travel through providing alternative travel options to single occupant vehicles (e.g. car-pooling etc.)
	PO 26. Telecommunication as alternative to travel	Using telecommunication services as alternatives to travel (e.g. tele-conferencing, teleshopping, distance learning etc.)

### 7.3.2 Respondent analysis

This research aimed to rank different transport emissions reduction policies based on a number of criteria. Therefore, respondents for this study were expected to be experts, and/or NGO and green energy activists in the field of Transport and/or Environment, and preferably both. Since the number of potential participants available with such expertise was relatively few and it was difficult or costly to contact them, the snowball sampling technique was applied to find appropriate respondents for this research (Sun et al., 2015; Wasserman & Faust, 1994). In a snowball sampling, initial respondents are termed as seeds, and seeds for this study were identified through a ‘peer review’ process (Christopoulos, 2009; Sun et al., 2015; Wasserman & Faust, 1994). Peers nominated a set of seeds from different organisations and subsequently, seeds from each organisation helped to reach the potential respondents for this study. The study



succeeded in recruiting 25 respondents for the research, drawn from the local and central government of New Zealand, non-governmental organisations (NGOs), green energy company, and independent experts. Of these, 10 were policy experts from central government (five from the Ministry of Transport and five from the Ministry for the Environment). The number of respondents involved from the local government was five, of whom three respondents were from Greater Wellington Regional Council and two respondents were from Wellington City Council. Equal numbers of other respondents (i.e. five activists from NGOs and green energy company, and five independent experts) took part in the study. Respondents from NGOs and a green energy company were from Generation Zero, 350.org, New Zealand Climate and Health Council, and Cycling Action Network and Perennial Energy (a green energy company). Independent experts were mostly researchers from different research centers and educational institutions.

Except for one telephone interview, interviews were conducted through face-to-face communication (in-person interviews). The main reasons for conducting in-person interviews include (i) face-to-face interviews offer a higher response rate, (ii) face to face interviews take less time, relevant with a large number of questions to answer, and (iii) interpretation of some of the questions for respondents may be required (Fowler Jr, 2013). Since one of the respondents was from a distant location, a telephone interview was conducted in this case. The interview guide was sent via email to the respondent beforehand in order to ensure effective and better communication.

### 7.3.3 Defining criteria

Use of various criteria to rank a policy alternative allows the respondents to express their objectives and preferences clearly (Sun et al., 2015). The MPPs and POs identified in this study were to be ranked based on scores against a number of criteria, and their respective weights. Four different criteria were used in this study, namely (i) benefits and co-benefits, (ii) mitigation potential, (iii) costs, and (iv) ethical considerations. The reason for choosing these four criteria was to ensure the incorporation of a wide range of aspects of sustainability in the decision making process. This helped the respondents to evaluate different transport emissions reduction policies holistically. Weights were also included in the policy ranking process because the importance to respondents of the various criteria varied. Some respondents put high priority on environmental aspects compared with social and economic aspects whereas some respondents value economic costs over environmental benefits. The weighting of a criterion helps the respondents to effectively express their preferences. This makes the decision

making process more comprehensive and meaningful. The details of the criteria used in this study are presented in table 11.

**Table 11. Description of the criteria**

<b>Criterion</b>	<b>Description/definition</b>	<b>Sustainability aspect</b>
1. Benefits and co-benefits (B&C)	All the perceived benefits and co-benefits that can be achieved through a particular transport emissions reduction policy (e.g. energy security, employment creation, health benefits etc.)	Economic/ social/ environmental
2. Mitigation potential (M)	The amount of emissions that can be reduced through a particular transport policy	Environmental
3. Costs (C)	The level of costs involved in the implementation of a transport policy or the costs that will be incurred by people or government due to a transport policy's implementation	Economic
4. Ethical considerations (E)	How ethical a particular transport policy is judged to be	Social

#### 7.3.4 Data analysis and ranking

An MCA technique helps to rank a finite number of alternatives against a set of criteria. There are various MCA techniques that help to model decision-makers' preferences, namely, the Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW), Simple Aggregate Value Function (SAVF), Preference Ranking Organisation Method for Enrichment Evaluations (PROMETHEE), Elimination and Choice Expressing Reality (ELECTRE), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) etc. The reasons why particular MCA techniques are chosen is often not clear in published studies. Nevertheless, among different MCA techniques, the AHP and SAW are the two most widely used techniques. Goulart Coelho, Lange, and Coelho (2017) reviewed 221 published papers and found that around 42% of the papers used the AHP technique followed by SAW (24%), and ELECTRE (10%). This study used the SAW technique to model experts' and activists' preferences. There

are a number of reasons for selecting the SAW technique over the popular AHP technique. Firstly, SAW is a well-proven technique and very simple to carry out while the AHP technique is very complex to implement (Pires et al., 2019). Secondly, the SAW technique requires less time for respondents to process a large number of alternatives and criteria while the AHP technique requires pair-wise comparisons and therefore requires a significant amount of time from expert respondents to process a large number of alternatives and criteria. Since this study investigated 26 policy options using four criteria, the risk of overburdening respondents needed to be minimised. Therefore, the SAW technique is used in this study to minimise the burden of the respondents. However, the SAW technique has some drawbacks. The SAW technique cannot be applied if there is any missing data (Pires et al., 2019). Another potential drawback is that this technique is sometimes seen as too intuitive to achieve a commitment and consensus for group discussion aggregation (Abdullah & Adawiyah, 2014). Since this study does not have any missing data and experts', and NGO and green energy activists' preferences are sought individually instead of as a group preference, the drawbacks of the SAW technique are not applicable for this study.

In this study, all the 25 experts and NGO and green energy activists from different organisations were asked initially to rate the criteria using a scale of 0 to 9 where '0' indicates a least important criterion and 9 indicates a highly important criterion. Then the experts and NGO and green energy activists were asked to rate different MPPs and POs using the scale where '0' indicates a weak and ineffective MPP or PO and 9 indicates a strong and effective MPP or PO. The SAW technique was used to process the data. The SAW technique is similar to the Simple Aggregate Value Function (SAVF) technique where the original weight ( $\omega_i$ ) is calculated by transforming the weighting score ( $\omega_i$ ) of each criterion into a normalized score (between 0 and 1, where ' $\sim 0$ ' indicates a criterion of very low importance and ' $\sim 1$ ' represents a highly important criterion). To compute a normalized score, the weighting against a particular criterion is divided by the total weighting against all criteria (Zaman et al., 2018). Once all the original weights for different criteria are determined, the weighted average ( $\bar{y}$ ) of an alternative is attained by multiplying the ratings ( $y_i$ ) by their respective original weights and then summing them. Alternatives are selected or ranked based on their respective weighted average values where a higher value indicates a better alternative (Pires et al., 2019). The equations for calculating the original weights ( $\omega_i$ ) and the weighted average ( $\bar{y}$ ) of an alternative are provided in equations 1 and 2 respectively.

$$\text{Original weights } (\omega'_i) = \frac{\omega_i}{\sum_{j=1}^n \omega_j} \quad (1)$$

where,  $\omega_1 + \omega_2 + \dots + \omega_n = 1$ ,  $0 < \omega'_i < 1$ .

$$\text{Weighted average } (\bar{y}) = \sum_{i=1}^n \omega'_i y_i \quad (2)$$

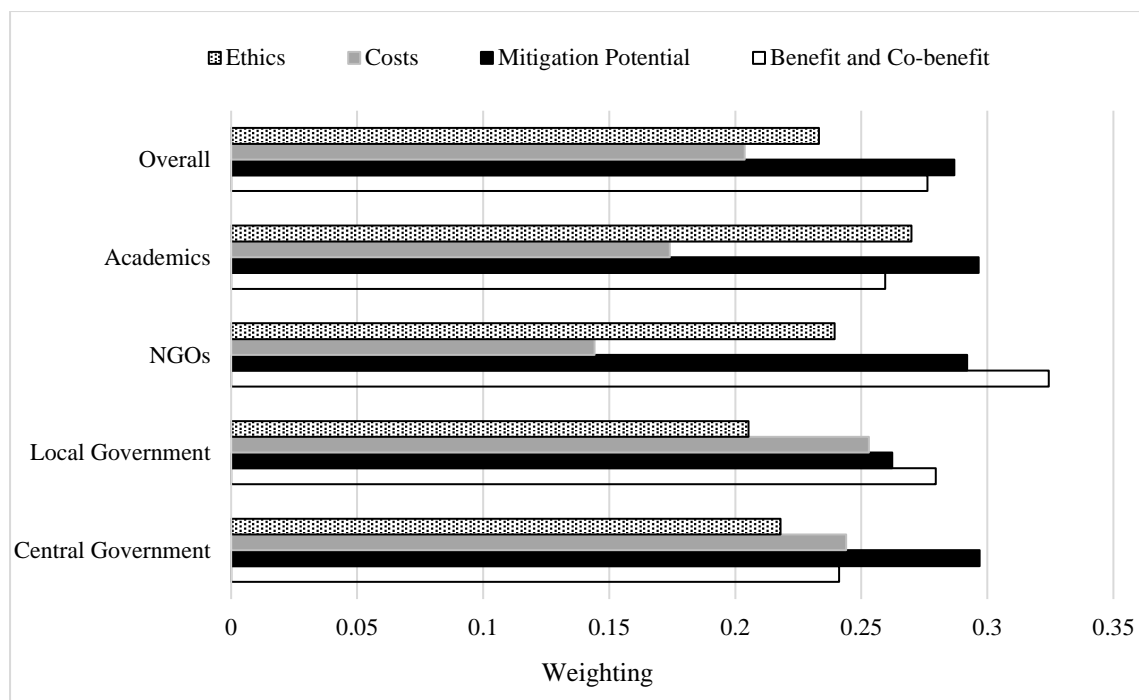
Here, the weighted average ( $\bar{y}$ ) indicates that a strong rating against one criterion can offset a bad rating against another criterion. Therefore, the SAW technique is a compensatory method (Gass & Harris, 1997) where every criterion plays an important role in the decision making process.

