Essays on the
Economics of Climate Change in New Zealand

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Economics, The University of Auckland, 2019.

Abstract

The core question in this study is how to investigate policies for climate change in New Zealand. By using different econometric techniques over the period from 1970 to 2014, this thesis investigates the economic and environmental impacts of implementing decarbonising policies in New Zealand. So this study aims at providing empirical evidences on the extent to which decarbonising policies in New Zealand could tackle emission reduction targets more efficiently and how various economic factors need to be taken into account when evaluating current conditions and deciding future actions. More precisely, in order to address the main research question, the thesis has three main empirical chapters which examine three different aspects but interrelated dimensions of the economics of climate change.

The first empirical essay investigated how economic performance is influenced by mitigation policies. The E3ME model is employed to analyse the potential environmental and macroeconomic impacts of environmental tax reform (ETR) in New Zealand. A number of different scenarios including a baseline are constructed to investigate the performance of the NZ ETS and other complementary mitigation policies over the commitment period (2021-2030). According to the study findings, higher carbon prices especially in the early years would be necessary to achieve the ambitious GHG emissions target in New Zealand. The results also suggest that a combined NZ ETS and carbon tax approach with revenue recycling could lead to significant economic benefits.

The second essay examined how effective the fuel tax and technology improvements are to influence decarbonising light petrol fleet in both short- and long-run. The study findings show that improving emissions standards in the long-term is more effective emission abatement policy than direct fuel tax in New Zealand. However, in the short-term, fuel tax is a better choice as it encourages consumers who drive and pollute a lot to choose a greener transportation.

The third essay revisited the relationship between the level of CO_2 emissions and some key economic and technology-related determinants. The empirical findings show that there are significant positive causalities from per capita real GDP and per capita energy consumption toward per capita CO_2 emissions which are in line with findings in previous studies. However, the financial development, trade openness and technology boost show significant negative influences on emission levels implying that their improvements help to decrease New Zealand's emissions.

To my wonderful wife,

Dr. Sepideh Firoozkoohi,

Without whose inspiration and encouragement

I would have never accomplished this study.

Acknowledgements

The preparation of this Ph.D. thesis was by no means a simple task; therefore, I am most appreciative to all the people who helped me in the compilation of this research project. Indeed, I take advantage of this opportunity to express my most and sincere heartfelt sense of appreciation and attitude to the most wonderful individuals who made and continue to make a change for the better in my personal and academic life.

First and foremost, I would like to express my special appreciation and thanks to my supervisors, Professor Basil Sharp and Dr. Stephen Poletti, who gave me the freedom to explore different exciting ideas.

The members of the Energy Centre have contributed immensely to my personal and professional time at Business School. The E3ME study discussed in this thesis would not have been possible without the technical and financial support of the Energy Centre. I would also like to acknowledge the team at Cambridge Econometrics – Hector Pollitt, Ana Gonzalez-Martinez, Eva Alexandri, and Unnada Chewpreecha – whose great support and guidance have shaped the ideas of the Essay One.

I gratefully acknowledge the financial support from the University of Auckland, the Energy Education Trust of New Zealand (EETNZ), and the Energy Centre at University of Auckland Business School in the form of scholarships and funds that made my Ph.D. work possible.

Besides, I have benefited greatly from conversations with many economic policy experts, among them, Suzi Kerr, Terry Barker, Jean-François Mercure, Barry Coates, Catherine Leining, and Ralph Samuelson.

Lastly, I would like to thank my family for all their love and encouragement. For my parents, Maryam and Siavash, my sisters Solmaz and Sahar for their endless help and support. Finally, and most importantly, I thank with love to Sepideh, my beloved wife for being a constant source of inspiration and enthusiastic support throughout the course of study.

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Chapter 1. Introduction

Almost all scientific reports, including the oldest IPCC [1] reports, confirm that humankind has a negative impact on the natural environment, leading to substantial long-term and irreversible climatic change. Increasing atmospheric concentrations of greenhouse gases (GHG) have a significant impact on the global temperature and sea level, which raise wide economic, ecological and climatic impacts (IPCC, 2007). Carbon dioxide, methane, nitrous dioxide and three groups of fluorinated gasses are the major human-induced GHGs. Temperature increases in the Northern Hemisphere in the last century have been the highest of any previous nine centuries.

Economists agree that factors affecting economic growth continue to be a subject of considerable controversy. Almost all economic activities relating to the environment directly or indirectly affect the ecological system, and thus the activities can damage the environment in various stages of extraction, production, transportation, and consumption. The impact of human activities on the ecological system increases as the level of human activities progress. Economic growth requires an expansion of energy and raw materials which can lead to a higher degree of environmental degradation and the loss of environmental quality. Moreover, the impact of energy consumption on economic growth is an important topic from a policy point of view. Energy-intensive economic activities also largely influence environment quality, and it is therefore, of special analytical and policy interest.

New Zealand has a unique emission profile with almost half of total emissions coming from agriculture sector only. The country also benefits from its high levels of renewable energy utilisation, primarily hydro generation, because of New Zealand's national and geographical circumstances. In addition, the continuous growth of GDP is a real challenge for New Zealand on the way to achieve its mitigation targets, which rose 67% from 1990 to 2008. Over that period the emissions in the energy sector increased by 46.8%, mainly due to emissions from transport and fossil fuel electricity generation (UNFCCC, 2011). Therefore, achieving

[1] The Intergovernmental Panel on Climate Change (IPCC) is a scientific and intergovernmental body under the auspices of the United Nations

mitigation targets seems to be more challenging for New Zealand than the other developed countries.

According to the current debates concerning global warming, air quality and other serious environmental issues, the analysis of the relationship between economic and environmental indicators helps New Zealand policymakers and planners to address socially and environmentally viable policy options.

This study aims to provide empirical evidence on the extent to which decarbonising policies in New Zealand cope with emission reduction targets and how various economic factors need to be taken into account when evaluating current conditions and deciding future actions. Thus, in order to understand the effects of climate change on New Zealand economy, three questions will be addressed: (1) how economic performance is influenced by mitigation policies; (2) in what way fuel tax and technology changes are effective to influence decarbonising the light petrol fleet in the long-run; (3) how technology improvements and economic indicators affect CO_2 emissions. Therefore, this PhD thesis consists of three chapters:

1.1. Essay One: Environmental Tax Reform (ETR) and New Zealand Economic Performance

Discussions about climate policy involve considering sophisticated inter-linkages between the energy system, environmental management system, economic integrity, political processes and issues of fairness and justice. Thus, an extensive analysis of all effects caused by climate change can benefit from an integrated evaluation tool combining energy, economic and climate interactions combining consideration of all the issues mentioned above within one modelling instrument. This could lead to development of a comprehensive integrated assessment of the costs and benefits of emission reduction policies.

New Zealand is committed to be part of a global response to the dramatically increasing GHG emissions level in the world. Therefore, government is actively tracking the latest global agreements on setting climate targets both at domestic and international levels. Hence, New Zealand is developing actions where it can make the greatest impacts.

Two primary economic instruments have been applied to reduce carbon emissions in the world, carbon (energy) taxes combined with reductions in other taxes like an environmental tax reform (ETR), and emission trading schemes (ETS). ETS is a market-based approach used to control pollution by providing economic incentives which has been criticised for its ineffectiveness in several studies (Ekins, 2009 and Venmans, 2012). Therefore, benchmarking of alternative approaches like ETR in order to replace or to combine with ETS is under investigation by researchers and policy makers.

The idea behind ETR is as simple as shifting taxation from goods to bads, in other words from labour to pollution (Skou Andersen et al., 2007). The aim is to apply specific taxes to persuade households and industries to behave in a way which is environmentally sustainable. However, implementing an ETR to achieve a climate mitigation target and at the same time reducing the tax burden on New Zealanders needs comprehensive study.

The New Zealand Emissions Trading Scheme (NZ ETS) is the primary policy tool covering most economic sectors for domestic emissions removals. The NZ ETS was stablished in 2008. It differs from the European ETS. The New Zealand version does not include a cap for pollutions, and therefore does not control total emissions within a specific period. Also NZ

ETS is widely criticized for its generous free allocations of emission units and for being ineffective in reducing emissions.

The CGE[2] approach has often been used in New Zealand to model the future effects of mitigation policies on the country's economy (e.g. NZIER & Infometrics, 2009; Infometrics, 2015; Daigneault, 2015). However, unlike these previous studies, I adopt the E3ME model in order to simulate the economic aspects of taking an action on climate change in New Zealand. The E3ME is a global macro-econometric E3 (Energy-Environment-Economy) model that links the world's economies to their energy systems and associated emissions. The model was constructed by international teams led by 4CMR (Department of Land Economy, University of Cambridge) and Cambridge Econometrics. The E3ME is econometric in design and can address issues related to consequences of developing policies in the areas of energy, the environment, and the economy. The model contains an economic module based on National Accounts developed by Richard Stone in Cambridge and formally presented in European Communities (2008). Detailed disaggregation linked by input-output relationships is a key feature of E3ME.

The main focus of this study is to analyse the potential effects of ETR on New Zealand economy using the E3ME econometric model.

[2] Computable General Equilibrium

1.2. Essay Two: Light Petrol Vehicles and CO_2 Emissions in New Zealand: Assessing the Effectiveness of Fuel Tax and Technology Improvements

The energy sector is dominated by the direct combustion of fossil fuels; therefore, fuel combustion is responsible for the largest amount of global CO_2 emissions. In turn, transport is the second biggest emitter after the electricity sector and contributes to the current trend in global emissions which is leading the world towards global warming exceeding 4°C (IPCC 2014). Road transport is responsible for nearly 23% of CO_2 of global fuel combustion greenhouse gas emissions and claims over 30% of total emissions growth each year (IEA 2015). Moreover, the global demand for transport is very uncertain as the pace and shape of economic developments continue to rapidly change almost everywhere in the world.

Currently, road transport does not seem to be highly regulated for emissions, and increasing level of income especially in emerging economies steers consumer choices towards increasingly emission intensive cars with higher capacity engines (e.g. Gallachoir et al., 2009; Zachariadis, 2013). It is clear that energy saving and emission reduction could be achievable through switching to more energy efficient vehicles. However, consumers usually follow their socio-economic characteristics in purchasing a new car and, interestingly the state of technology and age of cars are not among their first preferences (McShane et al., 2012). In addition, overconsumption of energy in countries like U.S. and the impact of this on greenhouse gas emissions is another big challenge for governments and policy makers.

New Zealand is a remote land and has a relatively lower population density (at 9.8 people per square kilometre) with people traditionally living in rural places. The country is historically very car-dependent as it has mountainous topography and long coastline. There are currently over 3.8 million vehicles on New Zealand's roads and around 91 percent of these are light[3] vehicles. New Zealand also has one of the oldest light vehicle fleets among developed countries, with an average of 14.1 years in 2014.

Between 1990 and 2016, the road transportation experienced a 82.1 percent growth in emissions. This is likely due to population growth and increase in demand for freight transport in New Zealand. In 2016, the transport sector was responsible for 17.2% of New Zealand's

[3] Light vehicles are those that have a gross vehicle mass less than 3.5 tonnes and include cars, vans, 4WDs, utes and light trucks.

total gross emissions and it is expected that its share will continue to grow unless appropriate emission reduction policies are taken into account.

The two aspects of transport sector externalities are of special interest to energy economists and policy makers: atmospheric emissions and the effectiveness of fiscal policy instruments to reduce the CO_2 emissions. Many studies have attempted to analyse the mitigation policies for road transport and those studies indicate that several variables affect carbon emissions from car fleet. This chapter examines the linkage between the level of CO_2 emissions from Light Petrol Vehicles (LPV) and some key determinants using econometric models and seasonal data from 2005 to 2014 in New Zealand. The analysis incorporates the effects of fuel tax, Trade-Weighted exchange rate Index (TWI) and the average emission rate of newly registered vehicles. In addition, this study also investigates how effective the fuel tax and technology improvements are to influence decarbonising light petrol fleet in both short- and long-run. This question is of special interest in the international literature, and it has not been previously investigated for the LPVs in New Zealand.

1.3. Essay Three: Dynamic Interaction between Economic Indicators, Technology and CO_2 Emissions in New Zealand

Exploring the current environmental issues, economists agree that factors affecting economic growth continue to be a subject of considerable controversy. The impact of human activities on the ecological system increases as the level of human activities progress. Along with economic growth, the amount of waste is also expected to increase compared to the limited capacity of the natural environment for storing the waste. Furthermore, serious damage to the environment is an inevitable consequence of worldwide improvements in the standard of living. Consequently, unrestrained and limitless economic growth is a result of an increase in environmental pollution.

Since the economy is an open system, three main stages (extraction, production, and consumption) all generate end products that ultimately return the waste to the environment (air, water or earth). So macroeconomic indicators cannot be separated from the environment in which economic activities are going on and from the society that provides the public needs of its members. As a result, economic activity can be considered as a process of energy transformation in connection with materials conversion. As materials and energy cannot be destroyed in any absolute sense, they emerged in the form of waste which will be eventually returned to the environment. Therefore, the more economic gains are achieved, the more waste will be produced. Hence, economists believe that economic pollution would occur if environmental degradation and its damaging consequences affected human health.

In terms of environmental sustainability index (ESI), New Zealand was ranked in 11th place among 180 countries in 2016 (Columbia University, 2016). The current study investigates the impact of the gross domestic product, energy consumption, financial development, trade openness and fossil fuel consumption ratio on New Zealand's carbon dioxide emissions. According to the current debates concerning global warming, air quality and other serious environmental issues, the analysis of the relationship between economic and environmental indicators helps New Zealand policy makers and planners to address socially and environmentally viable policy options.

This chapter is an attempt to investigate the long-run as well as the short-run linkages between the level of CO_2 emissions and some key determinants using econometric technique, namely, ARDL model in ECM framework and annual data from 1971 to 2013 in New Zealand.

To explore the environmental quality and economic growth nexus, the analysis incorporates the effects of real GDP per capita, energy consumption per capita, financial development, trade openness, and fossil fuel consumption ratio as a proxy for technology on per capita CO_2 emissions.

1.4. Structure of this Thesis

The plan of this thesis is as follows: Chapters 2 to 4 present the three essays. Each essay includes the relevant review of the literature and analyses. Chapter 5 provides the summary.

Chapter 2.

Essay One: Environmental Tax Reform (ETR) and New Zealand Economic Performance: Modelling with E3ME

2.1. Introduction

Following the Paris Agreement in 2015, New Zealand joined to the global collaboration to respond to the dramatically increasing GHG emissions level in the world. However, the emissions profile of New Zealand, for example with a large contribution to total emissions from agriculture and a small contribution from the power sector, makes future emission reductions challenging. It is likely that a combination of policy instruments will be required for New Zealand to meet its Paris target. This study analyses the potential environmental and macroeconomic impacts of one such instrument, environmental tax reform (ETR).

I use the global macro-econometric E3ME model, to carry out the assessment. A number of different scenarios including a baseline are constructed to investigate the performance of the NZ ETS and ETR over the period 2021-2030.

The essay is structured as follows: Section 2 contains a brief summary of national circumstances and the policy environment in New Zealand that provides the basis for this analysis; Section 3 provides the theoretical framework for my empirical analysis; Section 4 summarises a literature review of E3 models, macroeconomic modelling and ETR, and outlines previous studies in New Zealand; Section 5 recaps the E3ME modelling approach, while Section 6 describes the scenarios that were examined; detailed results from the scenarios are presented in Section 7, with concluding comments presented in Section 8.

2.2. New Zealand's National Circumstances

2.2.1 National Trends

The New Zealand government is actively tracking the latest global agreements (including Paris) on setting climate targets both at domestic and international levels. Hence, New Zealand is developing actions where it can make the greatest impacts.

In 2016, New Zealand's total greenhouse gas emissions were 78.73 million tonnes of carbon dioxide equivalent ($MtCO_2e$). This shows 12.91 $MtCO_2e$ (19.6 per cent) increase comparing to 1990 levels of 65.81 $MtCO_2e$ (Table 1). This is equal to an average growth of 0.75 percent in total GHG emissions since 1990. The increase is mainly associated with these sources:

- Road transport sector responsible for CO_2
- Extensive farming activities creating Methane (CH_4) emissions
- Agriculture sector utilising soils creates N_2O
- Emissions from industrial activities using fluorinated gases

New Zealand's emissions account for only 0.17 per cent of total world emissions. However, emissions intensity per person in New Zealand is relatively high, ranked fifth highest across 40 Annex 1 countries[4] in 2011, at 16.6 tonnes CO_2e per person (Figure 1 and Figure 2).

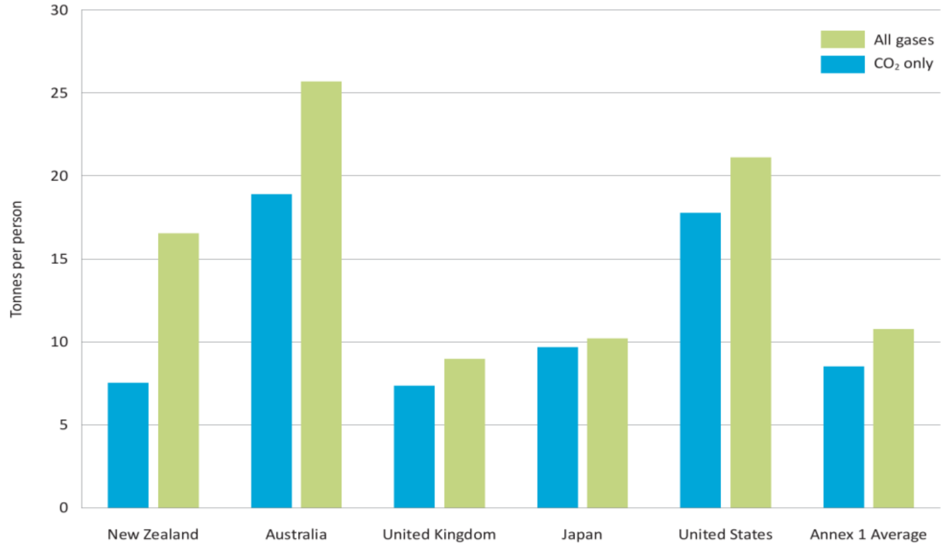


Figure 1: International comparisons for per capita emissions in 2011

Source: UNFCCC. Annex 1 countries' emissions for 2011.

[4] There are 43 Annex I Parties including industrialized countries and economies in transition.

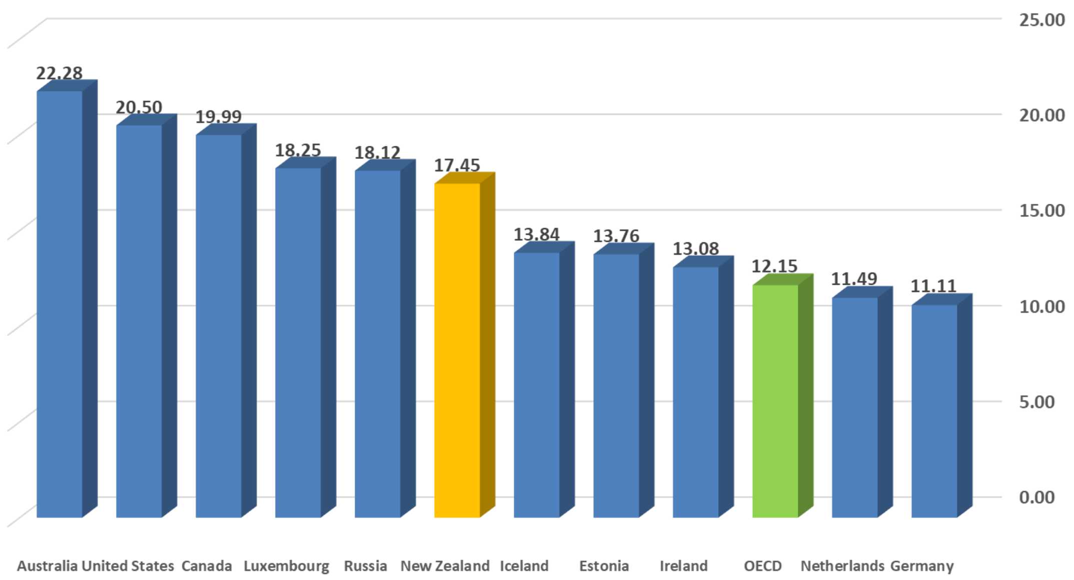


Figure 2: Total GHG per capita in 2015 (tonnes per person)

Source: OECD.Stat, 2018

Unlike other developed countries, New Zealand has an unusual emissions profile (Table 1 and Figure 3) that makes it difficult to find low-cost mitigation options.

Table 1: New Zealand's emissions by sector in 1990 and 2016

Sector	kt CO_2-equivalent 1990	kt CO_2-equivalent 2016	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
Energy	23,785.2	31,308.0	7,522.8	31.6
Industrial processes and product use	3,585.1	4,853.4	1,268.3	35.4
Agriculture	34,581.9	38,727.3	4,145.5	12.0
Waste	3,862.6	3,838.2	–24.4	–0.6
Gross (excluding LULUCF)	**65,814.8**	**78,726.9**	**12,912.1**	**19.6**
LULUCF	–29,539.5	–22,773.7	6,765.8	22.9
Net (including LULUCF)	**36,275.3**	**55,953.3**	**19,678.0**	**54.2**

Source: New Zealand's Greenhouse Gas Inventory 1990–2016.

Figure 3 represents how much each sector contributed to total emissions in 2016.

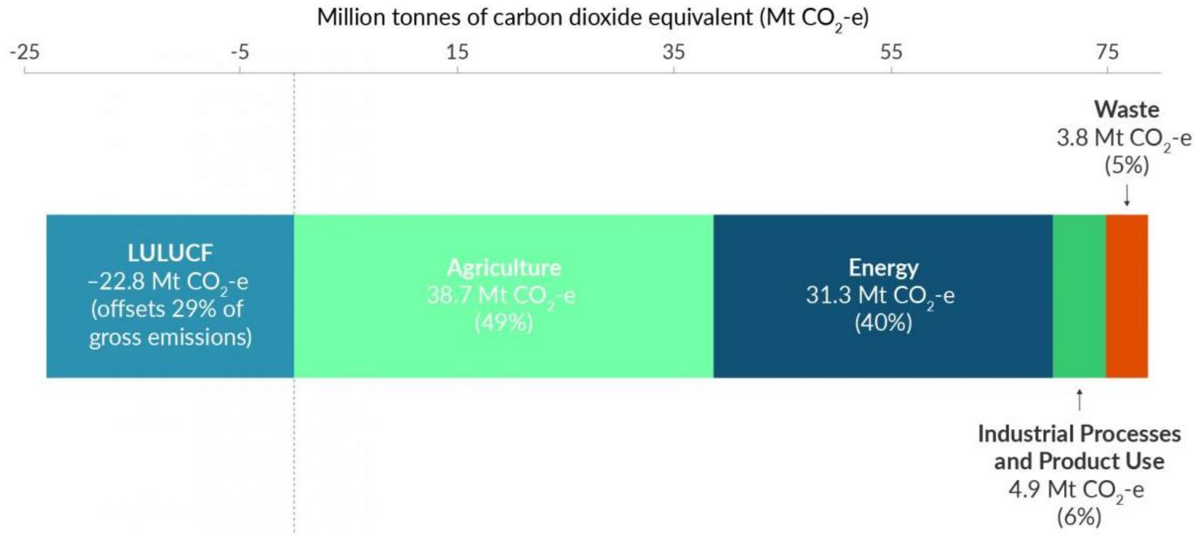


Figure 3: New Zealand's greenhouse gas emissions in 2016 by sector

Source: New Zealand's Greenhouse Gas Inventory 1990–2016.

2.2.2 New Zealand's Emissions Goals

New Zealand had a emissions reductions target to 1990 levels under the First Commitment Period (CP1) of the Kyoto Protocol (2008–2012). However, the country ended CP1 at about 19% above 1990 levels, with the difference being made up by trade in international permits.

New Zealand's future emission reduction targets are:

1) An unconditional goal to reduce emissions 5% below 1990 levels by 2020.
2) A medium-term target under the Paris Agreement to reduce emissions 30% below 2005 levels by 2030.
3) A long-term goal of 50% reductions below 1990 levels by 2050.

Emissions reductions must be carried out in the context of increase in economic production. GDP rose by 67% in the period 1990-2008. Over that period the emissions in the energy sector increased by 46.8%, mainly due to emissions from transport and fossil fuel electricity generation (UNFCCC, 2011).

2.2.3 Action on Climate Change

Around the world, two primary economic instruments have been applied to reduce carbon emissions: carbon (energy) taxes, sometimes combined with reductions in other taxes to constitute Environmental Tax Reform (ETR), and emission trading schemes (ETS). The aim in either way is putting a price on carbon emissions, reducing the negative externalities, and generating revenues for the government. However, there are some differences in implementing and functionalities of these carbon abatement instruments.

An ETS is a market based emission pricing system. Governments and jurisdictions establish the market in regional or national scales and issue tradable carbon credits. Polluters need to buy credits from market for each tonne of GHG emissions they emit. Industries that help sequestrate emissions are usually eligible for emission allowances. They can sell these permits to emitters in the market. The price in the market is usually set by supply-demand law; however, governments can intervene if the price is too low (or too high). In an emission trading scheme, a government issue limited number of permits in order to keep the carbon price reasonably high. Hence, the ETS is also called cap-and-trade. Tradable permits are auctioned by authorities and they let the market decides their price. Quantity limit plays an important role in cap-and-trade approach as it directly affects the market price and pushes industries to seek greener economic activities.

Carbon tax is another environmental instrument which is simpler in practice and sets a direct price on greenhouse gas emissions. Unlike in ETS which price is endogenous and is determined in the market, government sets an exogenous price as a carbon tax. An efficient carbon tax can force businesses to reduce their GHG footprints and by avoiding them from investing on emission-intensive activities. If businesses pass the levies to their customers, this in turn may lead to change in consumer behaviours towards having a more carbon-free life style.

Currently there are over 40 countries and jurisdictions all around the world that use carbon pricing mechanisms. Figure 4 illustrates a wide distribution of ETS and carbon tax policies that are already implemented or scheduled for implementation in different countries, cities, states and provinces. Some of these carbon pricing systems are not yet fully covering all sectors inside their jurisdictions; however, they capture around 13 percent of world annual GHG emissions (World Bank and Ecofys. 2017).

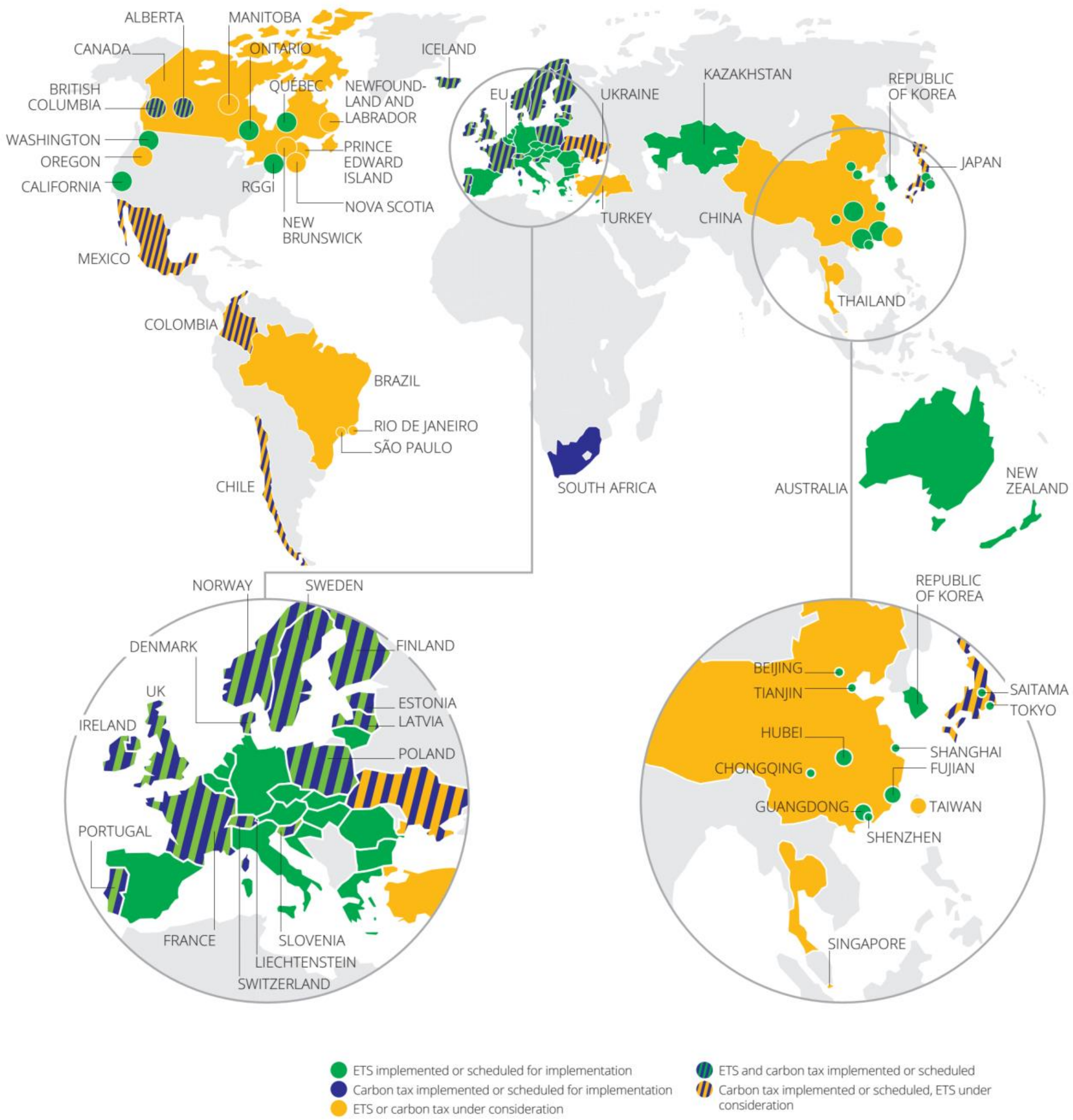


Figure 4: World map shows jurisdictions already implemented carbon pricing or scheduled for implementation (ETS and carbon tax)

Source: Carbon Pricing Watch 2017, World Bank.

2.2.4 ETS, Carbon Tax or both?

A carbon tax and an ETS share a lot of similarities as they are introduced to provide financial incentives for households and companies to cut their emissions. However, they act differently to reduce greenhouse gas emissions. While a carbon tax system relies on setting a right carbon price to address the emissions, in ETS the quantity of tradable permits plays a crucial role to give a right signal to the carbon market.

A carbon tax is a straight forward, clear, and predictable instrument that gives businesses an incentive to switch to cleaner technologies. Businesses are already familiar with corporate tax in small and large scales, so introducing another tax (carbon tax) is not basically a new thing for them. Nonetheless, a carbon tax is politically inexpedient as it is a challenge for risk-averse societies (Pizer, 1998).

