Regional consequences of climate change impacts on the primary sector

Economic analysis of scenarios for 2050

NZIER report to the Ministry of Business, Innovation and Employment

June 2025

About NZIER

New Zealand Institute of Economic Research (NZIER) is an independent, not-for-profit economic consultancy that has been informing and encouraging debate on issues affecting Aotearoa New Zealand, for more than 65 years.

Our core values of independence and promoting better outcomes for all New Zealanders are the driving force behind why we exist and how we work today. We aim to help our clients and members make better business and policy decisions and provide valuable insights and leadership on important public issues affecting our future.

We are unique in that we reinvest our returns into public good research for the betterment of Aotearoa New Zealand.

Our expert team is based in Auckland and Wellington and operates across all sectors of the New Zealand economy. They combine their sector knowledge with the application of robust economic logic, models and data and understanding of the linkages between government and business to help our clients and tackle complex issues.

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Key points

This economic analysis is part of a larger climate change programme

NZIER produced this macroeconomic analysis as part of a joint programme led by Manaaki Whenua Landcare Research. The programme was funded by the Ministry of Business, Innovation & Employment to understand the impacts of climate change on regional economies. Partners included Plant and Food Research and Scion, and the Ministry for Primary Industries provided expert and technical advice.

We analyse potential regional economic impacts in 2050

This report presents modelling of several scenarios for the New Zealand economy in 2050, and considers the impacts on regions and the food and fibre sectors. The scenarios consider potential changes in productivity and export markets, as well as impacts from climate change.

Scenarios and assumptions for modelling were developed collaboratively

The focus of the modelling was regional economies in 2050. We canvassed the range of issues facing regional economies collaboratively with partners Manaaki Whenua Landcare Research, Plant and Food Research, and Scion, and programme advisors from the Ministry of Business, Innovation and Employment and the Ministry for Primary Industries. We then collectively identified the priority issues. Some scenario details were then further developed with these experts. Other scenario details were based on climate change and commodity (crop) production modelling by our Crown Research Institute colleagues. The resulting scenarios focus on a moderate climate change trajectory (equivalent to Representative Concentration Pathway (RCP) 4.5).

We analysed scenarios with a macroeconomic model

To estimate the economic consequences of the future scenarios, we used the TERM-NZ computable general equilibrium (CGE) model maintained by NZIER with support from the Centre of Policy Studies at Victoria University in Melbourne. It is a static CGE model, so it considers 'before' and 'after' states but not the transition pathway. It considers economic impacts at the regional level and includes industry-level detail for the food and fibre sectors. Other CGE models have been used to analyse climate change impacts on New Zealand; TERM-NZ provides more detail about a single point in time than other models but does not provide the same information about pathways over time.

We created a baseline for 2050 by calibrating TERM-NZ to published inputs and outputs from the C-PLAN CGE model used to inform the New Zealand Climate Change Commission. By doing this, we placed the baseline in a moderate future context in which there is some global warming and climate change as well as some policy effort to mitigate and adapt.

Results varied across scenarios, regions and industries

We modelled three scenarios and a couple of variations for two of the scenarios. In all scenarios, the modelled shocks were focused on the primary sector or the industries in the food and fibre sectors. Some key findings include:

- From an analytical perspective, the results were unsurprising. A positive change to the economy resulted in a positive outcome, and a negative change to the economy resulted in a negative outcome.
- The impacts of the modelled scenarios amounted to a few percent of GDP or less. This was true regardless of the scenario: productivity changes (positive and negative), changes in export demand (positive and negative), or biophysical impacts of climate change (varied by region and industry).
- Climate change impacts on growing environments at a regional level were generally positive, with positive impacts on regional economies (except the West Coast). Most food and fibre sectors grew in most places. The economic impacts were concentrated in the regions where the food and fibre sectors are based.
- Alongside changes in GDP, regions experienced changes in employment and wages. Where the GDP results were positive, employment and wages tended to grow.

Our results are broadly consistent with prior research

This work has been the most detailed economic analysis yet of climate change impacts in New Zealand in terms of regions and industries. However, the aggregated results can be compared to prior research to some extent. Prior research has found that the economic impacts of climate change in New Zealand would amount to a few percent of gross domestic product (GDP) or less by 2050. Our results are similar at the national level.

Climate change research is full of uncertainties. Several researchers have estimated small economic impacts of climate change; however, Stern and others (e.g. Stern, Stiglitz, and Taylor 2022) have suggested that economic models do not capture the full picture regarding climate change impacts.

Scenarios are a subset of climate change impacts

It is important to note that these scenarios are a subset of what could happen in New Zealand under climate change, and the results should be interpreted as such. Potential impacts from climate changes are modelled individually, not collectively, and we do not account for extreme weather events or pest and disease potential impact on the economy and environment leading to 2050.

The value of fully developed scenarios

Our review of prior climate change research highlighted the number of variables that have been considered in prior work. It is not just ‘the economy’ that will change, but individual sectors with the economy and technologies used within those sectors. Furthermore, the social, political and environmental contexts in which those economies operate are also relevant. In other research, these details are organised into different Representative Concentration Pathways (RCPs) and Share Socioeconomic Pathways (SSPs). Our modelling could only consider a subset of these factors. Further research could more fully draw through the considerations of prior research to develop a more complete analysis of the potential impacts on the New Zealand economy under the same scenarios that other countries have investigated.