## 7.4 Results

This section illustrates the criteria weight results, and presents the ranking of different transport emissions reduction pathways (i.e. MPPs) and policy options (i.e. POs) based on their costs, benefits, mitigation potentials and ethical considerations. The preferences of different stakeholder groups such as central government, local government, NGOs and green energy company and academics are also presented to understand their criteria weights for decision-making and positions on the mitigation pathways and policy options.

### 7.4.1 Analysis of criteria weights

The criteria weights analysis reveals that the mitigation potential of a transport mitigation pathway or policy is seen as the most important criterion, followed by the benefits and co-benefits, ethical considerations and, lastly, costs. The emphasis on mitigation potential can be interpreted as an emphasis on effectiveness. Not surprisingly, weightings given to a particular criterion varied among different stakeholders. For instance, the central government experts and academics considered mitigation potential to be the most important criterion whereas the local government experts, and NGO and green energy activists put most weight on benefits and co-benefits. Ethical consideration were found to be the least important criterion for the central and local government experts while the NGO and green energy activists and academics considered cost to be the least significant criterion (**Figure 22**).



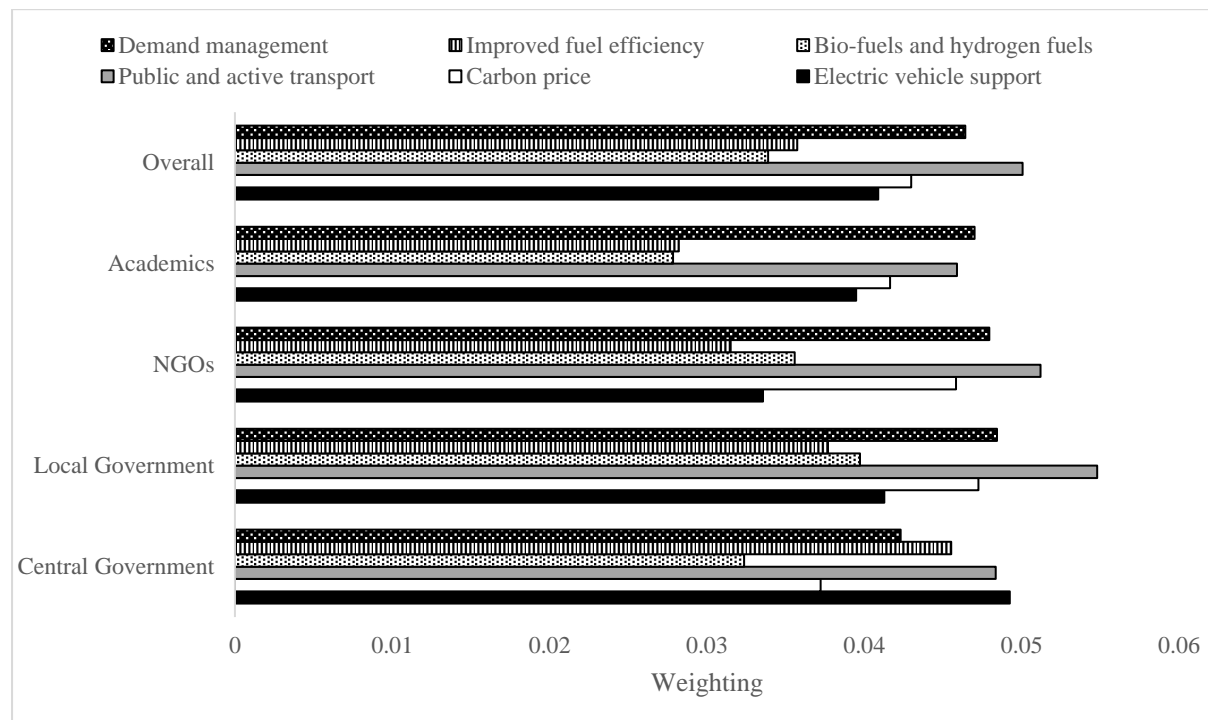
**Figure 22. Criteria weights of different stakeholder groups (Source: Experts', and NGO and green energy activists' interviews)**

#### 7.4.2 Multi-criteria analysis of mitigation policy pathways

Results from the MCA indicate that public and active transport is the most preferred mitigation policy pathway (recall that a pathway comprises a cluster of related policy options). In contrast, bio-fuels and hydrogen fuels are found to be the least preferred pathway (**Figure 23**). Travel demand management and carbon pricing were, overall, the second and third most preferred policy pathway of the six, respectively.

While there were some common elements (such as the general support of public and active transport, and travel demand management), the preferences of different stakeholder groups diverge significantly. For example, the central government experts most strongly supported the promotion of electric vehicles (taking into account the four weighted criteria), whereas the NGO and green energy activists did so the second least; central government and local government experts also had divergent views regarding a carbon price and fuel efficiency measures. The preferences expressed by local government experts, and NGO and green energy activists were found to be very similar, and relatively different from those of other stakeholders. Academics ranked travel demand management at the top followed by public and active transport, and so on, i.e. favoured regulatory options. Improvement in vehicle fuel efficiency was seen as the lowest priority by the local government experts, and NGO and green energy activists and academics, whereas the adoption of bio-fuels and hydrogen fuels was considered

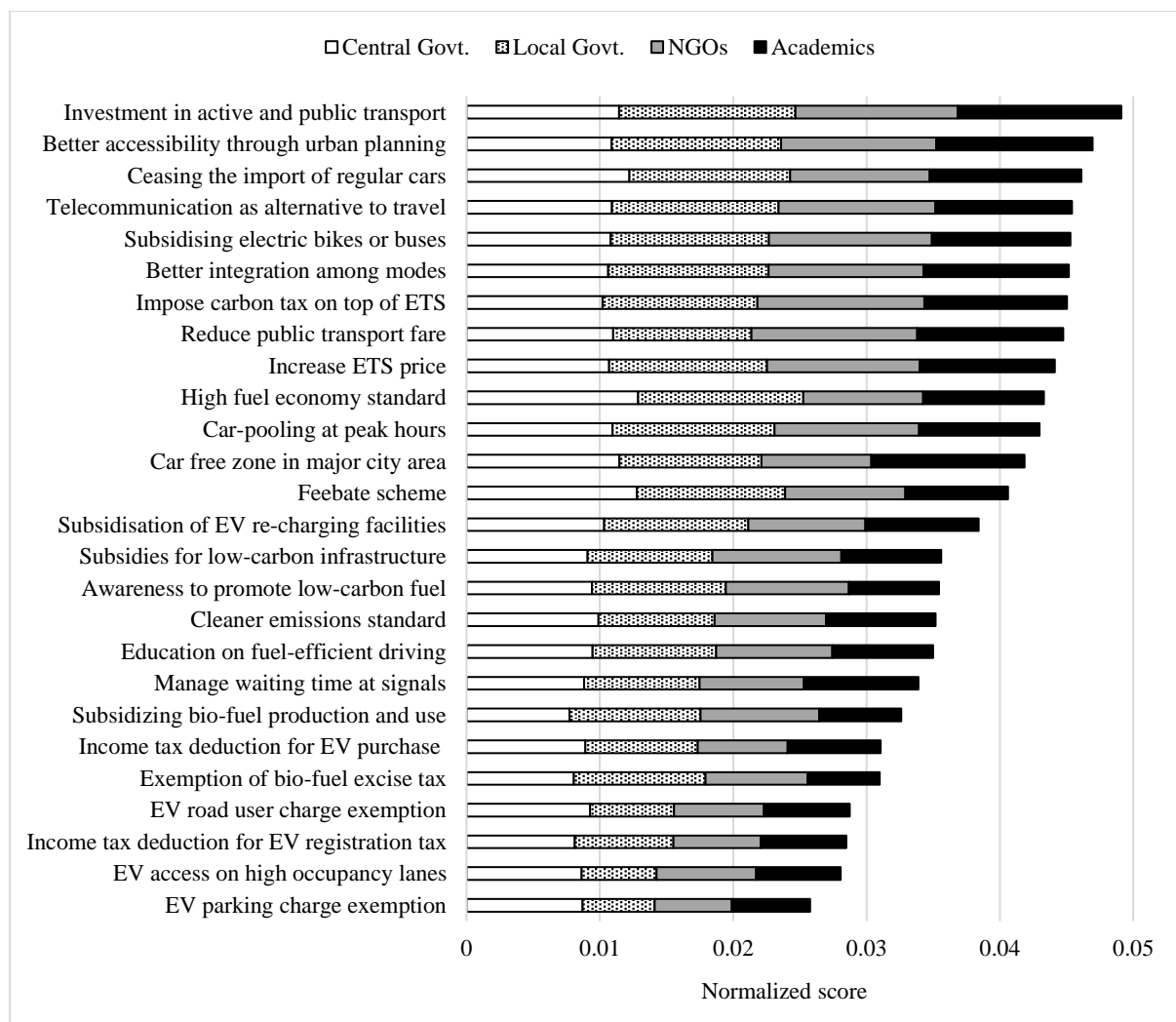
to be the least sustainable mitigation pathway by the central government and academics (Figure 23).



