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Economic Impact of New Zealand's Second Emission Reduction Plan - *Policy Results*

REPORT TO

Ministry for the Environment

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Contact person

Dr Eilya Torshizian, eilya@principaleconomics.com.

Authors

Dr Eilya Torshizian of Principal Economics prepared this report. The technical assistance of Professor Philip Adams of the Centre of Policy Studies and the feedback received from Dr Adolf Stroombergen of Infometrics Limited is highly acknowledged. The author is thankful for the comments received from the project's Steering Committee and the inter-agency teams.

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Address: Level 17, 55 Shortland Street, Auckland 1010, New Zealand

Abbreviations and acronyms

Abbreviation	Description
AR5	Annual Report 5 refers to New Zealand's Fifth Biennial Report (2022)
BEV	Battery-electric vehicles
BV	Battery-electric vehicles
CCC	Climate Change Commission
CERF	Climate Emergency Response Fund
CES	Constant elasticity of substitution
CGE	Computable General Equilibrium
CO2	Cardon Dioxide
EECA	Energy Efficiency & Conservation Authority
ENZ	Emission and Energy in New Zealand model
ERP	Emissions Reduction Plan
ETS	Emissions Trading Scheme
EV	Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GIDI	Government Investment in Decarbonising Industry
GNI	Gross National Income
GST	Goods and Services Tax
IC	Internal Combustion
ICE	Internal Combustion Engine
ICV	Internal Combustion Vehicle
KLEM	Substitution between Capital, Labour, Energy and Materials for each sector
LULUCF	Land Use, Land-Use Change and Forestry
MfE	Ministry for the Environment
MPI	Ministry of Primary Industries
$MtCO_2e$	Million Tonne Carbon Dioxide Equivalent
NAIRU	Non-accelerating inflation rate of unemployment
NDC	Nationally Determined Contribution
NPV	Net Present Value
PT	Public Transport
RES	Regional Equation System
VURM	Victoria University Regional Model
WAM	‘With Additional Measures’ refers to policy scenarios
WEM	With Existing Measures
WOM	Without measures

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Executive summary

The Emissions Reduction Plan 2 (ERP2) delineates Aotearoa New Zealand's strategy to attain its emissions reduction objectives for the 2026-2030 period, alongside setting a path towards achieving long-term emissions reduction objectives. ERP2 aims to reduce annual average emissions from 72.5 $MtCO_2e$ to 61 $MtCO_2e$. The Ministry for the Environment (MfE) engaged Principal Economics Limited, the Centre of Policy Studies, and Infometrics Limited to evaluate the comprehensive impact of the proposed ERP2 policies. This includes:

- Assessing the comprehensive economic repercussions of emissions mitigation policy packages within ERP2.
- Estimating and understanding of secondary or indirect consequences.
- Carrying out distributional analysis of these ramifications.

This is the second (final) report building on the findings of our first draft report in May 2024 and further investigating various assumptions.

Two out of four policy scenarios considered in our earlier report are further investigated in this report.

Our May report identified the impacts of four policy scenarios, namely the With Existing Measures (WEM), Constrained, Unconstrained, and Fourth Pathway scenarios. The current report further investigates the impacts of the WEM and (revised) Fourth Pathway scenarios. The key assumptions of the policy scenarios are shown in Table E.1.

As with the May report, the Fourth Pathway scenario represents the ERP2 mitigation policy package. However, it does not include the effects of the afforestation on Crown-owned land policy or the introduction of biomass at Huntly power station, as these decisions were made after the modelling had been completed. The ERP2 technical annex explains these in more detail.

Table E.1 Key assumptions of policy scenarios

Assumptions	Current Path (WEM)	Fourth Pathway
Policies	2023 "With Existing Measures" (WEM) policies are used as the starting point for all Pathways. These have then been adjusted to remove the effects of the clean car discount and GIDI and to defer the start of agricultural emissions pricing to 2030	Same as WEM plus • Electrify NZ policy and the investment in the EV charging network • the Carbon Capture, Utilisation and Storage (CCUS) and the Refrigerants Regulated Product Stewardship scheme assumptions
Emissions Prices	Rising then Falling Price path imposed	Different (higher) carbon pricing path from tightened ETS settings
Removals	MPI Central Projection	MPI Central Projection
Emissions profiles	Determined in model	Determined in the model

Source: Ministry for the Environment

For the analysis, we use our PE-Climate CGE model, which provides a high level of granularity for industrial and emission factors required for climate policy analysis.

PE-Climate is a dynamic computational general equilibrium (CGE) model designed to assess greenhouse emissions and policy options for New Zealand. The input-output database was updated for the latest data in 2020 and covers 72 industry sectors, 16 regions, and 30 household types. The GHG inventory data is updated for the 2024 published New Zealand GHG Inventory, which provides data for 2022. For the modelling, we take data on the interactions between various economic actors and introduce a shock to understand how the economy is affected.

The modelling shocks are defined carefully using the available literature, expert advice and stakeholders' inputs.

We then held various workshops with government officials to ensure the usefulness of our modelling approach and adjusted it where necessary. Figure 1.2 shows our high-level approach to converting policy assumptions to modelling shocks. Accordingly, we held three inter-agency workshops and regular meetings with the project's steering committee. Wherever practical, assumptions and approaches were aligned with those used in the Emissions in New Zealand (ENZ) model that underpinned the government's ERP2 emissions projections. The outcome of this process led to a cohesive assessment of the policies and a mutual understanding of the caveats of our modelling approach – as will be discussed in this report.

Figure E.1 Our approach for converting policies to modelling shocks and impact assessment

Source: Principal Economics

The impact of policies needs to be considered across different outcomes, such as GDP, household consumption, emission, and equity.

There are various trade-offs faced across scenarios (and policies). This includes:

- The high carbon price of the Fourth Pathway scenario leads to larger adverse economic and equity impacts.
- Overall, we observe similar patterns of economic impacts, with a decrease in GDP being associated with lower household consumption, lower real wages and lower exports (volume). As will be discussed, the short, medium and long-term dynamics of these effects are important for households (as well as the emission and economic outcomes).

- As presented in our earlier report, the emission targets are achievable, but there is a significant adverse impact on economic and equity outcomes.

Table E.2 shows the summary results for the policy scenarios for 2030 and 2050.

Table E.2 Summary results for 2030 and 2050

Variable shocked	WOM	WEM	Fourth Pathway	WOM	WEM	Fourth Pathway
Year	**2030**	**2030**	**2030**	**2050**	**2050**	**2050**
GDP and welfare						
GDP, billion 2022$	$394	$393	$393	$561	$559	$558
GDP, per cent change		-0.3	-0.3		-0.2	-0.4
Consumer welfare, billion 2022$	$229	$229	$229	$329	$329	$328
Consumer welfare, per cent change		-0.1	-0.1		-0.1	-0.3
CO2 prices, 2022$/tCO2e	$35	$69	$78	$35	$51	$53
Biogenic Methane price*	$35	$69	$78	$35	$51	$53
GHG emissions, MtCO2e						
Biogenic Methane	36.0	34.9	34.5	33.6	34.6	26.9
Other GHG, gross	55.6	36.2	39.5	37.8	31.6	23.5
Forestry removal	0.0	16.4	16.4	13.7	28.0	28.0
Other GHGs, net	55.7	19.8	23.2	24.1	3.6	-4.5
Electricity and vehicles						
Electricity production, TWh	62.0	63.2	63.8	111.3	112.0	112.5
Percent (%) of travel from EVs and hybrids						
Road transport	22.0	25.0	25.2	57.4	62.0	69.1
Household transport	30.5	32.3	32.5	95.5	99.1	100.0

Source: Principal Economics

Note: Fourth stands for the Fourth Pathway. Carbon prices are measured assuming free allocation – ie, any permits over industries' emissions can be sold for the market price and free of any immediate financial cost. Emissions are based on the 100-year time-horizon global warming potentials (GWP100) metric values from the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5), as required under the Paris Agreement (Decision 5/CMA.3)

* The Biogenic Methane prices do not include free allocation, which is effectively 100 per cent until 2030 i.e. the effective price is zero.

Agricultural output and related manufacturing activities are affected more adversely.

Agricultural output and related manufacturing will be significantly lower across all three pathways by 2050. However, the differences between scenarios are relatively small, suggesting it is the overall transition rather than the policy mix driving the change. We also identified that:

- Mining and some heavy manufacturing decline.
- Most services sectors see little impact, while forestry and related manufacturing expand slightly.
- There is a switch from ICE to BEV transport services. However, electricity prices rise because of progressively stronger demand for electricity to replace fossil fuels in industry. This leads to an increase in the cost of BEVs (relative to ICVs) such that usage of BEVs begins to fall.

While the large urban areas are least affected, the relative impacts of scenarios vary across regions.

The regional distribution of the impacts depends on the spatial distribution of industries affected by policies and the differences across the scenarios affecting those industries. Our results suggest that:

- Auckland and Wellington are least adversely affected in all scenarios due to the higher share of the services sector in these regions.
- The adverse impacts on the South Island are higher overall than those on the North Island.
- A comparison between the 2030 and the 2050 impacts suggests that some regions experience the impacts earlier than others.

Overall, Māori people are more adversely affected.

We disaggregated the impacts for income groups by household composition (having dependents or not), household age group (15 to 64 and 65 and over), and ethnicity (Māori and others). Our findings suggested that:

- The impacts range between -0.02 and -0.34 per cent for WEM and -0.15 and -0.31 per cent for the Fourth Pathway scenario.
- Overall, Māori households are more adversely affected in all scenarios and across all household income groups, but the difference is relatively small.

We will further sensitivity test policy and modelling assumptions in the next version of the report.

While dynamic CGE frameworks are widely used to assess climate change policies in New Zealand and internationally, each modelling framework has limitations. Our earlier report investigated a few sensitivity scenarios. We will address these modelling uncertainties by considering a range of sensitivity analyses of the Nationally Determined Contributions (NDC) scenarios in the next version of the report.

1 Introduction

The Emissions Reduction Plan 2 (ERP2) outlines how Aotearoa New Zealand will achieve its emissions reduction targets for 2026-2030 while establishing a trajectory for meeting long-term emissions reduction goals. The Ministry for the Environment (MfE) enlisted the services of Principal Economics Limited, the Centre of Policy Studies, and Infometrics Limited to assess the overall impact of the proposed policies on the Gross Domestic Product (GDP) across various sectors and to determine how they may grow or shrink.

Our assessment is completed in two phases. In the first phase, we investigated the impact of four policy scenarios: WEM (With Existing Measures), Unconstrained, Constrained and Fourth Pathway, and a range of sensitivity assumptions. The results were provided in our draft report in May 2024, available here. The current report investigates the impacts of revised WEM and Fourth Pathway policy scenarios. We will investigate the effect of a wider range of sensitivity assumptions on the Fourth Pathway scenario in the next version of the report.

1.1 Scope of this report

The scope of this report involves using Computable General Equilibrium (CGE) modelling to explore the economic implications of the proposed ERP2 policies. This includes:

- Estimating the overall economic effects of emissions mitigation policy packages within ERP2.
- Providing an estimate and insight into second-order or indirect impacts.
- Conducting distributional analysis of these impacts.

Beyond the initial impact assessment, which will inform the policies implemented for ERP2, this report's findings will have significant implications for various industries' investments and planning strategies. Our analytical outputs are detailed in an extensive spreadsheet appended to the current report.

1.2 Policy context: ERP2 aims to reduce annual average emissions from 72.5 $MtCO_2e$ to 61 $MtCO_2e$

By ratifying the Paris Agreement, New Zealand pledged to restrain "the rise in the global average temperature to well below 2°C above pre-industrial levels" and strive "to limit the temperature increase to 1.5°C above pre-industrial levels." Each participating nation was required to formulate a nationally determined contribution (NDC) from 2021 to 2030. Subsequent NDCs will encompass five-year intervals and must progressively enhance in ambition. Achieving an NDC involves both curbing domestic emissions and investing in emission reduction initiatives abroad, such as financing clean energy projects in other nations. The 2050 objective and emissions allocations (alongside strategies for emission reduction) form part of Aotearoa New Zealand's framework for curbing domestic emissions and are as follows:

- net zero greenhouse gas emissions (except biogenic methane)
- a 24-47 per cent reduction in biogenic methane (methane emissions from waste and agriculture biological processes)

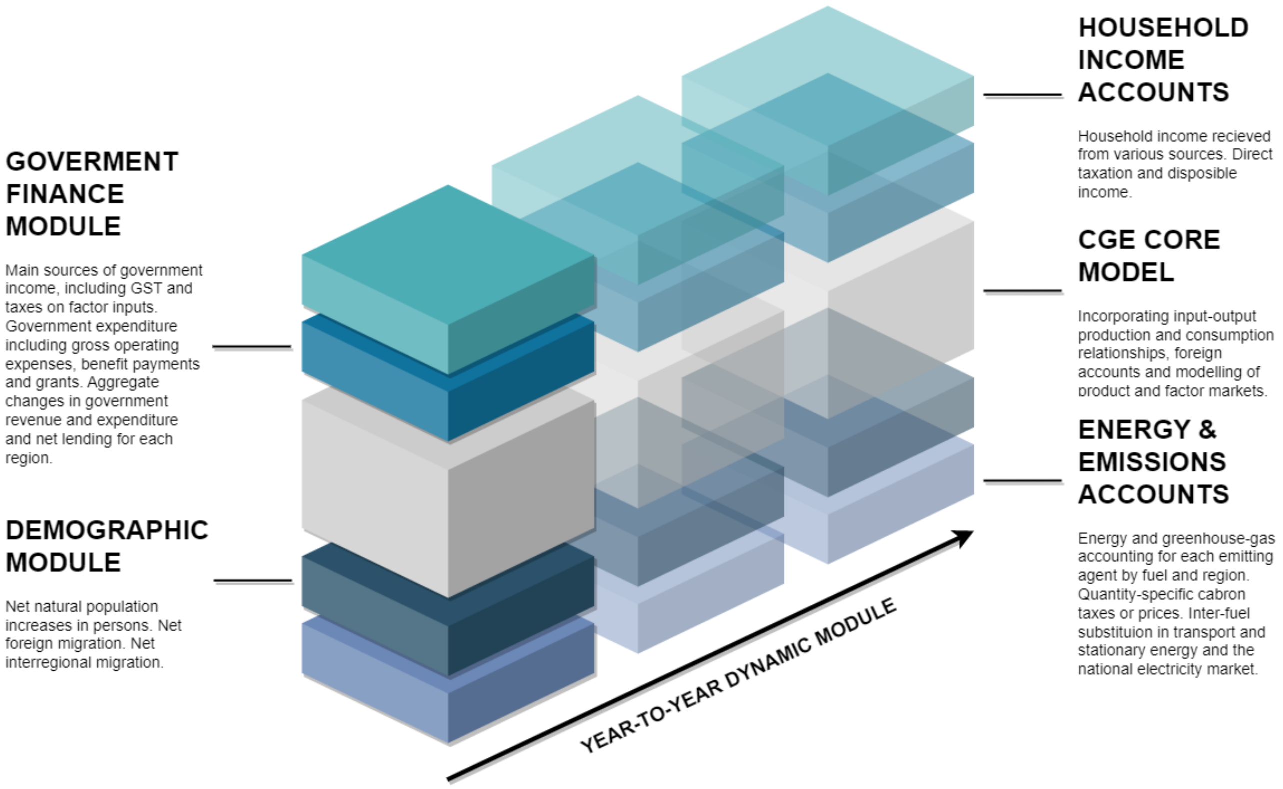
The first three emissions budgets were published in the first emissions reduction plan in May 2022. The amount of budgeted carbon dioxide equivalent for the first, second, and third budget periods are 290, 305, and 240 $MtCO_2e$, respectively.[1]

[1] The levels go up from the first to the second emissions budget because the first emissions budget period is a year shorter (four years rather than five years).