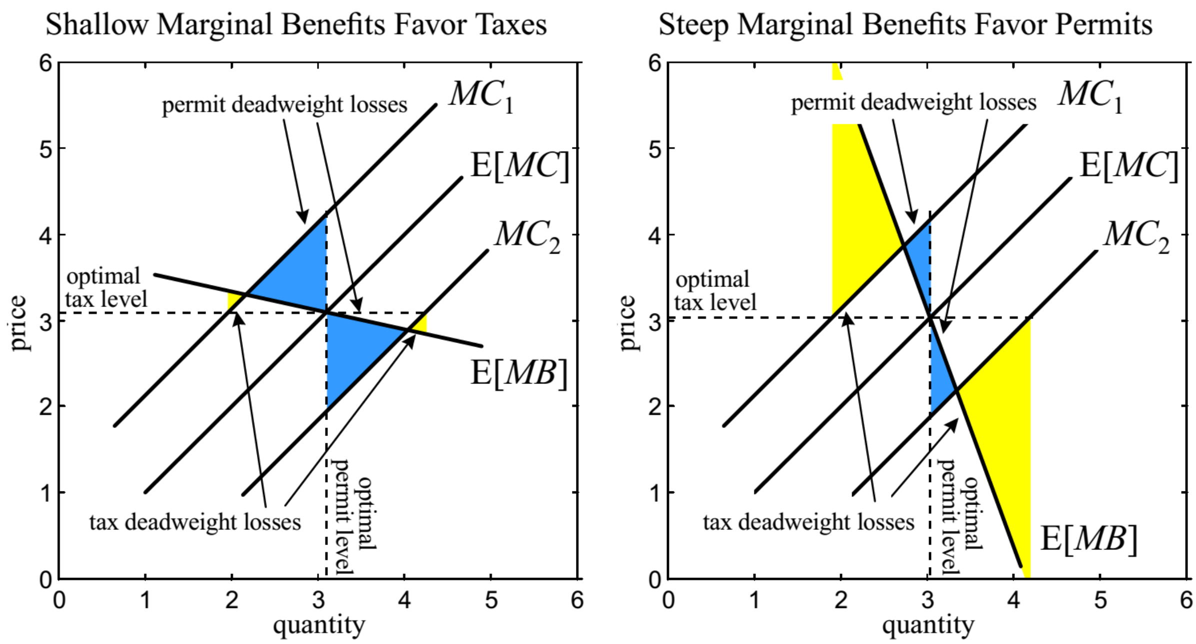
On the other hand, ETS seems to be more efficient carbon pricing when it comes to considering business cycles. The price volatility in carbon market can be a benefit for industries as the carbon prices fall in a downturn and rise in an upturn. However, the prices are not predictable and this is a negative point for long-term business plans. Another advantage for an emission trading scheme is that a domestic ETS can be linked to the international carbon markets for a better international collaboration and to achieve global decarbonisation targets, whereas it is not doable with a carbon tax. Nevertheless, some studies demonstrate that free emission allocation in ETS does not stimulate companies to invest on cleaner technologies (Carlson et al., 2000, Grubb and Neuhoff, 2014).

It has been widely argued that whether a carbon tax or an ETS is implemented, there are uncertainties around the environmental damage or the price of carbon in the real world. In other words, if we set a carbon tax, then we are certain about emission prices, but we are uncertain about how much will be the environmental damage or level of emissions that need to be decreased. Conversely, if a determined volume of tradable permits is going to be auctioned, then we certainly know how much emission volume is going to be reduced, but we are uncertain about the market price for the permits. The result of using these instruments (carbon tax and ETS) can be identical if we certainly know how much the price is for reducing an emission unit.

A classic work by Martin Weitzman (1974) showed that whether we use price or quantity tools, there will be uncertainty costs; however, we can reduce the costs to minimum if we choose the right tool. Decision around choosing the proper emission policy tool mainly depends on where the uncertainty lies.

Therefore, implementing a price control can be as inappropriate as using a quantity control if the marginal cost (to the economy) and the marginal benefit (to the environment) of our policies are uncertain (Pizer, 1998). Using two diagrams (Figure 5), William Pizer (1998) argued about the price and quantity controls. He showed that economists favour emission taxes over the quantity controls in the left diagram. In this scenario, we know how much price should be set to achieve a certain level of environmental benefits. But because the cost to the environment is uncertain (steep marginal cost curve), any volatility and move of marginal cost curve along marginal benefit curve could create big deadweight losses (blue areas).

On the other hand (right diagram), the MB curve is steeper than MC curve. In this scenario, we are certain about the quantity (permits) needed to reduce environmental externalities, but we are uncertain about the price for each unit of this reduction. Any small price volatilities could lead to significant inefficiency and welfare losses (yellow areas). Thus it is better not to intervene and let the market decides about the pollution price in this situation.



[a] E[MB] indicates expected marginal benefits, E[MC] indicates expected marginal costs, and MC_1 and MC_2 indicate alternative cost outcomes.

Figure 5: Deadweight Loss of Taxes versus Permits

Source: Pizer, W. A. (1998).

Accordingly, Pizer (1998, 2002) proposed a combined price and quantity mechanism to better tackle the GHG emissions based on his efficiency argument. He argued that a pure carbon tax is more efficient than a permit system in terms of welfare gains, and this is due to a relatively flat marginal benefit curve of the environment in reality. Nevertheless, a hybrid policy could minimise the risk of welfare loss and increase the reliability of the decarbonising plan. His proposal included auctioning limited number of permits in the first stage and then selling additional units at fixed price in the later stage.

There are several other studies that also supported the hybrid emission policy (Weitzman 1978; Roberts and Spence 1976; McKibbin and Wilcoxen, 2002). McKibbin and Wilcoxen (2002) pointed out the benefits of a hybrid mechanism when there is uncertainty around benefits and costs of the emission reduction policies. They proposed a hybrid approach with marketing long-term permits as a basis and using an additional price mechanism which works as a "safety valve". Free permit allocations are offered (in their designed system) to the industries that pollute less than a specified threshold. This brings in political support to the scheme too and prevents collecting too much revenue by government.

Currently, there exist several countries and jurisdictions around the world that have implemented hybrid mechanisms to diminish their GHG emissions. In Europe, there are 14 countries[5] that have implemented or scheduled to use both ETS and carbon tax. Alberta and British Columbia in Canada are the two other jurisdictions that have applied ETS and carbon tax simultaneously. Furthermore, some countries including Ukraine, Japan, Mexico, Colombia, and Chile that already have a carbon tax in place, are also considering an ETS as a complementary policy. Figure 4 shows the global distribution of various emission reduction policies.

2.2.5 Emissions Reduction Mechanism in New Zealand

At present, New Zealand utilises its own version of Emissions Trading Scheme (NZ ETS) as the primary policy instrument, which covers most of economic sectors for domestic emissions removals in New Zealand. The NZ ETS was the first nationwide scheme outside Europe; it was first legislated in September 2008 and amended in November 2009, November 2012, and again in November 2015. It covers large parts of New Zealand's economy and was linked to the other international schemes. The ETS was stablished to cover all economic sectors

[5] These countries include Norway, Sweden, Finland, Estonia, Latvia, Poland, Slovenia, Liechtenstein, Switzerland, France, Portugal, UK, Ireland, and Denmark.

and greenhouse gases since its start in 2008, but it was gradually implemented. The agriculture sector is yet to be included in the scheme. Table 2 shows sector roles and their entry dates in the NZ ETS.

Table 2: NZ ETS, sector roles and entry dates

Sector	Surrenders NZUs	Earns NZUs	Allocated NZUs	Year of entry
Forestry	√	√	√	2008
Energy (Electricity production)	√			2010
Fishing	√		√	2010
Industry	√		√	2010
Liquid fossil fuels	√			2010
Synthetic gases	√			2013
Waste	√			2013
Agriculture				Not yet decided

Emitters need to buy and hand over carbon credits. There are primarily two sources for the carbon credits: carbon market and government. However there is another source other than these two. Participants in the NZ ETS may be also eligible for some free allocations from the government. According to the NZ ETS regulations, afforestation and those that engage in trade-exposed activities are eligible to receive free carbon units. These free units can be then sold in the carbon market.

Before 2015, participants in the NZ ETS could hand over one emission unit (either a New Zealand unit allocated by government or an international 'Kyoto' unit) for every two tonnes of CO_2-eq emitted. However, the government detached the link and made the scheme a domestic ETS from 2015, due to a dramatic fall in effective carbon price (Figure 6). Government's price is fixed, so participants can buy NZ units at a fixed price of NZ$25 issued by the government; or refer to the NZ carbon market and prepare them. These are the primary units of trade in the scheme. Since 2015, the carbon price has been increased significantly in the NZ carbon market.

Table 3 indicates other permit units (international units) that were used in NZ ETS until 2015.

Table 3: Types of units surrendered in NZ ETS

Emission unit	Description
Forestry NZUs (New Zealand units)	Units given to foresters for removal activities or through the Forestry Allocation Plan. They may be converted to New Zealand assigned amount units (NZAAUs) for offshore sale.
Other NZUs	All other NZUs, including those given to Industrial Allocation recipients. They cannot be converted to NZAAUs for offshore sale.
NZAAUs (assigned amount units)	New Zealand-based AAUs. Can be either forestry NZUs that have been converted into NZAAUs or NZAAUs that have been granted to companies in New Zealand that have participated in Projects to Reduce Emissions (PRE) or the Permanent Forest Sinks Initiative (PFSI).
CERs (Certified Emission Reduction units)	CERs are units generated by Clean Development Mechanism (CDM) projects offshore. Participants in the NZ ETS could buy these units and surrender them to meet their obligations up to 31 May 2015.
ERUs (Emission Reduction Units)	ERUs are units generated by Joint Implementation (JI) projects offshore. Participants in the NZ ETS could buy these units and surrender them to meet their obligations up to 31 May 2015.
RMUs (Removal Units)	RMUs are Kyoto Protocol units generated through storing carbon in trees. Participants in the NZ ETS could buy these units and surrender them to meet their obligations up to 31 May 2015.
NZ$25 Fixed Price Option	Companies have the option to pay the Government a NZ$25 fixed price per unit to be surrendered, rather than surrender eligible units.

Source: Environmental Protection Agency 2015

2.2.6 Critiques of NZ ETS

ETS has been criticised for its ineffectiveness in several studies (e.g. Ekins, 2009 and Venmans, 2012) and the criticisms could be applicable to New Zealand. The government promotes ETS as a cost-effective solution. Currently, the sectors/activities participating in the NZ ETS are those that use fossil fuels for transportation, produce electricity, carry out industrial processes, and produce synthetic gases and waste. Emitters from these sectors must buy carbon credits either from the government or from abroad. The agricultural sector is not covered by NZ ETS, and it is also unlikely to be included in the future. Moreover, forestry carbon sequestration will not be used to achieve the mitigation target over the commitment period (2021-2030), and is hence excluded from carbon pricing.

There are also some exemptions for firms whose activities are emissions intensive and who are exposed to international trade. These kinds of firms such as aluminium smelting and food industries will receive free NZU allocations for compensating the loss of asset value resulting from the NZ ETS. In addition, according to the Kyoto Protocol, international aviation and marine transport are also exempt from the scheme.

The NZ ETS differs from the European EU ETS in that it does not include a cap for emissions, and therefore does not control total emissions within a specific period. However, in common with the EU ETS, New Zealand provides a generous free allocation of emission units, limiting the revenues obtained. Also in common with the EU ETS, the NZ ETS has been widely criticized for being ineffective in reducing emissions.

An expert review report (United Nations, 2011) has criticized the policy instruments that New Zealand uses to fulfil its mitigation targets. The review concludes that, although there is remarkable potential in some sectors for emission reductions, the system lacks strong tools and policies to achieve the target.

The expert review team (ERT) declared "great concern" about whether New Zealand will be able to reach its objectives by 2020 without an extensive mitigation policy. The ERT also pointed out that New Zealand's government may wish to consider alternative policy instruments for attaining its 2020.

The Sustainability Council of New Zealand has also stated that the impacts of current policies are overestimated, especially emissions reductions from the forestry sector and from the removal of coal from power sector fuel mix. The Council believes that around 88% of the anticipated reductions of 12 $MtCO_2e$ are highly unclear (Terry, 2009).

The perceived failure of NZ ETS is partly because of low credit prices, but also because the government has taken a gradual approach to implementing it (Mason, 2013). The latest spot price for NZUs has recently recovered to around $20 but was below $10 for around four years. Figure 6 shows how the prices of NZUs dropped as participants in NZ ETS started purchasing cheaper foreign credits. Under NZ ETS, New Zealand emitters have remarkably few constraints on buying international credits.

Figure 6: Spot price of New Zealand Units (December 2017)
Source: https://www.commtrade.co.nz

2.2.7 Approach Adopted in This Study

This study assesses the macroeconomic impact of implementing an Environmental Tax Reform (ETR) in New Zealand in order to meet emission reduction targets that seem difficult to achieve under NZ ETS only. Impacts on both emissions levels and the wider economy are considered. As described above, previous studies of ETR in New Zealand have used CGE models. This study uses E3ME, a macro-econometric non-equilibrium hybrid simulation model. The difference between modelling approaches is discussed in the next section.

2.3. Theoretical Framework

Integrated assessment models (IAMs) are generally defined as any model which includes both socio-economic and biophysical aspects of climate change in order to assess policy options for climate change control. In other words, IAMs are mathematical computer models based on precise assumptions about how the modelled system behaves and generate useful information for policy making.

IAMs reveal the effects of climate change on human livelihoods and how they affect the economic policies on GHG emissions. They try to predict the future economic conditions in regards to sustaining natural ecosystems and providing human societies with a safe and low-emission place to live. Therefore energy-economy-climate models are widely employed to show how economic activity, energy systems and environmental targets interact in both the short and long-term.

There are several pioneer researchers that employed models to study environmental issues. Initial attempts related to this area go back to the early seventies by Meadows et al. (1972) with publication of '*The Limits to Growth'*. They introduced innovative numerical approaches to analyse the relationship between energy resources and environmental economics. However, they did not consider the effects of human exploitation of planetary resources on global environment. Nordhaus (1973, 1979), and Manne (1976) developed new models for energy technology. Other researchers like Solow (1956), Stiglitz (1974) developed a new theoretical framework for the economics of natural resources.

There are numerous energy-economy models with diverse scope and theoretical precedent that have been developed to support mitigation policy studies. These models fall into several categories based on their objectives, time horizons and the structure used to build the model whether it is a bottom-up or top-down approach. Hence there are two sorts of macroeconomic models. Type one are bottom-up models in which all individuals (agents) have a very limited understanding of how the system works. So in these approaches we go from the specific to the general. On the other hand, in top-down models, some (or all) individuals have full information or a broad view about the system functionality. In these modelling we go from the general to the specific. The 'bottom-up and top-down' terms can also have different meanings in different areas of modelling. In energy modelling for example, bottom-up models are specified by technology and they typically come from an engineering background. Top-down models, however, are based on economic relationships.

Moreover, IAMs can be also divided into five broad categories according to their objectives: welfare optimization, cost minimization, simulation, general equilibrium, and partial equilibrium. On the whole, clime-economy models have different structures because they are designed to answer to their specific questions.

Some IAMs like DICE (Nordhaus, 1993), RICE (Yang and Nordhaus, 2006), MERGE (Manne and Richels, 2004) and MIND (Edenhofer et al., 2006a) are designed with a focus on welfare optimization. They aim to maximize the discounted present value of utility resulting from consuming goods and services. In these models a social welfare function (SWF) is defined to assign a numerical value to every social utility (product) gained (consumed). Although they assume a growing welfare per every extra unit consumed, the rate is diminishing over the time. The welfare optimisation paradigm has been criticised for its inconsistency regarding using different calculation methods in their SWFs (Füssel, 2013). In general, assigning values to social commodities and ranking them can cause artefacts if an inappropriate SWF is selected.

Some other IAMs like AIM (Kainuma et al., 1999) and WIAGEM (Kemfert, 2002) are general equilibrium models which incorporate economic sectors and use recursive dynamics. Their advantage lie in their very detailed and disaggregated structure which facilitate integration of bottom-up modules with top-down modules. In these models the objective is to find a set of prices that simultaneously bring the equilibrium to all sectors. They assume that perfect competition in all markets exist and then take a recursive approach as they need to set the prices in the beginning of each time period. Therefore, the lack of foresight in these models make them improper forecasting tools. Another drawback of general equilibrium models is related to their challenge for modelling endogenous technological improvements (Köhler et al. 2006). This is because general equilibrium models often assume a constant or decreasing returns to scale in their production functions to achieve more accurate model results. Multiple equilibria and unstable estimation results can be the consequences of assuming an increasing return to scale in these models. Hoekstra et al. (2017) asserts that general equilibrium models are not suitable techniques for studying climate and energy systems: "The energy domain is still dominated by equilibrium models that underestimate both the dangers and opportunities related to climate change."

Partial equilibrium models inherit most of their features from general equilibrium models. However, they only focus on a limited number of economic sectors. Thus these models keep the prices constant in other sectors. This is beneficial for them as they can skirt the problem with modelling endogenous technological change (Stanton et al., 2011).

E3ME (Barker, 1999) and E3MG (Barker et al., 2006) has been developed to simulate predicted future emissions and climate conditions. Simulation models apply various predetermined emission mitigation targets to calculate the investment and abatement costs of induced technologies. They are demand-driven models and unlike general equilibrium models, the simulation models are capable of depicting a dynamic system with increasing returns loaded to their production functions. Nevertheless, these models are not right tools for answering queries linked with social welfare maximisation or social cost minimisation.

The objective of some frameworks such as DNE21+ (Sano et al., 2006) and MESSAGE-MACRO (Rao et al., 2006) is cost minimization. They are designed to estimate the most cost-effective solution to mitigate GHG emissions. Their advantage is usually in their very detailed bottom-up energy models. Unlike other modelling approaches that only look after emissions, these models include a complete and distinct climate module to address the impacts of economic behaviours on climate change and its associated damages. However, although cost minimisation models are very capable bottom-up models and capture wide range of industry activities, they need complementary top-down macroeconomic models to assess and deliver the appropriate mitigation policy choices.

The core question is how to investigate policies for climate change, as a module of IAM. Examining the relationship between energy, the economy and the environment is one of the most important challenges facing social science. The connections between these three factors are, however, complex and various approaches have been taken in analysing the key relationships between these factors in order to recognize the implications. Whilst most of the previous studies employ recursive bottom-up CGE models which are based on normative assumptions and are limited to use only one year's data, this study employs E3ME, a macro-econometric non-equilibrium hybrid simulation model which incorporates the behaviour of firms, households and investors supported by large high-quality historical data. The model follows Post Keynesian economic framework. Thus, unlike CGE models, this top-down model assumes that the equilibrium does not necessarily exist in all markets.

2.4. Literature Review

In order to conduct a study about climate change, different types of information from economics, ecology and energy are involved. Hence an integrated assessment tool is needed to be stablished to investigate interlinkages between the natural systems and the human activities. In this section, a brief summary and comparison of different Integrated Assessment Models (IAMs) in climate change studies are provided.

2.4.1 Review of the Literature on E3 models

Nordhaus developed the Dynamic Integrated model of Climate and the Economy (DICE) over the last thirty years. The initial DICE was a linear model of energy supply and demand used to investigate the intensity of carbon dioxide in the aerosphere (Nordhaus, 1977). Its modern form was released in 1993 using a dynamic Ramsey-type economic growth function (Nordhaus, 1993). DICE is a global model and aggregates major economies from twelve regions into one single output. The production function has constant return to scale and energy consumption directly affects the GHG emissions levels. However, the only GHG emissions that is endogenously controlled is industrial CO_2, the other GHGs are monitored exogenously. In this model, climate system is defined under a new type of capital stock. Therefore, GHG emissions and its reductions considered as negative natural capital and investments respectively. Several updates have been applied, but in DICE2007 (the current version of the DICE model) labour force and population growth are treated exogenously. DICE2007 tracks the atmospheric concentration of CO_2 as a result of economic growth based on a Cobb-Douglas production function. DICE2007 predicts an increase of 3.2 °C in global average surface temperature by year 2100 according to the baseline scenario (no climate control). This is done by modelling future economic output and its associated environmental losses in the business as usual scenario. However, the way that the DICE model defines and uses the loss function is criticised by researchers. Tol (1996) discusses the sensitivity of loss function and its wrong approach in DICE:

"after a monetary value has been attached to the intangible damages, DICE treats them as market goods, which they are not. Tangible income can be used for either consumption or production, whereas intangible ´income´ is consumption. Bringing the intangibles back to where they belong, i.e. in the utility function, slightly raises the optimal GHG emission reduction. This is due to the fact that in DICE all losses are subtracted from the output, which is then divided between consumption and investment. Thus, moving the intangible losses from the production to the utility function implies enhancing the prospects for economic growth, thereby increasing the possibility and need for emission abatement" (Tol, 1996).

The RICE model (Regional Dynamic Integrated Model of Climate and the Economy) is a regionalized and disaggregated version of the DICE model (Nordhaus, 1993). It is a top-down model designed to examine national-level climate policies in order to evaluate diverse policies for international collaboration (Nordhaus and Yang, 1996). It divides the global economy into 10 different regions. Similar to DICE model, technology, population growth, investment, and emission reduction rates are also exogenous in the RICE model. Only CO_2 gas is endogenously modelled in RICE model. Two main functions (like DICE2007) are a Cobb-Douglas production function that look after the linkage between input and output, and a regional social welfare maximisation. Nonetheless, DICE and RICE are different for two main reasons: 1- DICE is a global model but RICE is a regionally disaggregated model. The population size and per capita consumption play major roles in each region's utility function; 2- trade among regions that affects their output level is only investigated in RICE. There are also other differences between these models. The capital mobility is fully accepted in the long-run in RICE model. Therefore, the real capital return will be equal among regions. Moreover, RICE model contains emission equations which specifically embedded for each region. This because Nordhaus and Yang (1996) found that international cooperative policies have better results in emission reduction plans in contrast to non-cooperative strategies. However, rich countries may lose welfare due to cooperation.

MERGE (an Integrated Assessment Model for Global Climate Change) has been developed by Manne and Richels (1996) to project regional and global effects of Greenhouse Gases (GHG) reductions. It contains 11 regions using a Ramsey-Solow Model to optimize long-term economic growth. MERGE also includes a bottom-up model which measures the global emission concentrations and their impacts on global temperature change. MERGE is very similar to the DICE model in term of sharing similar economic and damage modules. Both models use a social welfare function. The utility function in MERGE, however, is logarithmic. The climate module contains energy (CO_2) and non-energy (CH_4, NO_x) related GHG emissions. While energy related gases are projected inside the model, the non-energy related gases are treated exogenously. In addition, the model projects mitigation costs for afforestation. MERGE estimates an economic loss factor (ELF) defined as willingness-to-pay (WTP) to avoid temperature rise. The ELF is expressed in GDP and it is assumed that per every one degree temperature rise, GDP 0.1% drops.

Model of Investment and Technological Development (MIND) is a hybrid (top-down/bottom-up) optimal growth model and a part of DICE family (Nordhaus, 1993). The model aims to analyse the cost of climate protection targets under different mitigation options. MIND calculates the emission abatement costs and how investment in various energy options can tackle GHG emissions at lower welfare losses (Edenhofer et al., 2006a). Bauer (2005) developed MIND 1.0 by including an endogenous technology function. An important characteristic of the model is its diverse mitigation options. MIND provides options like increasing energy efficiency or switching to renewable energies to replace fossil fuels. Furthermore, it also includes a Carbon Capture and Sequestration (CCS) option. Energy module is at the heart of MIND model. Fossils fuels, non-fossil fuels, and renewables are considered with detail. Nevertheless, MIND inherits most of the shortcomings affiliated with DICE family models including uncertainty around its welfare function. MIND concludes that controlling climate change is possible without considerable losses in welfare.

The Asia-Pacific Integrated Model (AIM) is designed by Professor Matsuoka (1991) in the National Institute for Environmental Studies to develop national energy models in several Asian countries. It aims to analyse the effects of post-Kyoto scenarios using a recursive general equilibrium model (Kainuma et al., 1999). AIM includes over 20 CGE models, but the main ones are: impact model (AIM/impact), climate change model (AIM/climate), and GHG emission model (AIM/emission). AIM also includes a technology selection interface to assess the future technologies which covers over 100 alternative technology solutions to improve energy efficiency. It divides every region to three sectors: production sector, household sector and government sectors. The model has a potential ability to be applied to other issues like acid rain. Although, AIM has a desirable structure with detailed bottom-up sub-models, it still possesses common CGE weaknesses namely assuming (1) perfect competition markets, and (2) decreasing returns to scale in their production functions. One case study (Kainuma et al., 2001) using AIM in Japan revealed that relying only on market mechanism would not be enough to tackle GHG emissions and the country needs to employ carbon taxes too. The study proposed that recycling revenues from the carbon taxes can reduce the tax burden significantly.

WIAGEM (World Integrated Assessment General Equilibrium Model) is a cost-benefit approach to assess the mitigation options (Kemfert, 2002). It divides the world to 11 trading regions and focuses on the international energy markets for oil, coal and gas. The model uses a general equilibrium approach and includes a 50 year time period to investigate the impacts of GHGs on temperature and sea level resulting from human-made emissions. WIAGEM not only comprises all greenhouse gases, but it also looks after the carbon sequestration which is the result of afforestation and land use change activities. The model investigates the impact of spillover effect as well as an emission trading scheme in its climate control scenarios. However, this CGE model assumes full employment in all countries and it has no induced technology change included which all of these can probably yield inaccurate results.

E3ME (Barker, 1999) is an Economy-Energy-Environment Model of Europe. It is designed to be used as a framework to analyse the long-term implications of Energy-Environment-Economy (E3) policies in Europe. E3MG (Barker et al., 2006) was the global version of E3ME which covered 20 world regions. E3MG is a hybrid simulation model based on Keynesian non-equilibrium macroeconomic structure. The model's econometric base allows policy makers to get significant information from short term and medium term economic forecasts. Its capabilities are now encompassed in the global version of the E3ME model and ongoing research programmes have been shifted on to the E3ME platform from early 2014. The latest version of E3ME covers 53 world regions including Euro and non-Euro countries. The energy and export functions play major roles, and the treatment of trade is bilateral. E3ME includes an energy module providing comprehensive price levels of different energy sources in order to monitor the energy carriers and conversion technologies over the time. Therefore, climate module of E3ME mostly focuses on energy related GHG (CO_2). Moreover, technological changes are induced and E3ME offers options for switching to more efficient energy sources in terms of their price and emissions level. E3ME does not monitor land use change processes including afforestation or deforestation. However, the model tracks down the changes in the amount of non-energy GHG produced in economic sectors resulting from application of different mitigation scenarios. E3ME is able to use emission trading mechanism as well as exogenous carbon tax scenarios to simulate the abatement policies for all world economy regions.

Professor Kenji Yamaji and Professor Yasumasa Fujii developed the Dynamic New Earth model (DNE 21+) at the University of Tokyo (Sano et al., 2006). It is a Cost-Benefit approach based on a linear programming model and utilizes a bottom-up model with CGE framework to study the energy supply in order to minimize the overall future costs over a time horizon between 2000 and 2100. In DNE 21+, energy sources are divided to three broad categories: fossil fuels, renewable sources, and nuclear energy. The model includes endogenous technological changes so that cost effective technologies which yield more CO_2 reductions are preferred. However, DNE 21+ only covers carbon dioxide and the level of technology improvements is restricted.

MESSAGE-MACRO is another model aiming to assess cost-effective energy strategies developed by the Austrian International Institute for Applied Systems Analysis (IIASA) and contains 11 world regions (Messner and Schrattenholzer, 2000). It is a combination of a macroeconomic (MACRO) and very detailed energy supply model (MESSAGE). Although, the energy model has a linear function, the macroeconomic model is non-linear. While MESSAGE discover the optimal energy supply structure in each region, the macroeconomic part of the model (MACRO) looks for optimizing savings, investment and consumption decisions. MESSAGE and MACRO are linked through a set of two electric and non-electric energy production functions embedded within MACRO. The advantage of this model is in its structure as “Hybrid models can deliver insights that pure bottom-up models cannot” (Strachan and Kannan, 2008). Nevertheless, the uncertainty around the model’s bottom-up approach (general equilibrium model) and its neoclassical nature leaves some critics open (Edenhofer et al., 2006b).

Table 4: Characteristics of the models studied

Study	Model category	Characteristics	Regionally disaggregated
DICE	Welfare maximization	Bottom-up CGE Model	
RICE	Welfare maximization	Bottom-up CGE Model	√
MERGE	Welfare maximization	Bottom-up CGE Model	√
MIND	Welfare maximization	Hybrid CGE Model	
AIM	General equilibrium	Bottom-up CGE Model	√
WIAGEM	General equilibrium	Bottom-up CGE Model	√
E3ME	Simulation	Hybrid Non-Equilibrium	√
E3MG	Simulation	Hybrid Non-Equilibrium	√
DNE21+	Cost minimization	Hybrid Partial Equilibrium	√
MESSAGE-MACRO	Cost minimization	Hybrid CGE Model	√

2.4.2 Review of the Literature on Macroeconomic Modelling and ETR

In the early and mid-1990s countries such as Denmark, Norway, Sweden, Finland and the Netherlands followed by Germany and the UK implemented environmental taxes and charges as economic instruments in environmental policy, with broadly positive results. However, the outcomes vary across these countries.

Some of the previous studies has focused on analysing the effects of environmental tax on socio-economic factors and how a fiscal policy can address the negative externalities. Baumol and Oates (1971) claimed that a proper carbon tax could bring down the economic costs to minimum as well as boost the welfare levels.

However, a survey by Ekins and Barker (2001) showed that an environmental tax is efficient in reducing the amount of GHG emissions in EU. However, poorer households could be affected disproportionally. Their results were in line with that of Bruce et al. (1996).

According to Barker and Kohler (1998), environmental taxes could have a negative impact on the average welfare level in an economy. They used some evidence from OECD countries and argued that poorer households are especially vulnerable to these taxes.

An E3ME modelling work by Barker et al. (2009) attempted to find out to how much extent the international competitiveness is influenced by environmental tax reform in the European Union. The macroeconomic results showed that European countries that implemented ETR did not experience negative implications for their economic growth (GDP). Also, the ETR caused employment in some of the ETR countries to increase by as much as 0.5%. As a general rule, the effects of the ETR on inflation were positive.

Ekins (2009) modelled the links between ETR, the economy and CO_2 emissions At the EU level using two well-known macro-econometric models: E3ME and GINFORS. The research found that the ETR can play very important role to achieve large-scale reductions in GHG emissions. The macro-econometric approach undertaken in this research has confirmed the positive employment effect of ETR. However, the effect of ETR on output was small.

Lee et al. (2012) analysed potential economic and environmental effects of carbon taxation in Japan using the E3MG model. The results show modest costs for reducing emissions to meet the 25% reduction target in 2020. An average 1.2% reduction in GDP and 0.4% fall in employment compared to the baseline are inevitable. But, they believe that these cutbacks could be offset, if revenues are recycled efficiently.

2.4.3 Previous Analysis in New Zealand

A computable general equilibrium (CGE) model was employed by Scrimgeour et al. (2005) to assess the efficiency of environmental tax in New Zealand. The authors concluded that the energy intensive sectors are very likely to be negatively affected by the environmental taxation. Therefore, the government needs to carefully consider legislation and implementation of right policies.