**Figure 23. Multi-criteria analysis of mitigation policy pathways (Source: Experts’ and activists’ interviews)**

#### 7.4.3 Multi-criteria analysis of policy options

The MCA results of the 26 policy options show that investments in active and public transport are seen as the most sustainable policy option to reduce greenhouse gas emissions from New Zealand’s transport sector. Other top four policy options include: ensuring better accessibility through urban land use planning, ceasing the import of regular petrol cars into New Zealand by 2030, using telecommunication services as alternatives to travel, and subsidizing electric bikes or buses. In contrast, the policy option that is the least preferred by the experts, and NGO and green energy activists from different stakeholder groups is the exemption of electric vehicles from parking charges in certain public parking spaces. Surprisingly, policy options that aim to promote electric vehicle uptake in New Zealand are seen as the least suitable alternatives to reduce New Zealand’s transport sector emissions. The other bottom four policy options include: allowing electric vehicles into high occupancy lanes on motorways, deducting income tax for electric vehicle registration tax, exempting electric vehicles from road user charges, and exempting excise tax on biofuels (Figure 24).



**Figure 24. Multi-criteria analysis of transport policy options (Source: Experts', and NGO and green energy activists' interviews)**

## 7.5 Sensitivity analysis

In this section, the weighting of different criteria are varied to test the effects on experts', and NGO and green energy activists' preferences and overall results. The focus of this sensitivity analysis is to see how robust or sensitive the results are when criteria weightings vary. The results of the sensitivity analysis of the MPPs and POs are discussed in the following sub-sections.

### 7.5.1 Sensitivity analysis of mitigation policy pathways

In the sensitivity analysis of the pathways (MPPs), the preferences of the stakeholders based on each criterion are explored (**Figure 25**). Each criterion is given a highest weighting to investigate its impact in the ranking of the MPPs. Initially, the 'benefits and co-benefits' criterion is given the highest weighting ( $\omega_i = 0.75$ ), and other criteria weightings are kept

correspondingly low ( $\omega'_i = 0.08$ ). This is broadly in line with the preferences of NGOs, green energy companies and local government stakeholders. The results indicate that public and active transport is the most preferred MPP by the experts, and NGO and green energy activists followed by travel demand management, carbon price, electric vehicles, bio-fuel and hydrogen fuel, and lastly improved fuel efficiency.

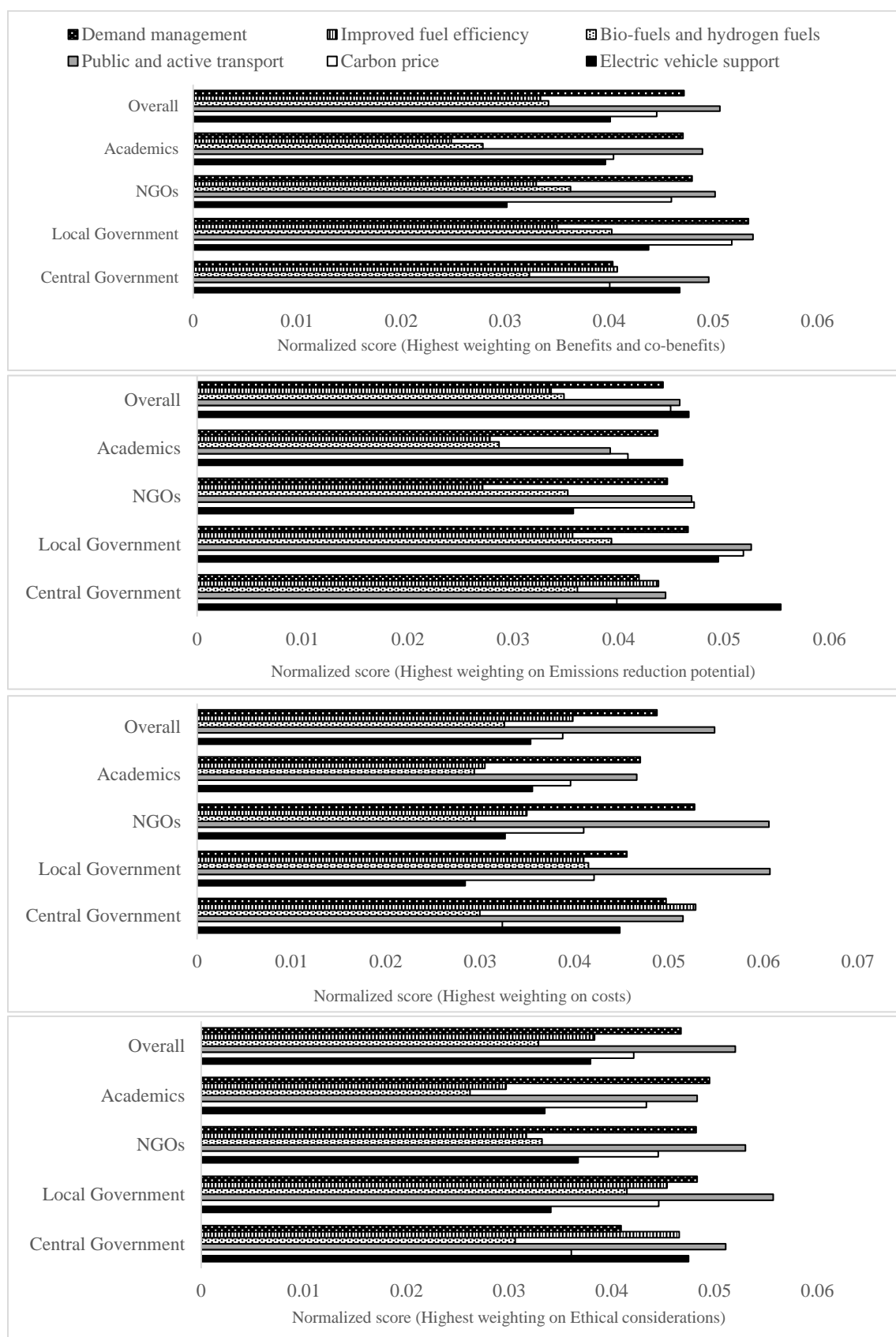
In a second sensitivity test, the highest weighting is placed on the 'emissions reduction potential' criterion ( $\omega'_i = 0.75$ ) and a correspondingly lower weighting is put against all other criteria ( $\omega'_i = 0.08$ ). This put 'electric vehicle support' as the top ranked MPP for New Zealand. The standings of other MPPs in the ranking include public and active transport (2<sup>nd</sup>), carbon price (3<sup>rd</sup>), travel demand management (4<sup>th</sup>), bio-fuel and hydrogen fuel (5<sup>th</sup>) and improved fuel efficiency (6<sup>th</sup>).

Putting the highest weighting against 'costs' ( $\omega'_i = 0.75$ ) and an equally lower weighting against all other criteria ( $\omega'_i = 0.08$ ) make the public and active transport pathway the least costly MPP for New Zealand followed by travel demand management, improved fuel efficiency, carbon price, electric vehicle support, and bio-fuel and hydrogen fuel.

Lastly, if the 'ethical consideration' criterion receives the highest weighting ( $\omega'_i = 0.75$ ) and other criteria get equally low weightings ( $\omega'_i = 0.08$ ), the public and active transport pathway comes at the top among all MPPs. The ranking (from top to bottom) of other MPPs based on ethical considerations is travel demand management, carbon price, improved fuel efficiency, electric vehicle support, and lastly bio-fuel and hydrogen fuel.

From the sensitivity analysis of the MPPs, it is evident that even for major changes in the criteria weights, the SAW method is largely stable and the preferences of the experts, and NGO and green energy activists do not change abruptly. Public and active transport tends to be the most preferred MPP while bio-fuel and hydrogen fuel are the least preferred MPP in most cases. This implies that any minor change in the criteria weights will not affect the preferences of the experts, and NGO and green energy activists. This lends credibility to the results of this study.





**Figure 25. Sensitivity analysis of mitigation policy pathways**

### 7.5.2 Sensitivity analysis of policy options

As with MPPs, a sensitivity analysis of the POs gives insight into the stability of the SAW method. Despite major changes in criteria weights, experts', and NGO and green energy activists' preferences on various POs do not vary significantly (Table 12). Investment in active and public transport is the most preferred while exempting EVs from parking charge at certain public parking spaces is the least preferred PO in most cases.