1.3 We used PE-Climate for the modelling of ERP2 policies

For this analysis, we used our extensive model of New Zealand's economy, PE-Climate, a dynamic Computable General Equilibrium (CGE) model designed for greenhouse analysis. We took data on the interactions between various economic actors and introduced a shock to understand how the structure of the economy was affected. The PE-Climate model draws on international best practice modelling. The model uses the latest available data and provides a high level of granularity for climate policy analysis. Figure 1.1 shows the high-level features of our PE-Climate model and Table 1.1 provides a summary of its technical features. Further technical details are available in the documentation of our model provided in Appendix A:. The model provides an extensive environmental component, which is crucial to modelling the ERP2 policies.

Figure 1.1 Principal Economics' Climate Computational General Equilibrium Model (PE-Climate)



Source: Principal Economics

Table 1.1 Technical features of PE-Climate

Topic	Description
Model summary	PE-Climate is a dynamic economic model designed for assessing greenhouse emissions and policy options for New Zealand. The Input-Output database is updated for the latest available data in 2020 and covers 72 industry sectors, 16 regions and 30 household types. The GHG inventory data is updated for the 2024 published New Zealand GHG Inventory, which provides data for 2022.
Key features	• Based on a neo-classical Computable General Equilibrium (CGE) core. Solved using GEMPACK software. • Industry-specific capital and investment are driven by dynamic relationships that relate capital supply to expected rates of return. • Full accounting for domestic margins, including passenger and freight transport and wholesale and retail trade. • Special treatment of travel, with domestic travellers choosing between domestic and overseas trips, and with foreign tourists and students buying bundles of tourism services comprising transport, accommodation, entertainment, etc. • Direct and income tax taxes are recognised, along with the current accounts of the private household and government. • Full accounting for greenhouse gas (GHG) emissions from combustion and non-combustion sources. Explicit recognition of specific GHG tax/prices distinguished by emission source (fuel type, emitter and GHG gas type). • Electricity is broken into five generation sectors and one distribution/transmission industry, with technology switching allowed across different power sources. • Range of relative-price substitution possibilities that allow for fuel-fuel and fuel-capital substitution in response to a GHG price. • Non-combustion abatement mechanisms that link the reduction in activity emissions to GHG price in agriculture, mining (fugitives) and elsewhere (industrial processes and waste). • Modelling of land supply decisions across agriculture and forestry, including LULUCF sequestration. • A full range of technological change variables across primary factors (capital, land and labour) and individual products (eg, fertiliser used in agriculture, or financial services used in consumption). Also, allows for changes in autonomous energy efficiency and electrification in the delivery of transport services (Battery electric vehicles replacing IC vehicles).
Key inputs and assumptions for baseline	• Foreign-currency import prices and the positions of foreign export-demand schedules. • Assumptions for growth drivers, including population, labour force participation and all-factor productivity. • GHG growth trajectories accommodation for by model-determined changes in GHG price (and vice versa) • Assumptions for shares in private transport and commercial transport of Battery electric vehicles and conventional ICVs.
Policies	Modelled as changes away from baseline due to the policy shock examined. Can deal with a full range of market and non-market (regulation, etc.) policies designed to improve energy efficiency and/or reduce GHG emissions. The client and modeller need to have a common understanding of policy and the translation from policy design into quantified shocks to model variables.

Source: Principal Economics

1.4 Scenarios considered in our analysis: WOM is the baseline of our analysis

For this analysis, we first clarify the terminology for scenario analysis. There are three common definitions for analysis of the ERP as follows:

- WOM (Without measures): without intervention. This is considered as the **baseline of our analysis.**
- WEM (With Existing Measures): which consists of current policies, including changes to ERP1 policies by the Government, and does not capture most of the new policies in the emissions reduction plan. This is the best estimate of the trajectory New Zealand is currently on.
- WAM (With Additional Measures): These are the policy scenarios, which include planned policies and measures in addition to existing policies.

Hence, our policy analysis is focused on one WAM scenario compared to WOM. The WAM scenario considered is the Fourth Pathway.[2] This scenario is similar to the WEM scenario, but also includes proposed ERP2 policies including Electrify NZ policy, with price effects realised from 2026 onwards, and an additional 10,000 electric vehicle (EV) charging facilities. This is the best estimate of the impacts of proposed ERP2 policies. However, it does not include the effects of the afforestation on Crown-owned land policy or the introduction of biomass at Huntly power station, as these decisions were made after the modelling had been completed. The ERP2 technical annex describes these in more detail.

In our description of the results, we refer to the WAM scenario together with the WEM as 'policy scenarios'. Table 1.2 shows the key assumptions and pathway definitions for our considered scenarios. We will further clarify the specific assumptions for each scenario in the next chapters.

Table 1.2 Key assumptions and pathway definitions

Assumptions	Current Path (WEM)	Fourth Pathway
Policies	2023 "With Existing Measures" (WEM) policies are the starting point for all Pathways. These have then been adjusted to remove the effects of the clean car discount and GIDI and to defer the start of agricultural emissions pricing to 2030	It is the same as WEM plus, • Electrify NZ policy and the investment in the EV charging network; • the Carbon Capture, Utilisation and Storage (CCUS) and the Refrigerants Regulated Product Stewardship scheme assumptions.
Emissions Prices	Rising then Falling Price path imposed	Different (higher) carbon pricing path from tighter NZ ETS settings
Removals	MPI Central Projection	MPI Central Projection
Emissions profiles	Determined in model	Determined in the model

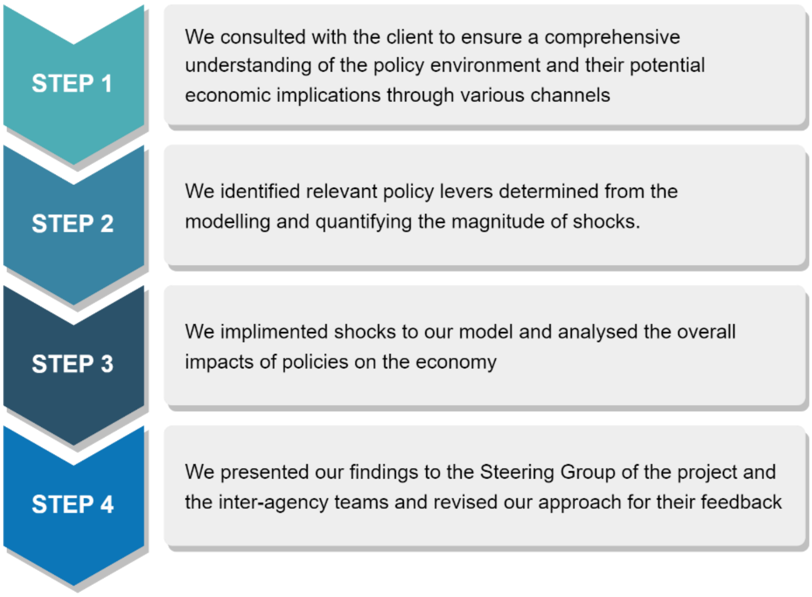
Source: Ministry for the Environment

2 The assumptions of this scenario are revised compared to our earlier report's Fourth Pathway scenario.

1.5 Our approach to defining modelling shocks is based on the literature, expert advice and stakeholders' inputs

It is critical to have a careful technical design for applying modelling shocks in CGE. Hence, we used a combination of the approaches applied in the literature and our expert advice to design the shocks. We then held various workshops with inter-agency teams to ensure our approach to modelling was useful and adjusted our approach, where required. Figure 1.2 shows our high-level approach to converting policy assumptions to modelling shocks. Accordingly, we held three inter-agency workshops in addition to regular meetings with the steering committee of the project. The outcome of this process led to a cohesive assessment of the policies and a mutual understanding of the caveats of our modelling approach – as will be discussed in this report.

Figure 1.2 Our approach for converting policies to modelling shocks and impact assessment



Source: Principal Economics

1.6 Report contents

This report progresses as follows:

- Chapter 2 provides details of the assumptions adopted based on the policies developed across government agencies,
- Chapter 3 presents the findings from our analysis of policy scenarios, including the economic, emission and equity outcomes,

In the end, we provide a list of limitations and suggestions for the next steps. The technical details are provided in the report's appendices.

2 Assumptions for the baseline and policy scenarios

The baseline of our analysis is similar to the baseline considered for the analysis of the Climate Change Commission report for the overall emission reduction budget (Winchester & White, 2022). Table 2.1 provides the details of the key macroeconomic assumptions used for the baseline. For more information about the abatement estimates for different policies see the ERP2 technical annex.

Table 2.1 Baseline (WOM scenario) assumptions (2020 to 2050)

Variable shocked	Comments
Real GDP	Made exogenous by endogenising all-industry, all-factor technological progress. Annual GDP growth to 2025 averages 2.2 per cent, then gradually declines to 1.6 per cent by 2050.
Population and labour force	In line with current Stats NZ projections for population. The labour force growth rate is initially 1.0 per cent, then gradually declines to 0.4 per cent in 2050
Unemployment rate	Assume not to change between 2023 and 2050, thus employment growth is in line with labour force growth. Employment growth accommodated by endogenous shifts in the real wage rate
Labour productivity	Labour-saving technological change improves at an average annual rate of 1.2 per cent. With all else equal, this reduces the improvement in all-factor technological progress required to achieve annual real GDP growth targets.
Terms of trade	Assume no change. Foreign-currency import prices are fixed, including the price of oil. Foreign-currency export prices are also fixed via endogenous outward shifts in world demand schedules for New Zealand exports
Carbon price	Applies to all sectors and to all sources of emissions. The price was kept constant at $35NZ per tonne of CO2-e in real terms.
Electricity generation	Generation from coal, gas and hydro are set exogenously. Generation from non-hydro renewable generation is determined endogenously. Generation from coal finishes in 2023. Generation from gas and hydro are held constant at 2020 levels through to 2050.
Electric vehicles	The share of BV services in total passenger vehicle services is assumed to rise from around 1.4 per cent in 2020 to 91 per cent in 2050. The share of BV services in commercial vehicle services will rise from a negligible level to 55 per cent by 2050
Autonomous energy improvement	Improves for all final energy types (coal, gas, refined oil and electricity) by 1 per cent per annum
Forestry land forestry sequestration	Determined endogenously with a total land used by agriculture and forestry held fixed. We assume no change in the supply of mining and urban land.
Forestry and agricultural yields	We assume land-saving technological change in all areas of agricultural use at an average annual rate of 1.0 per cent
Changes in non-combustion intensities	Emission intensities fall in land with the mechanism that links intensity to the price of emissions (see Section 3.4).
Sector-specific growth rates	Unconstrained.

Source: Ministry for the Environment; Winchester and White (2022)

2.1 Carbon taxes and prices are considered endogenously and exogenously for various scenarios

PE-Climate treats a GHG tax or price as a specific tax on emissions of CO2-e. On emissions from fuel combustion, the tax is imposed as a specific (per tonne of CO2-e) on the combustion of coal, gas and petroleum products used by industries and households – just like a specific sales tax on the use of fossil fuel. The carbon tax also acts as a specific tax (per tonne of CO2-e) on production for non-combustion emissions produced by industries – just like a specific production tax on non-combustion emitters such as the livestock industries. Any money earned from carbon taxes is returned directly to households as a non-distortionary lump sum.

On *Activity* emissions, it is imposed as a tax on the production of the relevant industries. The fifth biennial report under the United Nations Framework Convention on Climate Change assumes that without the introduction of new policies, the carbon price will increase from $35 in 2020 to $102 in 2030 (Ministry for the Environment, 2022, p. 47). This is significantly higher than the $35 per tonne of CO2-e carbon price (in real terms) used by Winchester and White (2022) for the modelling of ERP1. For more technical information about carbon tax in PE-Climate, see Appendix 4B.2.

Table 2.2 shows the carbon price assumptions for the scenarios which considered carbon price as exogenous – ie, fixed based on the scenario assumptions. On average to 2028, the assumptions are very similar and after 2028, the Fourth Pathway has a higher price compared to WEM.

Table 2.2 Carbon price assumptions (2023 dollars)

Year	CCC's pathway[3]	WEM	Fourth Pathway
2023	$57	$67	$63
2024	$62	$66	$62
2025	$67	$69	$64
2026	$73	$71	$67
2027	$79	$73	$69
2028	$86	$76	$72
2029	$94	$72	$75
2030	$102	$69	$78
2031	$111	$65	$76
2032	$121	$62	$75
2033	$132	$58	$73
2034	$143	$55	$72
2035	$148	$51	$70
2036	$152	$51	$69
2037	$157	$51	$68
2038	$161	$51	$67
2039	$166	$51	$65
2040	$171	$51	$64
2041	$176	$51	$63

3 Average of ETS settings, projected 3 per cent p.a. from 2035.

2042	$182	$51	$62
2043	$187	$51	$60
2044	$193	$51	$59
2045	$198	$51	$58
2046	$204	$51	$57
2047	$210	$51	$56
2048	$217	$51	$55
2049	$223	$51	$54
2050	$230	$51	$53

Source: Ministry for the Environment (2022); Ministry for the Environment.

2.2 Land use is fixed between agriculture and forestry

In PE-Climate, forestry sequestration is credited to the Forestry industry. In the emissions accounts it is represented as a negative number. When a tax or ETS price is applied to sequestration, the tax/price is effectively a subsidy. The subsidy shifts the forestry industry supply curve to the right, thereby increasing forestry production. More production means increased demand for land. We assume that the sequestration is proportional to land use. So increased forestry production leads to increased forestry land and hence more forestry sequestration.