A study by Freebairn (2011) investigated the efficiency of carbon pricing in an economy and its associated impacts on distributional equity. He reviewed different types of direct and indirect taxes in New Zealand and Australia, and pointed out the importance of social security payments, GST, and incomes taxes in shaping the macroeconomic stability. Freebairn argued that increasing carbon prices along with inelasticities around emissions costs can lead to drastic negative effects in these economies.

In 2009, NZIER and Infometrics provided a report to the Ministry for the Environment on the potential impacts of climate control policies. They attempted to model different policy scenarios short run (to 2012) and long run (to 2025). The study used a CGE model to determine the economic impacts of climate change mitigation policies. The authors concluded that widespread domestic carbon pricing plan is the best cost-effective way to achieve New Zealand's international obligations if the rest of the world implements carbon pricing, and technological change is induced by this pricing. The outcome of the modelling framework for the long term is unlikely to be accurate enough, as the study did not investigate the sector-specific or regional economic effects of mitigation policies. Furthermore, its CGE model cannot capture the impact of price uncertainty, complexity and administration costs. It also cannot consider ease of linkages to the international market.

CliMAT-DGE is another CGE model that was used by Daigneault (2015) to model the economic impact of post-2020 climate change contributions in New Zealand. The author asserted that a domestic carbon price at least \$300/tCO_2-e and without having to purchase international offsets is necessary to get closer to achieving a target of 10% below 1990 emissions levels. However, the study predicted a significant negative effect on economic growth and New Zealand's balance of trade due to the country's need for importing most commodities. As a typical CGE model, CliMAT-DGE is also not able to model endogenous technological improvements. Furthermore, agricultural emissions and forestry carbon sequestration were excluded from carbon pricing.

In 2015, the Ministry for the Environment commissioned Infometrics to prepare another report. Infometrics was asked to assess New Zealand's post-2020 participation in international agreements to reduce GHG emissions. Infometrics used the static-CGE model

ESSAM (similar to CliMAT-DGE) and estimated similar negative economic impacts. However, ESSAM forecasted smaller GHG reductions at higher costs compared with CliMAT-DGE by 2030.

2.5. Methodology

2.5.1 The E3ME Model

The E3ME model is a global macro-econometric E3 (Energy-Environment-Economy) model that links the world's economies to their energy systems and associated emissions. The model was constructed by Cambridge Econometrics with support from the University of Cambridge. E3ME is macro-econometric in design and can address issues related to consequences of developing policies in the areas of energy, the environment, and the economy. The model contains an economic module based on the system of National Accounts, as developed by Richard Stone in Cambridge and formally presented in European Communities (2008). Detailed sectoral disaggregation linked by input-output relationships is a key feature of E3ME.

The full model manual is available online from the model website www.e3me.com (Cambridge Econometrics, 2014).

The Cambridge model follows the post-Keynesian "history" approach of cumulative causation (Kaldor, 1957; Setterfield, 2002). In this approach waves of gross investment enhanced by R&D expenditures (Scott, 1989) affect energy demand and trade in the long term (McCombie and Thirwall, 1994, 2004). In other words, it is assumed that economic growth is demand-driven; no equilibrium; no full employment; different degrees of competition (Holt, 2007). E3ME uses historical data to calibrate the results with the aim of simulating future scenarios.

2.5.2 Hybrid Model

It has been widely argued that bottom-up models have produced unrealistic outcomes as they cannot consider the overall functioning of economy, while top-down models present limited possibilities for technological improvements (Grubb et al., 2002; Kohler et al., 2006). Another contrast between bottom-up and top-down models is found in the sorts of results regarding decarbonisation costs. While bottom-up models have generated very low cost low carbon energy options, top-down models have shown much higher costs (Kohler et al., 2006). A combined bottom-up and top-down simulation model avoids those problems and brings some advantages, as discussed by Grubb et al. (2002). The approach used in this study is based on the linkage of top-down and bottom-up models like studies previously done by Nakicenovic and Riahi (2003) and McFarland et al. (2004). Specifically, the FTT:Power model (Mercure, 2012) provides a disaggregated bottom-up treatment of the power generation sector, which is fully integrated (hard-linked) to the E3ME modelling framework (Mercure et al, 2016). The treatment of the other sectors, however, remains top-down.

2.5.3 Basic Model Structure

The E3ME model consists of collections of stochastic behavioural equations and accounting identities (Figure 7). It is based on an accounting framework and designed for projections for business and policy analysis.

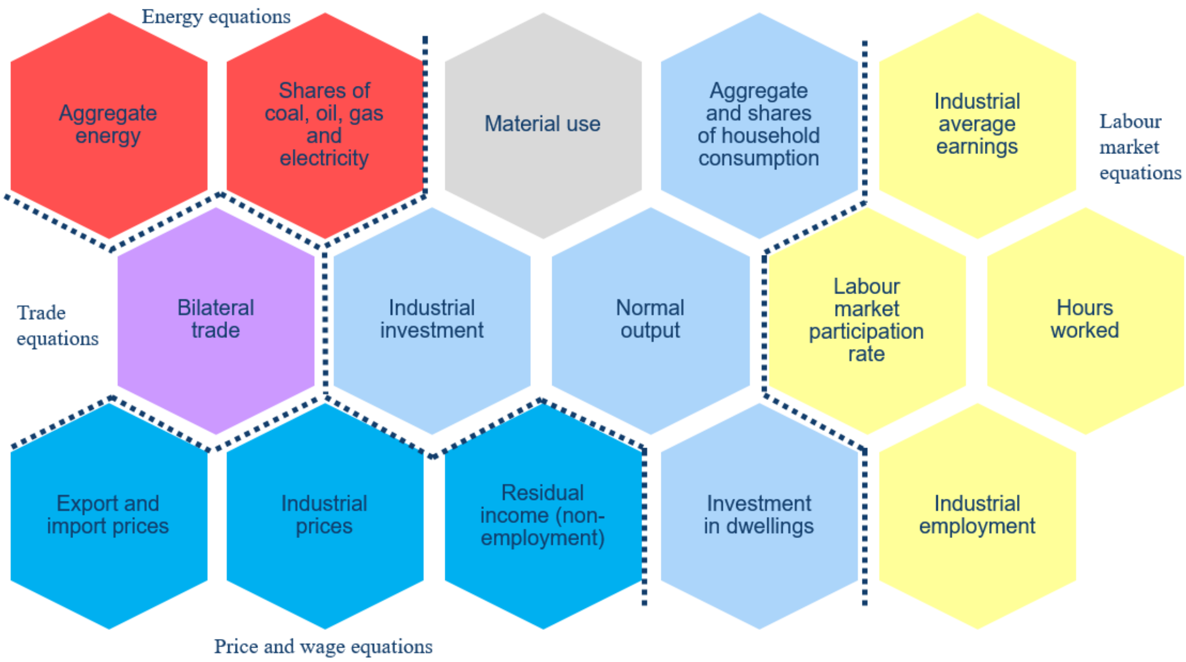


Figure 7: The stochastic equation sets in E3ME

Source: Cambridge Econometrics, 2014.

In general the E3ME contains:

- the global economy with an united accounting framework to cover energy sources and their associated emissions
- Series of historical data from 1970 at the NACE 2-digit level and with disaggregated sectors
- demand-driven econometric specification

Figure 8 shows how different modules in the model (energy, environment, economy, and technology) interact with each other. Economic activities and their demand for energy are calculated in economic module and then feed in to the energy module; energy prices and the level of their consumption are assigned within the energy module and transferred to economic and emission modules.

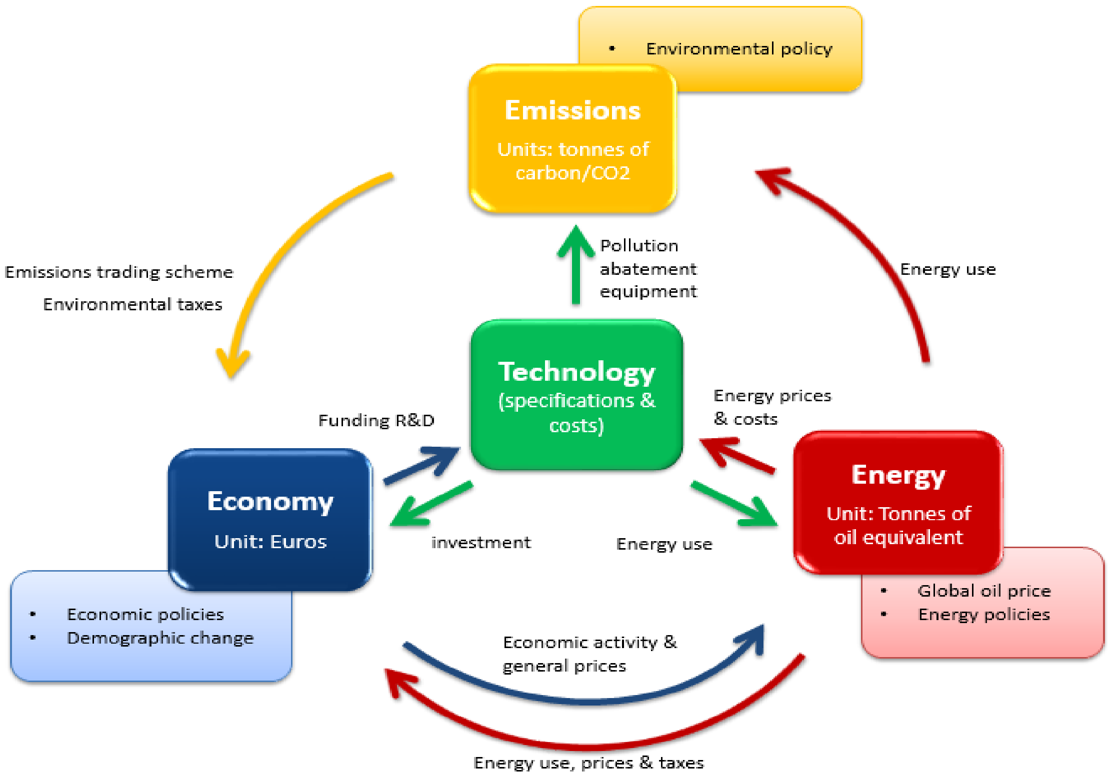


Figure 8: E3ME as an E3 Model

Source: Cambridge Econometrics, 2014.

2.5.4 E3ME's Economic Module

Regional economic structure is illustrated in Figure 9. New Zealand is counted as an independent region. In E3ME, the economic variables are estimated for each region. However, the model solves the variables for all regions simultaneously.

Unlike CGE models that consider optimum use of employment and economic output, the E3ME is demand-driven and puts limits on those variables. There are three economic loops in the model. Figure 9 illustrates the interactions between the loops. The general fact is that Type I multiplier exist in the model and according to that, increase in sectoral output will lead to buying more inputs from suppliers. These suppliers will pass the demand to the other suppliers and this loop continues. A full description of the E3ME model is available in the model manual (Cambridge Econometrics, 2014).

The loops are:

- The income loop: This is a Type II multiplier where an increase in sectoral output leads to more employment and consumtion, and eventually an economic growth.
- The investment loop: Similar to the income loop, but this time with additional investment to increase production capacity in order to cover future sectoral demand
- The trade loop: in this loop the bilateral trade between countries is also considered as an addendum to the previous two loops. The demand will be partly covered by importing the inputs from other countries.

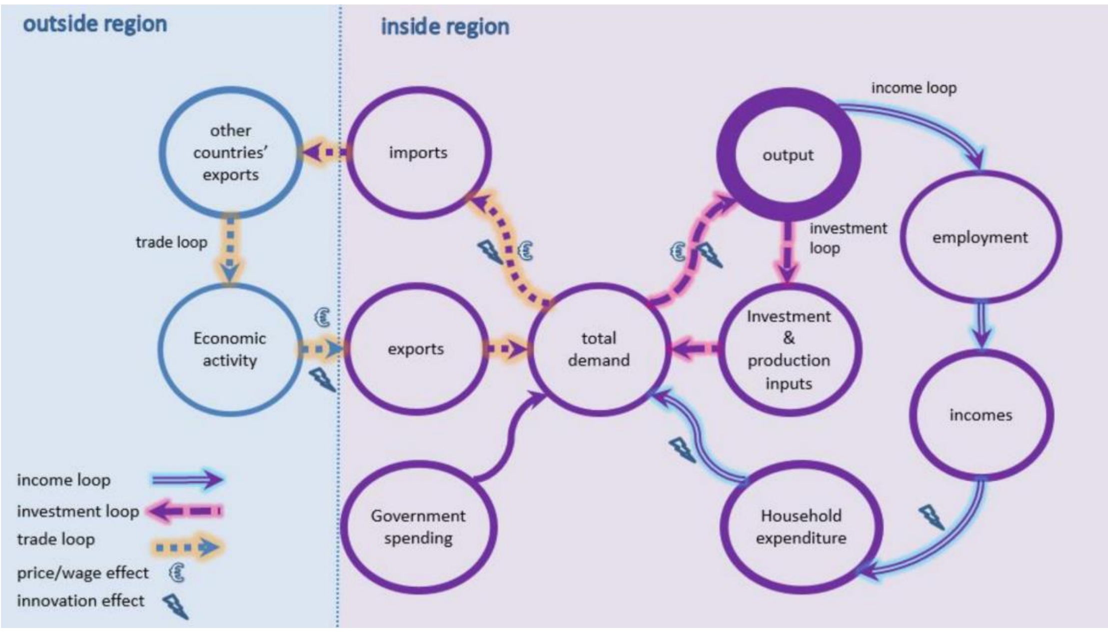


Figure 9: E3ME's basic economic structure

Source: Cambridge Econometrics, 2014.

2.5.5 Econometric Approach

The E3ME model consists of sectoral detailed econometric approaches combined with some features of CGE method. The model attempts to provide forecasts for simulating the global E3 interactions in the long-run. The method utilises developments in time-series econometrics, with the specification of dynamic relationships in terms of error correction models (ECM) which allow dynamic convergence to a long-term outcome.

2.5.6 Relative Merits of E3ME

E3ME is often compared to CGE models like the ones previously applied in New Zealand, or global tools like GEM-E3 and GTAP.

In CGE models it is assumed that households and firms react highly rational to the economic changes associated with policies. However, E3ME tracks historical responses to these changes with no prejudgment.

Some scholars criticise the CGE models for not being able to be tested ex-post against real results. Because of this, it is very difficult to test the accuracy of CGE modelling outcomes

(Kehoe, 2003). On the other hand, E3ME is built differently. It aims at understanding the changes in economic behaviour through historical data. It is a demand-driven model meaning that supply follows the demand. Unlike the CGE models that assume the economy utilises all the resources, E3ME do not assume optimal behaviour in capital and labour markets. Therefore, there is always possibility to have increasing macroeconomic variables such as employment and investment. Double dividends, in which additional regulation leads to both improvements in the environment and the wider economy, are therefore possible.

CGE models are constructed on neoclassical assumptions and if these assumptions do not match with the interactions within an economy, then the model outcomes could be unrealistic. Economists have criticised the basics of CGE (and DSGE) models and doubted that the outcomes of these models can be close to the reality (e.g. Beinhocker, 2007). They believe that the degree of rational behaviour is much higher than what really is in the world.

2.5.7 E3ME Limitations

Although E3ME looks promising and offers a more realistic simulation model than CGE models, it has some limits including:

- Data: E3ME is relied on extensive historical data to extract very important information about the economic behaviour. This make it very sensitive and vulnerable if there is no high-quality time-series.
- Econometric: The stochastic equations are not smart to deal with structural change. Another issue is related to historical relationships (known as Lucas critique). Lucas critique states that behavioural relationships that are fixed in economic models may change over time and circumstances.
- Complexity: There are complex linkages between different parts of models that cannot be fully described with econometric models.

Sub models: E3ME mostly focuses on energy models and does not monitor land use change processes including afforestation or deforestation.

2.6. Data and Scenario Design

The study requires extensive data. Data need to be pre-processed and sorted in their right categories. I collected and analysed a large time-series database covering 1970–2014 annually. Below, I explain how the data were collected, processed and transferred to the correct database within the model.

2.6.1 Data Update

E3ME was originally developed by the European Commission in order to appraise the policy impacts within European Union. The version of E3ME used in this study has a global scope and covers a detailed sectoral disaggregation in 53 world regions, including New Zealand.

The STAN database (from OECD) is the principal data source for all 53 global regions. An intensive effort was made to cleanse and fill out gaps in the data for New Zealand, with the time series covering the period 1970-2014. In order to fill the data gaps, national statistics were collected from Statistics New Zealand as the main data source. However, a collection of other public sources covering the demographic, economic and biophysical time-series data were also considered for controlling purpose. The data was obtained from GTAP Database, International Energy Agency (IEA), World Bank, and IMF. All the data in E3ME was derived from publicly available free data sources. Table 5 shows a summary of economic variables (classification and units) that was imported into E3ME. Furthermore, each data sheet contains various disaggregated socio-economic, demographic, and sectoral data covering 1970-2014 which stored in its specific spreadsheets. Table 6, for instance, represents sectoral disaggregation for employment factor (data sheet name: YRE).

Table 5: E3ME economic variables

Data sheet	Description	Units
Macro	Collection of variable where only regional total is required. E.G. GDP, Taxes	Diverse
PAR	Population by age group and gender	Thousands
LGR	Labour participation rates by age and gender	Rates
YRE	Employment by sector	Thousand persons, National Account definition
YREE	Employees by sector	Thousand persons, National Account definition
YRLC	Remuneration by sector	Million euros
YRH	Average weekly hours worked by sector	Average weekly hours worked
VCR	Consumer expenditure at current prices	Million euros
CR	Consumer expenditure at constant prices	Million euros, 2005 prices
VYRF	GVA at basic prices, current prices	Million euros
YRF	GVA at basic prices, constant prices	Million euros, 2005 prices
VYRM	GVA at market prices, current prices	Million euros
YRM	GVA at market prices, constant prices	Million euros, 2005 prices
VQR	Output at current prices	Million euros
QR	Output at constant prices	Million euros, 2005 prices
VKR	Investment at current prices	Million euros
KR	Investment at constant prices	Million euros, 2005 prices
VYRD	R&D expenditure at current prices	Million euros
YRD	R&D expenditure at constant prices	Million euros, 2005 prices
VQRM	Imports at current prices	Million euros
QRM	Imports at constant prices	Million euros, 2005 prices
VQRX	Exports at current prices	Million euros
QRX	Exports at constant prices	Million euros, 2005 prices
VGR	Government expenditure at current prices	Million euros
GR	Government expenditure at constant prices	Million euros, 2005 prices
IO	Symmetric Input-Output table for year 2005	Share of intermediate demand in total output

Table 6: Sectoral classification list for employment data (YRE)

1 Agriculture etc	16 Mech. Engineering	31 Air Transport
2 Coal	17 Electronics	32 Communications
3 Oil & Gas etc	18 Elec. Eng. & Instruments	33 Banking & Finance
4 Other Mining	19 Motor Vehicles	34 Insurance
5 Food, Drink & Tob.	20 Oth. Transp. Equip.	35 Computing Services
6 Text., Cloth. & Leather	21 Manuf. nes	36 Prof. Services
7 Wood & Paper	22 Electricity	37 Other Bus. Services
8 Printing & Publishing	23 Gas Supply	38 Public Admin. & Def.
9 Manuf. Fuels	24 Water Supply	39 Education
10 Pharmaceuticals	25 Construction	40 Health & Social Work
11 Chemicals nes	26 Distribution	41 Misc. Services
12 Rubber & Plastics	27 Retailing	42 Unallocated
13 Non-Met. Min. Prods.	28 Hotels & Catering	43 Forestry
14 Basic Metals	29 Land Transport etc	
15 Metal Goods	30 Water Transport	

Time-series data on energy and emissions have been taken from the EDGAR[6] database and IEA for all world regions. Table 7 indicates the classification and units of energy and emissions variables that are used in E3ME model and its FTT:Power sub-model.

Table 7: E3ME energy and emissions variables

Data sheet	Description	Units
EPR_NZ	Energy prices excluding taxes IEA	€/toe
EPRT_NZ	Energy prices including taxes IEA	€/toe
FCO2_NZ	User emissions of carbon dioxide	thousand tC
MEWE_NZ	IEA PG CO_2 emissions historical data NZ	$MtCO_2$
MEWG_NZ	IEA PG Generation historical data	GWh
FR01_NZ	Energy demand IEA data, hard coal	thousand toe
FR02_NZ	Energy demand IEA data, other coal	thousand toe
FR03_NZ	Energy demand IEA data, crude oil	thousand toe
FR04_NZ	Energy demand IEA data, heavy fuel oil	thousand toe
FR05_NZ	Energy demand IEA data, middle distillates	thousand toe
FR06_NZ	Energy demand IEA data, other gas	thousand toe
FR07_NZ	Energy demand IEA data, natural gas	thousand toe
FR08_NZ	Energy demand IEA data, electricity	thousand toe
FR09_NZ	Energy demand IEA data, heat	thousand toe
FR10_NZ	Energy demand IEA data, combustible waste	thousand toe
FR11_NZ	Energy demand IEA data, biofuels	thousand toe
FR12_NZ	Energy demand IEA data, hydrogen	thousand toe

In E3ME, emissions data were previously calculated using older IPCC guidelines in Second Assessment Report (SAR) in 1995. Therefore, the emission values for each greenhouse gas was quite outdated and based on old standards. Since the use of the global warming potentials (GWP) as per Fourth Assessment Report (AR4) of the IPCC is mandated by the UNFCCC for New Zealand's (and all Annex I Parties) Greenhouse Gas inventories starting from 2015, I have used the more recent values for updating emissions data in this study. Table 8 shows the old and new values for the main greenhouse gasses. As it can be seen in the table, there is a significant increase in GWP value for methane which is the source of almost half of New Zealand's GHG emissions. Therefore, New Zealand's total and net GHG emissions are now higher than estimated previously.

[6] Emission Database for Global Atmospheric Research (EDGAR)

Table 8: Global Warming Potentials (GWP) relative to CO_2 (adapted from table 2.14, IPCC Fourth Assessment Report, 2007)

Industrial designation or common name	Chemical formula	GWP for 100-year time horizon	
		Second assessment report (SAR)	4th assessment report (AR4)
Carbon dioxide	CO_2	1	1
Methane	CH_4	21	25
Nitrous oxide	N_2O	310	298

2.6.2 Scenarios

In July 2015, New Zealand's government submitted its provisional intended nationally determined contribution (INDC) to the UN. New Zealand ratified the Paris Agreement and submitted the NDC (Nationally Determined Contribution) to the UNFCCC on 4 October 2016. The target is to reduce GHG emissions to 30% below 2005 levels by 2030, which is equivalent to 11% below 1990 levels by 2030. The country has a longer-term target of reducing emissions by 50 percent below 1990 levels by 2050. Although the targets are quite ambitious, New Zealand anticipates accelerated emission reductions post 2030 once new mitigation technologies become widely available in agriculture sector specifically.

The E3ME approach undertaken in this research required the specification of possible scenarios to assess the set of policies for GHG mitigation. I have set a baseline or 'current policies' scenario in the model to represent New Zealand's current situation. Since the NZ ETS is likely to be the main mechanism in the upcoming decades, the study compares other alternative scenarios like applying an environmental tax reform (ETR) solely or alongside NZ ETS. In the baseline (B1), emission permit price based on current (2018) market price has been applied on sector-based GHG emissions. An average $25 per tCO_2-e carbon price is used in the baseline for 2018 and onwards, based on the NZU spot prices in 2018. The agriculture sector is exempted from NZ ETS because it is unlikely that New Zealand (or any other country) will implement a carbon policy on agriculture in the near future. Unlike previous studies by Infometrics (2015) and Daigneault (2015) that only exempted agriculture and forestry sectors from NZ ETS, I also considered exemptions of trade-exposed businesses and aviation in the E3ME modelling for New Zealand, according to the 'Climate Change Response Act 2002'.

I consider seven other scenarios for New Zealand. The first three scenarios are variants of the baseline. In scenario B2, a fixed $50 carbon price is used in the ETS, reflecting recent rises in the carbon price and assuming that the country will try to put some limitations on using foreign cheaper units, hence the floor price will be increased to $50 per tCO_2-e from 2019 onwards. Scenarios B3 and B4 assess the economic and environmental impacts of highly increasing carbon prices each year to achieve the NDC target (30% below 2005 levels by 2030). The carbon price paths for scenarios B3 and B4 are summarised in Figure 10.

The other scenarios consider implementing an ETR that would be necessary to reduce GHG emissions. The ETR is a carbon tax that covers all emission-intensive sectors while it includes a revenue recycling option in order to reduce the tax burden. Figure 11 illustrates how introducing a carbon tax will affect industries and households.

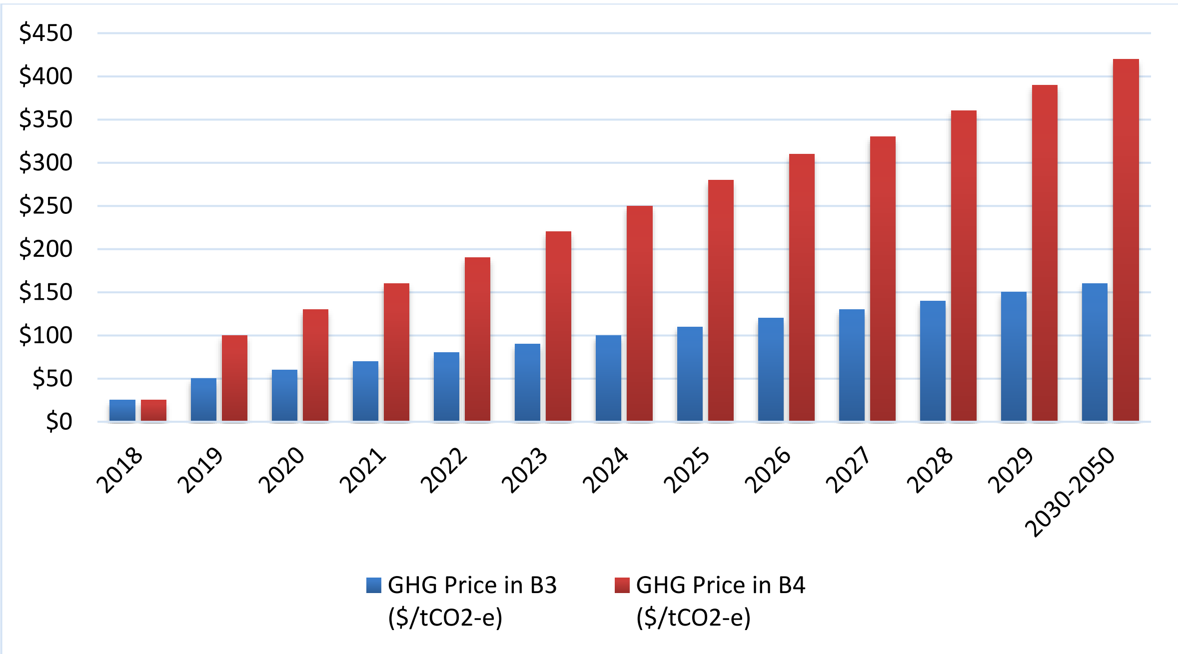


Figure 10: NZ ETS Carbon price paths to achieve NDC target in scenarios B3 and B4

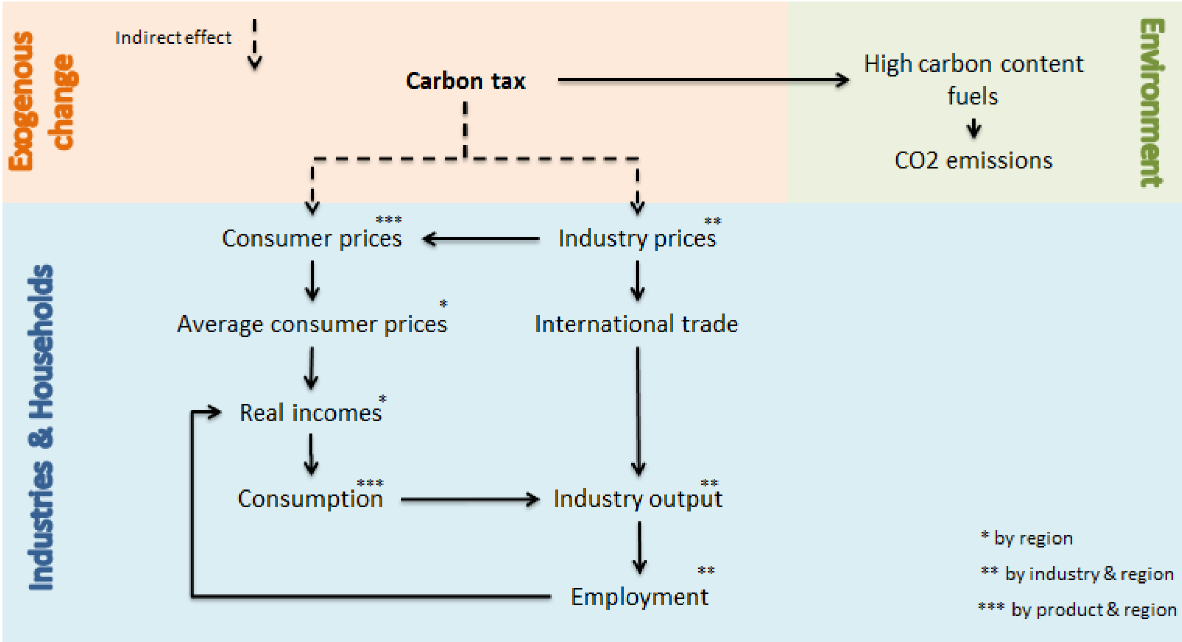


Figure 11: Impacts of a carbon tax

Source: Cambridge Econometrics, 2014.

In scenario S1, a carbon tax is levied on its own, assuming that there would be no ETS in the upcoming years in New Zealand. It is unlikely that the NZ ETS will not be available in the future; however, it would be very useful to see how a simple carbon tax can fulfil mitigation pledges without the NZ ETS. The carbon tax path for scenario S1 is similar to the carbon price path in scenario B3.

Since it is necessary to construct a scenario in which the overall tax burden is unchanged, I lower the GST rate from current 15% to 12.5% in 2016 and onwards. A reduction in GST could be expected to decrease the negative impacts of the carbon tax on New Zealand's economy.

Scenarios S2, S3 and S4 are constructed to have both NZ ETS and ETR (carbon tax and revenue recycling) on board but with different specifications for implemented carbon prices and revenue recycling methods. Typically, neutralizing is done by reducing another tax by an amount equal to the value of the carbon tax revenues. It is possible to change several domestic tax rates in E3ME through the assumptions. These include income tax, social security contributions (employers' and employees') and a GST. Social security contributions in E3ME model equals to New Zealand's KiwiSaver scheme.

Scenario S2 is a combination of B2 and S1, which comprise a $50 carbon price in the NZ ETS and applying an increasing carbon tax on non-ETS sectors at the same time. In this case, I have made the carbon tax revenue neutral by using the revenue generated to reduce employers' social security contributions. Reducing employers' social security contributions results in lower unit labour costs inputted to an industry. This in turn could generate more labour demand. Cost savings could also get passed on through industry prices, resulting in higher disposable income for households which will in turn generate further demand and consumption. The possible impacts of revenue recycling are illustrated in Figure 12.