A high weighting of the benefits and co-benefits criterion (sensitivity analysis 1) supports experts', and NGO and green energy activists' preferences for active and public transport infrastructure development, followed by the urban planning option for better accessibility, and the ceasing of the import of petrol and diesel cars into New Zealand by 2030. The bottom three POs under the sensitivity analysis 1 scenario include providing an income tax deduction for EV registration tax (ranked 24th), allowing EV access on high occupancy lanes (ranked 25th) and exempting EVs from parking charges in certain public parking spaces (ranked 26th).

Sensitivity analysis 2 prioritizes the mitigation potential criterion over other criteria and reveals that cessation of the import of petrol and diesel cars into New Zealand by 2030 is seen as the most preferred option for transport sector emissions reduction in the country. The other two most preferred options include the imposition of a carbon tax on top of the present emissions trading scheme (ETS) price (ranked 2nd) and an increase in the present ETS price. The two most unfavorable POs under the sensitivity analysis 2 scenario are the same as in the sensitivity analysis 1 scenario, while the third least preferred option is the exemption of EVs from road user charges.

Sensitivity analysis 3 puts high weighting on the costs criterion and illustrates that experts, and NGO and green energy activists are in favour of PO 25, i.e. managing peak hour travel through providing alternative travel options to single occupant vehicles (e.g. car-pooling etc.) because they think this PO is effective as well as the least costly. The other top two POs under this scenario include the use of telecommunication services as alternatives to travel (e.g. teleconferencing, teleshopping, distance learning etc.) and an increase in consumers' education on fuel-efficient driving. Under the sensitivity analysis 3 scenario, the three least preferred options due to their high costs (to people or government) and ineffectiveness are subsidisation of the production and use of bio-fuels and hydrogen fuels (ranked 26th), an income tax deduction for EV purchase (ranked 25th), and an age restriction or a cleaner emission standard to exclude old-car use (ranked 24th).

Lastly, a sensitivity analysis 4 scenario emphasizes the ethical considerations criterion. The findings show that experts, and NGO and green energy activists considered PO 13 (investment in active and public transport) as the most ethical as well as effective option for transport sector emissions reduction followed by PO 25 (ensuring better integration among different modes to improve transport network efficiency) and PO 13 (reducing the cost of public transport use). In contrast, the three least ethical and ineffective POs under this scenario are exempting EVs from parking charges in certain public parking spaces (ranked 26th), deducting EV registration tax from income tax (ranked 25th) and exempting electric vehicles (EVs) from road user charges (ranked 24th).

**Table 12. Sensitivity analysis of policy options**

Policy Option (PO)	Actual average weighting given by experts, and NGO and green energy activists ( $\omega'_{B\&C}$ = 0.27; $\omega'_M$ = 0.29; $\omega'_C$ = 0.21; $\omega'_E$ = 0.23)	Sensitivity analysis 1 (Priority on Benefits and co-benefits $\omega'_{B\&C}$ = 0.75; $\omega'_M$ = $\omega'_C$ = $\omega'_E$ = 0.08)	Sensitivity analysis 2 (Priority on Mitigation potential $\omega'_M$ = 0.75; $\omega'_{B\&C}$ = $\omega'_C$ = $\omega'_E$ = 0.08)	Sensitivity analysis 3 (Priority on Costs: $\omega'_C$ = 0.75; $\omega'_{B\&C}$ = $\omega'_M$ = $\omega'_E$ = 0.08)	Sensitivity analysis 4 (Priority on Ethical considerations; $\omega'_E$ = 0.75; $\omega'_{B\&C}$ = $\omega'_M$ = $\omega'_C$ = 0.08)
	Normalized score (Ranking)	Normalized score (Ranking)	Normalized score (Ranking)	Normalized score (Ranking)	Normalized score (Ranking)
PO 1. EV road user charge exemption	0.0287 (23)	0.0278 (23)	0.0271 (24)	0.0355 (17)	0.0267 (24)
PO 2. Feebate scheme	0.0406 (13)	0.0415 (12)	0.0419 (11)	0.0437 (5)	0.0359 (17)
PO 3. Income tax deduction for EV purchase	0.0311 (21)	0.0320 (18)	0.0340 (18)	0.0320 (25)	0.0272 (22)

PO 4. Income tax deduction for EV registration tax	0.0285 (24)	0.0265 (24)	0.0279 (23)	0.0371 (13)	0.0260 (25)
PO 5. Subsidisation of EV re-charging facilities	0.0384 (14)	0.0390 (14)	0.0375 (15)	0.0381 (12)	0.0396 (13)
PO 6. EV access on high occupancy lanes	0.0281 (25)	0.0244 (25)	0.0241 (25)	0.0396 (10)	0.0268 (23)
PO 7. EV parking charge exemption	0.0257 (26)	0.0239 (26)	0.0238 (26)	0.0352 (18)	0.0233 (26)
PO 8. Subsidising electric bikes or buses	0.0453 (5)	0.0469 (4)	0.0472 (6)	0.0369 (15)	0.0465 (6)
PO 9. Ceasing the import of regular car	0.0461 (3)	0.0500 (3)	0.0534 (1)	0.0344 (21)	0.0431 (11)
PO 10. Car free zone in major city area	0.0419 (12)	0.0447 (9)	0.0415 (12)	0.0420 (6)	0.0397 (12)
PO 11. Increase ETS price	0.0441 (9)	0.0459 (7)	0.0501 (3)	0.0343 (22)	0.0438 (9)
PO 12. Impose carbon tax on top of ETS	0.0450 (7)	0.0467 (5)	0.0502 (2)	0.0346 (20)	0.0452 (8)
PO 13. Investment in active and public transport	0.0491 (1)	0.0539 (1)	0.0494 (4)	0.0365 (16)	0.0524 (1)

PO 14. Reduce public transport fare	0.0447 (8)	0.0462 (6)	0.0452 (7)	0.0370 (14)	0.0477 (3)
PO 15. Better accessibility through urban planning	0.0470 (2)	0.0507 (2)	0.0492 (5)	0.0389 (11)	0.0474 (4)
PO 16. Exemption of bio-fuel excise tax	0.0310 (22)	0.0301 (21)	0.0311 (19)	0.0348 (19)	0.0293 (21)
PO 17. Subsidizing bio-fuel production and use	0.0326 (20)	0.0327 (17)	0.0343 (17)	0.0317 (26)	0.0298 (20)
PO 18. Awareness to promote low-carbon fuel	0.0354 (16)	0.0313 (19)	0.0289 (20)	0.0458 (4)	0.0387 (15)
PO 19. Subsidies for low-carbon infrastructure	0.0356 (15)	0.0363 (16)	0.0355 (16)	0.0338 (23)	0.0356 (18)
PO 20. High fuel economy standard	0.0433 (10)	0.0429 (11)	0.0445 (9)	0.0403 (8)	0.0436 (10)
PO 21. Cleaner emissions standard	0.0352 (17)	0.0380 (15)	0.0384 (14)	0.0329 (24)	0.0301 (19)
PO 22. Education on fuel-efficient driving	0.0350 (18)	0.0296 (22)	0.0282 (22)	0.0465 (3)	0.0394 (14)

PO 23. Manage waiting time at signals	0.0339 (19)	0.0303 (20)	0.0287 (21)	0.0398 (9)	0.0381 (16)
PO 24. Better integration among modes	0.0452 (6)	0.0455 (8)	0.0427 (10)	0.0416 (7)	0.0508 (2)
PO 25. Car-pooling at peak hours	0.0430 (11)	0.0396 (13)	0.0401 (13)	0.0489 (1)	0.0459 (7)
PO 26. Telecommunication as alternative to travel	0.0454 (4)	0.0435 (10)	0.0451 (8)	0.0484 (2)	0.0472 (5)
Note: To compute a normalized score, the rating against a particular policy option is divided by the total ratings against all policy options (Zaman et al., 2018)					

## 7.6 Discussion

This discussion takes into account the views of experts, and NGO and green energy activists expressed during the interviews conducted in this study. Experts', and NGO and green energy activists' strong preferences for active and public transport infrastructure development emphasize the importance of this PO over other alternatives in New Zealand. Some of the experts, and NGO and green energy activists stated that they preferred active and public transport support because this is a proven option and has been applied successfully in many developed as well as developing countries. Investing in active and public transport infrastructure development such as pedestrian ways, cycle lanes, and bus and rail infrastructure is likely to promote walking, cycling and public transport trip shares and reduce single car uses. Others supported this option due to its significant health co-benefits and congestion reduction abilities. Experts, and NGO and green energy activists also found it to score highly in ethical terms as low-income people cannot afford EVs or alternative low-carbon options, and public or active transport is therefore the only sustainable option for them. Some experts, and NGO and green energy activists consider that New Zealand roads are not wide enough to support a high level of individual car use both in the short and the long run, and therefore supporting

active and public transport use is the best available option under current and future circumstances. An increase in property values along rail or bus rapid transit (BRT) routes is another advantage of public transport infrastructure development since the government could potentially capture the value (in part) to fund other low-carbon transport projects. These factors lie behind experts', and NGO and green energy activists' expressed preferences for this PO.