Like most CGE models, in PE-Climate, an unchanging amount of land is allocated to farming and forestry via a Constant Elasticity of Transformation (CET) allocation. This means that the increased demand for land by the forest industry initially forces the price of land paid by the forest industry to rise increasing the supply of land to forestry and reducing land supplied for agricultural production. The latter suppresses agricultural production. It is important to note that land use is endogenous for the activity of other (underlying) sectors.

Table 2.3 shows the land use assumptions for each scenario, decomposed to afforestation (Afforest) and deforestation (Deforest). The main assumptions are based on MPI central projections. Compared to our earlier report, afforestation has increased significantly, and deforestation is almost unchanged.

Table 2.3 Land use scenarios

Unit: Hectares

Year	WEM		Fourth Pathway	
	Afforest	Deforest	Afforest	Deforest
2022	76,810	1,811	76,810	1,811
2023	76,326	1,822	76,326	1,822
2024	60,806	1,822	60,806	1,822
2025	29,699	1,822	29,699	1,822
2026	27,032	1,822	27,032	1,822
2027	27,197	1,822	27,197	1,822
2028	28,098	1,822	28,098	1,822
2029	27,648	1,822	27,648	1,822
2030	27,648	1,822	27,648	1,822
2031	27,354	1,822	27,354	1,822
2032	27,354	1,822	27,354	1,822
2033	27,354	1,822	27,354	1,822
2034	27,354	1,822	27,354	1,822
2035	27,354	1,822	27,354	1,822
2036	27,354	1,822	27,354	1,822
2037	27,354	695	27,354	695
2038	27,354	695	27,354	695
2039	27,354	695	27,354	695
2040	27,354	695	27,354	695
2041	27,354	695	27,354	695
2042	27,354	695	27,354	695
2043	27,354	695	27,354	695
2044	27,354	695	27,354	695
2045	27,354	695	27,354	695
2046	27,354	695	27,354	695
2047	27,354	695	27,354	695
2048	27,354	695	27,354	695
2049	27,354	695	27,354	695
2050	27,354	695	27,354	695

Source: Ministry for the Environment and Ministry of Primary Industries

2.3 Emission projections

We use the provided policy assumptions and estimate emissions, which will be presented in the next chapter. The WEM scenario has a lower abatement compared to the other scenarios, which are closely aligned. Under current policy settings, New Zealand is not expected to meet its 2050 emissions targets. This is consistent with the bottom-up analysis conducted in ENZ.

2.4 The Fourth Pathway's Improved Electricity Infrastructure

The Electrify NZ policy in the Fourth Pathway will be achieved through faster and longer generation consents. To support this change the cost of new generation capacity will marginally decrease to reflect easier consenting. The results of the ENZ model suggest the following energy generation cost reduction per year: Hydro by -0.1 per cent, Geothermal by -0.1 per cent, Wind by -0.8 per cent, Offshore wind by -1.07 per cent, Solar by -2 per cent, and Biomass by -0.25 per cent. Our modelling assumption is that these cost efficiencies will come into effect from 2026 onwards.

Another important initiative of the Fourth pathway is investment in the Electric Vehicle (EV) charging network, to be achieved via a $257 million investment to deliver 10,000 public EV chargers by 2030 and eliminate resource consents for EV charging points. Currently, the Ministry of Transport is working on modelling the impact of EV charging network investment. Consistent with our earlier report, we assume the increased EV infrastructure coverage will lead to a decrease in the effective price of electricity for vehicle use by 2 per cent.

3 Policy modelling results

We used the modelling framework described in 1.3 to model the impact of the assumptions described in Chapter 2. This chapter provides the results of our modelling. The details of our sensitivity testing will be presented in the next version of the report.

While the description in each section of this chapter is useful for understanding the specific impacts of policy packages, the overall impact of policies needs to be considered across different outcomes, such as GDP, household consumption, emission, and equity. The high-level trade-offs faced across policies include:

- The high carbon price of the Fourth Pathway scenario leads to larger adverse economic and equity impacts.
- Overall, we observe similar patterns of economic impacts, with a decrease in GDP being associated with lower household consumption, lower real wages and lower exports (volume). As will be discussed, the short, medium and long-term dynamics of these effects are important for households (and the emission and economic outcomes).
- As presented in our earlier report, the emission targets are achievable, but there is a significant adverse impact on economic and equity outcomes.

Table 3.1 shows the summary results for all policy scenarios for 2030 and 2050. In the next sections, we provide further details about the magnitude of the effects and the inter-temporal outcomes.

Table 3.1 Summary results for 2030 and 2050

Variable shocked	WOM	WEM	Fourth Pathway	WOM	WEM	Fourth Pathway
Year	**2030**	**2030**	**2030**	**2050**	**2050**	**2050**
GDP and welfare						
GDP, billion 2022$	$394	$393	$393	$561	$559	$558
GDP, per cent change		-0.3	-0.3		-0.2	-0.4
Consumer welfare, billion 2022$	$229	$229	$229	$329	$329	$328
Consumer welfare, per cent change		-0.1	-0.1		-0.1	-0.3
CO2 prices, 2022$/tCO2e	$35	$69	$78	$35	$51	$53
Biogenic Methane price*	$35	$69	$78	$35	$51	$53
GHG emissions, MtCO2e						
Biogenic Methane	36.0	34.9	34.5	33.6	34.6	26.9
Other GHG, gross	55.6	36.2	39.5	37.8	31.6	23.5
Forestry removal	0.0	16.4	16.4	13.7	28.0	28.0
Other GHGs, net	55.7	19.8	23.2	24.1	3.6	-4.5
Electricity and vehicles						
Electricity production, TWh	62.0	63.2	63.8	111.3	112.0	112.5
Percent (%) of travel from EVs and hybrids						
Road transport	22.0	25.0	25.2	57.4	62.0	69.1
Household transport	30.5	32.3	32.5	95.5	99.1	100.0

Source: Principal Economics

Note: Emissions are based on the 100-year time-horizon global warming potentials (GWP100) metric values from the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5), as required under the Paris Agreement (Decision 5/CMA.3)

* The Biogenic Methane prices do not include free allocation.

3.1 Economic impacts: GDP is most adversely affected by the Fourth Pathway scenario

The estimated economic impact of achieving the targets is consistent with the Climate Change Commission's advice (between -0.3 to -0.8 per cent in 2050 as per Figure 3.1). The variations over time are closely related to the policy assumptions, particularly carbon prices – as will be described in the next section. The WEM scenario has minimal adverse GDP impacts, but as described, the abatement of this scenario is also the lowest.

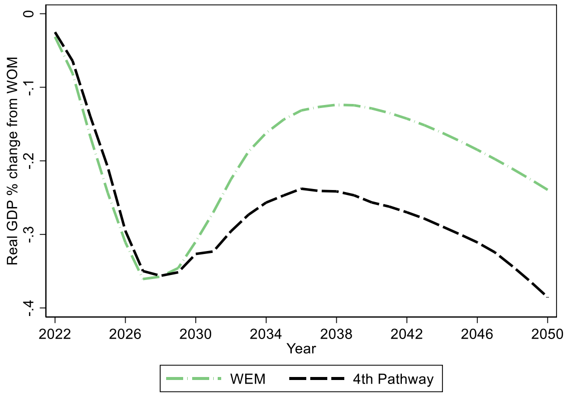
While the GDP impacts are negative from the early years, real household consumption is initially positive up to 2028. This is because any changes in real GDP are matched by a change in real domestic absorption, consisting of consumption, investment, and government expenditure. In the first year (2022), capital cannot change from its WOM level because it is put in place by the accumulation of gross investment net of depreciation in the preceding years. The ETS price is modelled as a tax. A tax with no change in capital leads to a fall in the price of capital and hence a fall in the rate of return on capital. This leads to a fall in investment relative to the WOM level which leads to a fall in domestic saving relative to the WOM level. Thus, consumption must rise relative to real GDP. Ultimately, in the first few years, consumption expands relative to GDP to such an extent that it increases relative to its WOM level. Less investment leads to less capital in the next year and in subsequent years and so to less GDP. Thus, throughout most of the period, real consumption falls below its WOM level. An NPV calculation of the changes in real consumption between 2022 and 2050 shows that the policies lead to lower national welfare when only the economic effects are accounted for (lower real household consumption is a proxy for material living standards).

As with the overall economic impacts, the impacts on consumption and trade are largest in the Fourth Pathway scenario. Lower export volumes are consistent with lower agricultural and related food manufacturing – this will be presented in the next sections.

Figure 3.2 shows the impacts on employment. Short-term adjustment in the labour market comes from a mixture of employment and wage effects. Over the medium to long term, wage impacts dominate, although this reflects a core underpinning assumption that the labour market will return to full employment over the medium term - NB this is a commonly used "closure" assumption in CGE models.

Figure 3.1 GDP impacts

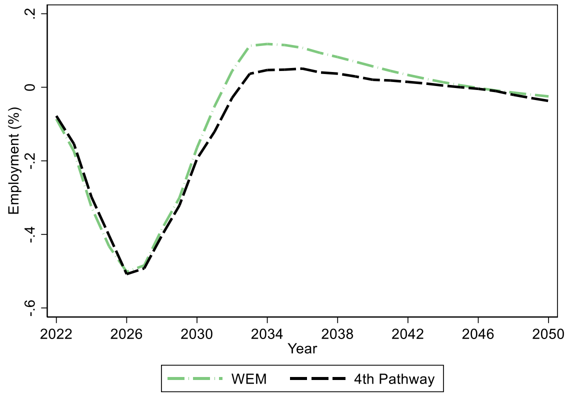
Unit: Percentage change – deviation from WOM



Source: Principal Economics

Figure 3.2 Employment impacts

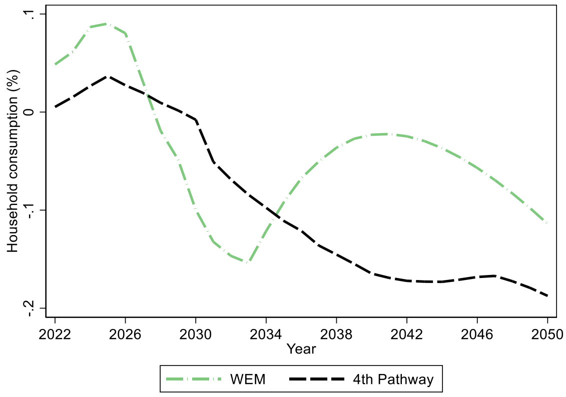
Unit: Percentage change - deviation from WOM



Source: Principal Economics

Figure 3.3 Household consumption impacts

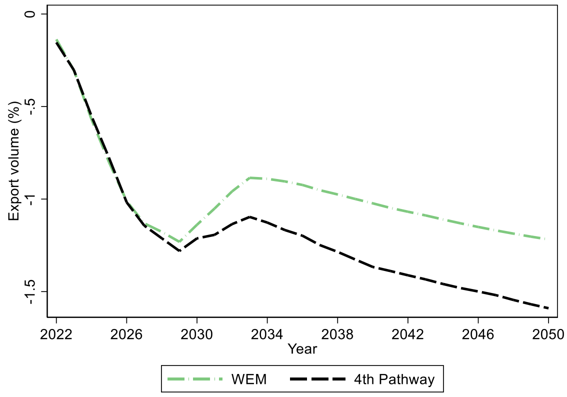
Unit: Percentage change - deviation from WOM



Source: Principal Economics

Figure 3.4 Export volume impacts

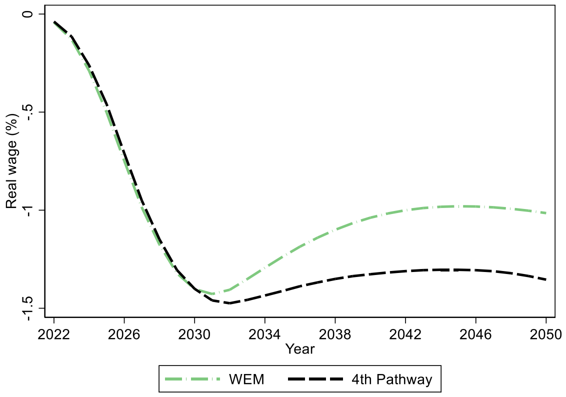
Unit: Percentage change - deviation from WOM



Source: Principal Economics

Figure 3.5 Real wage impacts

Unit: Percentage change - deviation from WOM



Source: Principal Economics

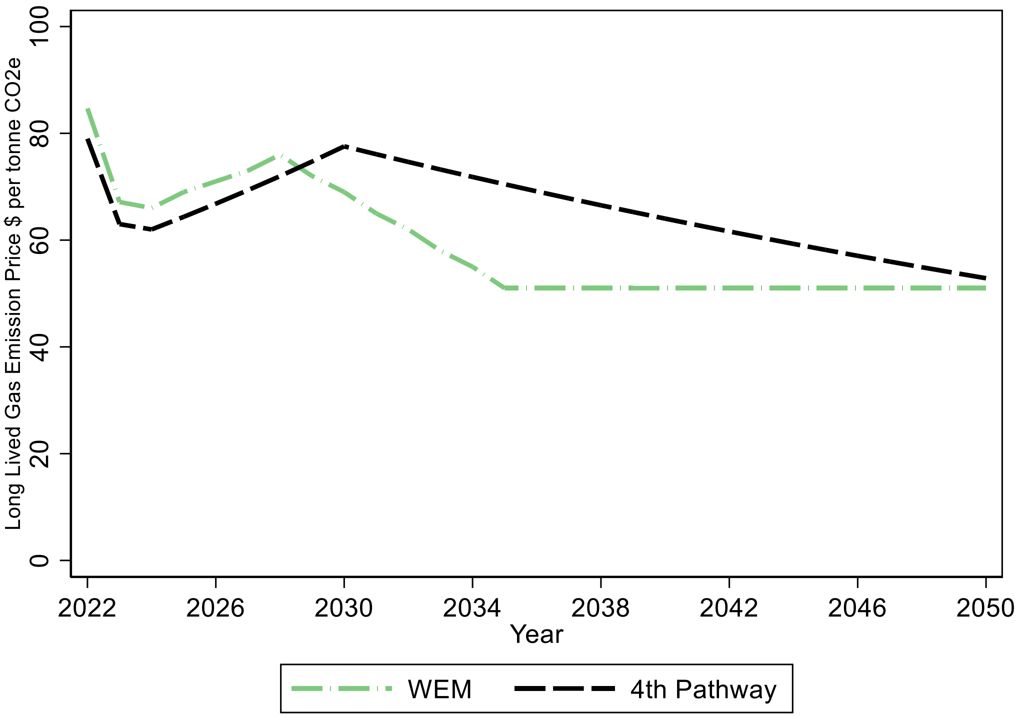
3.2 Emission prices: range between $51 and $85 depending on non-pricing policy assumptions and play a significant role in achieving the emission target

Both policy scenarios consider carbon prices to be exogenous. It is important to note that long-lived gas emission prices in the model are not ETS prices. They represent the economic incentive necessary to drive emissions reductions. This could be an ETS price or could be another policy instrument. As illustrated in Figure 3.6, while the price path is the same until 2028, it decreases significantly for the WEM scenario. It is important to note that the price is after free allocation.[4] In addition to the required carbon price, economic incentives will be required for Biogenic Methane emission reduction. In the model, we have applied this as a tax on Methane emissions.