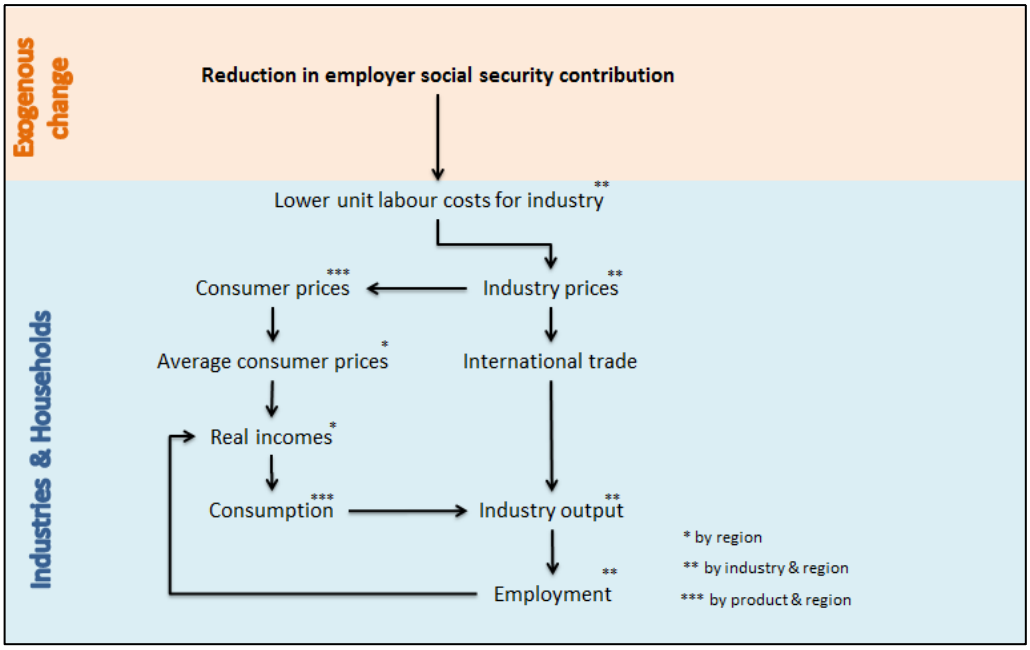


Figure 12: The impacts of revenue recycling

Source: Cambridge Econometrics, 2014.

In Scenario S3, I assume that the price for NZUs will significantly increase by $30 each year over the time-horizon 2019-2050 (same carbon price path as B4). Moreover, a complementary carbon tax is applied to non-ETS sectors to help New Zealand towards its mitigation targets under its commitment period (2021-2030). To neutralize the negative impacts of carbon taxes on New Zealand's economy and households, I have reduced the average rate for direct income taxes in scenario S3. This tax cut could reduce the tax burdens on employed people and consequently could stimulate the economy.

Scenario S4 is identical to S3 but with a different revenue recycling method. This helps us to compare the mitigation efficiency and economic performance of these scenarios with each other. All scenarios are summarised in Table 9, while Table 10 illustrates the tax inputs for each scenario.

Table 9: Summary of scenarios

Scenario	Mitigation Policy		Revenue Recycling Method
	NZ ETS	Carbon Tax	
B1	$25 current market price (BAU)	None	None
B2	$50 fixed	None	None
B3	$50 in 2019, Increasing by $10 each year	None	None
B4	$100 in 2019, Increasing by $30 each year	None	None
S1	None	$50 in 2019, Increasing by $10 each year	By reducing GST from 15% to 12.5%
S2	$50 fixed	$50 in 2019, Increasing by $20 each year	By reducing employers' social security contributions from 3% to 1%
S3	$100 in 2019, Increasing by $30 each year	$100 in 2019, Increasing by $30 each year	By reducing average income tax rates from 20.5% to 16%
S4	$100 in 2019, Increasing by $30 each year	$100 in 2019, Increasing by $30 each year	By reducing GST from 15% to 12.5%

Table 10: E3ME carbon tax inputs

Year	GHG Price for NZ ETS ($\$/tCO_2$-e)								Carbon Tax for non-ETS Sectors ($\$/tCO_2$-e)							
	B1	B2	B3	B4	S1	S2	S3	S4	B1	B2	B3	B4	S1	S2	S3	S4
2018	25	25	25	25	-	25	25	25	-	-	-	-	-	-	-	-
2019	25	50	50	100	-	50	100	100	-	-	-	-	50	50	100	100
2020	25	50	60	130	-	50	130	130	-	-	-	-	60	70	130	130
2021	25	50	70	160	-	50	160	160	-	-	-	-	70	90	160	160
2022	25	50	80	190	-	50	190	190	-	-	-	-	80	110	190	190
2023	25	50	90	220	-	50	220	220	-	-	-	-	90	130	220	220
2024	25	50	100	250	-	50	250	250	-	-	-	-	100	150	250	250
2025	25	50	110	280	-	50	280	280	-	-	-	-	110	250	280	280
2026	25	50	120	310	-	50	310	310	-	-	-	-	120	270	310	310
2027	25	50	130	330	-	50	330	330	-	-	-	-	130	290	330	330
2028	25	50	140	360	-	50	360	360	-	-	-	-	140	310	360	360
2029	25	50	150	390	-	50	390	390	-	-	-	-	150	330	390	390
2030-2050	25	50	160	420	-	50	420	420	-	-	-	-	160	350	420	420

2.7. Empirical Results

There is a total of eight model runs in this study. Each scenario run takes approximately 30-40 minutes to be completed in a personal computer. Before running the scenarios, they need to be carefully designed and proper modifications applied. Since the E3ME has no user interface, all the modification needs to be done via a text editor and Command Prompt. Given the fact that every scenario has its own specific configuration, it is a very time-consuming process and includes identifying the functions inside the model, assigning different settings and prices to the exogenous parameters, and finally making a distinct abatement policy option.

The baseline scenario (B1) assumes that the New Zealand's economy continues with business as usual (BAU) in the upcoming years and all other scenarios are measured against it.

In other words, current governmental policies for decarbonising the economy are compared to other feasible solutions.

2.7.1 Baseline Summary

The baseline is summarised in Table 11. All monetary outputs are reported in constant 2005 New Zealand dollars and emissions in million tonnes of CO_2-equivalent.

Table 11: Summary of New Zealand baseline (B1) estimates in 2020, 2030 and 2050

	2020	**2030**	**2050**	Average annual growth (2020-2050)
Economic Indicators				
RGDP	205.8	246.7	320.8	1.49%
Employment (millions of persons)	2.329	2.551	2.634	0.41%
Consumers' Expenditure	121.1	145.0	187.7	1.47%
Investment	37.9	45.8	61.2	1.61%
Exports	69.5	83.7	105.9	1.41%
Imports	55.7	68.8	90.8	1.64%
Consumer Price Index (2005=1)	1.26	1.55	2.52	2.34%
Energy and Emissions				
Energy Demand (thousand toe)	19113	19567	21204	0.35%
Total Gross Emissions (Mt CO_2-e)	81.9	80.5	79.4	-0.10%
Carbon Dioxide (CO_2)	*36.4*	*38.5*	*40.5*	0.36%
Methane (CH_4)	*34.7*	*32.6*	*30.2*	-0.46%
Nitrous Oxide (N_2O)	*9.0*	*7.1*	*5.5*	-1.63%
Fluorinated Gases (FGAS)	*1.8*	*2.3*	*3.2*	1.94%

The results from Table 11 indicate that, under the baseline scenario, GHG emissions just slightly decrease over 2020-2050. In other words, the NZ ETS with a spot carbon price around $25 would not remarkably reduce New Zealand's gross GHG emissions. This price can only keep the level of emissions roughly constant.

2.7.2 Environmental Impacts of Policy Scenarios

According to the NDC, New Zealand has set a mitigation target to reduce GHG emissions to 30% below 2005 levels by 2030. This is around 59.2 Mt CO_2-e in 2030. Therefore, an average 1.47 Mt CO_2-e reductions per year will be necessary to decrease emissions from the current GHG level of 82.1 Mt CO_2-e.

This section presents the modelled estimates and assessment of different mitigation cases to achieve the NDC target. Figure 13 shows simulated emissions path for eight GHG emissions reduction policy scenarios, including the baseline (B1). The first result is that a $50 fixed carbon price in scenario B2 does not lead to a significant decrease over time in the total gross emissions level. Therefore, the price signal is not strong enough to reduce the emissions.

In scenario B3, I assume that the carbon price under the NZ ETS will increase by $10 each year. This would lead to a decrease in total emissions level from 82.1 Mt CO_2-e in 2018 to 72.9 Mt CO_2-e in 2030. Although New Zealand's economy responds to this gradual increase in carbon prices, the reduction level is still not sufficient to achieve the 2030 pledge (59.2 Mt CO_2-e).

Scenario B4 follows Scenario B3 but with much higher carbon prices. The results indicate that the carbon price would reduce New Zealand's gross emissions by –13.3% in 2030 relative to the baseline. The GHG level amounts to 69.8 Mt CO_2-e at carbon prices of up to $420/$CO_2$-e by 2030. However, a further 10.6 Mt CO_2-e is still needed to fulfil the 2030 NDC target.

The same carbon price path in scenario B4 is applied in Scenario S1. However, a simple carbon tax is used to cover the whole economy, replacing NZ ETS. The aim is assessing an ETR in this case. There is also revenue recycling by reducing the GST from 15% to 12.5% in order to compensate the economic loss from possible higher energy prices. The results for scenario S1 show that the GHG levels decline in a similar way to B3, but with a delay. The delay is due to a sort of rebound effect, as an instant reduction in GST boosts economic activity, leading to higher consumption and emissions levels. In the long run, however, the economy benefits from investment in energy efficient equipment and appliances, hence rapid reductions in the later phases.

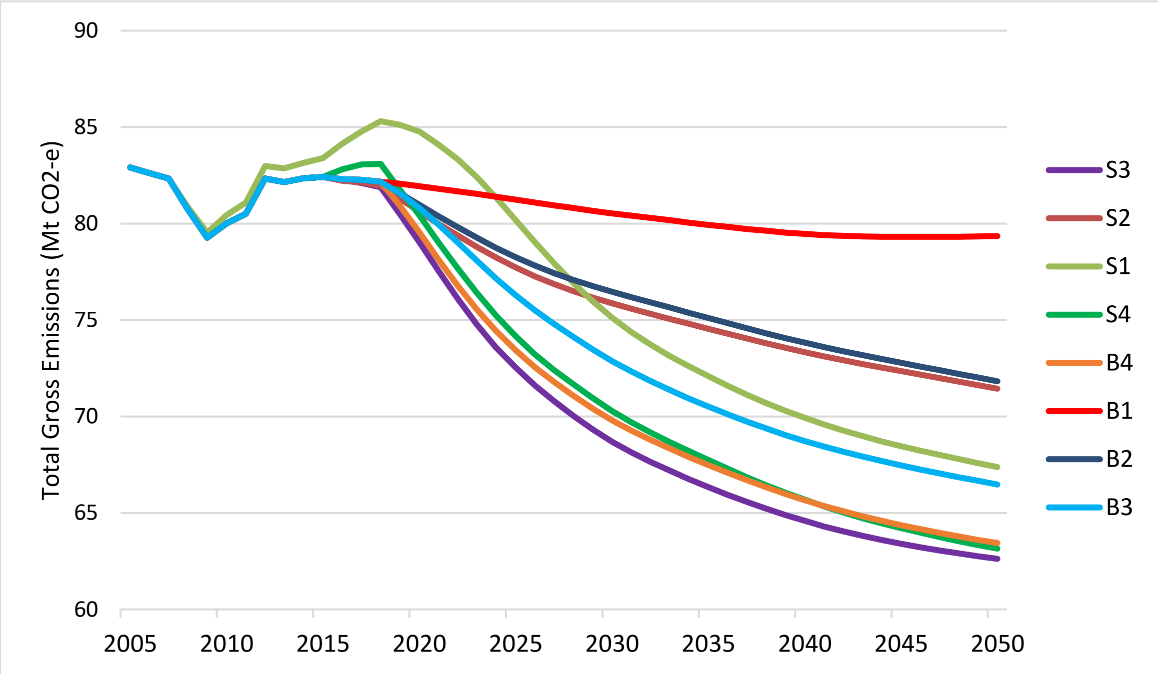


Figure 13: GHG emissions path for all scenarios

In scenarios S2, S3 and S4, a complementary carbon tax on non-ETS sectors is considered beside the NZ ETS. Since there are revenues earned by the government in these cases, the economy benefits from revenue recycling. I recycled revenues in scenario S2 by reducing employers' social security contributions from 3% to 1%. This is because current employers have to contribute at least 3% of an employee's gross pay to the employee's KiwiSaver account. Interestingly, while the carbon price in S2 is two times as high as in B2, both yield quite similar results. As a result, in S2 total gross GHG emissions amounts to 75.9 Mt CO_2-e and 71.4 Mt CO_2-e in 2030 and 2050 respectively.

Table 12 shows the difference between estimated GHG emissions for all scenarios and the baseline at the end of the commitment period in 2030. The results indicate that scenario S3 records the highest reduction in GHG emissions but is still well short of the NDC target.

Table 12: Estimated GHG reductions in 2030

	B2	B3	B4	S1	S2	S3	S4
	% change from the Baseline						
CO_2	-11.1	-20.7	-28.7	-14.5	-12.1	-30.8	-27.2
CH_4	-0.3	-0.6	-0.7	-0.7	-0.6	-0.8	-0.7
N_2O	-0.1	-0.1	-0.5	3.3	-3.1	-6.1	2.7
FGAS	-0.03	-0.15	-0.26	0.38	-0.75	-1.66	0.43
	Mt CO_2-e						
Total Gross GHG	76.5	72.9	69.8	75.1	75.9	68.7	70.3

S3 and S4 comprise the identical carbon pricing but with distinct revenue recycling methods. While scenario S4 includes the same approach as S1 in recycling revenues, I modelled the S3 by reducing average income tax rates from 20.5% to 16%. This helps us to see which mitigation policy works better for New Zealand considering both environmental and economic impacts. According to the modelling results, scenario S4 seems to have a lower GHG reduction rate than S3 and B4 overall.

Figure 14 shows the gap between estimated GHG emissions level and New Zealand's pledges in 2030 and 2050. The results indicate that the scenarios are a long way from the NDC target, let alone the 2050 target. It is clear that high carbon prices as early in the project period as possible, would be necessary to get close to the targets. More realistically, a range of other regulatory policies, particularly relating to agricultural methane emissions, seems to be required.

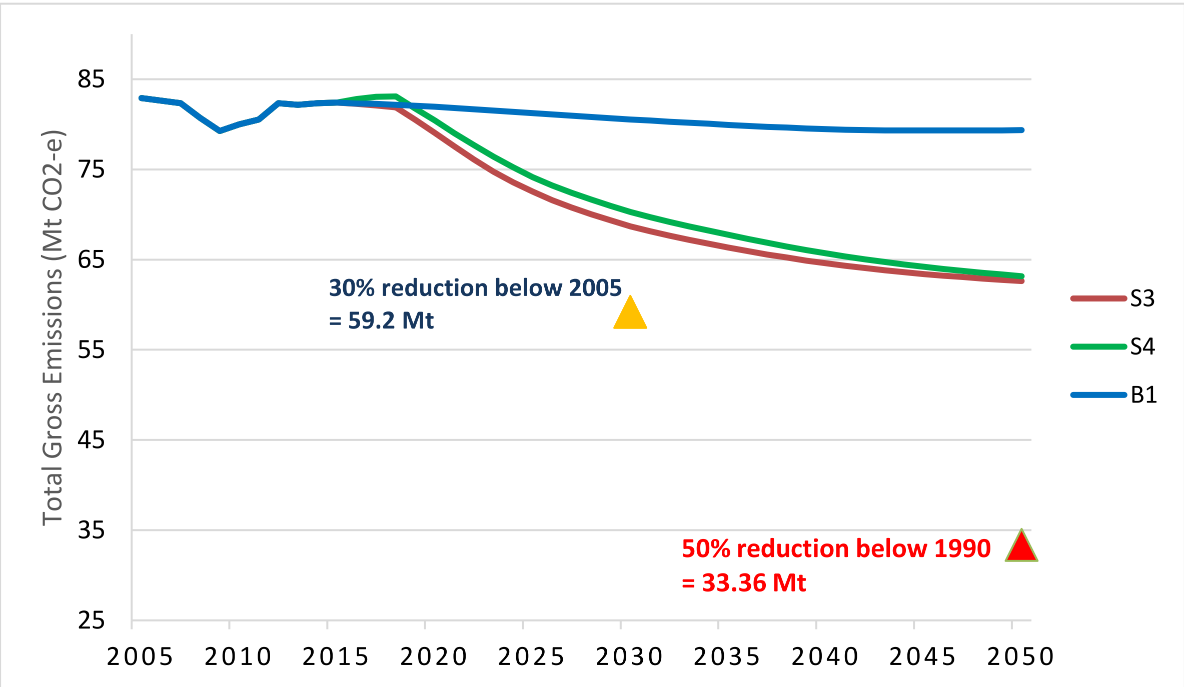


Figure 14: Projected GHG emissions path in selected scenarios and New Zealand's emission target in 2030 and 2050

2.7.3 Macroeconomic Impacts of Policy Scenarios

Figure 15 illustrates changes in real GDP in all scenarios compared to the baseline. The modelling results suggest an average 1.56% GDP growth of for the 2019-2050 period in scenarios S1 and S4. In both scenarios, I assume revenue recycling by reducing GST in the economy. It is notable that the other ETR scenarios (S2 and S3), with different revenue recycling methods, offer a significant decrease in GDP. Although the other mitigation cases show a negative impact on GDP in the long run, the negative growth is less than 1% in average.

As a result, I can now identify that the ETR scenarios are capable of reducing emissions as well as having positive impacts on New Zealand's economy. The double dividend results in this study are consistent with those of Andersen and Ekins (2010), and Ekins and Speck (2011). The results of the impact of an ETR on GHG emissions and on the economy, is also in line with other E3ME studies for other countries (e.g. Lee et al, 2012).

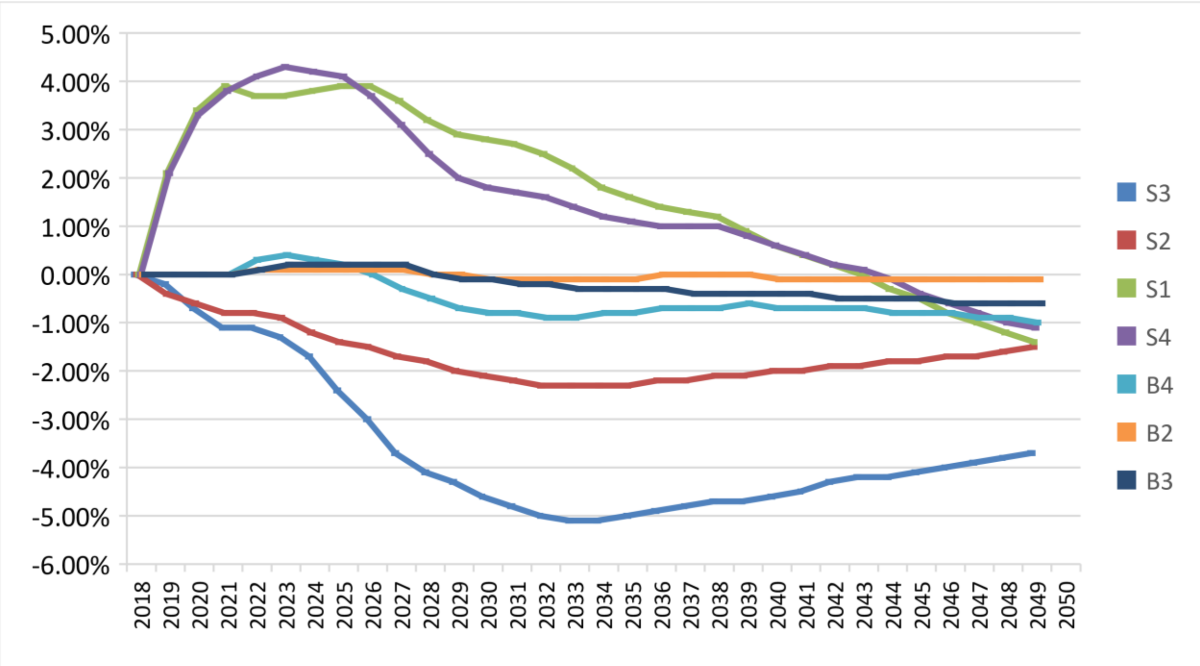


Figure 15: Change in GDP compared to baseline

The reason for the GDP increase in the ETR scenarios with revenue recycling (S1 and S4) is that the positive effects of reducing GST outweigh the negative effects of higher energy costs in New Zealand.

Table 13 demonstrates changes in key macroeconomic indicators in all the scenarios compared to baseline in 2030. The results indicate that scenarios S1 and S4 produce economic benefits. These two scenarios are the only ones that always record positive impacts on household consumption, employment, export, and investment indices in the modelling. The trade balance in S1 and S4 is negative; however, the policy impact on investment is quite remarkable and it is likely to boost industrial production and hence an increase in domestic consumption of goods and services. As a result, this creates additional jobs and could lead to an economic growth in New Zealand. Figures 16 and 17 illustrate the changes in employment and investment compared to the baseline.

Table 13: Estimated macroeconomic impacts in 2030

	B2	B3	B4	S1	S2	S3	S4
	% change from the Baseline						
GDP	-0.08	-0.27	-0.87	2.17	-2.27	-5.08	1.38
Employment	-0.02	-0.03	-0.04	0.64	-0.14	-0.33	0.54
Consumers' Expenditure	-0.11	-0.69	-1.70	3.58	-3.42	-7.92	2.36
Investment	0.16	1.25	0.97	6.55	-3.79	-6.63	5.63
Exports	-0.02	-0.05	-0.08	0.01	0.03	-0.04	0.01
Imports	0.15	0.29	0.08	4.13	-1.55	-2.91	3.80
Consumer Price Index	0.31	0.96	1.89	1.22	1.58	2.81	3.69
Industry Output	-0.14	-0.37	-1.30	4.20	-4.22	-9.22	3.21
Energy Demand	-5.02	-11.34	-17.69	-8.52	-6.17	-19.88	-16.33

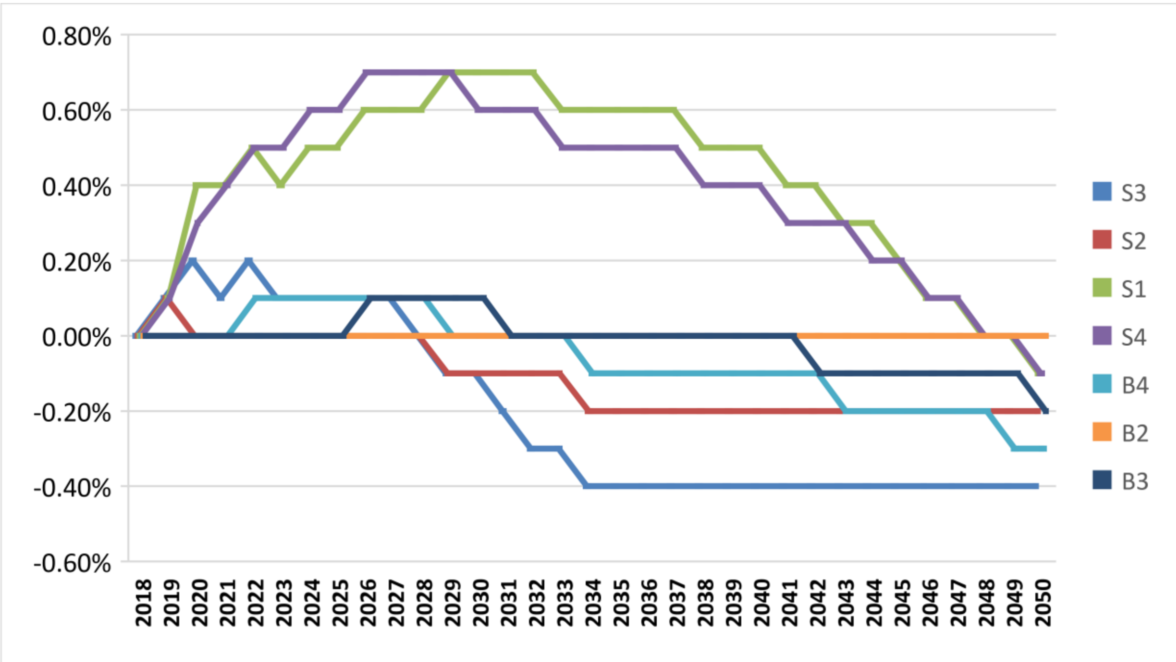


Figure 16: Change in employment compared to baseline

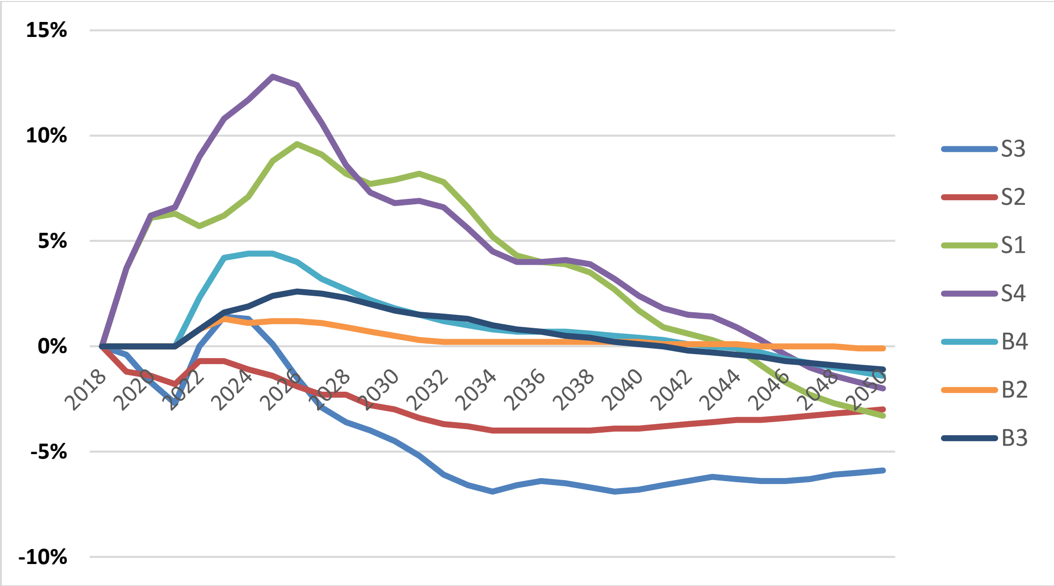


Figure 17: Change in investment compared to baseline

The macroeconomic outcomes obtained from the study explain the significance of approaches with revenue recycling. The revenue recycling scenarios (S1 and S4) cause economic benefits in comparison to the scenario without revenue recycling (B1, B2, B3 and B4). This is consistent with the "double dividend hypothesis" in Goulder (1995). While a mitigation policy amends environmental health, it could also lead to some gains in economic welfare by lowering the deadweight loss in the tax system. Therefore, a combination of environmental and economic improvements could be possible.

2.7.4 Treatment of Technology and Energy Efficiency

It is now generally accepted that technology should be endogenous in energy-economy modelling. There are two ways of doing it: explicitly (bottom-up, partial approaches), and implicitly (top-down, general approaches). E3ME is able to use both explicit and implicit methods. By default, technology improvement is treated endogenously in E3ME through running a very detailed energy model called "Future Technology Transformations for the power sector (FTT:Power)". However, there will always be a limitation that it is not possible to predict all future technologies. Hence applying an exogenous technology parameter can be helpful to stimulate innovation and R&D in each economic sector. In E3ME, this is possible through navigating the investments and assigning them to the specific sectors like agriculture sector. Almost half of GHG emissions in New Zealand come from the agriculture sector. It seems that technology innovations and R&D investments in agriculture sector are necessary to tackle agricultural greenhouse gases.

To address the technological changes in agriculture sector, it is required to define additional exogenous investment on top of what is determined in the E3ME model. For this purpose, I wrote extra commands and added them to the group of forecasting commands in the model. In the model, the exogenous investment parameter is called KRX and can be modified as below:

```
IF YEAR GE 2019;
    LET KRX(1,38)=0.05 * KRA(1,38)
END IF
```

The line above sets KRX in sector 1 (agriculture sector) region 38 (New Zealand) equal to 5% of the actual investment for this sector.

The additional investment needs to be funded. Thus I assumed that this can be possible via some savings resulting from increasing energy efficiency in the system (or simply switching to renewable energies). Energy efficiency in E3ME is modelled by adding exogenous changes to energy use. Although energy use is an endogenous component, exogenous change can be applied in the same way that I did for sectoral investment, using the variables below:

Table 14: Fuel variable names in E3ME

Variable name	Description	Dimensions and units	Mechanism
FREH	Exogenous change to electricity use	22 fuel user per region. Th toe	Gets applied to FRET. If negative can be interpreted as energy efficiency savings.
FROH	Exogenous change to heavy fuel oil use	22 fuel user per region. Th toe	Gets applied to FROT. If negative can be interpreted as energy efficiency savings.
FRGH	Exogenous change to gas use	22 fuel user per region. Th toe	Gets applied to FRGT. If negative can be interpreted as energy efficiency savings.
FRCH	Exogenous change to coal use	22 fuel user per region. Th toe	Gets applied to FRCT. If negative can be interpreted as energy efficiency savings.

I assumed that energy efficiency can be achieved through 5% energy saving in gas use (FRGH) and put these commands in the model:

```
IF YEAR GE 2019; DO
  FOR LL=1 TO 21
        LET FRGH(LL,38)= -0.05 * FRET(LL,38)
  LOOP LL
END IF
```

The lines of code above exogenously set gas use (FRGH) 5% below its actual amount (which is calculated endogenously) for fuel users 1 to 21.

In order to find out how New Zealand' economy respond to technology improvements in agriculture sector and savings in gas consumption, I created additional scenario named S4+. The new scenario is built on scenario S4 that also includes both technology improvements and energy efficiency savings coded. The new modelling results are then compared to original S4. The outcome reveals important facts about the impact of these additional policy options (Table 15). Macroeconomic indices demonstrate that S4+ performs better than original S4 by year 2030. Figure 18 also compares GHG emissions path in S4 and S4+ against business as usual scenario (B1). S4+ shows more GHG emissions reduction than S4 over 2020-2050.