Other experts, and NGO and green energy activists preferred this PO because they believe that future environmental costs will be much higher if this PO is not considered or implemented. However, although it is a positive option in the sense of not penalizing current car users, one of the challenges for public transport infrastructure development is its costs. In addition, some experts, and NGO and green energy activists do not consider public transport as an appropriate option for cold, snowy areas (like Queenstown) and/or low-density areas.

With regard to the reduction of public transport fares, experts, and NGO and green energy activists viewed this option as being less effective because people were seen not to be especially sensitive to a reduction in public transport fares. They were perceived as mostly using public transport only if it meets their needs.

The experts', and NGO and green energy activists' second most preferred PO is ensuring better accessibility through land-use planning to increase mixed use, higher density housing development along or near transport arteries. The main reason for supporting this PO is its perceived effectiveness in urban areas of New Zealand. Some experts, and NGO and green energy activists saw it as least costly with high emissions reduction potential. This PO was also found to be ethical as both poor and rich people would share the benefits. Some experts, and NGO and green energy activists support this PO because it would be likely to provide better accessibility to people with disabilities. A downside of this option is that it would take time to implement.

Based on experts', and NGO and green energy activists' preferences, another top preferred PO is ceasing the import of petrol or diesel cars into New Zealand by 2030. Experts', and NGO and green energy activists' strong preferences for this PO are due to a number of reasons. Firstly, New Zealand does not manufacture cars and this PO would not detrimentally affect New Zealand employment. Secondly, there is no direct cost involved in this PO, although there are implicitly indirect costs. This option was seen as incentivising the private sector to invest in EVs, alternative fuels etc. Thirdly, the implementation of this PO would effectively accelerate the renewal of New Zealand's vehicle fleet, and improve average vehicle efficiency.

As a result, the operational costs of vehicle use as well as emissions would (although likely rising in the short term) decrease over time. Lastly, a target of 2030 would provide people and other stakeholders with sufficient time to look for alternative options. However, some experts, and NGO and green energy activists criticised this PO for its slowness in achieving environmental benefits. They preferred more stringent minimum fuel economy standards or a cleaner emissions standard in the short run to the cessation of imports of petrol and diesel cars by 2030 because of the (apparently) quicker environmental benefits. They also acknowledged the ineffectiveness of a stringent minimum fuel economy standard or cleaner emissions standard in the long run.

With regard to an improved fuel efficiency standard, some experts, and NGO and green energy activists were concerned that New Zealand might become a dumping ground for cars if no fuel efficiency standard is introduced. Moreover, experts, and NGO and green energy activists found this PO to be very effective as it would promote EVs and would not require people to change their behavior, as would (for example) car sharing. In contrast, some experts, and NGO and green energy activists viewed introducing an age restriction or a cleaner emission standard to exclude old car use as essentially unethical because the impact of such a PO would be uneven and low-income people would be hurt severely compared to high-income people. Some experts, and NGO and green energy activists were also unsupportive towards setting a stringent fuel economy standard because this PO would be unlikely to reduce emissions. Fuel saving due to a fuel-efficient car use often encourages additional travel and thereby would not necessarily contribute to emissions reduction.

With regard to a feebate scheme, most of the central government experts supported this PO because it is a self-financing mechanism whereby buyers of high-emitting vehicles are charged to finance a rebate for buyers of low-emitting vehicles. However, NGO and green energy activists as well as individual experts saw it as unethical to penalize poor people who cannot afford efficient cars.

Experts, and NGO and green energy activists who were in favor of grants or tax-rebates for alternative transport fuel infrastructure development considered this option to be a transition mechanism from petrol to renewables. However, some experts, and NGO and green energy activists viewed alternative renewable fuels as less effective as they are often unsuccessful in changing people's behavior. Although some experts, and NGO and green energy activists considered educating consumers in fuel efficient driving to be useful, others considered it as



an ineffective policy and a poor use of money because there is no evidence that it has an impact on emissions reduction. The central government as well as local government have carried out a number of awareness programmes to promote cycling and energy efficiency projects. However, experts, and NGO and green energy activists interviewed noted that there has not been a significant measured change in people's behavior in New Zealand due to these programmes so far. However, it is unlikely that a programme to promote cycling awareness would have much impact by itself whereas a suite of cycling interventions can change behavior (Chapman et al., 2018).

Experts, and NGO and green energy activists who supported a carbon tax or an increased ETS price believe that such carbon pricing mechanisms will promote innovation so that the market economy can come up with efficient ways to reduce emissions. However, some experts, and NGO and green energy activists are also not favourably disposed towards taxes or increased ETS prices because they see them as imposing high costs on low-income people. Low-income people often live in rural or suburban areas and travel long distances for commuting or other purposes. They might be affected severely where they are unable to avoid the costs imposed by various carbon pricing techniques. Some experts, and NGO and green energy activists criticize the idea of a transport sector carbon tax on top of the ETS because it would create confusion among people and increase complexity. Another reason for not preferring an ETS is visibility – people cannot see the ETS prices on their invoices. One of the experts referred to a study on carbon pricing in British Columbia, where it was suggested that the visibility of a tax had a significant impact on consumers' behavioral changes.

Most of the POs related to EV support are found to be less preferred by the experts, and NGO and green energy activists. Some experts, and NGO and green energy activists viewed POs related to EV subsidisation, EV free parking and EV access to high occupancy lanes as unethical because EVs are mostly used by high-income people whereas low-income people often use bus or low-cost used cars. Experts, and NGO and green energy activists suggested that access to high occupancy lanes should be based on high occupancy, not based on EV ownership, because New Zealand does not have wide roads. Most importantly, exempting EVs from parking charges in certain public parking spaces is not likely to motivate people to purchase EVs.

Offering a deduction against income tax for EV purchase or EV registration tax was also found to be less ethical by some experts, and NGO and green energy activists because it seems to be

taking money from low-income households and giving it to the better off. However, among the two options of an income tax deduction for EV purchase and income tax deduction for EV registration, experts, and NGO and green energy activists preferred the first option because of the high purchase price of EVs. Some experts, and NGO and green energy activists suggested policies to widen the market in EV battery-purchasing sources. Anxiety about EV driving ranges, lack of charging infrastructure, and the non-reusability of EV batteries were some of the additional issues experts, and NGO and green energy activists thought needed to be addressed to promote EV uptake in New Zealand.

Some experts, and NGO and green energy activists criticised the subsidisation of biofuel production and use because it might have detrimental substitution effects. An increased production and use of biofuels is likely to replace existing forestry and farm activity and, it was thought, decrease food production and forestry. This, in turn, could affect food security and carbon sinks. In addition, recent bio-fuels fraud cases or schemes across the world have reduced biofuel acceptability to both the public and policy makers. With regard to hydrogen fuel infrastructure, experts, and NGO and green energy activists thought it was likely to be very costly and only suitable for heavy vehicles. In addition, hydrogen fuel was seen as explosive and the technology is relatively new to the New Zealand market. Most importantly, they emphasised the need for production of hydrogen fuels and biofuels from renewable sources. One of the challenges identified by the experts, and NGO and green energy activists with the production and use of bio-fuels or hydrogen fuels in New Zealand is the lack of coordination. Users of bio-fuels or hydrogen fuels consider that there is not enough production to switch their consumption to these alternative renewable fuels whereas the producers see not enough demand to increase their production. The coalition of powerful big emitters (oil companies) is one of the major challenges acting as a barrier to the take-up of biofuels or hydrogen fuels. One expert suggested community funding to promote the production and use of these alternative renewable fuels.

## **7.7 Policy implications and conclusions**

Experts, and NGO and green energy activists from various organisations viewed the six mitigation policy pathways and the 26 policy options in various ways. Experts from central government and academic institutions put high emphasis on the mitigation potential of an MPP or PO while the experts from local government, and NGO and green energy activists gave top priority to the benefits and co-benefits criterion. Both the central government and the local

government experts were more concerned about cost than the ethical considerations of policy options. In contrast, the NGO and green energy activists as well as the academics were less concerned about the cost and more concerned about the ethical considerations of policy options. This might have impacted the preferences of the experts, and NGO and green energy activists on various options. For instance, electric vehicle support is the most preferred MPP by the central government experts while individual experts (i.e. academics) attached the highest preference to travel demand management. The most favoured MPP for both local government experts, and NGO and green energy activists was public and active transport investment. With regard to the POs, the central government experts most preferred a stringent fuel economy standard for cars, and gave least support to a subsidy on bio-fuel production and use. In contrast, the most favored PO by the local government experts was an investment in public and active transport, and the least preferred option was the exemption of EVs from parking charges in certain public parking spaces. As with the local government experts, investment in public and active transport infrastructure development was also the most supported PO among individual experts. However, the individual experts' least preferred PO was the exemption of bio-fuel excise tax. The NGO and green energy activists were mostly supportive towards the imposition of a carbon tax on top of the current ETS price while they mostly disliked the exemption of EVs from parking charges in certain public parking spaces.