4 Free allocations is defined as any permits in excess of industries' emission can be sold for the market price and free of any immediate financial cost.

Figure 3.6 Policy Scenarios – Long Lived Gas emission price

Unit: 2023$/tonne CO2e



Source: Principal Economics

Note: The prices are after free allocation.[5]

3.3 Emission reduction: is the highest for the scenarios with significant carbon pricing

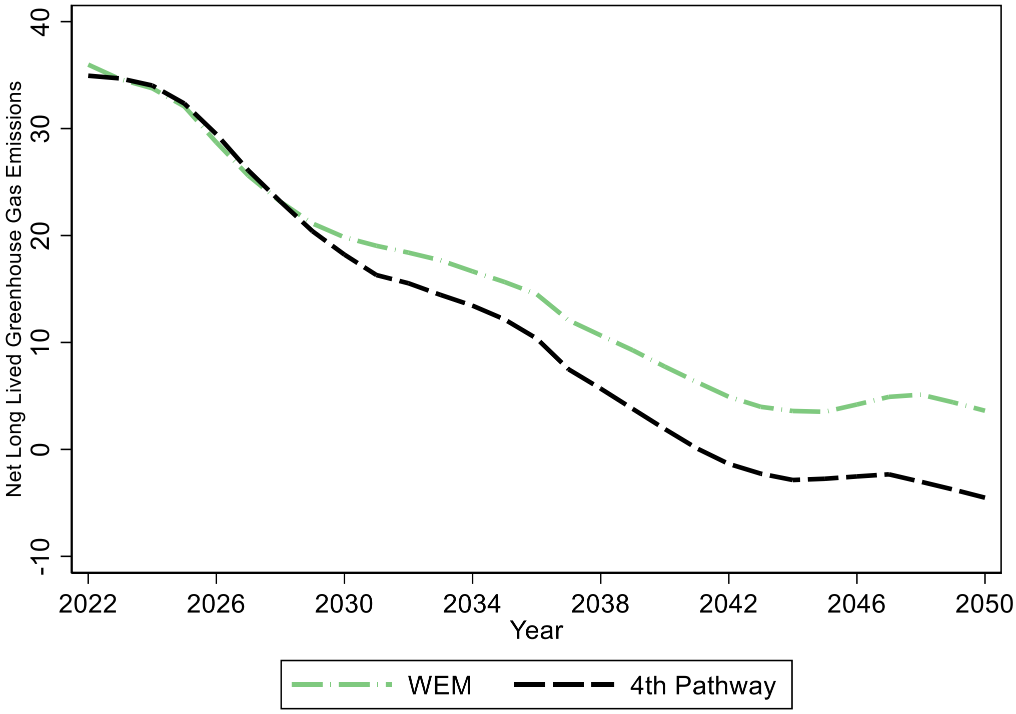
The output of the pricing and non-pricing policies leads to the GHG emission outputs shown in Figure 3.7. Accordingly,

- Under current policy settings, New Zealand is not expected to meet its 2050 emissions targets.
- The Fourth Pathway scenario meets the targets, which come at the cost of the pricing policies presented above and the equity impacts that we will present next.

[5] Free allocation is based on the price of permits that can be traded. Some industries are given the permits for free. Any permits in excess of their emission can be sold for the market price at the carbon price level. Hence, for these industries the opportunity cost of emitting is equal to the carbon price, but they do not face any immediate financial cost.

Figure 3.7 Policy scenarios: Net Long Lived Greenhouse Gas emissions

Unit: $MtCO_2e$

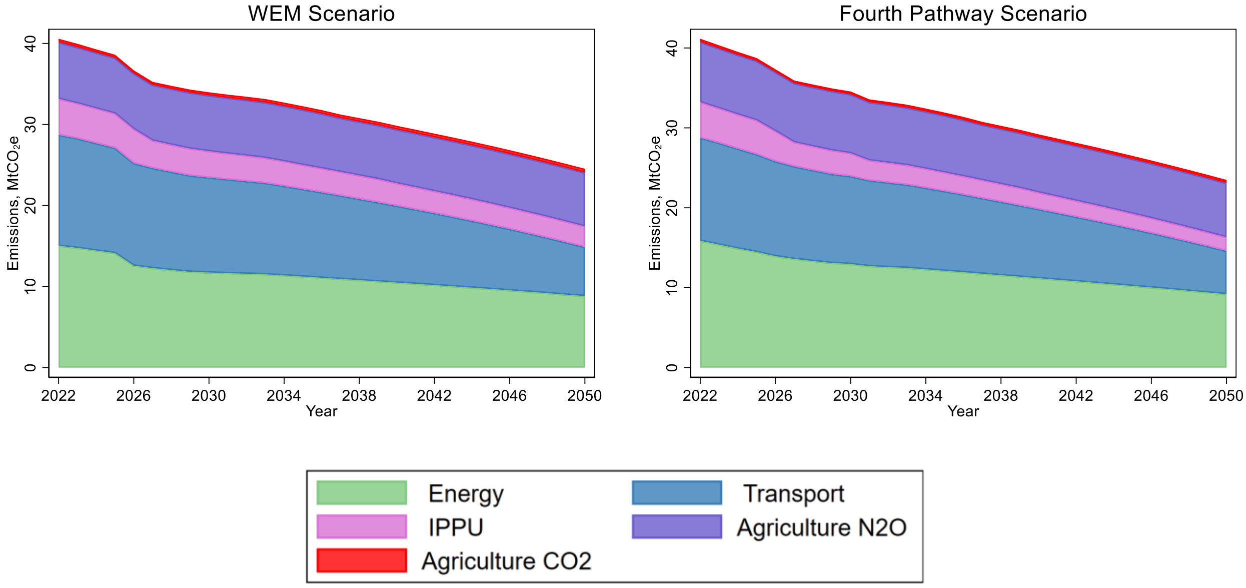


Source: Principal Economics

Figure 3.8 shows the gross Long Lived Greenhouse Gas emissions by sector for each scenario between 2020 and 2050. The overall reductions are consistent with the previous figure. The most significant impact across all scenarios is on the transport sector followed by energy, agriculture, and industrial processes. Compared with the current pathway, the energy sector's emissions are reduced more in the Fourth Pathway, which is led by the Fourth Pathway's assumed shift to clean energy from the Electrify New Zealand policy.

Figure 3.8 Policy scenarios: Gross Long Lived Greenhouse Gas Emissions by sector over time

Unit: $MtCO_2e$

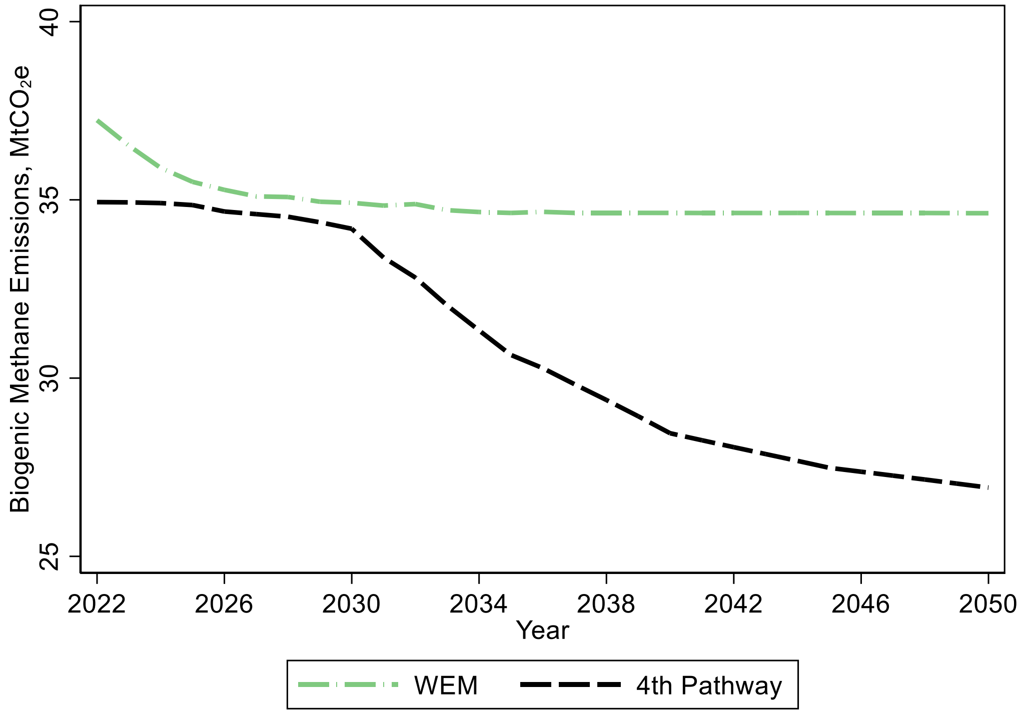


Source: Principal Economics

Figure 3.9 shows the biogenic methane emissions. A higher Methane price leads to higher Biogenic Methane emission reductions. The Fourth pathway has a higher Methane emission reduction, consistent with that modelled in ENZ.

Figure 3.9 Biogenic Methane Emissions

Unit: Million tonnes CO_2e



Source: Principal Economics

3.4 Equity impacts: overall Māori people are more adversely affected

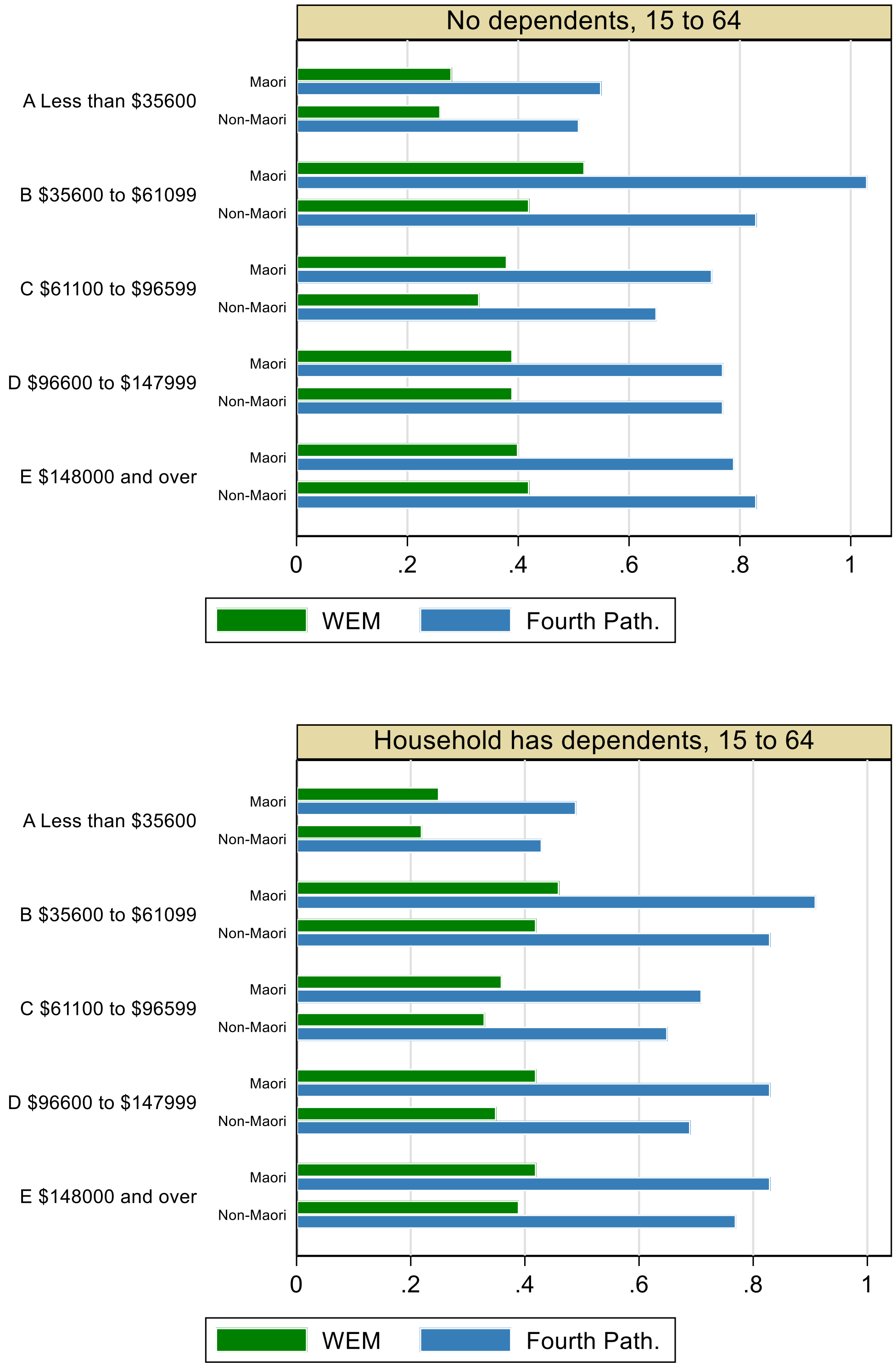
We disaggregated the impacts for income groups by household composition (Having dependents or not), household age group (15 to 64 and 65 and over), and ethnicity (Māori and others). Figure 3.10 shows the impacts for the working age group (15 to 64) and Figure 3.11 illustrates the impacts for the 65 and over age group. Accordingly,

- The impacts range between -0.2 and -0.6 per cent for WEM and -0.4 and -1.2 per cent for the Fourth Pathway scenario (compared to the WOM scenario).
- Overall, Māori households are more adversely affected in all scenarios and across all household income groups.[6]

[6] The fourth income quintile of the 65 and over age group with no dependents is an exception.