Table 15: Comparison of S4 and S4+ in 2030

	S4+
	% change from the S4 scenario
GDP	0.39
Employment	0.07
Consumers' Expenditure	0.25
Investment	1.60
Exports	0.36
Imports	0.67
Consumer Price Index	0.18
Industry Output	0.48
Energy Demand	1.73
Total Gross GHG	-1.40

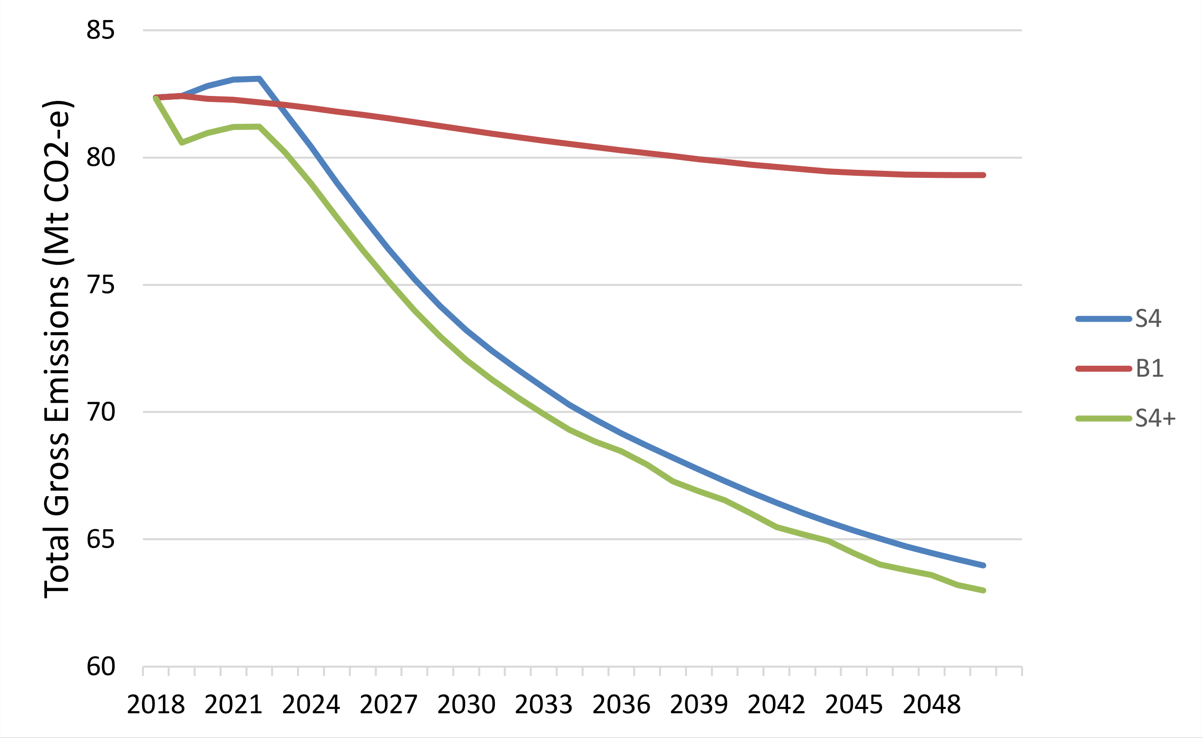


Figure 18: Projected GHG emissions path in selected scenarios

2.8. Conclusion

2.8.1 Main findings and policy implications

This study analyses the effects of implementing Environmental Tax Reform (ETR) on GHG emissions and New Zealand's economy as a whole. A number of scenarios, including a baseline, are constructed to investigate the performance of the NZ ETS and other complementary mitigation policies over the commitment period (2021-2030).

In the light of the model results, it is notable that higher carbon prices especially in the early years would be necessary to achieve the ambitious GHG emissions target in New Zealand – but that carbon pricing on its own appears insufficient to meet emission reduction targets. It is clear that pricing CO_2 can only go so far in helping New Zealand to meet its GHG emission reduction targets and additional policy (notably on agricultural emissions) will be required. This is simply because it is unlikely to see the agriculture sector is included in NZ ETS in the near future. However, other abatement policies through boosting R&D investments may help to cope with the emissions in this sector.

Nevertheless, this should not be interpreted as there being no role for carbon taxation in New Zealand. The model results suggest that a combined NZ ETS and carbon tax approach with revenue recycling could lead to economic benefits, while making some contribution in reducing emissions. This finding is in line with those of Weitzman (1978); Roberts and Spence (1976); McKibbin and Wilcoxen (2002); and Pizer (1998, 2002) of using an efficient hybrid mechanism to tackle the GHG emissions and, at the same time, minimising the welfare loss. Meanwhile, double dividend effect could be achievable, if New Zealand's government recycles the revenues from carbon taxes. This helps to decrease the burden of existing distortional taxes.

2.8.2 Limitations and recommendations for further research

The shortcomings of this study in general are mostly lied in the difficulties and complexities of modelling energy, economy, and environment concepts. As discussed in the literature review, every E3 model has its own advantages and disadvantages. This pretty much reveals the direction of limitations of this study with E3ME. One critique about E3ME is that it does not utilise a well deigned damage module in order to calculate the environmental damage from GHG emissions. Therefore, it cannot monitor land use change or carbon sequestration processes including afforestation or deforestation. A detailed sub-model for land use change can solve the problem in E3ME. Furthermore, E3ME is a global model and can simulate 53 regions. In this study, I have only focused on New Zealand and have made domestic scenarios. However, in future research creating scenarios for other regions can be also taken into account. So expanding the scope of emission trading scheme and including other countries that have bilateral trade with New Zealand may yield better results.

Chapter 3.

Essay Two: Light Petrol Vehicles and CO_2 Emissions in New Zealand: Assessing the Effectiveness of Fuel Tax and Technology Improvements

3.1. Introduction

The two aspects of transport sector externalities are of special interest to energy economists and policy makers: atmospheric emissions and the effectiveness of fiscal policy instruments to reduce the CO_2 emissions. Many studies have attempted to analyse the mitigation policies for road transport and those studies indicate that many variables affect carbon emissions from car fleet. This study examines the linkage between the level of CO_2 emissions from Light Petrol Vehicles (LPV) and some key determinants using econometric models and seasonal data from 2005 to 2014 in New Zealand. The analysis incorporates the effects of 'fuel tax', 'Trade-Weighted exchange rate Index' (TWI) and the 'average emission rate of newly registered vehicles'. In addition, this study also investigates how effective the fuel tax and technology improvements are to influence decarbonising light petrol fleet in both short- and long-run. This question is of special interest in the international literature, and it has not been previously investigated for the LPVs in New Zealand.

3.1.1 Background

The energy sector is dominated by the direct combustion of fossil fuels; therefore, fuel combustion is responsible for the largest amount of global CO_2 emissions. In turn, transport is the second biggest emitter after the electricity sector and contributes to the global warming (IPCC 2014). Road transport is responsible for nearly 23% of CO_2 of world's fuel combustion GHG emissions and claims over 30% of total emissions growth each year (IEA 2015). Figure 19 displays world CO_2 emissions from fuel combustion by sector in 2014. Moreover, the global demand for transport is very uncertain as the pace and shape of economic developments continue to rapidly change almost everywhere in the world. For example, if China, India, Russia, Africa and Latin America can actualise their economic potential, the world demand for transport will experience a remarkable growth over the next several decades. This could be partly because the level of incomes in developing countries will grow rapidly. As a result, dependence on private vehicles will be prioritised over using alternative solutions like public transport in these nations. Meanwhile, investing in transport infrastructure and developing choices other than road transport are usually very costly and time-consuming. Therefore, it is expected that cars will be more affordable for families in the developing countries. In turn, the intensity of car ownership will grow as the economic growth and population increase.

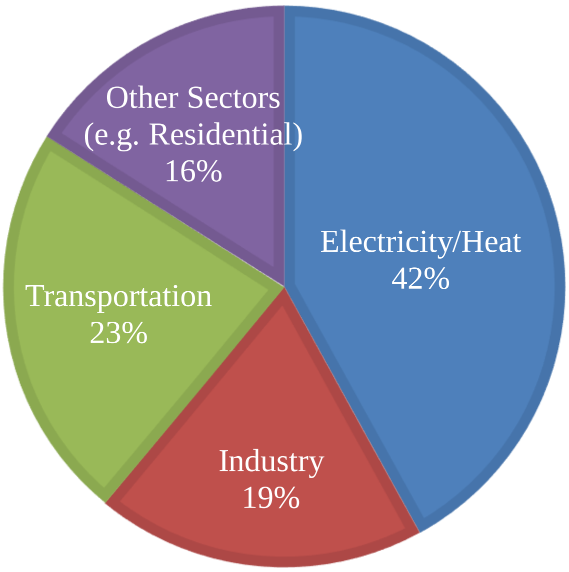


Figure 19: World CO_2 Emissions from Fuel Combustion by Sector in 2014

Source: International Energy Agency, 2015

Technology has been evolving rapidly and it affects the transport sector significantly. From ongoing technological developments in vehicles to increasing the energy efficiency in different transport modes, and from inventing new fuels like biofuels to reducing the car production costs, the role of technology in transportation is incontrovertible. Over the last decades, environmental regulations and technological improvements have reduced the private vehicles' emissions majorly in developed countries; nonetheless, the gain has been offset by a raise in the number of private cars and their use (Fuglestvet et al., 2008). For example, from

2003 to 2008 the car ownership in Beijing (China's capital) has doubled, and similarly the use of public transport fell dramatically from 70% in 1970 to as low as 24% in 2008.

The world's population is expected to reach 9.2 billion in 2050, with more than two-thirds of this population living in urban areas compared to about half the population of today. In consequence, traffic congestion, air pollution and noise will be an inevitable problem in emerging megacities mostly in Asia, Africa and Latin America. For instance, the traffic speed in Beijing has slowed from around 45 km/h in 1994 to less than 13 km/h in 2008 (Williams, 2008). As the traffic congestion is worsening in big cities, the need for a comprehensive and cost effective public transportation seems to be essential to tackle the urban mobility challenges.

Currently, road transport does not seem to be highly regulated for emissions, and increase income in levels especially in emerging economies steers consumer choices towards increasingly emission intensive cars with higher capacity engines (e.g. Gallachoir et al., 2009; Zachariadis, 2013). It is clear that energy saving and emission reduction could be achievable through switching to more energy efficient vehicles. However, consumers usually follow their socio-economic characteristics in purchasing a new car and, interestingly the state of technology and age of cars are not among their first preferences (McShane et al., 2012). In addition, overconsumption of energy in countries like U.S. and the impact of this on greenhouse gas emissions is another big challenge for governments and policy makers.

3.1.2 New Zealand's National Circumstances

New Zealand is a remote land and has a relatively low population density (at 9.8 people per square kilometre). The country is historically very car-dependent as it has a mountainous topography and long coastline. There are currently over 3.8 million vehicles on New Zealand's roads and around 91.5 percent of these are light[7] vehicles. Figure 20 illustrates the fleet composition from 2001 to 2015.

[7] Definition is made by the Ministry of Transport: "Light vehicles are those that have a gross vehicle mass less than 3.5 tonnes and include cars, vans, 4WDs, utes and light trucks."

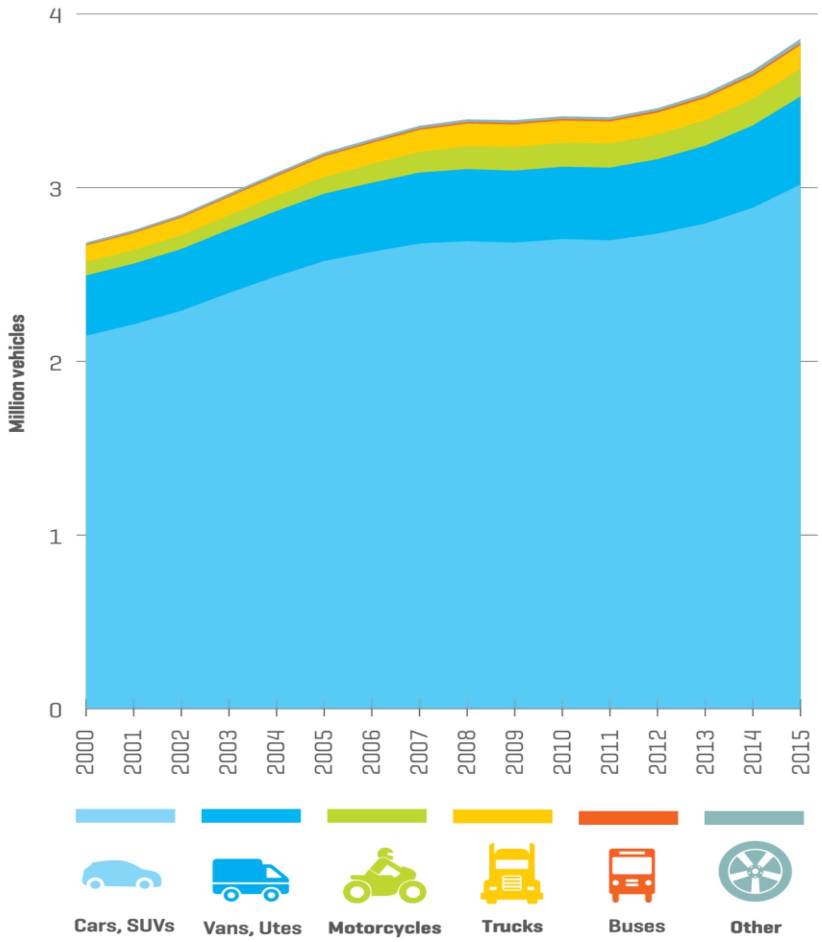


Figure 20: Fleet composition in New Zealand from 2001 to 2015

Source: Ministry of Transport, 2017

Between 2000 and 2007 a large number of new and used light vehicles were imported. The majority of imported fleet were used vehicles mainly from Japan. And for this reason, New Zealand's car ownership rate has been increased and is one of the highest in the world. In 2014 there were 657 light vehicles per 1000 population in New Zealand which was higher than in Australia, Japan, the United Kingdom and the United States (Figure 21).

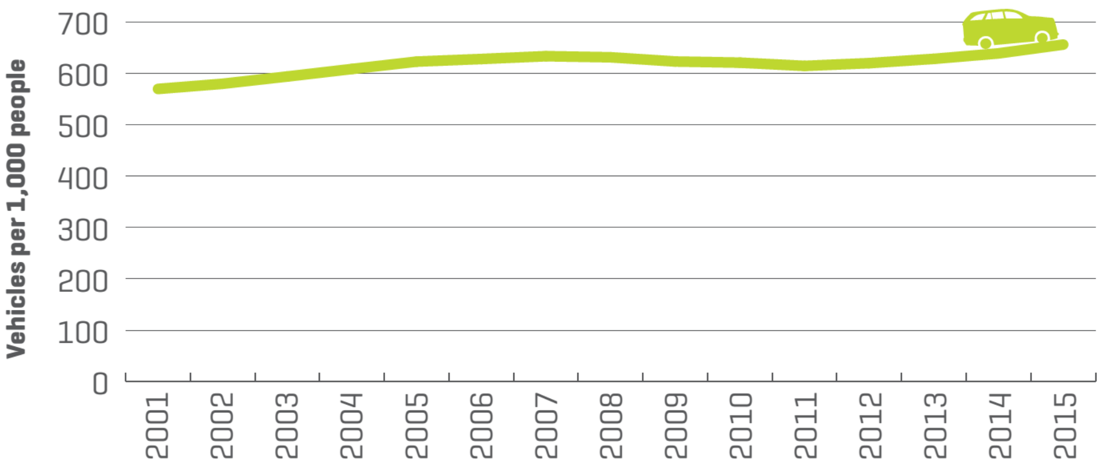


Figure 21: Light fleet ownership per 1000 population

Source: Ministry of Transport, 2017

The light vehicle fleets age in New Zealand is one of the highest among developed countries, with an average of 14.1 years in 2014. Figure 22 provides an international comparisons of fleet ages.

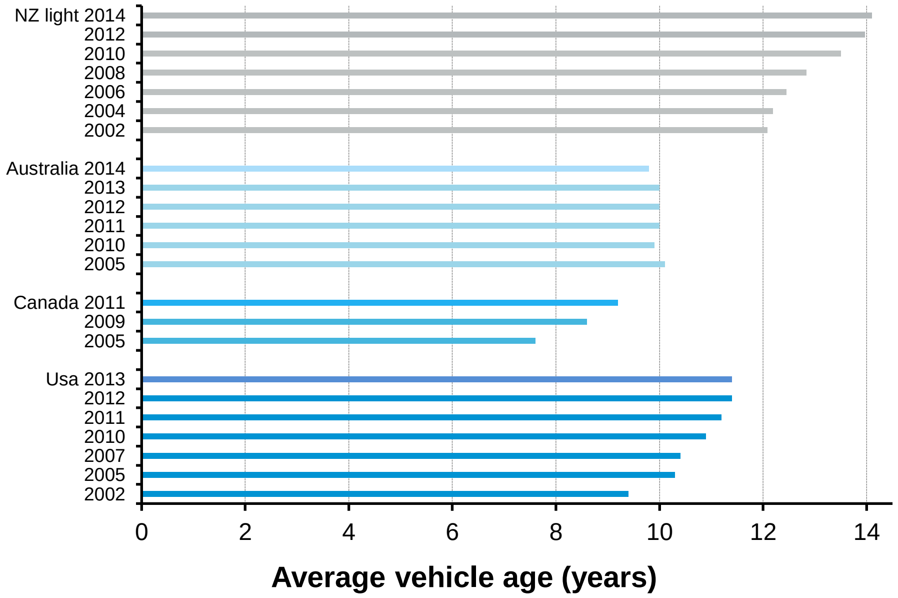


Figure 22: International comparisons of fleet ages

Source: Ministry of Transport, 2017

Since mid-2000s the average age of vehicles in the New Zealand light fleet has been increasing regularly (Figure 23). However, Australia for example managed to keep the fleet age almost constant in around 10 years. The reason behind older light fleet in New Zealand could be partly because the rust prevention techniques were developed in early 1990s. Another reason for this, could be the lack of clear, efficient and comprehensive standards for scrapping older cars by government.

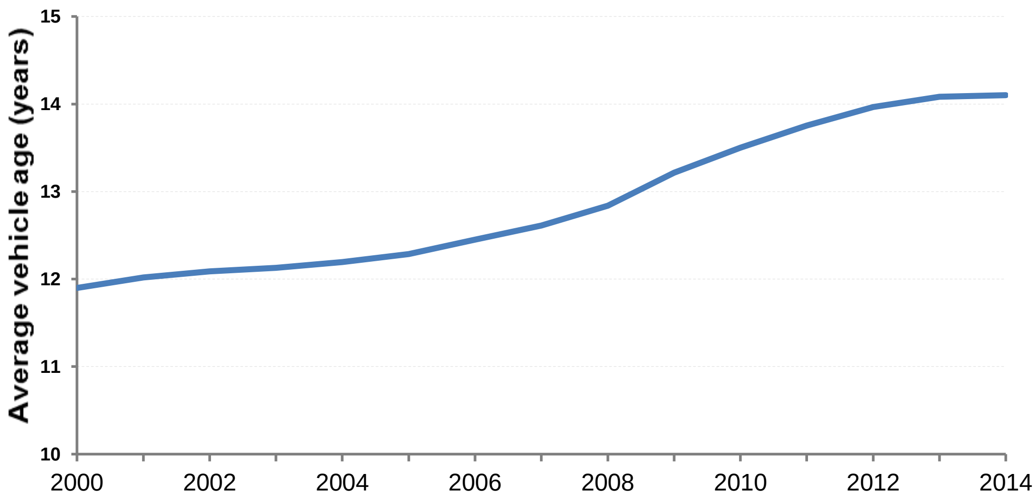


Figure 23: Average light fleet age in New Zealand
Source: Ministry of Transport, 2017

It is also notable that an older fleet have higher noxious emissions and will be less safe than a younger fleet. Given these points, an aging fleet is a very important and serious issue for the government and policy makers to deal with.

Table 16 below presents New Zealand's emissions by sector in 1990 and 2016.

Table 16: New Zealand's emissions by sector in 1990 and 2016

Sector	kt CO_2-equivalent 1990	kt CO_2-equivalent 2016	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
Energy	23,785.2	31,308.0	7,522.8	31.6
Industrial processes and product use	3,585.1	4,853.4	1,268.3	35.4
Agriculture	34,581.9	38,727.3	4,145.5	12.0
Waste	3,862.6	3,838.2	–24.4	–0.6
Gross (excluding LULUCF)	**65,814.8**	**78,726.9**	**12,912.1**	**19.6**
LULUCF	–29,539.5	–22,773.7	6,765.8	22.9
Net (including LULUCF)	**36,275.3**	**55,953.3**	**19,678.0**	**54.2**

Source: New Zealand's Greenhouse Gas Inventory 1990–2016.

Although the agriculture sector was the biggest emitter in 2016 (contributing 49 per cent of New Zealand's total GHG emissions), the increase in energy sector's emissions was more than twice the size of agriculture's emissions from 1990 to 2016. The reason for this rapid growth was mainly the road transportation, which increased by 6,137.3 kt CO_2-e over this period. In 2016, road transportation was the largest sources of emissions in the energy sector, contributing 13,612.6 kt CO_2-e (43.5 per cent) to energy emissions. This was, however, due to increase in renewable-based electricity generation over the last decades.

Between 1990 and 2016, the road transportation experienced an 82.1 per cent growth in emissions. This is likely due to population growth and increase in demand for freight transport in New Zealand. In 2016, the transport sector was responsible for 17% of New Zealand's total gross emissions (Figure 24) and it is expected that its share will continue to grow unless appropriate emission reduction policies are taken into account. In other words, New Zealand government may consider fiscal policies to incentivise the emission abatements in the transport sector.

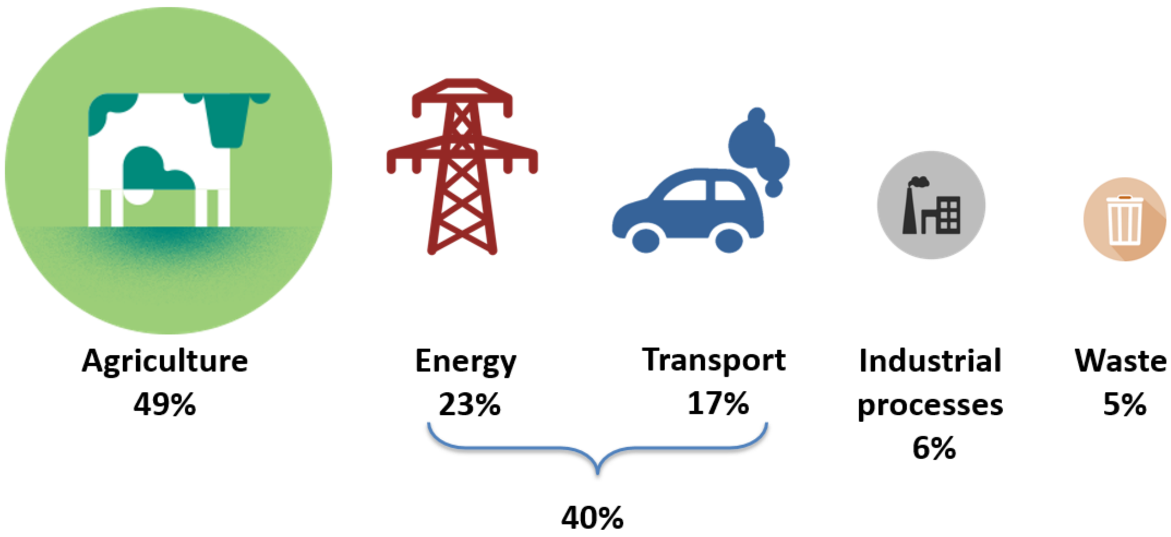


Figure 24: New Zealand's greenhouse gas emissions in 2016 by sector

Source: New Zealand's Greenhouse Gas Inventory 1990–2016.

3.1.3 Approach adopted in this study

This study is arranged as follows. After the introduction, theoretical framework of this study is stablished in section 2, previous studies and empirical results are discussed in Section 3. Section 4 provides a full description of econometric model and explains the time-series data set and their sources. Empirical results and analysis are provided in Section 5. The last section concludes this research.

3.2. Theoretical framework

Still counted as the most frequently cited work in the area of environmental economics, "The Problem of Social Cost" (1960) by Ronald Coase is dealing with the notion that how market can manage to use the resources more efficiently when legal rights are well defined. He tries to show the importance of property rights in economic structure. In his famous paper, he points out that property rights play central roles in avoiding externalities because if they are clearly defined, the pollution can be close to zero.

More than just an environmental challenge, the problem of carbon dioxide emissions raises wider issues of people's failure of attention to the fact that fossil fuels are the main sources of carbon dioxide emissions while people are not liable for the cost of the damages. While it is not quite possible to work out the magnitude of problems related to an individual's actions, the size and distribution of aggregated emissions is not that large enough to be measured.

The Coase theorem seeks to solve problems related to externalities. According to Coase theorem, the actors involving in the economy will attempt to bargain for the property rights. Accordingly, there are chances to find the most effective way to make a profit and have optimal use of resources. Coase states that economic efficiency will be eventually achieved; however, it requires two initial conditions: (1) clear information on marginal cost and marginal benefit (2) bargaining should be free of any transaction cost.

According to Coase, it is not practical for the usual economics approach to assume that there is no transaction cost. In other words, there should be transparency between anyone that want to handle market transactions and those who want to deal with, leading to a written agreement between two sides. Regarding CO_2 emissions as a global problem, it is impossible to say who causes damage to someone else by burning fossil fuels or how both sides should reach mutual agreement that cause no harm for both sides.

Coase points out that the alternative solution is government intervention to solve the problems faced to individual bargaining. According to him, this intervention affects the factors of production by making right decisions. There are chances for the government to control the market implementing clear policies. For example, firms and households are subjected to regulations by the government for paying taxes if they engage in a certain activity. Therefore, a free rider problem can be avoided if government take a nation-wide action. With an example, Coase tries to clarify the issue. In his example there is one big factory and hundreds of landlords around the factory. The factory can emit the pollution as much it can, and landlords can pay the factory not to pollute or lower the pollution level. Things can be more complex when some landlords do not pay their share.

Governments intervene in the market to have a control over the level of pollutions and their associated social costs. The goal is reducing the externalities with less burden on economy. This can be partly achieved through imposing a nation-wide tax on CO_2 emissions. However, the question is, does taxing in general help to shift the environmental quality? And are there other factors that can help reduce emissions?

GHG emissions are the results of economic activities. Therefore, a production function can be employed to understand the contribution of energy factor in economic growth as well as measuring its pollution. A neoclassic growth model by Solow-Swan coupled with classic Cobb-Douglas production function can be set within the framework.

3.3. Review of the Literature

There is a substantial amount of work done on the effects of fiscal policies on fuel consumption and transport sector externalities in different cities and countries. However, the findings for implementing policy instruments and their feasibility and efficiency vary across studies.

Regarding light-duty vehicles in the United States, Decicco (1995) adopted a model of motor vehicle stock turnover to investigate the impact of fuel-efficiency standards on petrol consumption ratings, and associated GHG and hydrocarbon emissions. The results demonstrated that in case of saving 2.9 million barrel of petrol per day, the level of carbon emissions will be reduced to 147 million metric tons per year, which is a significant fuel-economy improvement of six percent per year. Also, Harrington (1997) used remote sensing data on in-use emission to indicate a significant relationship between the efficiency of fuel consumption and carbon monoxide emissions reduction. The linkage becomes even stronger with vehicles aging.

By estimating the efficiency of carbon tax, a fuel tax, and fuel economy standards in cutting greenhouse gases, Crandall (1992) indicated that carbon tax is more efficient now than a petroleum tax. Accordingly, Fuel economy standards carry a cost of at least 8.5 times more than carbon tax with the same impact on carbon emissions. However, a failure to bringing down the marginal costs of fuel consumption, even in the case of older vehicles and non-vehicular consumption, results in the inefficiency of the fuel economy standards.

To anticipate fuel economy technologies, Austin and Dinan (2005) used simulation model and cost estimates to compare the cost of higher fuel-economy standards with the cost of a petrol tax. The results obtained from their study revealed that petrol tax would offer greater immediate savings by incentivising people to use drive fuel efficient vehicles. A study by Fischer (2008) and West and Williams (2005) confirmed Austin and Dinan's claims that petrol taxes efficiently minimize fuel consumption than mandating fuel-efficiency increases.

On the other hand, in other studies, including Portney et al. (2003), Dowlatabadi et al. (1996), and Bamberger (2002), increased Vehicle Miles Travelled (VMT) constitutes a problem in terms of enhanced fuel economy. Bamberger (2002) asserts that VMT positively affects overall cost of driving by increasing congestion and crash costs.

There is a doubt that fuel-economy standards have been effective at reducing vehicle miles travelled and labelled fuel economy regulations. Nivola and Crandall (1995) stated that if United States had increased petrol price by 25 cents a gallon nine years ago, on third of economic cost could have been saved. For light duty vehicle manufacturers, Wang (1994) offered an in demand permit scheme which he called it a better alternative to the existing Corporate Average Fuel Economy (CAFE) standards. Then, Portney et al. (2003) advocated using tradable fuel economy permits for CAFE to be more effective, revising the criterion for recognising the difference between light trucks and cars, as well as eliminating the difference between imported and domestic vehicle fleets.

In terms of enhanced CAFE standards, Dowlatabadi et al. (1996) asserted that diminishing returns affect fuel savings from increasing CAFE and hence has very limited effect on GHG emissions as well as air pollution. Their findings suggested that CAFE cannot be the most cost optimal solution for reducing GHG emissions and other gases including volatile organic compounds (VOC) and nitric oxide (NO).

According to Portney et al. (2003), the CAFE standards will make driving cheaper, if fuel consumptions in gallons per mile are minimized, which might bring in an overall increase of pollution. On the other hand, a study by Greening et al. (2000) showed that an increasing rate of travel as a consequence of a reduction in driving costs per mile and improving CAFE standards seems negligible.

An economic analysis by West and Williams (2005) revealed that a fuel tax would be more efficient abatement tool over the CAFE standard in a tax-distorted labour market. In other words, an increase in fuel tax can increase welfare level, while if the CAFE standard is dropped, welfare loss will occur shortly.

According to Goldberg (2003) and Parry et al. (2004), the degree of welfare gains is determined by myriad factors, including nationwide congestion and traffic accidents, using CAFE as a tax policy to remove fuel-inefficient cars, and the opportunity costs of driving more fuel efficient vehicles. Parry et al. (2004) pointed out that the welfare gains resulting from higher fuel economy standards might be very uncertain and heavily depends on people's opportunity costs and how they appreciate fuel efficient vehicles.

Molina (2004) believes that problems underlying urban air pollution caused by transport activities will remain unsolved if a single strategy applied to all existing circumstances. Instead, a range of various policy measures that best fit every city's specific requirements might be employed to tackle the related problems. Take for example the imposition of fuel taxes that might apply to certain conditions, but marginal decisions on travel are under the influence of a series of factors including road user charges and fuel taxes. According to Faiz et.al. (1990), discouraging people from owning a vehicle as well as using that should be central in setting vehicle use related charges. Therefore, a combination of taxes on vehicle ownership and fuel might fit the current situation rather than employment of a single strategy.

Some studies claim that fiscal policies such as congestion tax are very beneficial instruments to reduce the transport externalities especially when they are combined with emissions tax. Goulder (1995) and Timilsina and Shrestha (2007) argued that the energy tax as an alternative for emission tax would be very costly instrument because the energy tax does not directly address the emission reductions and hence could impose big deadweight losses to the economy.