The present policy instruments proposed by the New Zealand government to reduce greenhouse gas emissions from the transport sector include the current emissions trading scheme, electric vehicle support, investigation of alternative fuels and technologies, exemption from excise tax of bioethanol (Ministry of Transport, 2019a) and an awareness program concerning vehicle fuel economy (Ministry of Transport, 2019b). In 2016, the government announced the electric vehicles programme and took a number of measures to support electric vehicle uptake. These include exemption from road user charges of light and heavy EVs, support for infrastructure development of public EV charging stations, an EV information and promotion campaign, and funding to support innovation on EV projects (Ministry of Transport, 2019c).

Findings from this chapter reveal that few of these policy measures proposed or implemented by the government are viewed by experts, and NGO and green energy activists as particularly appropriate or sufficient for New Zealand when considering their costs, benefits, mitigation potential and ethical considerations. The top five POs preferred by the experts, and NGO and green energy activists from various sectors are (i) investing in active and public transport, e.g.

infrastructures such as pedestrian ways, cycle lanes, rail infrastructure etc.; (ii) ensuring better accessibility through land-use planning to increase mixed use, higher density housing development along/near transport arteries; (iii) ceasing the import of petrol and diesel cars into New Zealand by 2030; (iv) using telecommunication services as alternatives to travel (e.g. teleconferencing, teleshopping, distance learning etc.); and (v) subsidizing electric bikes or buses. On the other hand the five least preferred policy options are (i) exempting EVs from parking charges in certain public parking spaces; (ii) allowing EV access to high occupancy lanes on motorways; (iii) deducting registration fees from income tax for EVs; (iv) exempting EVs from road user charges; and (v) exempting excise tax on bio-fuels.

It is evident from the research described in this chapter that policies announced and in some cases implemented by the government such as the exemption of EV road user charges and the exemption of bioethanol excise tax are among the least preferred options in the view of a range of experts, and NGO and green energy activists. This illustrates a clear policy gap between the established direction of government transport and climate change policy and the policy viewed by experts, and NGO and green energy activists as the most sustainable.

## **Chapter 8: Summary discussion and Conclusions**

From this study, it is evident that the ever-increasing emissions from the road transport sector in New Zealand are due to a number of diverse drivers. Firstly, New Zealanders are using the oldest vehicles in the OECD. Secondly, urban areas are sprawling in nature. Thirdly, urban population as well as travel demand are rapidly growing. Fourthly, public transport infrastructures are inadequate, and cars are the main mode used to undertake trips. Lastly, the existing policies of the government such as the electric vehicle programme, introduction of an emissions trading scheme (ETS), vehicle emissions standards, and the promotion of biofuels have been found to be ineffective in tackling persistent transport emissions. Although there are various drivers of transport emissions, the results derived from an econometric model, the VECM, show that only vehicle fuel economy has a significant long-run causal relationship with transport emissions. An increase of vehicle fuel economy by 1% was found to be likely to reduce road transport emissions by 1.4%. The relationships between transport emissions and other drivers were not found to be significant at a significance level of 0.1. However, this does not imply that these drivers do not have an impact in the overall transport emissions. According to Hasan et al. (2019), the reason for drivers like urbanization rate, GDP per capita, passenger vehicle numbers and fuel price to be insignificant to drive transport emissions could be the relatively small changes in values over the study period. Since vehicle fuel economy has a significant long-run causal relationship with transport emissions, a newer and clean vehicle fleet is crucial to reduce transport emissions and achieve the net-zero carbon emissions by 2050.

The contribution of EVs to achieving a newer and cleaner vehicle fleet in New Zealand is undeniable because in 2018 about 84% of New Zealand's electricity came from renewable sources (Hasan & Chapman, 2019), among the highest in the world. The study results show that the emissions reduction potential of light EVs at user level (i.e. setting aside manufacturing and recycling emissions) in New Zealand is around 90%. However, from a life-cycle perspective, the emissions reduction potential of a light EV is about 60% for New Zealand which is similar to the study of EECA (2015) and Moro and Lonza (2018). Accordingly, a light electric vehicle share of around 45% would help this sector play its part to achieve the unconditional emissions reduction target of the government under the Paris agreement. Moreover, the findings of this study reveal that used EVs are the cheapest over a 12-year ownership period followed by used ICEVs, new ICEVs and new EVs. The PCO for a used light

EV is only 25.5 NZ cents per km while the PCO of a used light conventional car is 31.5 cents. The PCO for a clean car (a used or a new EV) will decrease from 2021 if the proposed ‘clean car discount’ scheme is enacted. The analysis of the study shows that the PCO for the new Toyota Corolla, and new and used Nissan Leaf would fall to 36.5 cents, 41.5 cents and 23.5 cents respectively if the clean car discount’ scheme is live in 2021. The findings of this study is similar to the findings of Wu et al. (2015), Falcão et al. (2017) and Palmer et al. (2018).

Findings also reveal that a carbon price of NZD 235/tonne of CO<sub>2</sub> - based on recent evidence about the social cost of carbon (i.e. its global damage cost) - could reduce transport sector emissions by around 44% from the 2016 level by 2030, and thus could help this sector play its part to achieve New Zealand’s Paris target. However, the increases in annual domestic transport expenditure due to a carbon price of NZD 235/tonne of CO<sub>2</sub> for lower, middle and high-income households would be around NZD 670, NZD 1,356, and NZD 2,133, respectively. The percentage increases in annual gross expenditure for these lower, middle and higher income households would be 3.57%, 3.58% and 2.67%, respectively. Since lower-income households would be affected rather more severely than other income groups (as their percentage increase in gross expenditure is relatively higher than for other income groups), experts, and NGO and green energy activists tend to suggest a carbon tax instead of an increased ETS price, as it is perceived to be easier for the tax revenue to be used in a progressive way to offset the cost burden on low-income households. In addition, an increased carbon price in the form of a tax might better allow the government to reduce other taxes and help to invest in renewable energy sources, public transport infrastructures, compensate affected companies etc. In principle, a similar arrangement could apply under the ETS, as long as ETS units were auctioned (there is as yet no experience of this in New Zealand).

This study has also used multi-criteria analysis to elicit the perceptions of a range of experts, and NGO and green energy activists on the merits of other alternative transport emissions reduction policies. It was concluded that supporting active and public transport was considered to be the most cost beneficial and ethical policy pathway, with high potential to reduce transport emissions. The ratings of other mitigation policy pathways from highest to lowest perceived merit are travel demand management, an increased carbon price in the form of a tax, EV support, improved fuel efficiency and bio-fuels and hydrogen-fuels. In terms of emissions reduction potential, ceasing the import of regular petrol cars into New Zealand by 2030 was found to be the most preferred policy option followed by introduction of a carbon tax. On the other hand, the least preferred transport emissions reduction policies based on experts’, and

NGO and green energy activists' preferences include exemption of EVs from road user charges and the exemption of bioethanol excise tax. Surprisingly, most of the policy options that are most preferred by transport and environmental experts, and NGO and green energy activists are absent in policy documents of the government while the least preferred policy options are in the policy documents (Ministry of Transport, 2019b).

From this study, it is evident that there is a clear policy gap between the policy measures already introduced, and policy measures perceived to be desirable. Since policy measures targeting the key factors responsible for increased GHG emissions in the transport sector are crucial to reduce emissions significantly, it is hoped that this study will help policy makers in identifying the major drivers behind growth in transport emissions, and the selection of appropriate policy options. The quantitative analyses performed in this study shed light on the costs and emissions reduction potential of electric vehicles and an increased carbon price. Moreover, the experts', and NGO and green energy activists' preferences on various transport emissions reduction policies should help policy advisers take a broader view of the costs, benefits, mitigation potential and ethical aspects of these policy measures and assist them in identifying the most attractive policies and projects for investment.

Although this is a New Zealand based study, the contribution of this study to the body of knowledge about various countries' climate change policies, and transport policies in particular, is significant. Firstly, the methodology used in different chapters is robust and can be adopted by other researchers to carry out similar quantitative and qualitative analysis for related studies. Secondly, the study results have immediate policy implications for a range of countries such as central and south American countries that have high shares of renewables in their electricity mix like New Zealand. Thirdly, the study has future policy implications for many nations because countries where transport emissions are not yet a major issue are likely in future to have to mitigate increasing transport emissions once they solve their other emissions issues.

In terms of future research, there is a good case for people's acceptance of various transport emissions reduction policies to be studied to understand how their views differ from experts', and NGO and green energy activists' preferences. A further study could also be done by including more criteria in addition to the four main criteria that are used in this study. Some of these additional criteria could be political acceptability, social acceptability and/or technical feasibility. The results then could be compared to understand how preferences change with the

inclusion of additional criteria. Another future study could be to carry out similar research in the post-COVID period to understand how COVID-19 has changed experts', and NGO and green energy activists' views on various transport emissions reduction policies.



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## Annex X1

Annex X1 presents the environmental footprint of electric versus fossil cars and it is an analysis on which The Conversation article was based. Citation of the Conversation article is as follows:

Hasan, M. A., & Chapman, R. (2019). Climate explained: the environmental footprint of electric versus fossil cars. *The Conversation*. <https://theconversation.com/climate-explained-the-environmental-footprint-of-electric-versus-fossil-cars-124762>

### **Climate explained: the environmental footprint of electric versus fossil cars**

Electric cars seem very attractive at first sight. But when we look more closely it becomes clear that they do still have a substantial carbon footprint and some downsides in terms of the extraction of lithium, cobalt and other metals. Of course, EVs don't relieve congestion in crowded cities and may even increase congestion over time.