Figure 3.10 Household consumption impact by household composition and ethnicity for the 15 to 64 age group

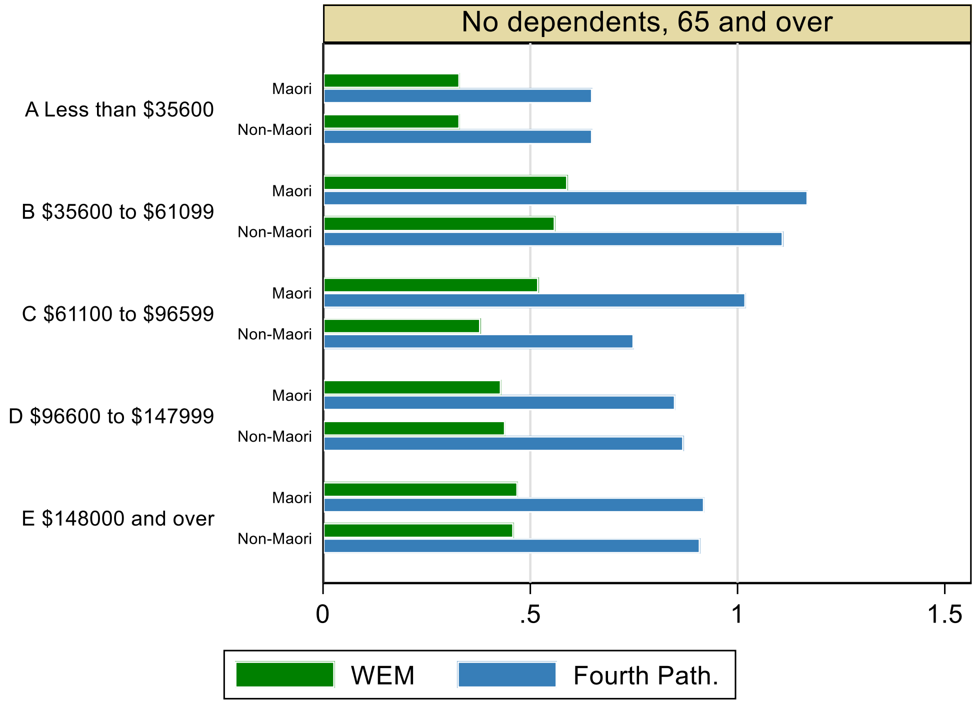
Unit: Percentage decrease in real consumption from WOM



Source: Principal Economics

Figure 3.11 Household consumption impact by household composition and ethnicity for the 65 and above age group

Unit: Percentage decrease in real consumption from WOM



Source: Principal Economics

3.5 Impact on industries: is more negative for agricultural output and related manufacturing activities

Table 3.2 shows the distribution of impacts across 72 industry sectors for different scenarios by 2050 – the presented figures are percentage changes from the WOM scenario. Accordingly,

- Agricultural output and related manufacturing are significantly lower across both pathways by 2050 relative to a "Without Measures" counterfactual.
- However, the differences between scenarios are relatively small, suggesting it is the overall transition rather than the policy mix driving the change.[7]
- Mining and some heavy manufacturing decline.
- Most services sectors see little impact, while forestry and related manufacturing expand slightly.
- There is a switch from ICE to BEV transport services.

[7] There might be opportunities arise in the transition, eg increased demand for New Zealand commodities from changing consumer preferences. These could be separately modelled, but are currently not incorporated in the model, which could lead to overstatement of the negative impacts. For example, our recent assessment of the economic impact of International Accreditation New Zealand (IANZ) highlighted that with the recent focus on emission reductions in trade, particularly because of the recent consideration of indirect emissions, exporters will likely benefit significantly from accreditation services. (Principal Economics, 2023)

There are variations across scenarios in terms of their impacts on industries based on the policies adopted for each scenario. For example, the Fourth Pathway assumes a shift towards renewables, which leads to a significant reduction in electricity generation using gas. The Fourth Pathway also has a slightly lower agricultural GDP compared to the current Pathway (WEM) due to the higher carbon price assumption and the wider economic impact of renewable electricity generation in the Fourth Pathway.[8]

Table 3.2 Impacts on industries

Unit: Percentage deviation from WOM

Industry	WEM	Fourth Path
Sheep and wool	-7.84	-11.39
Beef cattle	-8.38	-12.19
Dairy cattle	-6.12	-9.46
Other animal	-5.85	-8.59
Broadacre cropping	-4.02	-6.50
Other agriculture	-2.21	-3.51
Agricultural services	-3.03	-1.93
Fishing and aquaculture	2.28	2.74
Forestry and logging	0.36	11.95
Coal mining	-11.02	-13.05
Oil mining	-1.51	-2.50
Natural gas mining	-22.45	-25.09
Iron ore	1.52	1.69
Other mining	-0.47	-0.61
Meat products	-9.45	-13.74
Dairy products	-5.95	-9.53
Other food products	1.26	1.28
Drink products	1.60	1.82
Textiles, clothing and footwear	-0.41	-1.12
Wood products	1.08	3.01
Paper products and printing	2.00	3.33
Refined oil products	-4.52	-7.19
Basic chemicals	-11.19	-11.81

8 The fourth pathway differs from WEM by a shock that lowers the cost of renewable electricity and encourages greater use of renewable electricity at the expense of gas fired electricity. The technical change increases real GDP (Y), leading to more income and hence an expansion in real final domestic demand (C+I+G). The change in C+I+G absorbs all of the change in Y, leaving little room for a change in net exports (X-M). Lower electricity costs have the most marked effect on use of Electric vehicles (up) relative to internal combustion vehicles (down). Fewer IC services means less need for petroleum and oil products (nearly all of which is imported). Hence total imports fall. With (X-M) largely unchanged and less imports, exports must fall. The mechanism is weak real appreciation of the exchange rate. Real appreciation effects all exporting industries. The main ones are agricultural related (primary and secondary). Thus, agricultural exports fall leading to small reductions in agricultural production.

Chemical fertiliser	-2.90	-4.67
Plastic and rubber products	1.96	2.06
Non-metallic mineral products	0.44	0.39
Iron and steel	7.33	7.38
Metal products	-0.29	-0.59
Transport equipment	1.14	1.49
Appliances	2.81	3.60
Other equipment	2.69	3.47
Other manufacturing	2.19	2.93
Electricity generation - coal	0.00	0.00
Electricity generation - gas	0.00	-21.29
Electricity generation - geothermal	1.59	2.85
Electricity generation - hydro	0.00	0.00
Electricity generation - other renewable	1.59	7.19
Electricity supply	1.17	1.91
Gas supply	-1.08	-0.89
Water supply and waste services	-0.65	-0.93
Construction services	-0.31	-0.33
Wholesale trade services	-0.23	-0.38
Retail trade services	-0.25	-0.40
Hotels and accommodation	2.57	3.08
Restaurants and takeaway food	0.79	0.78
Road freight services	-1.90	-1.82
Road passenger services	0.41	0.30
Rail transport services	-1.48	-1.71
Water transport services	-0.29	-0.44
Air transport services	0.68	0.51
Other transport services	-0.46	-0.65
Information services	0.14	0.12
Financial services	-0.03	-0.12
Ownership of dwellings	0.03	-0.06
Rental services	-0.03	-0.10
Professional services	-0.08	-0.09
Administrative services	0.03	0.00
Public services	-0.09	-0.26
Education	0.30	0.23
Health	-0.05	-0.23
Arts and recreation services	0.33	0.22

Social services	0.36	0.30
Other commercial services	-0.16	-0.42
Services to domestic travellers	0.02	-0.16
Services to foreign tourists	1.86	1.86
Services to foreign students	5.39	7.10
Private transport services - ICV	-6.47	-10.37
Private transport services - BEV	0.80	1.02
Private transport services	0.16	0.05
Commercial transport services - ICV	-9.77	-14.81
Commercial transport services - BEV	7.30	11.70
Commercial transport services	-1.51	-1.53

Source: Principal Economics

Note: The blue colour presents a positive percentage change and the orange colour presents a negative percentage change. A darker colour shade shows a higher magnitude of effects.

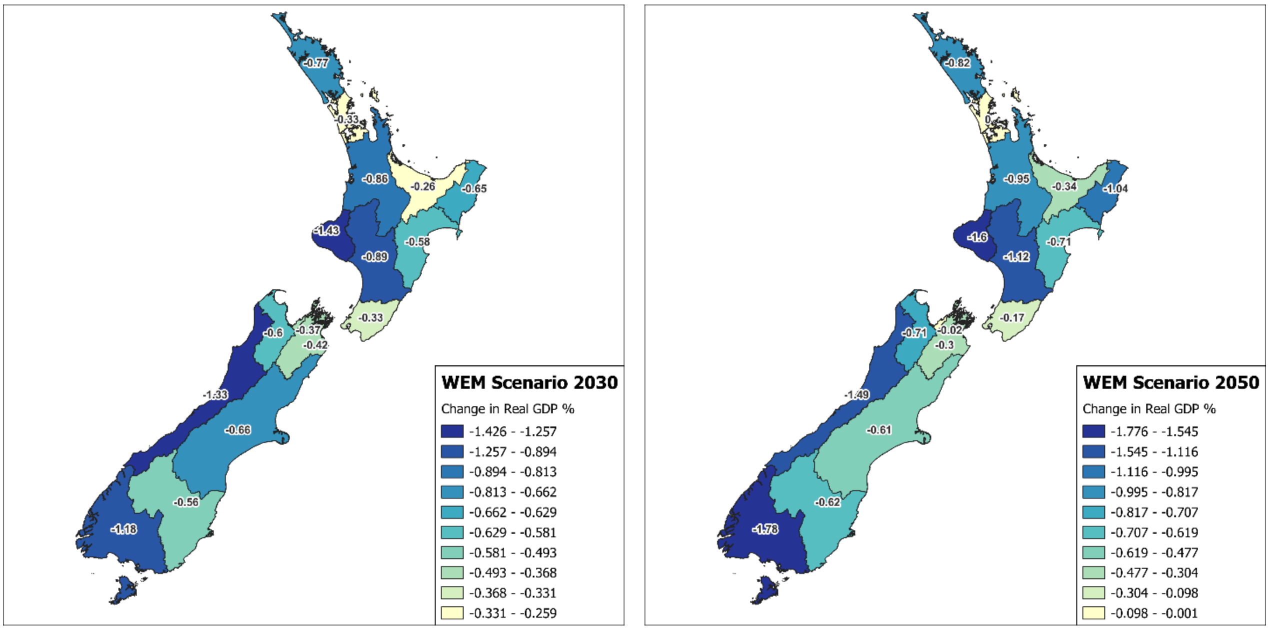
3.6 Regional impacts: While the large urban areas are least affected, the relative effects of scenarios vary across regions

Figure 3.12 to Figure 3.13 show the regional impacts for each scenario. The regional distribution depends on the spatial distribution of industries affected by policies and the differences across the scenarios in affecting those industries. As expected, the overall magnitude of the impacts is consistent with the order of scenarios observed at the national level. In this section, we are more interested in the distribution of impacts:

- Auckland and Wellington are least adversely affected – this is due to the higher share of the services sector in these regions.
- The adverse impacts on the South Island are overall higher than North Island – this is due to the higher concentration of the adversely affected industries in the South Island.
- A comparison between the 2030 and the 2050 impacts suggests that some regions experience the impacts earlier than others – which is explained by differences across the policies for emission budgets.

Figure 3.12 Regional real GDP impact for WEM by 2030 and 2050

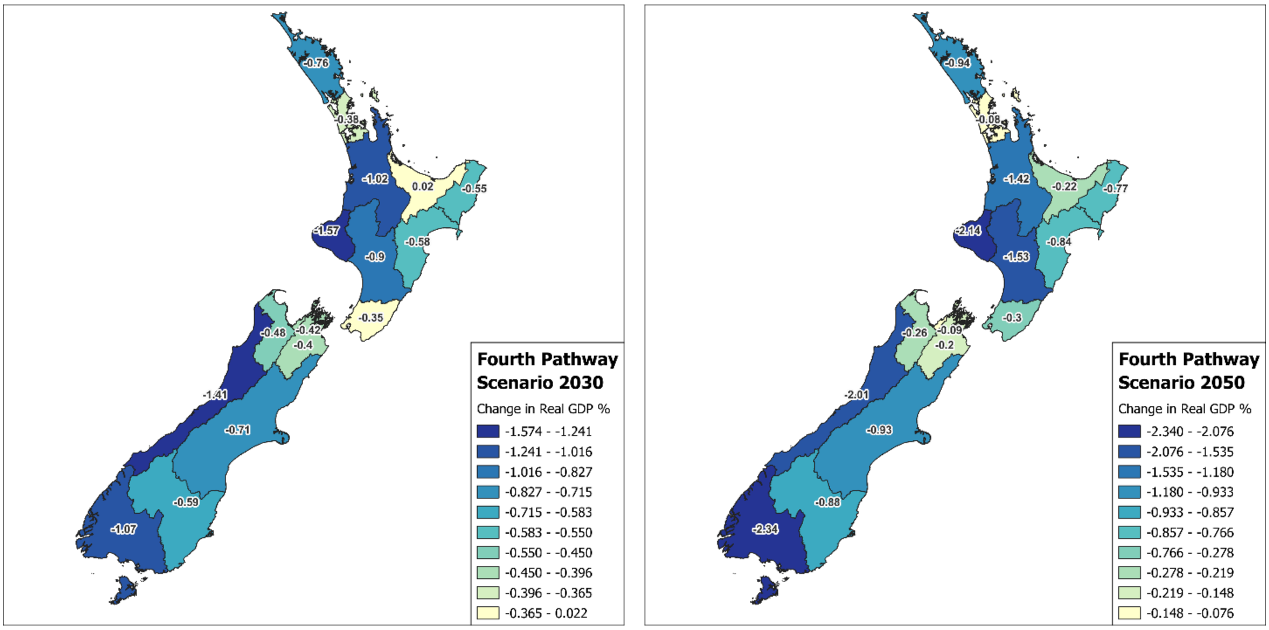
Unit: Percentage deviation from WOM



Source: Principal Economics

Figure 3.13 Regional real GDP impact for the Fourth Pathway scenario by 2030 and 2050

Unit: Percentage deviation from WOM



Source: Principal Economics

4 Limitations and the next steps

While dynamic CGE frameworks are widely used for the assessment of climate change policies in New Zealand and internationally, each modelling framework has its own limitations. We attempt to address these modelling uncertainties by considering a range of sensitivity analyses. We presented in the sensitivity testing scenarios in our earlier report, which showed significant economic, equity and emission trade-offs between scenarios depending on the policies adopted.

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Appendix A: PE-Climate: technical details

For ERP2 modelling, we used Principal Economics' New Zealand Climate (PE-Climate) model. PE-Climate is a dynamic Computable General Equilibrium (CGE) model of New Zealand designed for greenhouse analysis. It is built in the ORANI/MONASH tradition and solved using GEMPACK software.[9]

At the core of PE-Climate is based on the ORANIG model, described fully in Horridge (2000). To that is added a range of environmental enhancements developed for the Victoria University Regional Model[10], and several new mechanisms are required for the current project. The model is calibrated to a 2020 database[11] which distinguishes 72 industries[12], 16 sub-national regions as defined in the Census, and thirty household types.