Transport sector externalities need to be reduced, but it can be a challenge within cities. This is because cities have their own specific situations. Kingham et al. (1999) advised against the application of fuel taxes alone to reduce transport emissions. Their findings indicated that fuel taxes can be very beneficial tools as they can lower congestion and at the same time help reduce emissions. They argued that tax strategies should be accompanied by other strong motivations. Particularly, a fuel tax does not encourage car owners to switch to public transportation from private transportation if people are not satisfied with public transport services.

However, other studies (Acutt and Dodgson, 1997; Sterner, 2007; and Michaelis and Davidson, 1996) claim that fuel taxes could minimize the carbon dioxide. Newbery (2001) argued that fiscal taxes on road transport fuels could be very useful tools to reduce environmental damages and at the same time to make revenues for the government. Hence he called them “a second-best mechanism”.

Musgrave (1989), on the other hand, pointed out that fuel tax imposes lower enforcement costs and prevents frauds. Nevertheless, the entire policy framework for emission reductions might not work out even though the implementing of fuel taxes are simple and they can effectively reduce the emissions.

Table 17 displays a brief summary of literature review.

Table 17: Brief summary of literature review

Study	Result
Decicco (1995) Harrington (1997)	Significant relationship between the efficiency of fuel consumption and reduction of emissions
Michaelis and Davidson (1996) Acutt and Dodgson (1997) Sterner (2007)	Fuel taxes could minimize the carbon dioxide
Austin and Dinan (2005) West and Williams (2005) Fischer (2008)	Fuel taxes efficiently minimize fuel consumption than mandating fuel-efficiency increases
Crandall (1992) Goulder (1995) Timilsina and Shrestha (2007)	Energy tax is always more costly than the emission tax
Dowlatabadi et al. (1996) Greening et al. (2000) Bamberger (2002) Portney et al. (2003, 2004) Goldberg (2003)	Enhanced fuel economy might bring in congestion, crash cost and an overall increase of pollution (rebound effect)
Musgrave (1989) Faiz et.al. (1990) Kingham et al. (1999) Molina (2004)	Fiscal policy is effective but not enough

3.4. Methodology

3.4.1 Model Description

In the light of previous literature (Faiz et al., 1990; Musgrave, 1989; Michaelis and Davidson, 1996; Acutt and Dodgson, 1997; and Sterner, 2007) on effectiveness of fiscal policies on fuel consumption and level of emissions, in this section, I set up a time-series econometric model[8] based on a Cobb-Douglas function to examine the long-run relationship and causality issues between the level of CO_2 emissions from Light Petrol Vehicles (LPV) and some determinant variables. The proposed relationship between the light fleet emissions and its determinant variables is defined as follows;

$$E = f(TAX, GKM, TWI)\ , \qquad (1)$$

where, E is total CO_2 Emissions from petrol combustion in light vehicles, TAX is the average tax rate on petrol per litre (including duties, taxes, levies and ETS), GKM is the average emissions rate of newly registered vehicles (in CO_2 Grams/Km) as a proxy to technology improvements, and TWI is Trade-Weighted exchange rate Index.

According to the literature, it is well argued that fuel tax (TAX) has direct negative effect on fuel consumption. Therefore, a proper fuel tax helps to reduce the level of fuel

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8 In the primary model, I considered a lot more variables than the model currently includes. However, some of them failed to meet prerequisite econometric tests and some others showed unrealistic results when they were used in combination of other variables in one equation. The primary model with full list of tested variables was:

$$\boldsymbol{E} = f(NLP, TRAVEL, \boldsymbol{TAX}, POP, \boldsymbol{GKM}, PPRICE, \boldsymbol{TWI}, HYBRID, LKM, R170, UNEMP, TRPP)$$

where

E = Total CO_2 Emissions from light petrol vehicles
NLP = New+Used Petrol vehicles Registration
TRAVEL = Light Petrol Travel (km)
TAX = Average tax rate per litre petrol
POP = Population
GKM = Average emissions rate of newly registered vehicles (g/km)
PPRICE = Regular Petrol Price
TWI = Trade-Weighted exchange rate Index
HYBRID = Number of Hybrid+EV newly registered
LKM = Average fuel consumption L/km (New+Used petrol vehicles)
R170 = Number of newly registered petrol vehicles with emissions rate <=170 g/km
UNEMP = Unemployment Rate
TRPP = Kilometres Travelled Per Person

consumption, which in turn decreases the overall transport emissions (E) in the country. Thus, negative relationship between emissions and petrol tax is hypothesized.

Moreover, it is expected that positive correlation exists between fleet emissions and technology improvements. The development of greener and more efficient vehicles is a growing preference for car manufacturers, and hence facilitate cutting greenhouse gas emissions. The GKM in the model is used as a proxy to the technology developments and it represents grams of carbon dioxide emitted per kilometre travelled by newly registered vehicles.

The exchange rate is a very important component and plays a central role in the model since automobile industry in New Zealand is import-oriented except for some small-scale local producers. So the country heavily relies on importing new and used vehicles to substitute old fleet. It can be argued that if New Zealand dollar gains (i.e. NZD/AUD increases), then this will raise the purchasing power of NZD, and hence encourages imports. Thus, a positive relationship between the level of transport emissions and Trade-Weighted exchange rate Index (TWI) is expected.

In order to explain the dynamic behaviour of TWI variable in the short-run, I also included a dummy variable for dramatic drops in exchange rate to capture structural breaks over time. The TWI experienced significant drops in the first half of year 2006, second half of 2008 and first half of 2009.

The long-run extended model is as follows;

$$lnE_t = \alpha_1 + \alpha_2 lnTAX_t + \alpha_3 lnGKM_t + \alpha_4 lnTWI_t + \varepsilon_t \qquad (2)$$

with sign expectation;

$\alpha_2 < 0$, $\alpha_3 > 0$ and $\alpha_4 > 0$

where,

E_t= Total CO_2 Emissions from light petrol vehicles in time ‘t’

TAX_t= Average tax rate per litre petrol in time ‘t’

GKM_t= Average emissions rate of newly registered vehicles in time ‘t’

TWI_t= Trade-Weighted exchange rate Index in time ‘t’

ε_t= The error term in time ‘t’

3.4.2 Data Sources

To carry out this study, seasonal time series data for the period of 2005-2014 is collected from different data sources. The data for light fleet emissions and tax rates per litre petrol is obtained from Ministry of Business, Innovation and Employment (MBIE) energy data series. The average emissions rate data is collected from NZ vehicle fleet data provided by Ministry of Transport. Trade-Weighted exchange rate Index is obtained from Reserve Bank of New Zealand. Seasonal adjustments are applied to the data in order to remove the seasonal components from the time series.

3.4.3 Econometrical Methodology

I employed the VAR[9] methodology to examine the causal linkage between light vehicle emissions and some key determinants in the short-run, in the long-run, and overall. The VAR models are very capable to analyse multivariate time series. They are originally univariate autoregressive models that are extended to do effective multivariate estimations and are very popular tools to investigate dynamic economic behaviours. The advantage of this method lied in offering a robust analysis with VAR and vector error correction models (VECM) in both short-run and long-run. These modelling approaches (VAR and VECM) have been widely used in previous empirical studies.

In this section the methodology framework is outlined. Dickey and Fuller (1979) unit root tests are described first. Secondly, cointegration tests by Johansen and Juselius (1990) are adopted to find the long-term relationship between the variables. Finally, Granger causality tests[10] are explained.

9 Vector Auto Regression
10 Engle and Granger (1987)

3.4.4 Unit Root Tests

To evaluate whether or not the variables under consideration are stationary at levels, 1st difference or mixed, I conduct the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The ADF test is done to find out if the model variables are stationary. The stationary means the variables are integrated of the same order.

Equation (3) shows the ADF model which includes both an intercept (α_0) and linear time trend (t).

$$\Delta Y_t = \alpha_0 + \alpha_1 t + \gamma Y_{t-1} + \sum_{i-1}^{p} \beta_i \, \Delta Y_t + \varepsilon_t \qquad (3)$$

where; Y is the variable that we are testing its stationarity, and γ is fixed coefficient. t shows the time while Δ the first difference operator.

If γ is negative and statistically significant (H1: γ<0), the null hypothesis of a non-stationary series (H0: γ=0) is rejected. If the null hypothesis is not rejected we conclude that the series is not I(0) and non-stationary. Therefore, it is desirable to reject null hypothesis.

The ADF test was extended and emerged in Phillips-Perron (PP) test. The Phillips-Perron (PP) test gives more robust results for the aggregate data (Choi, 1992). However, the PP and ADF usually share the same outcomes.

ADF and PP approaches will be tested for model variables and the results will be demonstrated in the 'empirical results' section.

3.4.5 Cointegration Test: Johansen's Procedure

Engle-Granger (1987) extended the cointegration concept (long-run relationship between variables) which was initially introduced by Granger in 1969. The method by Engle-Granger suffered from a number of weaknesses and Johansen (1988, 1991, 1994, and 2006) addressed theses weaknesses by introducing generalized multivariate models for examining cointegraion in the econometric models.

In this study, I perform Johansen's procedure is as follows:

$$\Delta y_t = \sum_{i=1}^{p-1} \Pi_i \Delta y_{t-1} + \Pi \Delta y_{t-p} + \varepsilon_t, \qquad (4)$$

where $y_t = (kx1)$ vector of variables $(\beta_1 y_{t-1},\ \beta_2 y_{t-2},\ \dots,\ \beta_p y_{t-p})$, $\Pi(\alpha\acute{\beta})$ is the number of independent cointegrating vectors, and $\Pi\Delta y_{t-p}$ is the error correction factor.

The rank of Π plays a crucial role in Johansen's procedure. If rank (Π) = 1, it means that one single cointegrating vector exist. If rank (Π) = 0, then there is no cointegration. There are two tests that help identify the rank:

Trace test

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{k} \ln(1 - \lambda_i) \text{ , and} \qquad (5)$$

Maximum eigenvalue test

$$\lambda_{max}(r,\ r+1) = -T \ln(1 - \lambda_{r+1}) \qquad (6)$$

where r equal the number of cointegrating vectors in both tests. The null hypothesis is r = 0 while the alternative is r > 0 or r ⩽1.

3.4.6 The Granger Causality in the Vector Error Correction Model

Granger (1969) and Sims (1972) showed that the causality between economic variables can be valid if the variables are cointegrated. This means that causality exists if two variables move together during the time and it can be either unidirectional or bi-directional. The Granger causality however does not show the causality's direction (Masih and Masih, 1998). The VECM framework can help to detect the direction of causality and whether it is valid in short-run or long-run.

Engle and Granger (1987) stated that error correction Model (ECM) is only applicable when the variables are I(1). In this case, the error term in the ECM represents series' speed when they move toward long-run equilibrium.

Granger (1986, 1988) proposed a simple way to test bivariate relationship between variables in the long-run as below:

$$Y_t = \alpha_{10} + \sum_{j=1}^{k} \alpha_{1j} Y_{t-j} + \sum_{j=1}^{k} \beta_{1j} X_{t-j} + u_t \quad (7)$$

$$X_t = \alpha_{20} + \sum_{j=1}^{k} \alpha_{2j} Y_{t-j} + \sum_{j=1}^{k} \beta_{2j} X_{t-j} + \upsilon_t \quad (8)$$

while X_t is the independent variable in equation 7, it is dependent variable in the other one (equation 8). Y_t is dependent variable and explanatory variable in (7) and (8) respectively.

The direction of Granger causality can be tested with these null hypotheses:

If $\sum_{j=1}^{n} \beta_j$ and $\sum_{j=1}^{n} \alpha_j = 0$, then X and Y has no relationship.

If $\sum_{j=1}^{n} \beta_j$ and $\sum_{j=1}^{n} \alpha_j \neq 0$, shows two-way Granger causality.

If $\sum_{j=1}^{n} \beta_j = 0$ and $\sum_{j=1}^{n} \alpha_j \neq 0$, causality from X to Y exists.

If $\sum_{j=1}^{n} \beta_j \neq 0$ and $\sum_{j=1}^{n} \alpha_j = 0$, causality from Y to X exists

3.5. Empirical Results

The empirical findings is discussed in this section and it consists of ADF and PP unit root tests, the result of Johansen Juselius cointegration method, ECM in a Vector Error Correction Model (VECM), and the Granger causality tests.

The study utilise Johansen and Juselius's (1990) cointegration approach to examine the long-run relationships. This method usually includes three steps: first, unit root test are carried out to find out whether the model variables are integrated of the same order; second, avoiding the auto-correlation issue in the VAR model by setting the optimal lag length; and finally, detecting the order of cointegration by estimating the VAR model. The last step is important because it provides the trace and Max-Eigen test results which help validate the cointegration vectors (Enders 2004, 2010). In the following sections I present the outcomes for every step. Figure 25 illustrates the historical trends of model variables.

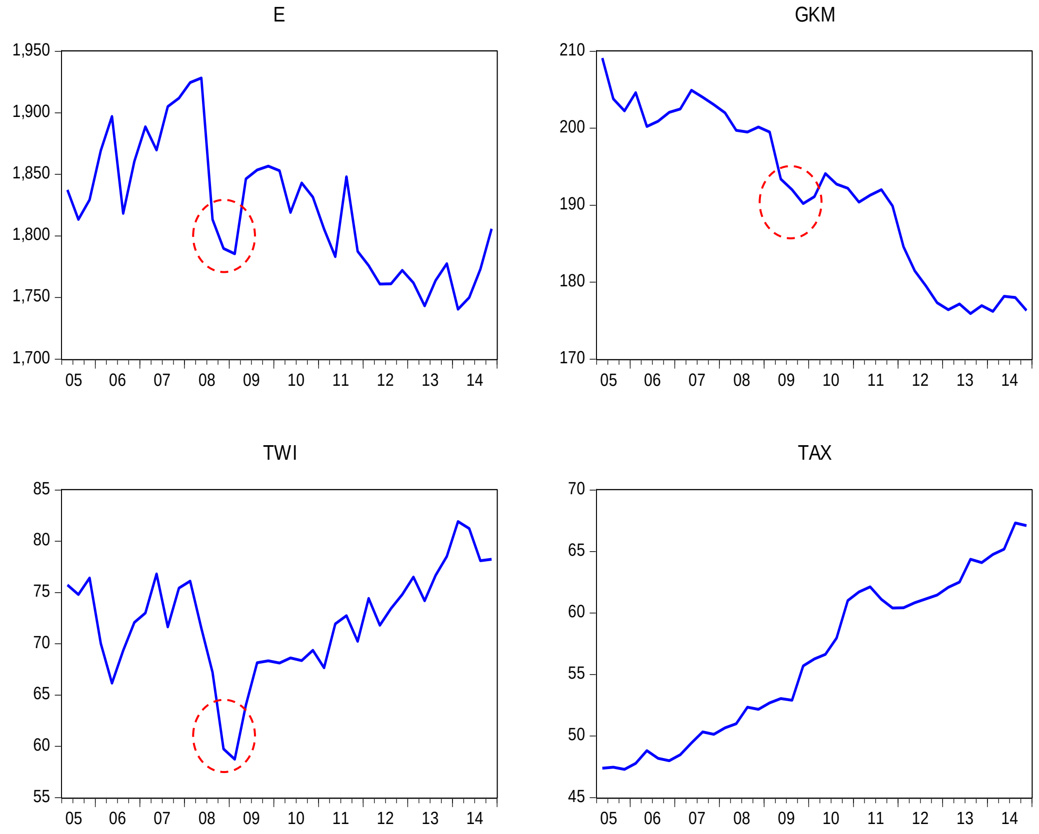

Figure 25: Time trend of model variables, 2005-2014

Source: Study results

3.5.1 Unit Root Test Results

In the very first stage, the existence of any unit root test among the model variables are investigated. The unit root test determines whether the variables have stationarity at the level or at the first difference. In other words, a unit root test finds out the integration order of all variables. In order to carry out the unit root test, I employed Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Tables 2 and 3 report the results for the ADF and PP tests.

Table 18 shows that t-stat results of ADF test at level and at first difference. According to the results, the null hypothesis is rejected so that all series contain a unit root at their level form. This means that they are all non-stationary and share a common stochastic component. As it is expected, the macroeconomic variables are usually are integrated of order one, I(1).

Table 18: The t-Stat Results of Augmented Dickey Fuller Tests

Data Series	At level		At first difference		Decision
	Intercept	Intercept & trend	Intercept	Intercept & trend	
lnE	-2.114	-3.290	-6.664*	-6.575*	I(1)
lnTAX	-0.060	-2.280	-5.767*	-5.680*	I(1)
lnGKM	-0.697	-2.645	-5.483*	-5.400*	I(1)
lnTWI	-1.841	-2.291	-5.386*	-5.394*	I(1)

Note: '*' indicates significant at 99% level.

The PP unit root test is slightly different in its method for testing heteroscedasticity and auto-correlation of error terms (Phillips and Perron, 1988). Table 19 displays the PP test results. The results confirm the ADF test results for rejecting null hypothesis of I(0). Thus I conclude that all series (variables) integrated of order one.

Table 19: The t-Stat Results of Phillips-Perron Tests

Data Series	At level		At first difference		Decision
	Intercept	Intercept & trend	Intercept	Intercept & trend	
lnE	-2.053	-3.037	-7.357*	-7.438*	I(1)
lnTAX	-0.035	-2.280	-5.756*	-5.662*	I(1)
lnGKM	-0.734	-2.250	-5.485*	-5.394*	I(1)
lnTWI	-1.992	-2.350	-5.426*	-6.016*	I(1)

Note: '*' indicates significant at 99% level

3.5.2 Selection of Optimal Lag Lengths

In the second step of Johansen Juselius cointegration method, it is necessary to find out the optimum lag for the VAR model. Lütkepohl (2005) explained that the lack of using an optimal lag can generate auto-correlation problems. In order to find the optimum lag length Enders (2010) and Lütkepoh (2005) recommend to use five different criteria: Hannan-Quinn Information Criterion (HQ), Schwarz Information Criterion (SC), Akaike information Criterion (AIC), Final Prediction Error (FPE), and sequential modified likelihood ratio (LR).

Table 20 presents the results for each criterion. According to the literature (Liew, 2004; Ivanov and Kilian, 2005), AIC and FPE are superior to the other criteria in the case of small sample (sample size 60 and below). Based on the lag length results, four out of five criteria suggest 4 lags. Therefore, the analysis here is proceeded by the use of 4 lags.

Table 20: The Results of Optimum Lag Length for Multivariate Estimation

Lag	LogL	LR	FPE	AIC	SC	HQ
0	245.6	NA	7.92e-12	-14.2	-14.0	-14.2
1	371.2	214.2	1.27e-14	-20.7	-19.8*	-20.4
2	386.6	22.7	1.37e-14	-20.6	-19.0	-20.1
3	405.3	23.2	1.30e-14	-20.8	-18.5	-20.0
4	434.7	29.3*	7.49e-15*	-21.6*	-18.5	-20.5*

Note: '*' indicates lag order selected by the criterion

3.5.3 Results of the Johansen-Juselius Cointegration Tests

According to the results in the first step, the series have unit root of I(1). Therefore, in this section I perform the Johansen-Juselius cointegration test to specify the number of cointegration vectors. Trace and maximum eigenvalue tests are used to find the number of vectors. Johansen and Juselius (1990) recommended to consider the first eigenvector if there are there more than one cointegration vectors available in the VAR system (Mukherjee and Atsuyuki 1995).

Table 21 summarises cointegration tests for the proposed VAR system. The max-eigenvalue and the trace tests are performed to assess the hypothesis for availability of cointegrating vector (r) in the model. The results of these two tests suggest that there only a single cointegrating vector exist in the model.

Therefore, based on the outcomes I summarise that the VAR model only includes a unique cointegrating vector. This means that the LPV emissions and its determinants are moving together and follow each other. In other words, the variables in the model exhibit a long-run relationship with each other.

Table 21: The Results of Johansen Cointegration Tests

Hypothesis		Unrestricted Cointegration Rank Test			
H0	**H1**	λ Trace	5% critical value	λ Max	5% critical value
r=0	**r>0**	51.740*	47.856	30.091*	27.584
r≤1	**r>1**	21.648	29.797	13.622	21.132
r≤2	**r>2**	8.027	15.495	7.763	14.265
r≤3	**r>3**	0.264	3.842	0.264	3.842

Note: ‘r’ denotes the number of cointegrating vectors. ‘*’ indicates significant at 95% level

3.5.4 Estimates of the Cointegrating Vector

Johansen procedure is needed to be applied in order to obtain the long-term coefficients of the model. The presence of cointegration between variables indicates a long-term relationship among the variables. Table 22 presents the vector error correction model parameters and the long run relationship between lnE, lnTAX, lnGKM and lnTWI while the appropriate time lags are applied for 2005Q3-2014Q4 period.

Table 22: Johansen Maximum-likelihood Estimates (Normalized) of the Cointegrating Vector with a Dummy Variable

Dependent Variable	Independent Variables			
lnE_t	$lnTAX_{t-1}$	$lnGKM_t$	$lnTWI_{t-1}$	Constant
	-0.365*	1.300*	0.142*	1.389
	(0.069)	(0.179)	(0.029)	

Source: The results are calculated by authors using EViews 9.0 software.

Note: The asymptotic standard errors are shown in parenthesis and * denotes 1% significance level.

The estimates of the cointegrating coefficients (normalized on the coefficient of lnE) in Table 22 can be re-written as:

$$lnE_t = 1.389 - 0.365 * lnTAX_{t-1} + 1.300 * lnGKM_t + 0.142 * lnTWI_{t-1} \qquad (9)$$

As per Table 6, all long-run coefficients are statistically significant at 1% level which indicate, in general, that all variables included in the system are significantly contributing to the long-run relationships in the model. These results are in alignment with previous studies and my expectations. The normalised cointegrating vector given in equation 9 above suggest the following results.

A significant negative long-run relationship between lnE and lnTAX is found in this VAR model. In other words, the model suggests that, in the long-run, a reduction in the LPV's emission level, with one quarter delay, is associated with the increase in the fuel tax rate. This result is in line with Michaelis and Davidson (1996), Acutt and Dodgson (1997) and Newbery (2001) studies which assert that fuel taxes are very effective tool when it comes to reducing CO_2 emissions. However, the coefficient in the model suggests that one percent increase in fuel tax will lead to decrease of emissions by only 0.365 percent. This shows a quite inelastic long-run relationship between fuel taxes and LPV emissions in New Zealand.

The lnGKM have a significant positive influence on emission levels, which is also in favour of my hypothesis. A percentage decrease in average LPV's emission rate per kilometre travelled will reduce total emissions by 1.299 percent. This implies that improving the emissions standards in New Zealand vehicle fleet could significantly cut the emission outputs. Therefore, the technological improvements could play a very substantial role in reducing the private vehicles' emissions. Moreover, the long-run elasticity between emissions standards and LPV emissions is relatively high and around 3.5 times more than fuel tax elasticity. As a result, an improved emissions standard is more effective emission abatement policy than direct fuel tax in New Zealand.

A significant positive long-run relationship between lnE and lnTWI is found in the VAR model. This means that the emissions from light petrol vehicles are positively correlated with New Zealand's trade-weighted exchange rate. The positive relationship is consistent with my hypothesis which states that relative gains in New Zealand dollar leads to importing more new or used vehicles and consequently an increase in total CO_2 emissions. As a result, New Zealanders tend to buy more good-quality second-hand cars considering their budget constraints. Although newer cars have better fuel-economy standards and less pollution in comparison to older fleet, the lower rate of car scrapping along with considerable share of second-hand imports remove those CO_2 cuts from importing newer technologies. Figure 26 shows how petrol vehicle registrations (new and used) follow the trade-weighted exchange rate with one quarter lag in New Zealand from mid-2006 till end of 2014.

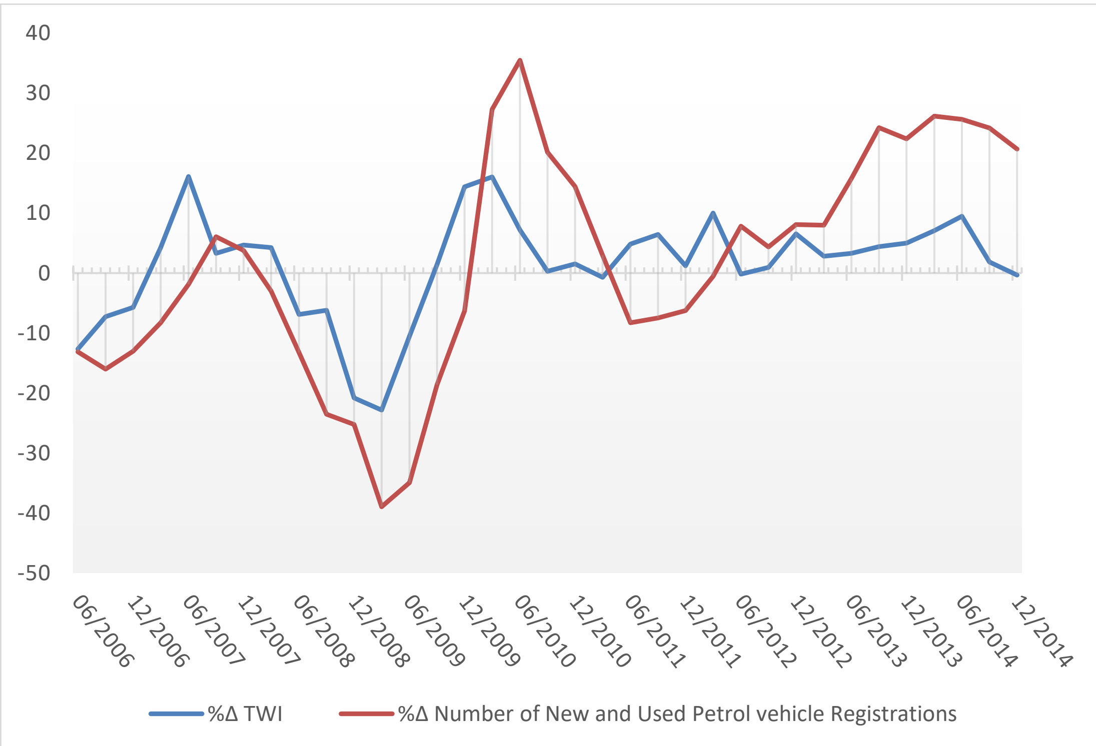

Figure 26: Percentage Change in New Zealand's TWI and number of vehicle registrations

3.5.5 Vector Error Correction Models for Dynamic Adjustments

Given that the finding that lnE, lnTAX, lnGKM and lnTWI are cointegrated in the long-run, I utilize the cointegration vector to construct the error correction model (ECM). The aim is to find out the estimated long-term equilibrium influence the short-term dynamics. Table 23 shows the Vector Error Correction Estimates of LPV emissions as an endogenous variable.

Table 23: Vector Error Correction Estimates (D(lnE) as dependant variable)

Error Correction:	Coefficient	standard error	t-statistic
ECT(-1)	-0.959	0.275	-3.485**
D(lnE(-1))	0.518	0.228	2.276*
D(lnE(-2))	0.181	0.234	0.772
D(lnE(-3))	0.285	0.194	1.472
D(lnE(-4))	0.218	0.178	0.272
D(lnTAX(-2))	0.048	0.178	3.294**
D(lnTAX(-3))	0.586	0.178	-1.845
D(lnTAX(-4))	-0.329	0.171	-0.416
D(lnTAX(-5))	-0.071	0.078	-3.030**
D(lnTWI(-2))	-0.235	0.057	-2.161*
D(lnTWI(-3))	-0.123	0.052	-2.506*
D(lnTWI(-4))	-0.131	0.044	-2.733*
D(lnTWI(-5))	-0.119	0.313	-0.978
D(lnGKM(-1))	-0.306	0.268	-1.497
D(lnGKM(-2))	-0.401	0.363	-0.591
D(lnGKM(-3))	-0.215	0.288	-1.687
D(lnGKM(-4))	-0.486	0.005	0.246
Constant	0.001	0.178	0.272
Dummy TWI	-0.051	0.010	-5.366**
R-squared: 0.897			
Adj. R-squared: 0.764			
F-statistic: 6.766			

Note: The superscripts (*) and (**) indicate statistically significant at the 95% and the 99% levels respectively.

The coefficient of the lagged error correction term (ECT(-1)) is most important parameter in the ECM. It represent the speed of model's adjustment toward an equilibrium point in the long-run. The value of ECT coefficient is negative in sign and statistically valid at the 99% level. Therefore, causality running from lnTAX, lnGKM and lnTWI to lnE exist. According to the findings in Table 23, the error correction term is found to have high speed of convergence to equilibrium, ranging at 96%. It shows that LPV emissions converges to its equilibrium state in the long-run with a pace of 0.96 after own and other variables shocks in the system. Therefore, if there is a disturbance occurred in the whole system, the change of LPV emissions (lnE) will have a considerable force to keep the model in its equilibrium whenever it moves too far.

In addition, the coefficient of dummy variable for dramatic drops in exchange rate is significant at the 99% levels. As a result, the exchange rate volatilities has a considerable impact on purchasing power of New Zealanders in international car market and hence the total LPV emissions level will be affected.

3.5.6 Granger Causality Test

Detecting the direction of short-run causations between dependant and independent series is the final step in the VAR model. The null hypotheses of Granger non-causality tests are tested by Wald χ^2 and F-statistics obtained from Wald Coefficients restriction. To understand the validity of short-run causations from lnTAX, lnGKM and lnTWI to lnE, I refer to the results provided in Table 24 to discuss.

Table 24: The Results of Granger Causality in VECM Framework

Null Hypothesis	Chi-Square	Lag	Probability	Conclusion
D(lnTAX(-1)) does not Granger cause D(lnE)	12.675*	4	0.013	YES
D(lnWTI(-1)) does not Granger cause D(lnE)	24.272**	4	0.0001	YES
D(lnGKM) does not Granger cause D(lnE)	4.254	4	0.373	NO

Note: The superscripts (*) and (**) indicate statistically significant at the 95% and the 99% levels respectively.

The Chi-square of independent variables from Wald coefficient restrictions test are given in Table 24. The null hypothesis is set to show that there is no short-run causality running from fuel tax to emissions level. Thus, fuel tax has a significant short-run impact on LPV emissions. Likewise, there is an indication of strong short-run causality running from trade-weighted exchange rate towards emissions and it is statistically significant at the 99% level.

However, the findings suggest that the granger causality from emission standards of vehicles entering New Zealand to CO_2 emissions does not exist at the 95% significant level. Therefore, the technology cannot have a meaningful effect on LPV emissions in the short-term, but nevertheless it is a substantial component in the long-run equilibrium model. This implies that imposing direct tax on fuel is more effective short-term policy to reduce the CO_2 emissions than improving vehicle technologies.

3.6. Conclusion

3.6.1 Main findings and policy implications

This essay is an attempt to investigate the linkage between the level of CO_2 emissions from Light Petrol Vehicles (LPV) and some key determinants using econometric models and seasonal data from 2005 to 2014 in New Zealand. The analysis incorporates the effects of fuel tax, Trade-Weighted exchange rate Index (TWI) and the average emission rate of newly registered vehicles as a proxy for technology.