In this response to the question above, we touch briefly on the lithium issue, but focus mainly on the big environmental issue, which is the carbon footprint of electric cars.

The increasing use of lithium-ion batteries as a major power source in electronic devices, including mobile phones, laptops and electric cars has hugely increased lithium mining worldwide<sup>2,3</sup>. There seems little near-term risk of lithium being mined out, but there is a major environmental downside of lithium mining. The mining process requires extensive amounts of water, which can cause aquifer depletion and adversely affect ecosystems<sup>4</sup>.

Turning to climate change, it really matters whether electric cars emit less carbon than conventional vehicles, and how much less.

#### **- Emissions reduction potential of EVs**

The best way to compare is based on a life cycle analysis which tries to consider all the emissions of carbon dioxide during vehicle manufacturing, use and recycling. Life cycle estimates are never entirely comprehensive, and emission estimates vary by country, as circumstances vary.

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<sup>2</sup> <https://www.sciencedirect.com/science/article/pii/S0301420717305457>

<sup>3</sup> <https://www.sciencedirect.com/science/article/pii/S1385894719314780>

<sup>4</sup> <https://www.sciencedirect.com/science/article/pii/S0303243419300996>

New Zealand, with high renewable electricity levels, has much greener electricity for electric car (EV) recharging than say Australia or China, so EVs are better suited to New Zealand<sup>5</sup>. But this is only one part of the story, and one should not assume that, overall, electric cars in New Zealand have a close-to-zero carbon footprint or are wholly sustainable. They are not.

A life cycle analysis of emissions considers three phases: the manufacturing phase (also known as cradle-to-gate), the use phase (well-to-wheel) and the recycling phase (grave-to-cradle).

#### **- The manufacturing phase**

In this phase, the main processes are ore mining, material transformation, manufacturing of vehicle components and vehicle assembly. A recent study<sup>6</sup> estimated emissions for a conventional fossil-fuelled car (compact sedan model) in this phase to be about 10.5 tonnes of carbon dioxide (tCO<sub>2</sub>) per car, while the estimated emissions for an electric car were about 13.0 tonnes (including the electric car battery manufacturing).

Emissions from the manufacturing of a lithium-nickel-manganese-cobalt-oxide battery alone (usually known as an NMC battery) were estimated to be 3.2 tonnes. If the vehicle life is assumed to be 150,000 kilometres, emissions from a fossil-fuelled car and an electric car in the manufacturing phase would be 70gCO<sub>2</sub>/km and 87gCO<sub>2</sub>/km, respectively. Emissions from electric car manufacturing are thus higher than for fossil fuelled cars.

#### **- The use phase**

In the use phase, emissions from an electric car are solely due to its upstream emissions, which depend on how much of the electricity comes from fossil or renewable sources. The emissions from a fossil-fuelled car are due to both upstream emissions and tailpipe emissions.

Upstream emissions of EVs essentially depend on the share of zero or low-carbon sources in the country's electricity generation mix. To understand how the emissions of electric cars vary with a country's renewable electricity share, consider Australia and New Zealand.

In 2018, Australia's share of renewables in electricity generation was about 21%<sup>7</sup> (less than China's at 30%). In contrast, the share of renewables in New Zealand's electricity generation

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<sup>5</sup> <https://www.eeca.govt.nz/news-and-events/media-releases/research-confirms-environmental-benefits-of-electric-vehicles/>

<sup>6</sup> <https://www.sciencedirect.com/science/article/pii/S0360544219307133>

<sup>7</sup> <https://www.tai.org.au/content/rooftops-providing-more-shelter-record-solar-contribution>

mix was about 84%. Using these data and estimates from recent assessments<sup>8,9</sup>, electric car upstream emissions in Australia can be estimated to be about 170gCO<sub>2</sub>/km while upstream emissions in New Zealand are estimated at about 25gCO<sub>2</sub>/km on average. This indicates that using an electric car in New Zealand is likely to be about seven times better in terms of upstream carbon emissions than in Australia.

The above studies show that the use phase emissions from a fossil-fuelled compact sedan car were about 251gCO<sub>2</sub>/km. Therefore, the use-phase emissions from such a fossil-fuelled car were about 81gCO<sub>2</sub>/km higher than the emissions from a grid-recharged EV in Australia, and much worse than the emissions from use of an electric car in New Zealand.

#### - **The recycling phase**

The key processes in the recycling phase are vehicle dismantling, vehicle recycling, battery recycling and material recovery. The emissions in this phase for a fossil-fuelled car and an electric car (including battery recycling) are estimated at 1.8 tonnes and 2.4 tonnes, respectively. This difference is mostly due to the emissions from battery recycling which is about 0.7 tonnes. For a vehicle life of 150,000 km, the per-kilometre emissions from a fossil-fuelled car and an electric car in the recycling phase were around 12gCO<sub>2</sub>/km and 16gCO<sub>2</sub>/km, respectively.

This illustrates that electric cars are responsible for more emissions than their petrol counterparts in the recycling phase. Note that the recycled vehicle components can be used in the manufacturing of future vehicles, and batteries recycled through direct cathode recycling can be used in subsequent batteries. This could have significant emissions reduction benefits in the future (e.g. potentially about 4.9 tCO<sub>2</sub>e of emissions reduction for fossil-fuelled cars and about 6.6 tCO<sub>2</sub>e of emissions reduction for electric cars including battery recycling, but these figures are too uncertain to include in our analysis).

In summary, we conclude on the basis of recent studies that fossil-fuelled cars generally emit more than electric cars only in the use phase of a life cycle, and the total life cycle emissions from a fossil-fuelled car and an electric car *in Australia* were 333gCO<sub>2</sub>/km and 273gCO<sub>2</sub>/km, respectively. That is, using average grid electricity, EVs come out about 18% better in terms of their carbon footprint.

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<sup>8</sup> <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6358150/>;

<sup>9</sup> <https://www.sciencedirect.com/science/article/pii/S0360544219307133>

Likewise, electric cars *in New Zealand* work out a lot better than fossil-fuelled cars in terms of emissions, with life-cycle emissions at about 333gCO<sub>2</sub>/km for fossil-fuelled cars and 128gCO<sub>2</sub>/km for electric cars. In New Zealand, EVs perform about 62% better than fossil cars in carbon footprint terms.

Since New Zealand's electricity is cleaner than Australia, switching to an electric car in New Zealand will have greater environmental benefits in terms of mitigating global warming, as well as reducing local air pollutants.

Table 1: Emissions in different phases for a compact sedan car based on recent studies

	ICEV (gCO <sub>2</sub> /km)	EV (Australia)	EV (New Zealand)
Manufacturing phase	70	87	87
Use phase	251	170	25
Recycling phase	12	16	16
Total	333	273	128
Emissions reduction potential		18%	62%



## Appendix A: Human ethics approval



Phone 0-4-463 6028  
Email [judith.loveridge@vuw.ac.nz](mailto:judith.loveridge@vuw.ac.nz)

### MEMORANDUM

TO	Md Arif Hasan
FROM	Dr Judith Loveridge, Convenor, Human Ethics Committee
DATE	23 November 2018
PAGES	1
SUBJECT	<b>Ethics Approval</b> <b>Number:</b> 0000026732 <b>Title:</b> Understanding the costs, benefits and mitigation potentials of New Zealand's transport emissions reduction policies

Thank you for your application for ethical approval, which has now been considered by the Human Ethics Committee.

Your application has been approved from the above date and this approval is valid for three years. If your data collection is not completed by this date you should apply to the Human Ethics Committee for an extension to this approval.

Best wishes with the research.

Kind regards,

A handwritten signature in cursive script, reading 'J. A. Loveridge'.

Judith Loveridge

Convenor, Victoria University of Wellington Human Ethics Committee

## Appendix B: Interview consent form

### Doctoral Thesis: Understanding the costs, benefits and mitigation potentials of New Zealand's transport emissions reduction policies

#### CONSENT TO INTERVIEW

This consent form will be held for 2 years.

**Researcher:** Md Arif Hasan, School of Geography, Environment and Earth Sciences

- I have read the Information Sheet and the project has been explained to me. My questions have been answered to my satisfaction. I understand that I can ask further questions at any time.

I understand that:

- I may withdraw from this study at any point before 30 October 2019, and any information that I have provided will be returned to me or destroyed.
- The identifiable information I have provided will be destroyed on 25 February 2022.
- Any information I provide will be kept confidential to the researcher and the supervisor.
- I understand that the results will be used for a PhD dissertation, and academic publications and conferences.
- My name and/or any information that would identify me will not be used in reports.
- I would like a copy of the transcript of my interview: 

Yes	No
<input type="checkbox"/>	<input type="checkbox"/>
- I would like a summary of my interview: 

Yes	No
<input type="checkbox"/>	<input type="checkbox"/>
- I would like to receive a summary of the final report and have added my email address below: 

Yes	No
<input type="checkbox"/>	<input type="checkbox"/>

Signature of participant: \_\_\_\_\_

Name of participant: \_\_\_\_\_

Date: \_\_\_\_\_

Contact details: \_\_\_\_\_

## **Appendix C: Information sheet for participants**

### **Doctoral Thesis: Understanding the costs, benefits and mitigation potentials of New Zealand's transport emissions reduction policies**

#### **INFORMATION SHEET FOR PARTICIPANTS FOR INTERVIEWS**

You are invited to take part in this research. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to participate, thank you for considering this request.