In the following nine sections, we explain key aspects of the core model including industry classifications, the nature of markets, major components of demand, capital and employment in dynamic simulations, lagged adjustment in the labour market, modelling of the travel economy, household and government current accounts and net national income, the regional extension and the modelling of multiple households for distributional analysis.

A.1 Industry classification

PE-Climate is a dynamic, multi-sector model of New Zealand. Of the 72 industries, three produce primary fuels (*13. Coal*, *15. Oil* and *16. Gas*), one produces refined oil products (*26. RefinedOil*), five generate electricity and one supplies electricity to final customers. The five-generation industries are defined according to the primary source of fuel: *37. Eleccoal* includes all coal-fired generation technologies; *38. Elecgas* includes all plants using turbines, cogeneration and combined cycle technologies driven by burning gas and oil products; *39. Elecgeotherm* covers all geothermal plants; *40. Elechydro* covers hydro generation; and *41. Elecwind* covers the remaining forms of renewable generation from biomass, biogas, wind, solar etc.

At the bottom of the list are nine dummy industries (64-72) included to facilitate the modelling of travel (see Section 2.6) and of the introduction of Battery electric vehicles to replace internal combustion vehicles (see Section 3.3.2). There are three dummy travel sectors:

- 64 Domtravel produces services that New Zealanders buy when travelling locally. These include accommodation and entertainment services and petrol. The industry sells to households and businesses. Imports of domestic travel are purchased when New Zealanders travel overseas.
- 65 ForTourists produces services purchased by foreign tourists in New Zealand. These include air transport (NZ airlines only), accommodation and entertainment services. The industry sells only to export.
- 66 ForStudents, similar to industry 65 but covering the expenditure of foreign students while living in New Zealand. The composition of this expenditure is broader than tourist spending as it includes a broader range of items bought for every-day use.

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9 ORANI/MONASH models are large CGE models solved in percentage changes. Their origins lie in the work of Peter Dixon – see Dixon and Rimmer (2001). GEMPACK (General Equilibrium Modelling PACKage) is a suite of economic modelling software described fully in Horridge et al. (2018). It is especially suitable for CGE models, but can handle a wide range of economic behaviour.

10 See Adams and Parmenter (2013). Full technical documentation is in Adams et. al. (2015).

11 The database is built from Input/Output, national accounts and demographic statistics for the year ended first quarter of 2020, and from greenhouse and energy data aggregated over the same four quarters. Further details of the database construction and summary statistics are available on request.

12 72 products produced by the 72 industries.

There are six dummy vehicle services industries. The first three cover the provision of services from light passenger vehicles (cars and vans). The second three cover services of large commercial vehicles (including buses and trucks), and services provided by agricultural, mining and construction equipment traditionally powered by IC motors. *67. ICVPservices* and *68. BVPservices* produce passenger services from IC vehicles and Battery-electric vehicles.[13] These industries sell only to *69 PVServices,* which sells vehicle services to final customers (households and service industries such as wholesale and retail trade). *70. ICVCservices* and *71. BVCservices* produce commercial services from IC vehicles (and equipment) and Battery-electric vehicles. Their only customer is *72 CVServices,* which sells vehicle and equipment services to final industrial customers in agriculture, mining, manufacturing, construction and transport.

A.2 The nature of markets

PE-Climate determines supplies and demands of commodities through optimizing behaviour of agents in competitive markets. Optimizing behaviour also determines industry demands for labour and capital. Labour supply at the national level is determined by demographic factors, while national capital supply responds to rates of return.

The assumption of competitive markets implies equality between the basic price (i.e., the price received by the producer) and marginal cost in each sector. Demand is assumed to equal supply in all markets other than the labour market (where excess-supply conditions can hold). The government intervenes in markets by imposing *ad valorem* sales taxes on commodities. This places wedges between the prices paid by purchasers and the basic prices received by producers. The model recognizes margin commodities (e.g., retail trade and road transport) which are required for the movement of a commodity from producers to the purchasers. The costs of the margins are included in purchasers' prices of goods and services.

A.3 Demand

A.3.1 Inputs to be used in the production of commodities

The core model recognises two broad categories of inputs: intermediate inputs and primary factors. Firms in each regional sector are assumed to choose the mix of inputs that minimises the costs of production for their levels of output. They are constrained in their choices by a three-level nested production technology. At the first level, intermediate-input bundles and a primary-factor bundle are used in fixed proportions to output.[14] These bundles are formed at the second level. Following Armington (1969), intermediate-input bundles are combinations of domestic goods and goods imported from overseas. The primary-factor bundle is a combination of labour, capital and land. At the third level, labour is formed as a combination of inputs from different occupational categories.

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13 The Input/Output data on which this model is based does not distinguish vehicle type. The activities of running vehicles and other IC equipment are accounted for by industries and final users buying separately fuel, vehicle equipment such as tyres and batteries and equipment (transport and other). In PE-Climate, we reconfigure the primary Input/Output data by creating separate dummy industries that sell the services of two vehicle type (ICVs and BEVs). This is reasonably straightforward. However, for the purposes of modelling greenhouse policy, we also need to distinguish passenger transport services, which can be electrified relatively easily, from commercial vehicle services, which cannot. To do this we have had to include all IC powered vehicles and equipment into one "vehicle" type, even though the vehicles and equipment perform very different roles.

14 A miscellaneous input category, *Other costs*, is also included and required in fixed proportion to output. The price of O*ther costs* is indexed to the price of private consumption. It is assumed that the income from O*ther costs* accrues to the government.

The assumption of fixed proportions between composite inputs to production does not apply for the electricity supply industry, which can substitute between different generation providers, and the passenger and commercial vehicle service industries, which can substitute between ICV and BEV services.

A.3.2 Domestic final demand: household, investment and government

A single representative household buys bundles of goods to maximise a utility function subject to an expenditure constraint.[15] The bundles are combinations of imported and domestic goods. A simple consumption function, with a fixed average propensity to consume (APC), is usually used to determine aggregate household expenditure as a function of household disposable income.

Capital creators for each sector combine inputs to form units of capital. In choosing these inputs, they minimise costs subject to a technology similar to that used for current production, with the main difference being that they do not use primary factors directly.

The national government demands commodities for consumption. In PE-Climate, there are several ways of handling these government demands, including:

- by a rule such as moving government expenditures with aggregate household expenditure, domestic absorption or GDP;
- as an instrument to accommodate an exogenously determined target such as a required level of government budget deficit; and
- exogenous determination.

For baseline simulations, we generally adopt the first rule, with government and household consumption moving together. For policy simulations, we often use the second rule so that government consumption adjusts endogenously to maintain the fiscal balance at its baseline level.

A.3.3 Foreign demand (international exports)

PE-Climate adopts the ORANI specification of foreign demand. Each export-oriented sector faces its own downward-sloping foreign demand curve. Thus, a shock that reduces the unit costs of an export sector will increase the quantity exported, but reduce the foreign-currency price. By assuming that foreign demand schedules are specific to the product, the model allows for differential movements in foreign-currency prices across exported products.

A.3.4 Demand for margin services

Margins are services used to facilitate the flow of commodities from producers to users (for domestically-produced commodities), or from the point of entry to users (for imported goods). Typical examples of margins are trade and transport services.

In PE-Climate six industries produce margin commodities, namely *45. TravelWR*, *49. RoadFreight*, *51. RailTransprt*, *52. WaterTransprt*, *53. AirTransport* and *54. OthTransport*. In the absence of margin-using technical change, each margin service is assumed to be used in fixed proportion to the commodity flow that they facilitate. For example, if household consumption of hotels were to rise by 3 per cent, then the usage of all margins associated with the use of hotels by the household would increase by 3 per cent.

A.3.5 Land demand and supply

In PE-Climate, the land is an input to production for the agricultural, forestry, mining and dwelling services industries. In most CGE models that identify land, the standard treatment is to treat land as industry-specific and in fixed supply. Hence, when a land-using industry expanded, the scarcity value of its land increases, leading to an increase in its rental price but no change in the quantity of land used.

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15 In Section 2.9 we explain how expenditure of the single representative household is split into expenditures of different household types to obtain distributional results.

For the simulations to be conducted with PE-Climate we assume that land is supply constrained for use in the mining and dwellings industries, but there is limited mobility for agricultural and forestry use. Total land available for agriculture and forestry is assumed to be fixed, along with a portion of each industry's initial land allocation. For forestry, the land in fixed supply consists mainly of national parks and other areas set aside for environmental purposes. For the agricultural industries, the share of fixed land in total land is less than for forestry. Fixed agricultural land consists of land which for reasons of climate, soil type and infrastructure (availability of irrigated water, for example), cannot easily change use.

For mobile land in agriculture and forestry, an industry can increase its land usage but that increase has to be met by reduced usage by other industries within the sector. Mobile land is assumed to be allocated between users to maximize the total return to land subject to a Constant Elasticity of Transformation (CET) constraint defining production possibilities across the various land-using sectors.[16] This is the same treatment as adopted in GTAP. With this mechanism in place, if demand for bio-sequestration offsets pushes up demand for land in the forestry sector, then forestry's use of mobile land will increase, increasing the region-wide price of land and causing non-forestry (agricultural) industries to reduce their mobile land usage.

A.4 Capital and investment in dynamic (year-to-year) analysis

PE-Climate recognises industry-specific stocks of capital and flows of investment. This is in contrast to models developed in the GTAP tradition[17] which assume that there is one type of capital built by a single investor. In PE-Climate, because capital is distinct to each industry, it cannot move freely between industries. Instead, each industry has a capital supply function which determines capital supply (investment) as a function of the industry's rate of return.

PE-Climate's dynamic theory of investment is explained below.

For some industry i, investment undertaken in year t is assumed to become operational at the start of year t+1. Under this assumption, capital in industry i accumulates according to:

$$K_i(t+1) = (1 - DEP_i) \times K_i(t) + Y_i(t) \qquad \text{(Equation A.1)}$$

where:

$K_i(t)$ is the quantity of capital available in industry i at the start of year t;

$Y_i(t)$ is the quantity of new capital created in industry i during year t; and

DEP_i is the rate of depreciation for industry i.

Given a starting value for capital in t=0, and with a mechanism for explaining investment, Equation A.1 traces out the time paths of industries' capital stocks.

Following the approach taken in the MONASH model investment in year t is explained *via* a mechanism of the form:

$$\frac{K_i(t+1)}{K_i(t)} = F_i\left[\frac{EROR_i(t)}{RROR_i(t)}\right] \qquad \text{(Equation A.2)}$$

where,

16 We assume, for each industry, that the price of mobile land is the same as the price of fixed land.

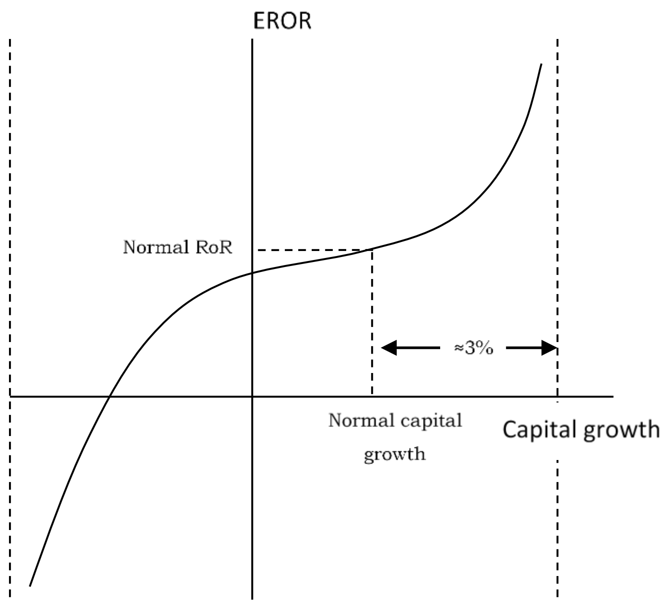
17 GTAP stands for Global Trade and Protection. The GTAP model is described fully in Hertel *et. al*. (1997).

- *$EROR_i(t)$* is the expected rate of return in year t;
- *$RROR_i(t)$* is the required rate of return on investment in year t;
- *F_i* is an increasing function of the ratio of expected to required rate of return.

In standard closures of the model, *RROR* is an exogenous variable which can be moved to achieve a given growth rate in capital. As shown in Figure A.1, the function F() has an inverse logistic form. This has been chosen to prevent unrealistic large short-term investment responses to changes in anticipated capital rentals and other factors affecting the rates of return.

In the current version of PE-Climate, it is assumed that investors take into account only of current rentals and asset prices when forming expectations about rates of return (static expectations). An alternative treatment available in the MONASH model, but not currently for PE-Climate, allows investors to form expectations about rates of return that are consistent with model-determined present values of the rentals earned from (rational expectations).

Figure A.1 Relationship between capital growth and expected rate of return



Source: Principal Economics

A.5 Lagged adjustment process in the national labour market

In comparative static analysis, one of the following two assumptions is made about the national real wage rate and national employment:

- The national real wage rate adjusts so that any policy shock has no effect on aggregate employment (a typical long-run assumption); or
- The national real wage rate is unaffected by the shock and employment adjusts (a typical short-run assumption).

One of the dynamic features of PE-Climate is the allowance for a third, intermediate position, in which real wages can be sticky in the short run but flexible in the long run, and employment can be flexible in the short run but sticky in the long run. For year-to-year policy simulations, it is assumed that the deviation in the national real wage rate increases over time in proportion to the deviation in national employment from its baseline-forecast level. The coefficient of adjustment is chosen so that the employment effects of a shock are largely eliminated after about ten years. In other words, after about ten years, the benefits of favourable shocks, such as outward shifts in export demand curves, are realized almost entirely as increases in real wage rates. This is consistent with macroeconomic modelling in which the NAIRU is exogenous. The idea is expressed through the equation:

$$\left\{\frac{W_t^p}{W_t^f}-1\right\}=\left\{\frac{W_{t-1}^p}{W_{t-1}^f}-1\right\}+\alpha\left\{\frac{E_t^p}{E_t^f}-1\right\} \qquad \text{(Equation A.3)}$$

Equation A.3 says that while employment in the policy simulation is, say, above its baseline forecast level, the real wage rate moves further and further above its forecast level. This leads to lower demand for labour, and employment adjusts downward over time until it returns to the baseline forecast level, at which point adjustment pressure on the wage rate ceases. The implication of this is that favourable shocks generate a short-run gain in aggregate employment and a long-run gain in real wages.

A.6 Travel

The visitor economy has been seen as one of New Zealand's growth areas for a number of decades. But more importantly for this study it has become a key contributor to the economy's GHG emissions through its use of petroleum products. Thus it deserves special attention in the PE-Climate model.