Two popular time series econometric approaches are adopted: Vector Error Correction Model (VECM) and cointegration test (Johansen cointegration test in a VAR system). The variables were statistically analysed and passed the preconditions for a VECM approach including unit root tests, optimal lag tests, Johansen-Juselius cointegration tests, the VECM and the Granger causality test. In the light of cointegration test, I concluded that the co-integration between variables exists and therefore there is a long-run relationship between the series; despite there may be disequilibrium in the short-run.

According to the study results, in the long-run model, a significant negative relationship between LPV's emission level and fuel tax rate is found which is in line with those of Michaelis and Davidson (1996), Acutt and Dodgson (1997) and Newbery (2001), emphasising on effectiveness of fuel taxes in reducing CO_2 emissions. The coefficient of fuel tax suggests that one percent increase in fuel tax will lead to decrease of emissions by 0.365 percent which represents a quite inelastic long-run relationship. However, the average emission rate variable shows a significant positive and elastic (1.299) influence on total emission levels. This implies that improving the vehicle emission standards in New Zealand vehicle fleet could significantly cut the emission outputs in the long-term. Likewise, New Zealand's trade-weighted exchange rate has a positive long-run impact on LPV emissions. This positive efficacy is consistent with my hypothesis which states that relative gains in New Zealand dollar leads to importing more new or used vehicles and consequently an increase in total CO_2 emissions.

The estimates of Error Correction Model and the Wald Granger causality demonstrate the existence of short-run causalities running from fuel tax and trade-weighted exchange rate towards emission levels. However, vehicle emission standards have no meaningful short-term effect on LPV emissions. Hence I conclude that using a direct tax on fuel is more effective short-term policy to reduce the CO_2 emissions than improving vehicle technologies. The short-run analysis also revealed that exchange rate volatilities has an important impact on change in buying preferences of New Zealanders towards less fuel economy cars.

To conclude, variables of the model have significant contribution to the long-run and short-run relationships. In particular, the model results suggest that improving emissions standards in the long-term is more effective emission abatement policy than direct fuel tax in New Zealand. However, in the short-term, fuel tax is a better choice as it encourages consumers who drive and pollute a lot to choose a greener transportation.

There is no doubt that transport sector externalities need to be reduced, but it can be a challenge within cities. This is because cities have their own specific situations. Although fuel taxes can be very beneficial tools as they can lower congestion and at the same time help reduce emissions, these strategies however should be accompanied by other strong motivations. Particularly, a fuel tax does not encourage car owners in New Zealand to switch to public transportation if people are not satisfied with public transport services.

Therefore, beside the investments in efficient and affordable public transportation which is crucial, a set of complementary regulatory policies including charging more levies and license fees on old and polluting vehicles, setting stricter emissions standards for vehicles entering the fleet, charging for road use, subsidising hybrid and electric vehicles and setting comprehensive standards for scrapping older cars would promote energy conservation, minimise emissions and raise revenues.

3.6.2 Limitations and recommendations for further research

Although the model results indicate that fuel tax, fleet technology improvement, and exchange rate heavily affect the level of emissions from light vehicles in New Zealand, there are some shortcomings around the model. The first issue is associated with the limited data availability. The quarterly data on new cars emissions rate are only available from March 2005. This is due to the fact that before 2005, vehicles entered the fleet had limited information. Furthermore, the study utilise a VECM framework. Although the adopted methodology fits very well and cope with the common time-series drawbacks, using other econometric approaches may demonstrate different results.

Fuel tax is the only fiscal policy instrument that has been considered in this study. While technology improvements have shown greater impact on carbon emissions in the long-run, other policies could be also taken into account. Thus, further research around assessing the regulation changes on importing new and used light vehicles as well as investigating other decarbonising plans like government's scrappage scheme would shed more light on the aims of this study.

Chapter 4.

Essay Three: Dynamic Interaction between Economic Indicators, Technology and CO_2 Emissions in New Zealand

4.1. Introduction

Climate change and its impacts on our planet becomes one of the most serious challenges for humankind in the upcoming years. As growing world economy continues to contribute to the global warming, scholars raise their even more concerns about the role of emerging economies.

Countries have been always competing over using their ecological resources as much as they can in the recent couple of centuries. So, the environmental degradation is not a new issue. However, the industrialisation, and technology improvements have increased its pace dramatically. Ehrlich and Holdren (1971) argued that environmental degradation and depletion of resources are driven by several factors acting simultaneously. They pointed out that booming population, always increasing affluence, and polluting technology are the main drivers and have deteriorated the environment. Therefore, an international consensus on controlling these problematic elements can be helpful to reduce the size of environmental damage. Meanwhile, social scientists believe that the climate change is an intergenerational problem and needs to be assigned to individuals more seriously (Clayton et al. 2016). They claim that individual's motivation and their behaviour towards accepting mitigation policies are significantly important.

Countries and jurisdictions endeavour to enhance their economy. Almost all economic activities, directly or indirectly affect the ecological system, and thus the activities can damage the environment during various phases from extraction and production to transportation and consumption. Hence economic growth and its factors continue to be a subject of considerable controversy.

The negative impact of human activities on the ecological system speeds up as we expand our activities. While the higher economic growth is traditionally associated with the higher use of energy and raw materials; negative externalities, nonetheless, seems to be an inevitable result of the efforts for supplying our basic needs on the earth. In other words, the economic growth is not achieved without sacrificing the ecosystem. Although human beings probably cannot survive without using the natural resources, putting intensive pressure on the environment costs us a quite permanent damage to the ecosystem.

It is characterized that in the global economy, three main stages (extraction, production, and consumption) all generate end products that ultimately return the waste to the environment (air, water and soil). There are plenty of fossil fuels consumed every day which accordingly cause biological changes in the environment. The level of pollution defers from country to country, but the fact is that the overexploitation of natural resources endangers the global living standards and contributes to eradication of the wildlife.

Economic activities can be considered as a process of energy transformation. As materials and energy cannot be destroyed in any absolute sense, they emerge in the form of waste which will be eventually returned to the environment. Therefore, the more economic gains are achieved, the more waste will be produced. Indeed, improved standard of living which is highly associated with the economic growth, putting serious damage to the environment. Consequently, the higher degree of environmental degradation and the loss of environmental quality is a result of unrestrained and limitless economic growth.

There is no doubt that sustainable development is strongly associated with environmental sustainability. This is because there is a dual relationship between the environmental quality and overall services provided by the natural resources in one side, and the economic development planning and its performance on the other side. Therefore, economic policies play a significant role in preventing environmental pollutions. However, there is always a big challenge for policy makers trying to manage a sustainable and efficient use of natural resources and at the same time securing a national goal towards a sustainable economic growth.

The current study investigates the impact of the gross domestic product, energy consumption, financial development, trade openness and fossil fuel consumption ratio on New Zealand's carbon dioxide emissions. According to the current debates concerning global warming, air quality and other serious environmental issues, the analysis of the relationship between economic and environmental indicators helps New Zealand policy makers and planners to address socially and environmentally viable policy options.

The essay is structured as follows: After stablishing the theoretical framework in Section 2, Section 3 summarises a brief literature review of the impacts of multiple factors on environmental quality; Section 4 describes the proposed model and the econometric method; detailed results from the model estimation are presented in Section 5, with concluding comments presented in Section 6.

4.2. Theoretical framework

This section outlines the conceptual background of the Environmental Kuznets Curve along with theoretical discussions surrounding its shape and other involving factors.

Exploring the idea of the inverted U-shape relationship between economic development and income inequality by per capita income, Kuznets (1955) indicates that economic growth gives rise to increased inequality at low levels of economic development. However, he refers to chances of equality of income distribution in case of further economic development. In his paper, Kuznets examined the mechanisms which were identified to underlie the relationship between economic development and income inequality and used examples of empirical time series analysis from Germany, the US, and the UK to support his argument. Kuznets' studies inspired many researchers to conduct more analysis on the Kuznets curve, taking into account theoretical grounds and empirical evidence on the existence of the curve (Kijima et al., 2010).

However, the studies conducted in the 1990s pointed out instances of income inequality and per capita income in the original Kuznets Curve when the level of environmental degradation and per capita income followed an inverted U-shaped pattern. The pattern was latter called Environmental Kuznets Curve (EKC). Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), and Panayotou (1993) did one of first EKC analyses using an inverted-U curve in order to investigate the relationship between per capita income and pollution indicators (Dinda, 2004). The term "Environmental Kuznets Curve" was first introduced by Panayotou (1993) and since then the term has been widely used to represent the relationship between the level of per capita income and the level of environmental quality. The original Kuznets Curve and the shape of EKC are illustrated in Figure 27.

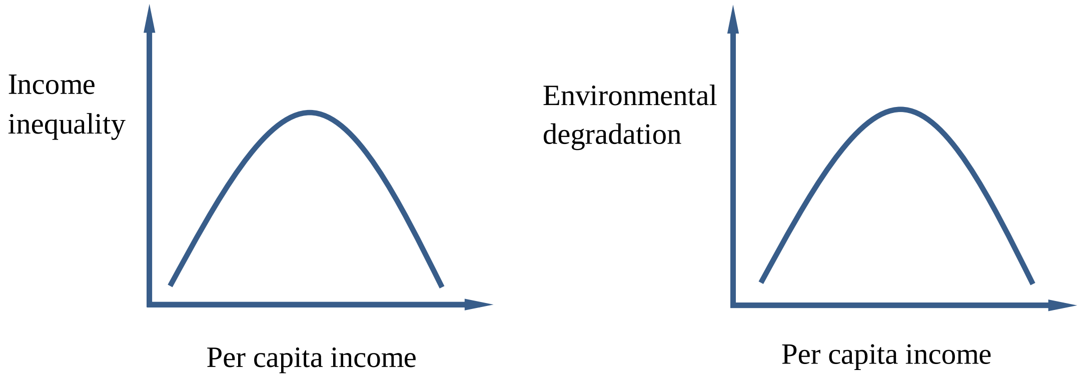

Figure 27: Original Kuznets Curve (left), Environmental Kuznets Curve (right)

Changes in people's living priorities and their demand for better environmental quality standards take place when people enjoy improved standard of living and high income. Therefore, if people's demands grew for a healthy and safe environment, the reduction in environmental degradation and structural changes in the economy would occur. Political pressure on government for environmental protection and regulations rises when people opt for environmentally friendly products and help environmental organizations to promote cleaner technologies. In theory we call this situation "abatement effect" or "pure income effect" (Panayotou, 1993). Illustrating the shape of EKS, Dasgupta and Bnoit (2002) believe that marginal propensity to consume should reduce or even be constant if per capita income grows.

Considering technology, composition and scale effects, Grossman and Krueger (1991) state that the environment is under the influence of economic growth. Scale effect refers to the situation when more resources are used and thus the output increases. In this situation harmful emissions from waste disposal are inevitable and thus economic growth exerts a damaging impact on the environmental quality. Nevertheless, the composition effect has the opposite effect on the state of environment. Accordingly, a rise in the average income leads to the structural changes in production and towards less potentially harmful activities for the environment. As agricultural-based economy moves towards industrialisation, the environmental quality worsen. However, the transition to a technology-based economy improves the environment significantly. Thus, the environmental quality improves when dirty technologies are substituted by cleaner ones and more budget are spent on R&D. Figure 28 is used to outline and represent these various effects.

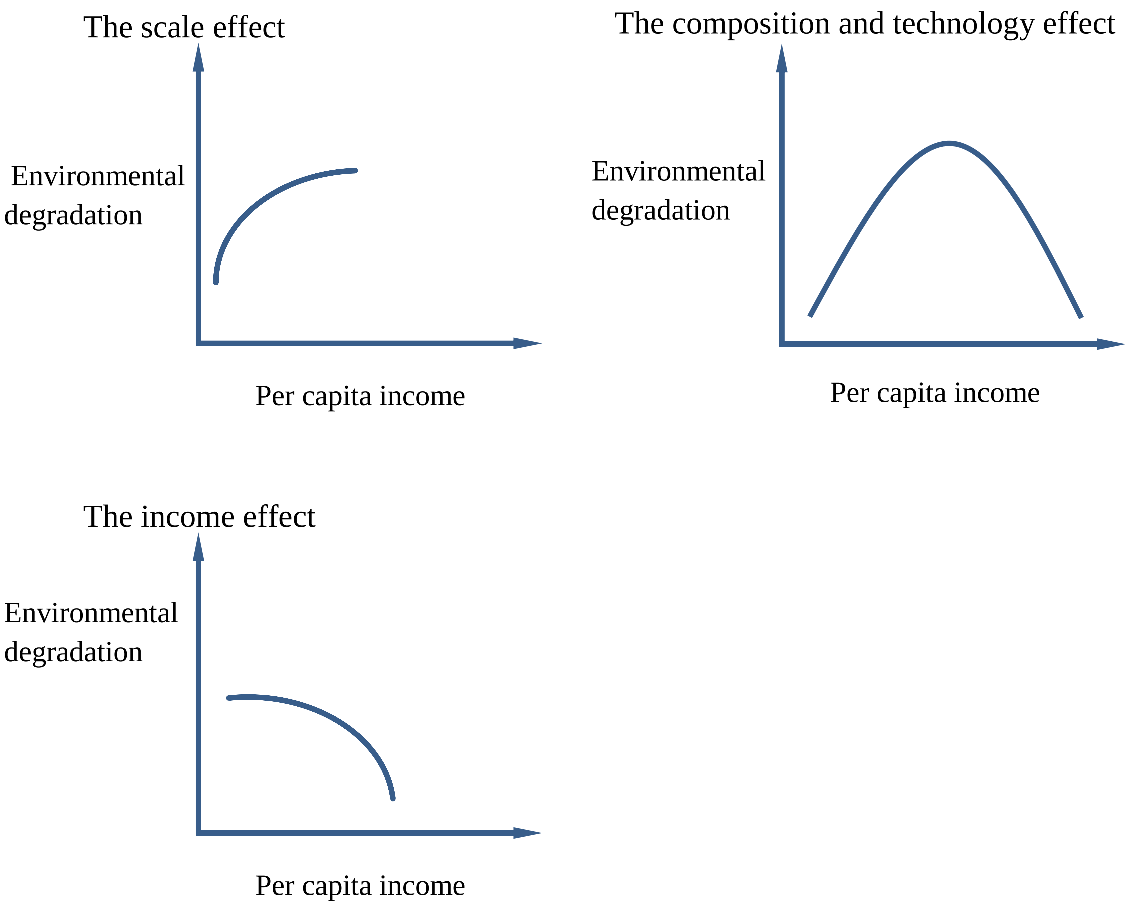

Figure 28: The scale, composition and technology, and income effects

Vukina et al. (1999) state that in the EKC, the dominant effect is the scale effect when an economy is in its earlier stages. However, the combination of the income effect and the positive composition and technology effects as well as the demand for pollution abatement will prove to be more powerful and it leads to improvements in environmental quality.

4.3. Review of the Literature

The section includes evidenced-based analysis addressing the environmental quality and economic growth nexus. Several studies are conducted to test the validity of inverted-U relationship between environmental degradation and economic growth (Figure 29). Grossman and Krueger (1991) were the first to study this relationship under the name of 'environmental Kuznets curve (EKC)'. However, the empirical findings of the existing literature vary across studies due to the diversity in economic structures across the countries and the use of different econometric models. Therefore, the literature utilises control variables such as energy consumption (Ang, 2007; Alam et al., 2007), foreign trade (Halicioglu, 2009), population growth and growth of electricity demand (Tol et al., 2009), financial development (Tamazian et al., 2009), foreign direct investment (Pao and Tsai, 2011), trade openness (Managi et al., 2009; Shahbaz et al., 2013a; Shahbaz et al., 2013b), urbanization (Dhakal, 2009; Sharma, 2011; Farhani and Ozturk, 2015) to eliminate any specification bias. Nonetheless, results differ for model components across studies.

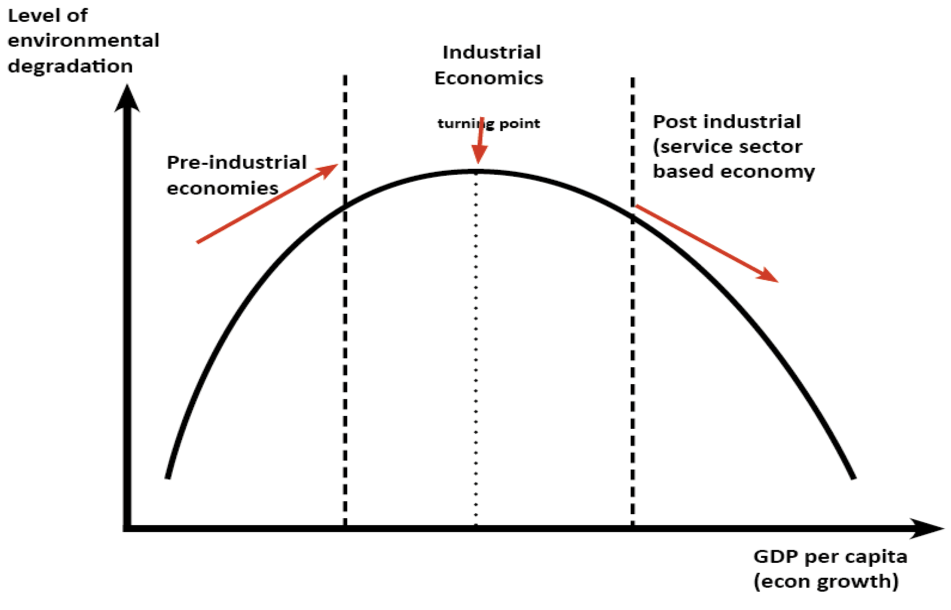

Figure 2929: Environmental Kuznets Curve (EKC)

Tamazian et al. (2009) adopted a reduced-form modelling approach with Panel data over 1992–2004 to investigate the impact of financial development on carbon emissions in BRIC countries (Brazil, Russia, India, and China). The results demonstrated that both financial development and economic growth decreases environmental degradation. Furthermore, they argue that adopting financial liberalization policies could play an important role in cutting CO_2 emissions by funding R&D projects in these economies.

Similarly, by estimating the efficiency of advanced financial system and institutional quality in cutting carbon emissions in 24 transition economies, Tamazian and Rao (2010) showed that how important is the institutional framework in decreasing the environmental degradation.

On the other hand, in other studies, including Frankel and Romer (1999), Dasgupta et al. (2001), Sadorsky (2010), Zhang (2011) and Al-Mulali et al. (2015), financial development decreases environmental quality. Zhang (2011), for instance, asserts that households have higher tendency to purchase energy-intensive items with the aid of financial intermediation.

Some studies shed doubt on whether financial development have been effective at reducing carbon dioxide emissions. Using an ARDL[11] bounds testing approach, Jalil and Feridun (2011) and Ozturk and Acaravci (2013) found no meaningful long-term causality from financial developments to CO_2 emissions and vice versa. However, they showed that economic growth and energy consumption have positive effect on emission levels and confirmed the EKC hypothesis in the case of China and Turkey.

In terms of foreign direct investment, Pao and Tsai (2011) adopted panel cointegration approach with Granger causality test to investigate the impact of FDI, GDP, and energy use on CO_2 emissions in BRIC countries. Their findings suggest that FDI has no considerable long-term effect on environmental quality. Nonetheless, energy consumption and GDP are the main contributors to pollution. Moreover, the EKC hypothesis is confirmed.

Using time series data for newly industrialized countries (NIC), Hossain (2011) have indicated that there are short-run causal relationships between urbanization and GDP and between GDP and CO_2 emissions. Similarly, Sharma (2011) using a panel of 69 countries analysed the key determinants of CO_2 emissions. The results demonstrate a negative relationship between urbanization and CO_2 emissions while GDP and energy consumption show positive impacts on pollution. Farhani and Ozturk (2015), however, claim a significant

[11] Auto regressive distributed lag model

and positive long-term link between urbanization and carbon emissions in Tunisia applying ARDL bounds testing approach.

To test the impact of trade openness on environmental degradation, Managi et al. (2009) used instrumental variables technique. With a mixed results for the OECD and non-OECD countries, they found that freer trade decreases emissions in OECD countries and adds emissions in non-OECD countries. Furthermore, they concluded that in the presence of effective environmental regulatory, the quality of the environment will be improved. Shahbaz et al. (2013a) for Malaysia, Shahbaz et al. (2013b) and Kohler (2013) for South Africa, likewise, confirmed that trade openness is beneficial for environmental quality. In this regard, according to Shahbaz et al. (2013b), improvements in environmental performance is achievable by pursuing trade liberalization policies.

In contrast, other studies claim that trade openness has contributed to environmental degradation. Loi (2012) explored the relationship between trade liberalization and environmental quality for six Asian countries over the period of 1980-2006. The study found that the trade has negative environmental effect. More recently, in the same way, Farhani and Ozturk, (2015) have investigated the validity of EKC and the long-term impact of some key economic indicators including trade openness on carbon dioxide emissions in Tunisia. The results obtained from their study reveal that the long-run coefficient of trade openness variable has a positive sign, meaning that freer trade increases emissions in Tunisia. However, the t-statistic for the same coefficient is negative in sign and does not match with their conclusion. Table 25 displays a brief summary of literature review.

Table 25: Brief summary of literature review

Study	Case	Result
Tamazian et al. (2009)	BRIC countries (Brazil, Russia, India, and China)	Financial development and economic growth decreases environmental degradation
Tamazian and Rao (2010)	24 transition economies	Advanced financial system cut carbon emissions
Frankel and Romer (1999), Dasgupta et al. (2001), Sadorsky (2010), Zhang (2011) and Al-Mulali et al. (2015)	Different countries	Financial development decreases environmental quality, higher tendency to purchase energy-intensive items with the aid of financial intermediation
Jalil and Feridun (2011) and Ozturk and Acaravci (2013)	China and Turkey	No meaningful long-term causality from financial developments to CO_2 emissions
Pao and Tsai (2011)	BRIC countries	FDI has no significant long-term impact on environmental quality
Sharma (2011)	Panel of 69 countries	Negative relationship between urbanization and CO_2 emissions
Farhani and Ozturk (2015)	Tunisia	Trade openness and urbanization has positive effect on CO_2 emissions
Managi et al. (2009)	OECD and non-OECD	Freer trade decreases emissions in OECD countries and adds emissions in non-OECD countries
Shahbaz et al. (2013b) and Kohler (2013)	Malaysia and South Africa	Trade openness is beneficial for environmental quality
Loi (2012)	Six Asian countries	Trade has negative environmental effect

4.4. Methodology

4.4.1 Model Specification

In the light of previous literature (e.g. Jalil and Feridun, 2011; Ozturk and Acaravci, 2013; Pao and Tsai, 2011; Sharma, 2011) on the impact of economic activities on fuel consumption and level of emissions, here, I make a time-series econometric model to examine the long-run linkage and causality issues between the level of CO_2 emissions in New Zealand and some determinant variables. The proposed relationship between the carbon dioxide emission and its determinant variables is defined as follows;

$$CO_2 = f(GDP, EU, FD, TR, FFC), \qquad (10)$$

where, CO_2 is total carbon dioxide emissions in metric tons per capita, GDP is real GDP per capita in constant 2005 US$, EU is energy use (kg of oil equivalent per capita), FD is an indicator for financial development which is calculated using domestic credit to private sector as share of GDP, TR is trade openness (measured using exports and imports as share of GDP), and FFC is fossil fuel energy consumption (as share of total energy consumption) as a proxy to technology improvements in New Zealand.

According to the literature, economic growth has a direct positive effect on energy use and emissions (Ang, 2007; Apergis and Payne, 2009; Acaravci and Ozturk, 2010). This is because countries are demanding more energy resources, especially fossil fuels to achieve their macroeconomic targets. Thus, a positive relationship between emissions and GDP is hypothesized. Moreover, it is expected that positive correlation exists between emissions and energy consumption. Whether the economies are developing, emerging or developed, the energy supply plays a very crucial role in maintaining or improving the production level.

The literature mostly uses energy consumption and economic growth as the main components in the emission model. However, in some studies, financial development is used as an important determinant of environmental performance (Shahbaz et al., 2013a,b; Tamazian et al., 2009; Tamazian and Rao, 2010). A well-designed financial sector could attract domestic and foreign investments, which would motivate the whole economy and could positively affect the environmental quality (Frankel and Romer, 1999). Thus, a negative causation from financial developments to CO_2 emissions is expected.

Trade openness is another very important component and plays a central role in the model since New Zealand is a trade-dependent economy. The country heavily relies on open trade agreements with its trade partners. Therefore, more trade liberalization policies could lead to attracting more direct investments in trade-exposed sectors, which in turn could lead to more efficient use of resources (King and Levine, 1993; Tadesse, 2005). So, by expanding bilateral trade I expect an impact similar to financial developments in the long-term.

Moreover, in order to capture the impact of technological changes on emission levels, I include the consumption of fossil fuels as a share of total energy consumption. Although New Zealand imports the majority of energy in the form of petroleum products, introducing and maintaining renewable energy technologies has helped the country to experience a consistent growing in renewable energies while the non-renewable energy ratio decreased. Thus, the study aims to examine the impact of historical changes in technology on emission levels with an assumption that there could be a potential positive relationship between FFC (fossil fuel consumption) and CO_2. Indeed, this study is the first attempt to incorporate the ratio of fossil fuel consumption as a separate determinant of CO_2 emissions in the analysis.

The long-run linkage among the series is specified in below (ln represents the natural logarithm):

$$lnCO_{2_t} = \alpha_1 + \alpha_2 lnGDP_t + \alpha_3 lnEU_t + \alpha_4 lnFD_t + \alpha_5 lnTR_t + \alpha_6 lnFFC_t + \varepsilon_t \quad (11)$$

with sign expectation;

$\alpha_2 > 0$, $\alpha_3 > 0$, $\alpha_6 > 0$

and

$\alpha_4 < 0$, $\alpha_5 < 0$

where,

CO_{2_t}= Total carbon dioxide emissions in metric tons per capita in time ‘t’

GDP_t= Real GDP per capita in constant 2005 US$ in time ‘t’

EU_t= Energy use (kg of oil equivalent per capita) in time ‘t’

FD_t= Financial development indicator, domestic credit to private sector (% of GDP) in time ‘t’

TR_t= Trade openness indicator, measured by dividing the sum of exports and imports (volume of trade) by GDP in time ‘t’

FFC_t= Fossil fuel energy consumption (as share of total energy consumption) in time ‘t’

ε_t= The error term in time ‘t’

4.4.2 Data Source

To carry out this study, annual time series data for the period of 1971-2013 are considered. The data on CO_2 emissions (CO_2, in metric tons per capita), real GDP per capita (GDP, in constant 2005 US$), energy use (EU, in kg of oil equivalent per capita), financial development indicator (FD, domestic credit to private sector as share of GDP), trade openness (TR, exports and imports as share of GDP), and fossil fuel energy consumption (FFC, fossil fuel energy consumption as share of total energy consumption) are taken from the World Development Indicators (WDI) online database.

4.4.3 Econometrical Methodology

The auto regressive distributed lag model (ARDL) methodology is employed for this study to investigate the causal linkage between CO_2 emissions and some key determinants in the short- and long-run. The ARDL technique is an alternate cointegration approach and possesses some beneficial features. Firstly, after finding the optimal lags order, the model can be easily estimated with OLS. Secondly, both short and long-run relationships among variables can be tested simultaneously. Third, unlike Johansen and Engle-Granger cointegration techniques, in the ARDL method the variables do not necessarily need to be I(0) or I(1). In other words, there is no need for unit root testing prior to the estimation. Nevertheless, this method cannot be done if there is any I(2) variable in the model. Fourth, coefficient estimates remain unbiased which removes the endogeneity problem. Furthermore, the ARDL model emendates the bias of lagged variables (Inder, 1993) and provides enough lags to handle Hendry's (1995) specific modelling approach (Ma and Jalil, 2008; Ang, 2010). And finally, the ARDL framework is a very good choice for estimating models with small number of samples.

4.4.4 The ARDL Approach's Procedures

Before proceeding to cointegration test, it is necessary to do unit root tests. Augmented Dickey Fuller (ADF) is used to find out any unit root among model variables. The ADF test helps to examine the stationarity of each series.

To apply an ARDL method, there are some steps that need to be done. The initial step is called bounds test. This test includes computing the conditional unrestricted error correction model (UECM) in order to know if there exist a robust long-run relationship between variables.

$$\Delta lnCO_{2_t} = \delta_0 + \sum_{i=1}^{p} \delta_1 \Delta lnCO_{2_{t-i}} + \sum_{j=0}^{q} \delta_2 \Delta lnGDP_{t-j} + \sum_{k=0}^{r} \delta_3 \Delta lnEU_{t-k} + \sum_{l=0}^{s} \delta_4 \Delta lnFD_{t-l} + \sum_{m=0}^{v} \delta_5 \Delta lnTR_{t-m} + \sum_{n=0}^{w} \delta_6 \Delta lnFFC_{t-n} + \beta_1 lnCO_{2_{t-1}} + \beta_2 lnGDP_{t-1} + \beta_3 lnEU_{t-1} + \beta_4 lnFD_{t-1} + \beta_5 lnTR_{t-1} + \beta_6 lnFFC_{t-1} + \varepsilon_t \quad (12)$$

In the ARDL estimation, p, q, r, s, v, w are the highest number for lags, Δ is the first difference operator; and δ_0 is a constant value. The $\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6$ parameters correspond to the short-run relations, whereas $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ liaise with the long-run relations; ε_t is the random error.

Long-run equilibrium is examined using the Wald or F-statistic test. The existence of a cointegration is determined by examining the null hypothesis (H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$, for no cointegration) while an alternative hypothesis (H_1: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq 0$) shows a long-run cointegraiton exists.

Pesaran et al. (2001) discussed the Wald test in more details and suggested some further instructions in testing the stationarity of variables and in order to increase the accuracy. He proposed upper and lower critical values. If the Wald stat shows a value more than upper critical value, then the variables are cointegrated. The value under lower critical value means that there is no cointegration among the series. If the value is between the upper and lower bands, then the more investigation on stationarity of the variables will be needed.

Once the bounds test is finished successfully, in the next stage, the short and long-run relationships between dependent variable and explanatory variables can be computed. To do that, first, the optimum lag for the ARDL model is calculated. Then, the ARDL (p, q, r, s, v, w) is estimated as in Equation (13).

$$lnCO_{2_t} = \gamma_0 + \sum_{i=1}^{p} \gamma_1 lnCO_{2_{t-i}} + \sum_{j=0}^{q} \gamma_2 lnGDP_{t-j} + \sum_{k=0}^{r} \gamma_3 lnEU_{t-k} + \sum_{l=0}^{s} \gamma_4 lnFD_{t-l} + \sum_{m=0}^{v} \gamma_5 lnTR_{t-m} + \sum_{n=0}^{w} \gamma_6 lnFFC_{t-n} + \rho_t \quad (13)$$

where p, q, r, s, v, w show the optimal lags of the variables CO_2, GDP, EU, FD, TR, and FFC respectively, γ_0 is a drift term, and $\gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5$, and γ_6 represent the long-run elasticities in the model.