#### **Who am I?**

My name is Md Arif Hasan and I am a Doctoral student in Environmental Studies at Victoria University of Wellington. This research project is work towards my thesis.

#### **What is the aim of the project?**

In the transport sector, decision making is quite complex as there are multiple goals that a government would like to reach. It is posited that a trade-off among these goals is made by government through the inclusion of different experts and policy advisers in the decision making process, to illuminate the potential alternative goals in terms of costs, benefits (including co-benefits), emissions reduction potentials and ethical considerations. This research aims to understand opinion on the costs, benefits, mitigation potentials and ethical considerations of different transport emissions reduction policies by eliciting views from experts and policy advisers. There are no right or wrong answers, we are interested in your opinion. This research project has been approved by the Victoria University of Wellington Human Ethics Committee (0000026732).

#### **How can you help?**

You have been invited to participate because you have adequate knowledge on costs and benefits of different transport emissions reduction policies along with their mitigation potentials. If you agree to take part I will interview you for 20 to 30 minutes at your office or at any of your convenient location. You can choose to not answer any question or stop the interview at any time, without giving a reason. You can withdraw from the study by contacting me at any time before 30 October 2019. If you withdraw, the information you provided will be destroyed or returned to you.

#### **What will happen with the information you give?**

This research is confidential. This means that the researchers named below will be aware of your identity but the research data will be combined and your identity will not be revealed in any reports, presentations, or public documentation.

Only my supervisors and I will read the transcript of the interview. The interview transcripts and summaries will be kept securely and destroyed on 25 February 2022.

#### **What will the project produce?**

The information from my research will be used in PhD dissertation, and academic publications and conferences.

**If you accept this invitation, what are your rights as a research participant?**

You do not have to accept this invitation if you don't want to. If you do decide to participate, you have the right to:

- choose not to answer any question;
- withdraw from the study before 30 October 2019;
- ask any questions about the study at any time;
- receive a copy of your interview transcript if you want;
- read over and comment on a written summary of your interview if you want;
- be able to read any reports of this research by emailing the researcher to request a copy.

**If you have any questions or problems, who can you contact?**

If you have any questions, either now or in the future, please feel free to contact my supervisor or me:

**Student:**

Name: Md Arif Hasan

University email address:

mdarif.hasan@vuw.ac.nz

**Supervisor:**

Name: Ralph Chapman

Role: Director, Environmental Studies Program

School: Geography, Environment and Earth  
Sciences

Phone: 04 4636153

Email: ralph.chapman@vuw.ac.nz

**Human Ethics Committee Information**

If you have any concerns about the ethical conduct of the research you may contact the Victoria University Human Ethics Committee (HEC) Convenor: Dr Judith Loveridge. Email [hec@vuw.ac.nz](mailto:hec@vuw.ac.nz) or telephone +64-4-463 6028.

## Appendix D: Interview guide

### Doctoral Thesis: Understanding the costs, benefits and mitigation potentials of New Zealand's transport emissions reduction policies

#### INTERVIEW GUIDE

Date: .....

Research student: Md Arif Hasan, PhD student in Environmental Studies, Victoria University of Wellington

Interviewee (Optional):

Organisation/ Role (Optional):

Email/Contact number (Optional):

#### 1. Introduction

Discuss and sign the Information Sheet for Participants and Informed Consent Form.

#### 2. Can you please score the following criteria for assessing transport mitigation policies (these will be used to derive weights to be applied to the ratings you provide below):

Criteria for evaluating New Zealand's transport emissions reduction policies	Your score of this criterion on a scale of 0-9 ('0' indicates this criterion is very unimportant, while '9' indicates a highly important criterion)
A. Benefits and co-benefits in terms of emissions reduction (including for example health gains, cleaner environment, new employment, cost saving, etc.)	.....
B. Potential for emissions reduction	.....
C. Costs	.....
D. Ethics (e.g. this is the 'right' thing to do)	.....

#### 3. Please rate the following six Mitigation Policy Pathways (9-indicates a very strong pathway while 1 indicates a very weak pathway; and enter DK if you don't know)

Mitigation Policy Pathway (MPP)	Switching from fossil-fuelled vehicles to low or zero emission vehicles	Putting a high price on carbon	Increasing active and public transport trip share and reducing trip demand	Promoting alternative renewable fuel sources	Increasing vehicle fuel economy	Managing traffic and travel demand
Rating of pathway based on its benefits and co-benefits						

in terms of emissions reduction (including for example health gains, cleaner environment, new employment, cost saving, etc.)						
Rating of pathway based on its <b>potential for emissions reduction</b>						
Rating of pathway based on its <b>costs</b>						
Rating of pathway based on its <b>ethics (e.g. this is the ‘right’ thing to do)</b>						

**4. Rating of individual Policy Options within each mitigation policy pathway (9-indicates a very strong policy while 1 indicates a very weak policy; and enter DK if you don’t know)**

Mitigation Policy Pathway (MPP)	Policy Option	Rating on scale: From 1 (very weak policy) to 9 (very strong policy)			
		Benefits and co-benefits in terms of emissions reduction	Potential for emissions reduction	Costs	Ethics (e.g. this is the ‘right’ thing to do)
1. Switching from fossil-fuelled vehicles to low or zero emission vehicles	1. 1 Exempting electric vehicles (EVs) from road user charges				
	1.2 Introducing a fee-bate scheme (fee for high-emitting vehicles and rebate for low-emitting vehicles)				
	1.3 An income tax deduction for EV purchase				
	1.4 An income tax deduction for EV registration tax				
	1.5 Subsidisation of EV re-charging facilities				
	1.6 Allowing EV access to high occupancy lanes on motorways				
	1.7 Exempting EVs from parking charges in certain public parking spaces				
	1.8 Subsidising electric bikes or buses				

Mitigation Policy Pathway (MPP)	Policy Option	Rating on scale: From 1 (very weak policy) to 9 (very strong policy)			
		Benefits and co-benefits in terms of emissions reduction	Potential for emissions reduction	Costs	Ethics (e.g. this is the 'right' thing to do)
	1.9 Ceasing the import of petrol and diesel cars into New Zealand by, say, 2030.				
	1.10 Excluding petrol and diesel vehicles from a major area of a city by, say, 2030.				
2. Putting a high price on carbon	2.1 Increasing the present ETS price with a rising price floor to better reflect the social cost of carbon <sup>10</sup> while offsetting the regressive effects of a higher carbon price through reducing income tax for low-income earners or lowering public transport costs				
	2.2 Putting a transport carbon tax on top of the ETS price to better reflect the social cost of carbon* while offsetting the regressive effects of a higher carbon price through reducing income tax for low-income earners or lowering public transport costs				
3. Increasing active and public transport trip share and reducing trip demand	3.1 Investing in active and public transport, e.g. infrastructures such as pedestrian ways, cycle lanes, rail infrastructure etc.				
	3.2 Reducing the cost of public transport use				
	3.3 Ensuring better accessibility through land-use planning to increase mixed use, higher density housing development along/near transport arteries				
4. Promoting alternative renewable fuel sources	4.1 Exempting excise tax on bio-fuels				
	4.2 Subsidising the production and use of bio-fuels, hydrogen, etc.				

<sup>10</sup> Researchers have estimated this to be in a range (using approximate interquartile estimates) of around NZ\$ 100 to NZ\$175 (2030 estimates).

Mitigation Policy Pathway (MPP)	Policy Option	Rating on scale: From 1 (very weak policy) to 9 (very strong policy)			
		Benefits and co-benefits in terms of emissions reduction	Potential for emissions reduction	Costs	Ethics (e.g. this is the 'right' thing to do)
	4.3 Promoting alternative fuel use through awareness building and information dissemination				
	4.4 Grants or tax-rebates for alternative transport fuel infrastructure development				
5. Increasing vehicle fuel economy	5.1 Setting a high minimum fuel economy standard to ensure the entry of only fuel-efficient cars from manufacturing countries				
	5.2 Introducing an age restriction or a cleaner emission standard to exclude old-car use				
	5.3 Educating consumers in fuel-efficient driving				
6. Managing traffic and travel demand	6.1 Using advanced technology to manage waiting time at signals				
	6.2 Ensuring better integration among different modes to improve transport network efficiency				
	6.3 Managing peak hour travel through providing alternative travel options to single occupant vehicles (e.g. car-pooling etc.)				
	6.4 Using telecommunication services as alternatives to travel (e.g. tele-conferencing, teleshopping, distance learning etc.)				

*N.B. Please use the blank spaces to write in any policy options you support which have not been mentioned.*

## 5. Conclusion



Please indicate any reasons for giving priority to a particular mitigation policy pathway (MPP) over others.

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Please indicate any reasons for giving a high rating to any particular policy option:

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Thank you very much for participating in this research! – **Md Arif Hasan**