PE-Climate extends more conventional CGE frameworks by distinguishing the economic aspects of tourism in a way that allows tourism's contribution to major national accounting aggregates and GHG emissions to be determined. It does so by the inclusion of three new "dummy" tourism industries.

- *64. DomTravel* – inputs are the visitor expenditures by New Zealanders. Expenditure includes all associated taxes and margins. Spending on domestically produced DomTravel is spending associated with visitation within New Zealand. Because of the nature of data on tourism spending, that spending includes spending on holidays, on business, and for education. Spending on imported DomTravel is spending by New Zealanders travelling overseas on holidays, on business, and for education. DomTravel uses no capital or labour. It sells only to the representative consumer (non-business travel) or to industries (business travel).
- *65. ForTourists* - inputs are expenditures by foreigners in New Zealand other than students visiting for education. Expenditure includes all associated taxes and margins. The industry uses no capital or labour and sells only to export.
- 66. ForStudents – inputs are expenditures by foreign students in New Zealand, including all associated taxes and margins. The industry uses no capital or labour and sells only to export.

The new industries share the same commodity input structures as existing industries in the model. Specifically, by assumption, each chooses a mix of inputs that minimises the costs of production for a given level of output. Intermediate-input bundles are used in fixed proportions to output. These bundles comprise combinations of international imported goods and domestic-goods with the same name.

Any user in the model can purchase output of the new tourism industries. However, in practice, the sources of demand are restricted to those described above. Domestically-produced and imported *DomTravel* are used by industries for current production and households. In both uses, the ratios of domestically-produced and imported versions respond to changes in relative price. For example, an increase in the price of the domestically-produced *DomTravel* relative to the price of the imported good, causes industries and households to shift from domestic travel (domestic DomTravel) to foreign travel (imported DomTravel).

Export demand is the only source of demand for *ForTourists* and *ForStudents*. That demand is also price responsive. For example, an increase in the price of *ForTourists* due to real appreciation of the exchange rate will reduce the simulated number of foreign tourists entering New Zealand.

This approach of specifying tourism service industries not only improves the model's treatment of travel, it also enhances its explanation of the effects of environmental policies. For example, a carbon price or tax which increases the price of petroleum products in a conventional model would reduce demand for petroleum, but have relatively little impact on demand for other travel-related products. With the new industries in place, the increase in fuel price increases the price of tourism bundles, leading to a reduction in demand not only for fuel but also for the other complementary products which comprise tourist expenditure bundles.

A.7 Household and government current accounts and Net national income

Current expenditure by the representative household is explained by a function that links nominal consumption to nominal household disposable income (HDI) *via* a coefficient of proportionality – the Average Propensity to Consume (APC). Household disposable income is defined as labour income plus income from capital and land that accrues to the local population less taxes on individuals. In algebraic terms we assume:

$$HDI = LABINC + CAPINC + LANDINC - TAX_{INDIVIDUAL} \quad \text{(Equation A.4)}$$

LABINC is set equal to the sum of labour cost across industries. *CAPINC* and *LANDINC* are weighted sums of industry capital and land costs. The weights reflect guesses of local ownership shares. The local ownership share for most of the service and agricultural industries is assumed to be one, but for some of the manufacturing and mining industries the local shares are assumed to be 0.75 and in some cases 0.5. Hence:

$$CAPINC = \sum_{IND} LS_i \times CAP_i \quad \text{(Equation A.5)}$$

and

$$LANDINC = \sum_{IND} LS_i \times LAND_i \quad \text{(Equation A.6)}$$

where:

CAP_i and $LAND_i$ are the costs of capital and land in industry I and LS_i is the local ownership share.

Individual tax collections are set initially to observed values and expand through the baseline in line with nominal Gross National Income (GNI). We assume a simple average – marginal tax rate, which is typically exogenous. GNI is defined as:

$$GNI = GDP - \sum_{IND} (1 - LS_i) \times [CAP + LAND_i] \quad \text{(Equation A.7)}$$

, where GDP is nominal GDP.

For government revenue we identify five lines of revenue all from taxation:

- GST taxation receipts
- Taxes on individuals
- Taxes on companies
- Duties
- Taxes on greenhouse gas emissions

Changes in each item of government revenue are linked to those in the model core through the use of relevant drivers of underlying economic activity (usually expressed in percentage change form) and, in the case of taxes, to the relevant average tax rates. The relevant drivers are:

- GST taxation receipts – nominal final domestic demand (Gross national expenditure)
- Taxes on individuals – nominal Gross National Income
- Taxes on companies – nominal cost of capital
- Duties – nominal GDP
- Taxes on greenhouse gas emissions – quantity of GHG emissions (covered by the tax or price).

A.8 Regional extension

The Regional Equation System (RES) that has been incorporated into PE-Climate is based on a top-down method that, with minimal requirements for regional data, allows national-level results (generated in the core PE-Climate system) to infer the implications of forecasting scenarios and policy scenarios for growth in output and employment at the regional level (Dixon, *et. al.,* 1982, Chapter 6).

The RES first divides the industries distinguished in PE-Climate into two groups, *national* industries and *local* industries *National* industries produce products that are readily traded between regions (e.g., most agricultural, mineral and non-perishable manufactured goods and some services such as public administration and defence). *Local* industries produce perishable goods or services that are not readily traded between regions. Local industries in the current application of PE-Climate are industries 1, 47, 48, 57-59, 61 and 62.

In the RES, the regional outputs of *national* industries are assumed to be independent of regional demand for them. Using the system in conjunction with PE-Climate, percentage changes in the regional outputs of *national* industries are assigned exogenously in ways that are compatible with the relevant PE-Climate national-level results. The default assignment in our simulations is to assume that for a given *national* industry all regional percentage changes are the same as the national-level percentage changes. In algebraic terms,

$$x1tot(i,r) = natx1tot(i) \qquad \text{(Equation A.8)}$$

where *x1tot(I,r)* is the percentage change in the output of national industry i in region r; and *natx1tot(i)* is the percentage change in national output of i from PE-Climate.

Assignments in which (7) does not apply for all regions are also possible so long as they conform to the constraint:

$$\sum_{REG} S(i,r) \times x1tot(i,r) = natx1tot(i) \qquad \text{(Equation A.9)}$$

where *S(i,r)* is the share of region r in the national output of industry i.

The RES includes regional multiplier effects by requiring that the outputs of *local* industries in region r meet the region's demand for *local* commodities. In computing a region's demand for *local* products, the system includes the intermediate and investment demands of the region's *national* and *local* industries, household demand and government demand. As it does for *national* industries, the system ensures that the percentage change in the regional outputs of *local* industries are consistent with the economy-wide percentage changes generated by PE-Climate (i.e., constraint (8) holds for all industries).

A.9 Household types

PE-Climate allows for thirty types of households, based on household income quintiles, ethnicity (Māori and others), household composition (having dependants under 15 years old or not), and the average age of household – these categories are shown in Table A.1. The data is derived from New Zealand Household Economic Survey 2023. The survey collects information from 4,000 respondents.

Table A.1 PE-Climate's household types

Code	Household Age Group	Household Composition	Household Income Quintile	Ethnicity
H1	15 to 64	Household has dependents	A Less than $35600	Māori
H2	15 to 64	Household has dependents	A Less than $35600	Non-Māori
H3	15 to 64	Household has dependents	B $35600 to $61099	Māori
H4	15 to 64	Household has dependents	B $35600 to $61099	Non-Māori
H5	15 to 64	Household has dependents	C $61100 to $96599	Māori
H6	15 to 64	Household has dependents	C $61100 to $96599	Non-Māori
H7	15 to 64	Household has dependents	D $96600 to $147999	Māori
H8	15 to 64	Household has dependents	D $96600 to $147999	Non-Māori
H9	15 to 64	Household has dependents	E $148000 and over	Māori
H10	15 to 64	Household has dependents	E $148000 and over	Non-Māori
H11	15 to 64	No dependents	A Less than $35600	Māori
H12	15 to 64	No dependents	A Less than $35600	Non-Māori
H13	15 to 64	No dependents	B $35600 to $61099	Māori
H14	15 to 64	No dependents	B $35600 to $61099	Non-Māori
H15	15 to 64	No dependents	C $61100 to $96599	Māori
H16	15 to 64	No dependents	C $61100 to $96599	Non-Māori
H17	15 to 64	No dependents	D $96600 to $147999	Māori
H18	15 to 64	No dependents	D $96600 to $147999	Non-Māori
H19	15 to 64	No dependents	E $148000 and over	Māori
H20	15 to 64	No dependents	E $148000 and over	Non-Māori
H21	65 and over	No dependents	A Less than $35600	Māori
H22	65 and over	No dependents	A Less than $35600	Non-Māori
H23	65 and over	No dependents	B $35600 to $61099	Māori
H24	65 and over	No dependents	B $35600 to $61099	Non-Māori
H25	65 and over	No dependents	C $61100 to $96599	Māori
H26	65 and over	No dependents	C $61100 to $96599	Non-Māori
H27	65 and over	No dependents	D $96600 to $147999	Māori
H28	65 and over	No dependents	D $96600 to $147999	Non-Māori
H29	65 and over	No dependents	E $148000 and over	Māori
H30	65 and over	No dependents	E $148000 and over	Non-Māori

Source: Principal Economics

Appendix B: PE-Climate: environmental enhancements

In this section, the key environmental enhancements of PE-Climate to are described. These are:

- Energy and emissions accounting.
- GHG taxes and prices.
- Inter-fuel substitution mechanisms.
- Abatement of non-combustion emissions.

B.1 Energy and emissions accounting

PE-Climate tracks emissions of greenhouse gases according to: emitting agent (72 industries and the household sector) and emitting activity (4). Three of the emitting activities are the burning of fuels (coal, natural gas and petroleum products). A residual category, named *Activity*, covers non-combustion emissions from agriculture, fugitives, industrial processes and waste net of sequestration from forestry. *Activity* emissions are assumed to be proportional to the level of activity in the relevant industries (animal-related agriculture, gas mining, cement manufacture, etc.).

The resulting 73 $\times$ 4 matrix of emissions is designed to include all emissions except those arising from land clearing. Emissions are measured in terms of carbon-dioxide equivalents, CO2-e. Table B.1 summarises PE-Climate's emission data for the model's year of record, 2022. Note that PE-Climate accounts for domestic emissions only; emissions from use of New Zealand exports in other countries are not included.

According to Table B.1, in 2020 the burning of coal, gas and oil products accounted for 7, 13 and 34 per cent of New Zealand's total GHG emissions. The residual comes from non-combustion sources. The largest emitting sector is the sheep, beef and dairy cattle industries which contributes around 68 per cent of all emissions. The next largest emitters are the passenger and commercial transport sectors which together contribute nearly 29 per cent to the overall level of emissions. Other large emitters are non-dairy agricultural industries, and the producer of waste services. Somewhat offsetting these emissions is forestry sequestration, all of which is attributed to *Forestry* (industry 9).

Table B.1 PE-Climate's emission data

Emitting agent	Emission from:				Total
	Coal	Gas	Petroleum	Activity	
1 SheepWool	0.01	0.00	0.00	9.54	9.55
2 BeefCattle	0.01	0.00	0.00	7.22	7.23
3 DairyCattle	0.02	0.02	0.00	19.62	19.66
4 OtherAnimal	0.00	0.00	0.00	1.16	1.16
5 BroadacCrop	0.00	0.00	0.00	0.30	0.30
6 OtherAg	0.11	0.00	0.00	1.56	1.67
7 AgServices	0.00	0.00	0.00	0.00	0.00
8 Fishing	0.00	0.00	0.00	0.00	0.00
9 Forestry	0.01	0.00	0.00	-23.31	-23.31
10 Coal	0.05	0.00	0.00	0.22	0.27
11 Oil	0.00	0.00	0.00	0.40	0.40
12 Gas	0.00	0.00	0.00	0.72	0.72

13 IronOre	0.00	0.00	0.00	0.00	0.00
14 OtherMin	0.17	0.06	0.00	0.00	0.23
15 MeatProds	0.08	0.00	0.00	0.39	0.47
16 DairyProds	0.27	0.31	0.00	0.57	1.15
17 OthFood	0.01	0.01	0.00	0.35	0.37
18 Drinks	0.00	0.00	0.00	0.17	0.17
19 TCF	0.01	0.00	0.00	0.00	0.01
20 WoodProds	0.01	0.00	0.00	0.00	0.01
21 PaperPrintin	0.00	0.00	0.00	0.00	0.00
22 RefinedOil	0.00	0.00	0.00	0.00	0.00
23 BasicChem	0.05	1.16	0.00	0.25	1.47
24 Fertilisers	0.00	0.10	0.00	0.00	0.10
25 Plastics	0.00	0.24	0.00	0.00	0.24
26 ConcrtNonMet	0.16	0.01	0.00	0.54	0.70
27 IronSteel	0.13	0.04	0.00	0.00	0.17
28 MetalProds	0.29	0.14	0.00	2.22	2.64
29 TransportEqp	0.00	0.00	0.00	0.00	0.00
30 Appliances	0.00	0.00	0.00	0.00	0.00
31 OtherEqp	0.00	0.00	0.00	0.00	0.00
32 OtherMan	0.01	0.00	0.00	0.00	0.01
33 ElecCoal	1.60	0.00	0.00	0.00	1.60
34 ElecGas	0.00	2.70	0.10	0.00	2.80
35 ElecGeotherm	0.00	0.00	0.00	0.00	0.00
36 ElecHydro	0.00	0.00	0.00	0.00	0.00
37 ElecWind	0.00	0.00	0.00	0.00	0.00
38 ElecSupply	0.00	0.00	0.00	0.00	0.00
39 GasSupply	0.00	0.72	0.02	0.00	0.73
40 WaterWaste	0.00	1.18	0.11	3.27	4.56
41 Construction	0.01	0.00	0.00	0.00	0.01
42 WholesaleTr	0.06	0.15	0.00	0.00	0.21
43 RetailTr	0.00	0.00	0.00	0.00	0.01
44 Hotels	0.00	0.00	0.00	0.00	0.00
45 Restaurant	0.00	0.00	0.00	0.00	0.00
46 RoadFreight	0.02	0.00	0.00	0.00	0.02
47 RoadPass	0.00	0.00	0.24	0.00	0.24
48 RailTransprt	0.00	0.00	0.00	0.00	0.00
49 WatrTransprt	0.00	0.00	0.00	0.00	0.00
50 AirTransport	0.00	0.00	1.52	0.00	1.52
51 OthTransport	0.01	0.00	0.27	0.00	0.28

52 InfoServ	0.00	0.00	0.00	0.00	0.01
53 FinanceServ	0.00	0.00	0.00	0.00	0.01
54 OwnerDwellng	0.00	0.00	0.07	0.00	0.07
55 RentalServ	0.00	0.00	0.00	0.00	0.00
56 ProfServ	0.02	0.00	0.00	0.00	0.02
57 AdminServ	0.00	0.00	0.00	0.00	0.00
58 PublicServ	0.00	0.00	0.00	0.00	0.00
59 Education	0.09	0.00	0.00	0.00	0.09
60 Health	0.21	0.00	0.00	0.00	0.21
61 ArtsRecreate	0.00	0.00	0.00	0.00	0.00
62 SocialServ	0.00	0.00	0.00	0.00	0.00
63 CommServ	0.00	0.00	0.00	0.00	0.00
64 DomTravel	0.00	0.00	0.00	0.00	0.00
65 ForTourists	0.00	0.00	0.00	0.00	0.00
66 ForStudents	0.00	0.00	0.00	0.00	0.00
67 ICVPservices	0.00	0.00	8.59	0.00	8.59
68 BVPservices	0.00	0.00	0.00	0.00	0.00
69 PVservices	0.00	0.00	0.00	0.00	0.00
70 ICVCservices	0.00	0.00	7.01	0.00	7.01
71 BVCservices	0.00	0.00	0.00	0.00	0.00
72 CVservices	0.00	0.00	0.00	0.00	0.00
73 Residential	0.08	0.00	0.00	0.00	0.08
Total	3.52	6.86	17.93	25.19	53.50

Source: Principal Economics

B.2 Carbon taxes and prices

PE-Climate treats a GHG tax or price as a specific tax on emissions of CO2-e. On emissions from fuel combustion, the tax is imposed as a sales tax on the use of fuel. On *Activity* emissions, it is imposed as a tax on the production of the relevant industries.