Equation (14) is a normalized form of Equation (13) on CO_2 emission levels that includes the long-run coefficients.

$$lnCO_{2_t} = \tau_0 + \tau_1 lnGDP_t + \tau_2 lnEU_t + \tau_3 lnFD_t + \tau_4 lnTR_t + \tau_5 lnFFC_t + \varepsilon_t \quad (14)$$

where $\tau_0 = \frac{\gamma_0}{1-\gamma_1(L)}$, $\tau_1 = \frac{\gamma_2(L)}{1-\gamma_1(L)}$, $\tau_2 = \frac{\gamma_3(L)}{1-\gamma_1(L)}$, $\tau_3 = \frac{\gamma_4(L)}{1-\gamma_1(L)}$, $\tau_4 = \frac{\gamma_5(L)}{1-\gamma_1(L)}$, $\tau_5 = \frac{\gamma_6(L)}{1-\gamma_1(L)}$ $\tau_0, \tau_1, \tau_2, \tau_3, \tau_4, \tau_5$ are the long-run coefficients, (L) are the lag agents for the model variables.

In the last step, the ARDL method is followed by estimating the error correction model (ECM). Hendry's general to specific method is also used for estimating the error correction model.

$$\Delta lnCO_{2_t} = \delta_0 + \sum_{i=1}^{p-1} \delta_1 \Delta lnCO_{2_{t-i}} + \sum_{j=0}^{q-1} \delta_2 \Delta lnGDP_{t-j} + \sum_{k=0}^{r-1} \delta_3 \Delta lnEU_{t-k} + \sum_{l=0}^{s-1} \delta_4 \Delta lnFD_{t-l} + \sum_{m=0}^{v-1} \delta_5 \Delta lnTR_{t-m} + \sum_{n=0}^{w-1} \delta_6 \Delta lnFFC_{t-n} + \varphi ECT_{t-1} \quad (15)$$

where Δ is the first difference component, $\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6$ represent the short-run coefficients, and φ indicates how fast are the adjustments unto the long-run equilibrium.

As the last phase, the ARDL models need to be assessed in terms of their statistical validity.

4.4.5 Diagnostic and Stability Tests

The last step includes assessing the reliability of the ARDL model. This is done through diagnostic and stability test.

It is quite common to see correlation between macro-economic variables in time series data. Given this fact, the autocorrelation and heteroscedasticity are general issues with OLS[12] estimators. Thus, to prevent such problems in the ARDL technique, an adequate lag augmentation is required. Furthermore, the Newey-West approach is used to acquire valid OLS estimators with HAC[13] standard errors. As a result, the model outcomes are still creditable even though autocorrelation and heteroskedasticity exist.

In addition, the consistency of the long-run parameters as well as the short run dynamics are examined. I apply the cumulative sum of recursive residuals (CUSMUS) and cumulative sum of squares of recursive residuals (CUSMUSQ) stability tests for the ARDL model.

4.5. Empirical Results

In this chapter, I investigate the impacts of economic growth, energy consumption, financial development, trade openness and fossil fuel ratio on CO_2 emissions using ARDL econometric approach and ECM. Figure 30 illustrates the historical trends of model variables.

12 Ordinary Least Squares
13 Heteroskedasticity and Autocorrelation-Consisten

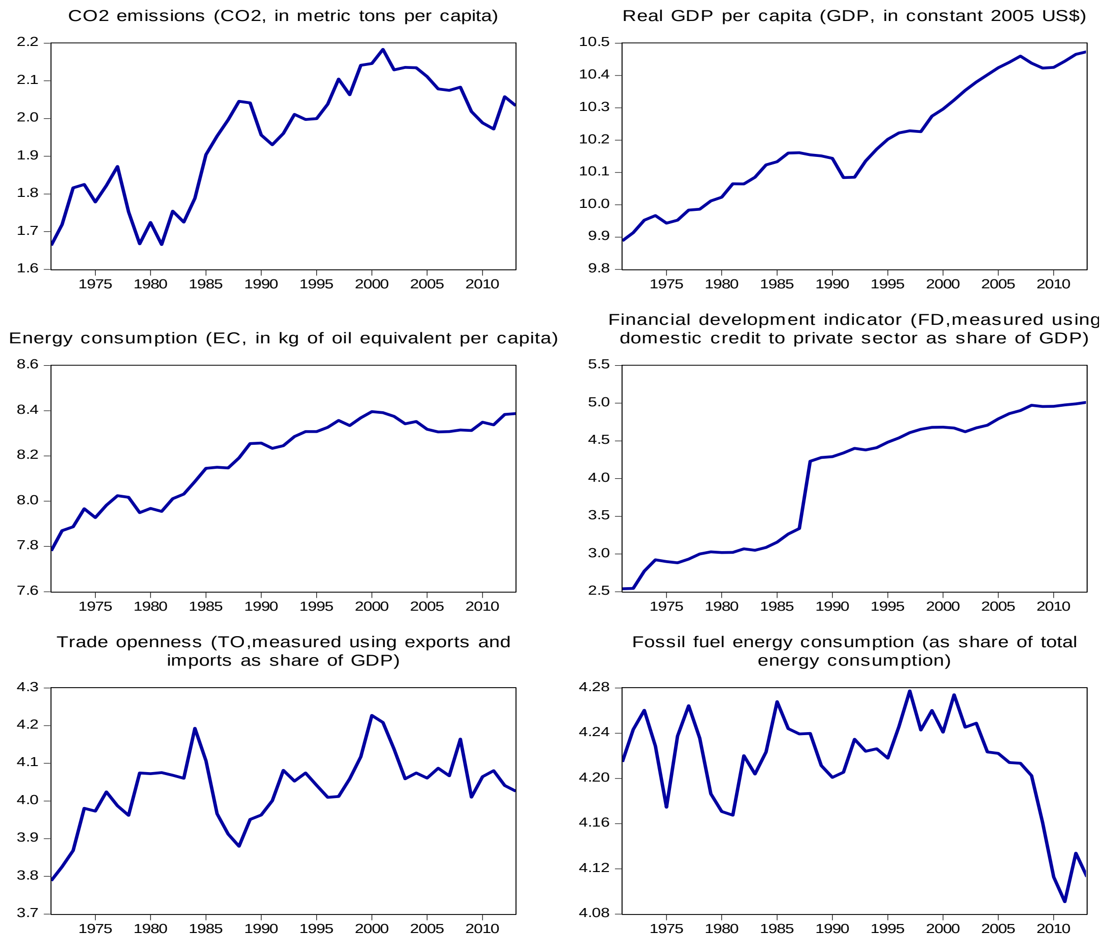

Figure 300: Time trend of model variables plotted in natural logarithm for case of New Zealand, 1971−2013

Source: Study results

4.5.1 Unit Root Test Results

To evaluate whether or not the variables under consideration are stationary at levels, 1st difference or mixed, I conduct the Augmented Dickey-Fuller (ADF) unit root test. In the ARDL technique, usually, there is no need to pre-test the variables in terms of the availability of the unit root. However, the unit root test helps to find out whether or not there is any I(2) variable in the model. The ADF test examines the stationarity of the variables. For each variable the ADF test is done at the level and at the first difference. The test results are shown in Table 26.

Table 26: The t-Stat Results of Augmented Dickey Fuller Tests

Data Series	At level		At first difference		Decision
	Intercept	Intercept & trend	Intercept	Intercept & trend	
$lnCO_2$	-1.894	-1.798	-6.113*	-6.134*	I(1)
lnGDP	-0.594	-2.589	-4.652*	-4.593*	I(1)
lnEU	-2.505	-2.016	-6.751*	-6.925*	I(1)
lnFD	-1.237	-1.442	-5.914*	-5.970*	I(1)
lnTR	-3.350**	-3.164			I(0)
lnFFC	-1.583	-1.996	-6.630*	-6.636*	I(1)

Note: '*' and '**' indicate significance at the 1% and 5% levels respectively

In Table 26, the t-test statistics for all variables except the trade openness (lnTR) are statistically insignificant. This rejects the null hypothesis of non-stationarity. According to the results, the lnTR is stationary at level at 95% significance level, whereas all other variables are non-stationary at their level. Therefore, the ARDL model seems to be a better fit for the series than the Johansen cointegration model.

4.5.2 ARDL Bounds Test

In the first step of the ARDL approach, bounds cointegration test is employed to detect the long-run relationship between CO_2 emissions and model components. To do that, the F-test is used to examine the lagged level series in the ECM framework of the ARDL model. Table 27 displays the results of bounds cointegration test and its diagnostic tests.

Table 27: ARDL Bounds Test for Cointegration

Panel A: Bounds testing to cointegration		
Estimated equation	$lnCO_2$=f(lnGDP, lnEU, lnFD, lnTR, lnFFC)	
Optimal lag structure	(1, 0, 3, 3, 4, 3)	
F-statistics (Wald-statistics)	4.859*	
Significant level	Lower bounds, I(0)	Upper bounds, I(1)
1%	3.41	4.68
5%	2.62	3.79
10%	2.26	3.35

Panel B: Diagnostic tests	Statistics
R^2	0.987
Adjusted-R^2	0.972
F-statistics (Prob-value)	70.540 (0.000)*
Jarque–Bera normality test	0.254 (0.881)
Breusch–Godfrey LM test	2.029 (0.162)
Breusch-Pagan-Godfrey heteroskedasticity test	1.332 (0.269)

Sources: The results are calculated by author using EViews 9.0 software.

Note: The superscripts (*) indicates statistically significant at 1% level of significance.

According to the results in Panel (A), there is very significant long-run relationship between CO_2 emissions and the explanatory variables. At 1% level of significant, the F-statistics shows a higher value (4.85) than the upper bounds of critical values (4.68). This rejects the null hypothesis of no cointegration.

Panel B represents some diagnostics tests including heteroscedasticity, serial correlation, and normality tests. These tests show how robust the ARDL bound cointegration tests are. The diagnostic tests indicate no statistical problem.

4.5.3 Long-run Impact

The model parameters are estimated in the second step of the ARDL method. Then their statistical significance are assessed as well as explaining their meaning in the economic theory. Table 28 shows the long-run coefficients in the ARDL model using logarithm of per capita CO_2 emissions as dependant variable, and logarithm of real GDP per capita, energy consumption per capita, trade openness, financial development, and fossil fuel share as explanatory variable. Where, energy consumption, economic growth, and the ratio of fossil fuels are correlated positively with CO_2 emissions. However, in the long-run, trade openness and financial development have negative effects on CO_2 emissions.

Table 28: Long-run coefficients from ARDL model ($lnCO_2$ as dependant variable)

Variable	Coefficient	standard error	t-statistic
lnGDP	0.773	0.162	4.772
lnEU	1.541	0.389	3.958
lnFD	-0.222	0.085	-2.608
lnTR	-1.127	0.292	-3.858
lnFCC	1.491	0.326	4.580
constant	-19.410	2.711	-7.160

Sources: The results are calculated by author using EViews 9.0 software.

Note: The superscripts (*) indicates statistically significant at 1% level of significance.

The estimates of the cointegrating coefficients (normalized on the coefficient of $lnCO_2$) in Table 28 can be re-written as:

$$lnCO_{2_t} = -19.41 + 0.77lnGDP_t + 1.54lnEU_t - 0.22lnFD_t - 1.13lnTR_t + 1.49lnFFC_t + \varepsilon_t \quad (16)$$

$\alpha_2 = 0.77$, inelastic GDP

$\alpha_3 = 1.54$, elastic EU

$\alpha_4 = -0.22$, inelastic FD

$\alpha_5 = -1.13$, elastic TR

$\alpha_6 = 1.49$, elastic FFC

As revealed by Table 28, in the long-run, the economic growth has a positive effect on CO_2 emissions and is statistically significant at the 1% level. The result show that a 1%

increase in GDP per capita is associated with 0.772% increase in per capita CO_2 emissions. The empirical evidences also show that a 1.540% increase in per capita carbon emissions is linked with 1% increase in per capita energy consumption. It reveals that, in the long-run, a quite elastic linkage between emission levels and energy consumption exists.

Furthermore, the model results present a negative and pretty much inelastic (-0.222) causality from financial development toward CO_2 emissions in the long-run. Although the relationship is not that much strong between these two, the financial development contributes to decreasing New Zealand's emissions. Generally speaking, the financial reform policies can create more competition and incentivise the international financial corporations to enter to the capital market by facilitating their entrance. In addition, financial reforms helps to absorb more direct investments on R&D platforms and offer different ways of financing low-cost environment friendly projects.

There is another remarkable outcome and it is the negative impact of trade openness on carbon dioxide emissions. The associated elasticity is -1.127 meaning that for every one percent increase in trade openness ratio, CO_2 emissions will decrease 1.127% in the long-run. In other words, trade openness can help to improve the quality of the environmental by decreasing CO_2 emissions. Looking at this from a pragmatic point of view, this result shows that trade liberalization policies, trade opening (along with facilitating foreign direct investment in trade-exposed sectors), and growing online shopping experience could potentially cut the country's carbon emissions.

These findings are in line with results of Managi et al. (2009), Shahbaz et al. (2013a), and Shahbaz et al. (2013b) which claim that freer trade boosts the environment quality. Moreover, there is a positive impact of the ratio of fossil fuel energy consumption on carbon dioxide emissions. The associated elasticity is 1.490 meaning that for every one percent decrease in fossil fuel ratio, CO_2 emissions will decrease by around 1.490% in the long-run. This means that carbon emissions are relatively elastic to changes in fossil fuel consumption ratio in the long-run as continues percentage decrease in fossil fuel consumption causes higher percentage decrease in per capita carbon emissions. In other words, the technological improvements could stimulate demand for more efficient and low-carbon energy sources, and if more investments and subsidies are provided to trigger more demand for greener energies, the economy will be able to reduce the emissions much faster. This in turn could enhance efficiency of the economy and provide effective factors of production.

4.5.4 Short-run Impact

In the final stage of the ARDL technique, the associated ECM part is made to capture the short-run dynamic relationships between carbon emissions and its important determinants over the period 1971-2013.

Table 29 presents the short-run dynamic regression. The important component is the error correction term (ECT), which has a coefficient of -0.682. It is an index for that shows how fast the model moves toward its long-term equilibrium.

Table 29: Short-run dynamic relationships between dependent variable (D(lnCO_2)) and ARDL model components

Error Correction:	Coefficient	standard error	t-statistic
D(lnGDP)	0.528	0.136	3.874
D(lnEU)	1.142	0.209	5.454
D(lnEU(-1))	-0.072	0.247	-0.293
D(lnEU(-2))	-0.284	0.194	-1.461
D(lnFD)	-0.022	0.048	-0.467
D(lnFD(-1))	0.115	0.048	2.421
D(lnFD(-2))	-0.062	0.041	-1.517
D(lnTR)	-0.207	0.090	-2.297
D(lnTR(-1))	0.206	0.109	1.893
D(lnTR(-2))	0.092	0.105	0.876
D(lnTR(-3))	0.281	0.100	2.808
D(lnFFC)	0.700	0.218	3.214
D(lnFFC(-1))	-0.387	0.257	-1.503
D(lnFFC(-2))	-0.254	0.237	-1.075
ECT(-1)	-0.683	0.162	-4.209

Sources: The results are calculated by author using EViews 9.0 software.

Note: '*', '**' and '***' indicate significance at the 1%, 5% and 10% levels respectively.

The ECT has a negative coefficient and represents the adjustment speed from any disequilibrium in previous years toward the long-run equilibrium. Results reveal that the speed range is quite high as it is 68% and statistically significant. In other words, each year, the model fixes itself by correcting 68% of the disequilibrium in the previous year. The statistical significance of the ECT also reveals that these variables have strong relationships in the short-run.

4.5.5 Stability Test

According to Hansen (1992), model misspecification can cause different estimated coefficients in time series data. Hence the stability tests including cumulative sum of recursive residuals (CUSUM) and CUSUM of square (CUSUMSQ) developed by Brown et al. (1975) are also applied. The tests seem to be very important as the stability of the long-run coefficients is very crucial. Model coefficients are assessed and any systematic changes is recognised by the CUSUM test. The CUSUMQ test, however, finds out whether or not any instability happened to the model coefficients. The tests apply to the residuals of the ECM model.

Figure 31 illustrates the CUSUM and CUSUMSQ test outputs. The coefficients of the ECM model show no sign of systematic or stochastic instability as they stay within 5% critical boundaries. As a result, I can conclude that the adopted ARDL model produces accurate estimations and shows robust results for short and long-run linkages between CO_2 emissions and the explanatory variables.

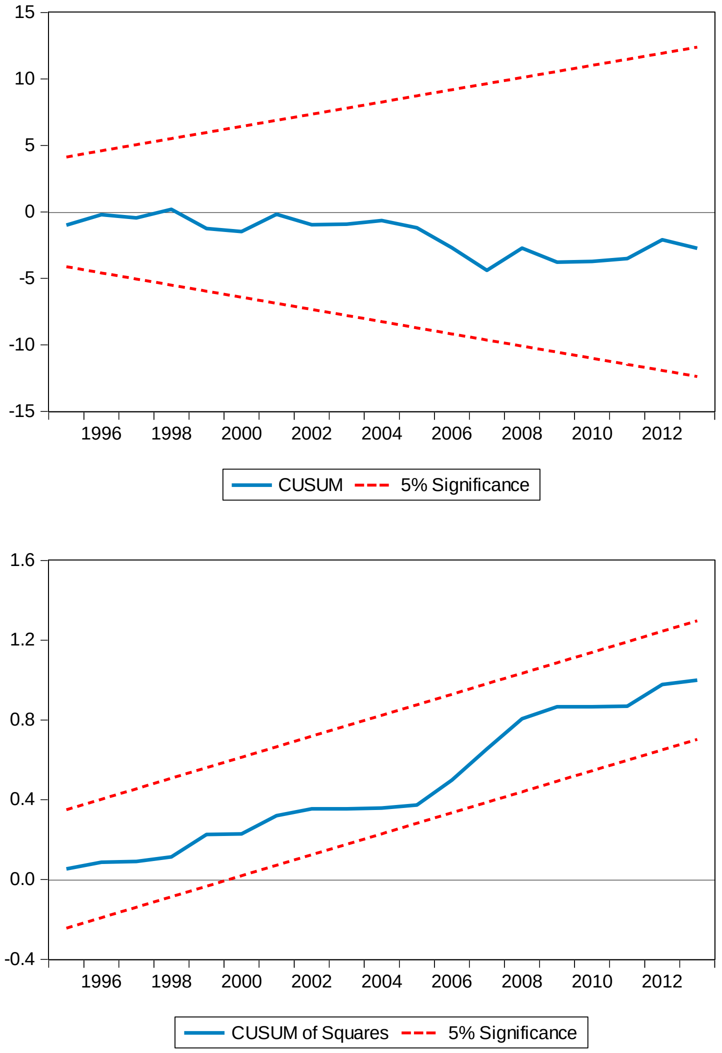

Figure 31: CUSUM and CUSUMSQ of recursive residuals

4.6. Conclusion

4.6.1 Main findings and policy implications

The essay attempts to investigate the short- and long-run linkages between the level of CO_2 emissions and some key determinants using econometric models and annual data from 1971 to 2013 in New Zealand. The analysis incorporates the effects of per capita real GDP, per capita energy consumption, financial development, trade openness, and fossil fuel consumption ratio as a proxy for technology on per capita CO_2 emissions. In order to achieve that, I employed the auto regressive distributed lag model (ARDL) methodology to examine if cointegration exist among the model variables. ARDL model results in ECM framework confirm that variables are cointegrated. Consequently, the model components show that a long-run correlation exist; despite the fact that, in the short-run, there can be disequilibrium.

According to the model outcomes, in the long-run model, significant positive causalities from per capita energy consumption and per capita real GDP toward per capita CO_2 emissions are found which are in consistent with findings in those of Ang (2007), Apergis and Payne (2009), and Acaravci and Ozturk (2010). The model coefficients suggest that one percent increase in GDP and energy use growth rates will lead an increase of CO_2 emissions by 0.772 and 1.540 percent respectively. Nevertheless, the financial development shows a significant negative (-0.222) influence on emission levels. This means that whilst the relationship is not that much strong between these two, the financial development contributes to decreasing New Zealand's CO_2 emissions. It is believed that the financial reform policies can create more competition and incentivise the international financial corporations to enter to the capital market by facilitating their entrance. In addition, financial reforms helps to absorb more direct investments on R&D platforms and offer different ways of financing low-cost environment friendly projects.

Likewise, in the long-run a significant and negative (-1.127) linkage between trade openness and New Zealand's CO_2 emissions is found. This adverse impact is in line with my hypothesis which states that trade liberalization policies along with facilitating foreign direct investment in trade-exposed sectors and growing online shopping experience could potentially reduce environmental degradation in New Zealand. These findings are consistent with those of Managi et al. (2009) in OECD countries, Shahbaz et al. (2013a) in Malaysia, and Shahbaz et al. (2013b) in South Africa.

In addition, another considerable observation of study finding is that carbon emissions is relatively elastic (1.490) to changes in fossil fuel consumption ratio. Therefore, continues percentage decrease in fossil fuel consumption ratio causes higher percentage decrease in per capita carbon emissions. In this regard, I argue that the technological improvements could stimulate demand for more efficient and low-carbon energy sources, and if more investments and subsidies are provided to trigger more demand for greener energies, the economy will be able to reduce the emissions much faster. This, in turn, could increase economic efficiency and provide effective factors of production.

These results suggest, nevertheless, that New Zealand as a trade-dependent economy is favourably affected by trade agreements and financial system developments. Therefore, it can be beneficial for New Zealand from a policy perspective to explore financial reforms further with a view to aiding the technological innovations and energy efficient R&D investments, considering this fact that financial developments often have a positive effect on the latter.

Trade liberalization policies along with facilitating foreign direct investment in trade-exposed sectors and growing online shopping experience could potentially reduce environmental degradation.

Technological improvements could stimulate demand for more efficient and low-carbon energy sources, and if more investments and subsidies are provided to trigger more demand for greener energies, the economy will be able to reduce the emissions much faster. This, in turn, could increase economic efficiency and provide effective factors of production.

4.6.2 Limitations and recommendations for further research

The current study attempts to examine an advanced version of the environmental Kuznets curve (EKC) with control variables in New Zealand. The model results show that there are strong relationships between economic indices and the environmental quality. However, the scope of the study on environmental measure has been limited to carbon dioxide emissions only and did not consider other GHG emission like methane which contributes to the half of GHG emissions in New Zealand. Furthermore, the literature has utilised different methodologies to investigate EKC. The issue is that different econometric methods yield different outcomes for EKC studies. While I used ARDL bound test as it seems to be a better fit considering model variables, the other studies have applied a variety of other econometric methodologies. This might lead to diverse results across studies even if they examine the same case study with the same datasets. Another shortcoming could be related to the lack of an internationally defined measure and its data source for technology change. In this essay, a ratio of fossil fuel consumption to total used energy is used as a proxy for technology. An international comparison of the model outputs in New Zealand against other countries can help populate the variable.

Chapter 5. Summary

The core question in this study is how to investigate policies for climate change in New Zealand. Examining the relationship between energy, the economy and the environment is one of the most important challenges facing social science. The connections between these three factors are, however, complex and various approaches have been taken in analysing the key relationships between these factors in order to recognize the implications.

By using different econometric techniques over the period from 1970 to 2014, this thesis investigated the economic and environmental impacts of implementing decarbonising policies in New Zealand. So this study aimed at providing empirical evidences on the extent to which decarbonising policies in New Zealand could tackle emission reduction targets more efficiently and how various economic factors need to be taken into account when evaluating current conditions and deciding future actions. More precisely, in order to address the main research question, the thesis has three main empirical chapters which examine three different aspects but interrelated dimensions of the energy-environment-economy nexus. The first empirical chapter investigated how economic performance is influenced by mitigation policies. The second empirical chapter examined how effective the fuel tax and technology improvements are to influence decarbonising light petrol fleet in both short- and long-run. The third empirical chapter examined how technology improvements and economic indicators affect emission levels.

The purpose of this chapter is to draw conclusions about the theoretical and empirical findings and their related recommendations and policy implications. The main contributions and conclusions of this thesis could be summarized as below.

5.1. Essay One: Environmental Tax Reform (ETR) and New Zealand Economic Performance: Modelling with E3ME

In Chapter 2, the E3ME model, a global macroeconometric model that links the world's economies to their energy systems and associated emissions, was employed to analyse the potential environmental and macroeconomic impacts of environmental tax reform (ETR) in New Zealand. A number of scenarios, including a baseline, were constructed to investigate the performance of the NZ ETS and other complementary mitigation policies over the commitment period (2021-2030).

In the light of the model results, I found that higher carbon prices especially in the early years would be necessary to achieve the ambitious GHG emissions target in New Zealand – but that carbon pricing on its own appears insufficient to meet emission reduction targets. It is clear that pricing CO_2 can only go so far in helping New Zealand to meet its GHG emission reduction targets and additional policy (notably on agricultural emissions) will be required. This is simply because it is unlikely to see the agriculture sector is included in NZ ETS in the near future. However, other abatement policies through boosting R&D investments may help to cope with the emissions in this sector.

Nevertheless, this should not be interpreted as there being no role for carbon taxation in New Zealand. The model results suggested that a combined NZ ETS and carbon tax approach with revenue recycling could lead to economic benefits, while making some contribution in reducing emissions. This finding is in line with those of Weitzman (1978); Roberts and Spence (1976); McKibbin and Wilcoxen (2002); and Pizer (1998, 2002) of using an efficient hybrid mechanism to tackle the GHG emissions and, at the same time, minimising the welfare loss. Meanwhile, double dividend effect could be achievable, if New Zealand's government recycles the revenues from carbon taxes. This helps to decrease the burden of existing distortional taxes.

The complexity and sensitivity of energy-economy-environment models raise various issues. This means that the outcomes of the E3 models need to be interpreted with caution. Like many other IAMs, E3ME also has some drawbacks. The main drawback could be its reliance on extensive reliable time-series data. The other shortcoming lies in its structure. E3ME does not utilise a well deigned damage module in order to calculate the environmental damage from GHG emissions. Therefore, it cannot monitor land use change or carbon sequestration processes including afforestation or deforestation. A detailed sub-model for land use change can solve the problem in E3ME. Furthermore, E3ME is a global model and can simulate 53 regions. In this essay, I only focused on New Zealand and made domestic scenarios. However, in future research creating scenarios for other regions can be also taken into account. So expanding the scope of emission trading scheme and including other countries that have bilateral trade with New Zealand may yield better results.

5.2. Essay Two: Light Petrol Vehicles and CO_2 Emissions in New Zealand: Assessing the Effectiveness of Fuel Tax and Technology Improvements

Chapter 3 investigated the linkage between the level of CO_2 emissions from Light Petrol Vehicles (LPV) and some key determinants including fuel tax, Trade-Weighted exchange rate Index (TWI) and the average emission rate of newly registered vehicles as a proxy for technology. On the basis of the empirical findings, in the long-run model, a significant negative relationship between LPV's emission level and fuel tax rate was found. However, the average emission rate variable showed a significant positive and elastic influence on total emission levels. This implies that improving the vehicle emission standards in New Zealand vehicle fleet could significantly cut the emission outputs in the long-term. Likewise, New Zealand's trade-weighted exchange rate has a positive long-run impact on LPV emissions. This positive efficacy is consistent with my hypothesis which states that relative gains in New Zealand dollar leads to importing more new or used vehicles and consequently an increase in total CO_2 emissions. I finally concluded that improving emissions standards in the long-term is more effective emission abatement policy than direct fuel tax in New Zealand. However, in the short-term, fuel tax is a better choice as it encourages consumers who drive and pollute a lot to choose a greener transportation.

There is no doubt that transport sector externalities need to be reduced, but it can be a challenge within cities. This is because cities have their own specific situations. Although fuel taxes can be very beneficial tools as they can lower congestion and at the same time help reduce emissions, these strategies however should be accompanied by other strong motivations. Particularly, a fuel tax does not encourage car owners in New Zealand to switch to public transportation if people are not satisfied with public transport services. Therefore, beside the investments in efficient and affordable public transportation which is crucial, a set of complementary regulatory policies including charging more levies and license fees on old and polluting vehicles, setting stricter emissions standards for vehicles entering the fleet, charging for road use, subsidising hybrid and electric vehicles and setting comprehensive standards for scrapping older cars would promote energy conservation, minimise emissions and raise revenues.

There were also some shortcomings around this essay. The first issue was associated with the limited data availability. The quarterly data on new cars emissions rate are only available from March 2005. This is due to the fact that before 2005, vehicles entered the fleet had limited information. Furthermore, the study utilised a VECM framework. Although the adopted methodology fitted very well and coped with the common time-series drawbacks, using other econometric approaches may demonstrate different results. Fuel tax was the only fiscal policy instrument that was considered in this essay. While technology improvements showed greater impact on carbon emissions in the long-run, other policies could be also taken into account. Thus, further research around assessing the regulation changes on importing new and used light vehicles as well as investigating other decarbonising plans like government's scrappage scheme would shed more light on the aims of this research.

5.3. Essay Three: Dynamic Interaction between Economic Indicators, Technology and CO_2 Emissions in New Zealand

In Chapter 4, I aimed at investigating the relationship between the level of CO_2 emissions and some key economic and technology-related determinants using ARDL econometric approach and annual data from 1971 to 2013 in New Zealand. The analysis incorporated the effects of real GDP per capita, energy consumption per capita, financial development, trade openness, and fossil fuel consumption ratio as a proxy for technology on per capita CO_2 emissions. The empirical findings showed that there are significant positive causalities from per capita real GDP and per capita energy consumption toward per capita CO_2 emissions which are in line with findings in previous studies (Ang, 2007; Apergis and Payne, 2009; Acaravci and Ozturk, 2010). However, the financial development and trade openness showed significant negative influences on emission levels implying that their improvements help to decrease New Zealand's emissions. Furthermore, I observed strong positive correlation between fossil fuel consumption ratio and carbon emissions. In this regard, I argued that the technological improvements could stimulate demand for more low-carbon energy sources. This, in turn, could increase economic efficiency and provide effective factors of production.

These results suggest, nevertheless, that New Zealand as a trade-dependent economy is favourably affected by trade agreements and financial system developments. Therefore, it can be beneficial for New Zealand from a policy perspective to explore financial reforms further with a view to aiding the technological innovations and energy efficient R&D

investments, considering this fact that financial developments often have a positive effect on the latter.

Trade liberalization policies along with facilitating foreign direct investment in trade-exposed sectors and growing online shopping experience could potentially reduce environmental degradation. Technological improvements could stimulate demand for more efficient and low-carbon energy sources, and if more investments and subsidies are provided to trigger more demand for greener energies, the economy will be able to reduce the emissions much faster. This, in turn, could increase economic efficiency and provide effective factors of production.

Although the model showed econometrically credible results, there were however some limitations in this essay. The scope of the study on environmental measure was limited to carbon dioxide emissions only and did not consider other GHG emission like methane which contributes to the half of GHG emissions in New Zealand. Furthermore, the literature utilised different methodologies to investigate EKC. The issue is that different econometric methods yield different outcomes for EKC studies. While I used ARDL bound test as it seems to be a better fit considering model variables, the other studies have applied a variety of other econometric methodologies. This might lead to diverse results across studies even if they examine the same case study with the same datasets. Another shortcoming could be related to the lack of an internationally defined measure and its data source for technology change. In this essay, a ratio of fossil fuel consumption to total used energy was used as a proxy for technology. An international comparison of the model outputs in New Zealand against other countries can help populate the variable.

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