In PE-Climate, sales taxes (notably the GST) are generally assumed to be *ad valorem*, levied on the basic value of the underlying flow. Carbon taxes, however, are specific, levied on the quantity (CO2-e) emitted by the associated flow. Hence, equations are required to translate a carbon tax, expressed per unit of CO2-e, into *ad valorem* taxes, expressed as percentages of basic values. The CO2-e taxes are specific but coupled to a single price index (typically the price of consumption) to preserve the nominal homogeneity of the system. Suppressing indices, an item of CO2-e tax revenue can be written (using a generic notation) as:

$$Tax = S \times E \times I \qquad \text{(Equation B.1)}$$

where: *S* is the specific rate ($NZ per tonne of CO2-e); *E* is the emission quantity (tonne of CO2-e); and *I* is a price index (base year = 1) used to preserve nominal homogeneity.

Ad valorem taxes in PE-Climate raise revenue

$$TAX = \frac{V \times P \times Q}{100} \qquad \text{(Equation B.2)}$$

where: *V* is the percentage *ad valorem* rate; *P* is the basic price of the underlying taxed flow; and *Q* is the quantity of the underlying taxed flow.

To translate from specific to *ad valorem* the RHSs of equations B.1 and B.2 are set equal to each other, yielding:

$$V = \frac{S \times E \times I \times 100}{P \times Q} \qquad \text{(Equation B.3)}$$

As can be seen from Equation B.3, to convert specific CO_2-e taxes to *ad valorem* taxes frequent use is made of the ratio of the indexed value of emissions (*E×I*) to the value of the *ad valorem* tax base (*P×Q*). Indeed, values for the ratio across all fuels and users and the matrix of specific tax rates are the primary additional data items added to PE-Climate for modelling GHG taxes and prices.

Production taxes in PE-Climate are also assumed to be *ad valorem*, and levied on the basic value of production. Accordingly, the linking equation for a GHG tax/price on *Activity* emissions is:

$$V = \frac{S \times E \times I \times 100}{P \times Z} \qquad \text{(Equation B.4)}$$

where *Z* is the volume of production for which P is the basic price.

B.3 Inter-fuel substitution

In the core specification of PE-Climate, there is no price-responsive substitution between composite units of commodities, or between composite commodities and the composite of primary factors. With fuel-fuel and fuel-factor substitution ruled out, a GHG tax/price will induce abatement only through activity effects.

We correct this in three ways:

- first, by introducing inter-fuel substitution in electricity generation using the "technology bundle" approach[18];
- second, by allowing for BEVs to replace ICVs in the provision of passenger and commercial vehicle services; and
- third, by introducing a weak form of input substitution in sectors other than electricity generation to mimic "KLEM substitution"[19].

B.3.1 Price-responsive substitution in electricity

As noted in Section 2.1, electricity generation industries are distinguished based on the type of fuel used. There is also an end-use supplier (*42. Elecsupply*). Generation is sold directly to the end-use supplier and is not sold to anyone else. The electricity supply industry sells electricity to all final customers.

The end-use supplier can substitute between the different generation technologies in response to changes in generation costs. Such substitution is price-induced, with the elasticity of substitution between the technologies

18 The technology bundle approach has its origins in the work done at the Centre of Policy Studies, Monash University in the early 1990s, and at ABARES for the MEGABARE model (Hinchy and Hanslow, 1996).

19 KLEM substitution allows for substitution between capital (K), labor (L), energy (E) and materials (M) for each sector: see Hudson and Jorgenson (1974), and Berndt and Wood (1975).

typically set at 5. For example, if the price of hydro generation rises relative to the price of gas generation, then *ElecSupply* will shift towards gas generation and away from hydro generation.

This modelling of electricity supply and power demand is adequate for most PE-Climate simulations, but if more detailed supply information is required it can be overwritten by results from a detailed bottom-up model of the electricity system. Adams and Parmenter (2013) provide details of how detailed bottom-up electricity modelling can be inserted into a PE-Climate-like model. They also discuss the strengths and weaknesses of such an approach.

Finally, note that for emerging electricity generation technologies - wind, solar and geothermal - learning-by-doing mechanisms are added into the model. These operate primarily in the baseline, ensuring that over time levelised prices fall due to progressive reductions in primary-factor usage per unit of output.

B.3.2 Price-responsive substitution in supply of vehicle services

As explained in Section 2.1, PE-Climate has six dummy transport-related industries that facilitate modelling of household and industry demand for road transport services. Without enhancement, the model would have only one generic type of road transport vehicle sold to households and businesses, with demand for vehicles being determined separately from the demand for fuel (petroleum and electricity) and parts and repairs. Thus, vehicle usage might move in a different direction to fuel used, and there is no scope for specific substitutability between electricity and petroleum products as transport fuels. This is inadequate for greenhouse applications of the model.

In enhanced version of the model we distinguish two vehicle types used for private passenger transport: passenger BVs and passenger ICVs, and two vehicle types used for commercial transport (and equipment): commercial BVs and commercial ICVs. All are imported, with no domestic substitutes. These vehicles are purchased initially by four new dummy transport service sectors:

- the passenger BV services sector uses capital (the stock of passenger BVs), electricity and inputs required for the day-to-day running of electric vehicles (such as repairs and servicing);
- the passenger ICV services sector uses capital (the stock of passenger ICVs), petroleum and other inputs required for the day-to-day running of ICVs.
- the commercial BV services sector uses capital (the stock of commercial BVs), electricity and inputs required for the day-to-day running of electric vehicles; and
- the commercial ICV services sector uses capital (the stock of passenger ICVs), petroleum and other required inputs.

The two passenger vehicle service sectors sell only to the general Passenger services industry. The two commercial vehicle service sectors sell only to the general Commercial services industry. These aggregator industries, in turn, sell vehicle services to final customers – the household and industries. Demand by the aggregator sector for ICV and BV services is determined as solutions to a cost minimisation subject to a CES aggregator function. The substitution elasticity is set to 5 in both cases. Thus, for example, if the price of ICV services for passenger transport were to rise by 1 per cent relative to the price of BV services for passenger transport, then all else unchanged the demand for BV services relative to ICV services for passenger transport would rise 5 per cent.

With these new vehicle service industries in place, the household and businesses no longer directly purchase road vehicles (and equipment), fuels and other relate items. Instead, they purchase vehicle services that cover the full cost of using vehicles. This significantly improves the model's treatment of price-induced energy substitution for passenger vehicle use, and its treatment of the relationship between energy (electricity and petroleum) and vehicles. [20]

Finally note that we do not distinguish different vehicle types within each of the four broad categories. In other words, there is no explicit modelling of age, fuel efficiency or quality profiles. Depreciation rates are set such that vehicles are replaced on average every ten years.

B.3.3 Inter-fuel substitution outside of electricity and transport services

For other energy-intensive commodities used by industries, PE-Climate allows for a weak form of input substitution. If the price of cement (say) rises by 10 per cent relative to the average price of other inputs to construction, the construction industry will use 1 per cent less cement and a little more labour, capital and other materials. In most cases, as in the cement example, a substitution elasticity of 0.1 is imposed. For important energy products (petroleum, electricity and gas and gas) the substitution elasticity in industrial use is 0.25.

B.4 Abatement of non-combustion emissions

Non-combustion (or *Activity*) emissions include: agricultural emissions (largely from animals); fugitive emissions (e.g., gas flaring); emissions from industrial processes (e.g., cement manufacture); and emissions from land-fill rubbish dumps. In modelling with PE-Climate, it is assumed that in the absence of an emissions price, non-combustion emissions move with industry output, so that non-combustion emissions intensity (emissions per unit of output) is fixed.

PE-Climate's theory of abatement of non-combustion emissions in the presence of an emissions price is similar to that developed for the VURM model. It assumes that as the price of GHG emissions rises, *targeted* non-combustion emissions intensity (emissions per unit of output) falls (abatement per unit increases) through the planned introduction of less emission-intensive technologies.

More specifically, for *Activity* emitter i it is assumed that abatement per unit of output can be achieved at an increasing marginal cost according to a curve such as that shown in Figure C.1. In this figure, units are chosen so that complete elimination of non-combustion emissions corresponds to an abatement level of 1. However, complete elimination is not possible. So as shown in the figure, the marginal cost of abatement goes to infinity as the abatement level per unit of output reaches a maximum level, 1-MIN, where MIN is the proportion of non-combustion emissions that cannot be removed. From Figure C.2, an intensity function for emissions can be derived of the form:

$$Intensity_i = MAX_i\left\{MIN_i,\ F_i(T)\right\} \qquad \text{(Equation B.5)}$$

where: $Intensity_i$ is the target level of non-combustion emissions intensity; MIN_i is the minimum possible level of emissions intensity; and F_i is a non-linear monotonic decreasing function of the real level of the emissions price, T ($ per tonne of CO2-e in constant prices).

To ensure that emissions intensities do not respond too vigorously to changes in the emissions price, especially at the start of a simulation in which the price of GHG emissions rises immediately from zero, a lagged adjustment mechanism

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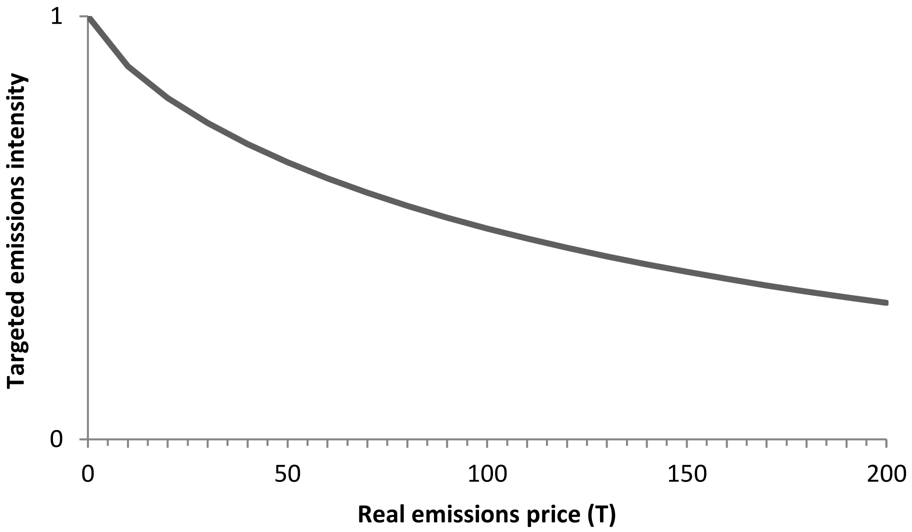
20 Note that without these new industries, if the price of petroleum were to fall relative to the price of electricity, then petroleum would be simply substituted for other commodities, including cars. But, with the new industries in place, a change in the price of petroleum induces substitution only through its effect on the price of Hybrid-vehicle and ICV services. If the change in petroleum price reduces the price of ICV and Hybrid services, then these services (including the associated capital and energy) will be substituted for BEV services.

is also put in place, allowing actual emissions intensity to adjust slowly towards targeted emissions intensity specified by (13).

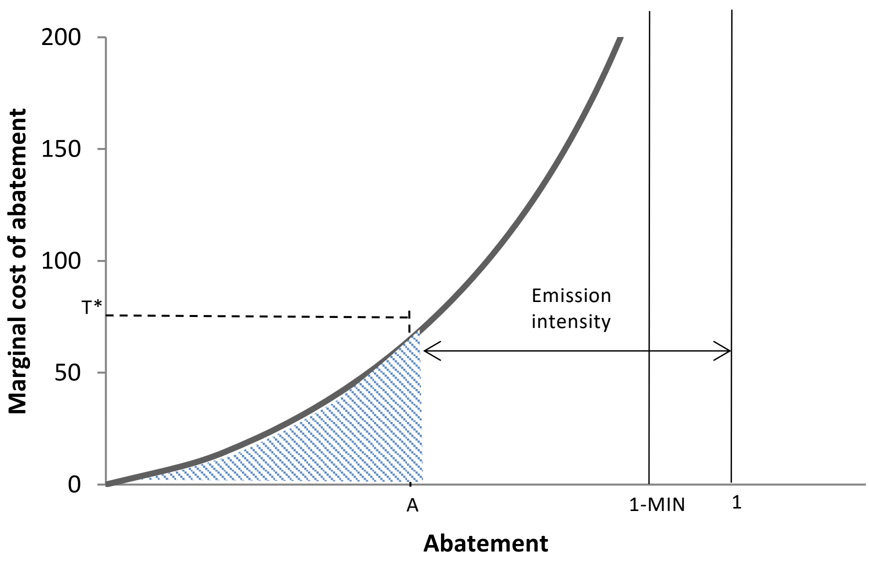
In PE-Climate, the abatement cost per unit of output (the shaded area in Figure C.2) is imposed as an all-input using technological deterioration in the production function of the abating industry.

Figure B.1 Marginal abatement curve for the hypothetical industry



Source: Principal Economics

Figure B.2 Emissions intensity as a function of the real carbon price



Source: Principal Economics