Policy implications of the research

The aim of the research was to consider the impacts of climate change on regional economies. The results suggest the following implications for policymakers:

- The impacts of climate change – temperature and rainfall, but excluding adverse events – could amount to an increase of a percentage point or less GDP by 2050.
- However, those impacts vary by a factor of ten across regions and industries. Some primary sectors are more affected, which affects the regional distribution of impacts. Policy should be sensitive to these details to prepare and plan for the impacts of climate change.
- The impacts of changes in export markets – at least changes of the size modelled here – are of the same order of magnitude as climate change impacts. From a policy perspective, both issues are of similar importance. The eventual impacts could be greater or less depending on the changes to the export market.
- Improving productivity over baseline growth by just 10 percent by 2050 – a 0.3 percent increase per year over the baseline – would offset losses from the climate impacts that we modelled, a subset of all climate change impacts.
- Our research partners indicated the potential for climate change to increase the productivity of some primary industries (land-based activities) in places in New Zealand. Our modelling suggests an increase in processing capacity would be needed to handle any increased volume of raw product.

Our modelling result relies on biophysical modelling that does not include all climate change impacts; for example, the impact of future adverse events like Cyclone Gabrielle is excluded. Also, some recent research on pasture growth shows the potential for stronger negative effects on pasture growth rates than the biophysical modelling used here. The economic impacts demonstrated with the modelling would depend on the inputs used.

Despite limitations, we have confidence in the analysis

As with any research and any modelling, this work has limitations. We signal those limitations throughout the report and explain the possible implications. For example, we are building this analysis on a description of the 2020 economy that may not reflect the structure of the economy in 2050. Nevertheless, we have confidence in our findings. We have used a well-understood economic method, worked closely with other experts and advisors, considered the domestic and international literature, and sense-checked the analytical results against theoretical expectations. While we have identified several areas for further research, we also believe that these results provide sufficient guidance for policy development.

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1 Introduction: scope and limitations

1.1 Scope of the research programme

This report is an output from an interdisciplinary, collaborative research programme funded by the Ministry of Business, Innovation and Employment (MBIE) and led by Manaaki Whenua Landcare Research (MWLR). Partners in the programme included Plant and Food Research (PFR) and Scion, and programme advisors came from MBIE and the Ministry for Primary Industries (MPI). MBIE commissioned the research to investigate the potential impacts on regional economies resulting from climate change impacts on the primary sector.

During the programme, the team compiled information and conducted new modelling about potential climate change impacts under different warming scenarios for both mid-century (circa 2050) and end-of-century (circa 2100) time periods. This information then informed further research and modelling about the spatially disaggregated impacts on the production of existing commodities and crops, as well as the potential for new exemplar commodities and crops. The research produced detailed data on potential future impacts, including two time periods, four warming scenarios and multiple plant species (annual and perennial) on a fine geographic scale.

NZIER has been responsible for macroeconomic modelling informed by the research. We used a model of the New Zealand economy, TERM-NZ, that we maintain at the Institute and use for many projects and purposes. The modelling for this research programme was based on four sources of information:

- Our model of the New Zealand economy incorporates data from Stats NZ about the economy at the national level, details about disaggregation by industrial sector and by region, and expertise on macroeconomic modelling from the Centre of Policy Studies at Victoria University in Melbourne, Australia.
- Research and modelling by the New Zealand Climate Change Commission informed a baseline view of the economy in 2050 under moderate climate change impacts and moderate policy choices.
- Consultation with MBIE and MPI provided descriptions of multiple potential futures for New Zealand in 2050 that we used to create scenarios for modelling.
- The research and modelling by the rest of the programme team provided data about potential impacts on regional pastoral agriculture, horticulture, arable agriculture and forestry.

The aim of the modelling is three-fold:

- provide MBIE with estimates of regional economic impacts
- demonstrate the possible range of those impacts
- organise a large amount of data and information in a coherent framework.

We can quantify the regional economic impacts because our model provides a regional breakdown of economic activity by industrial sector. We can demonstrate the range of impacts by developing scenarios based on the expert knowledge of multiple advisors from the government, who contributed by considering climate change and its impacts in a broad context. Finally, we worked to understand the potential effects of climate change, build on the existing work in New Zealand, place that work in the context of international research, and then translate that information into economically consistent modelling.

1.2 Limitations of the research and modelling

As the report makes clear, projections and forecasts about climate change are complex and varied. There is no agreed likely future. There is also no consensus pathway or trajectory towards a specific future. There are contingencies, dependencies and probabilities, as well as diverging views about human propensities, technological, socio-economic development and global politics. However, we cannot account for all possible permutations within this project. Instead, we have tried to put our scenarios in the broad context of climate change research to be clear about the contribution of this research and to signal what more could be done.

We acknowledge our work has limitations. We have just one model among many of the New Zealand economy, and it is limited in its coverage of businesses, workers and households. It is also a static model (a model of a single point in time) rather than a dynamic model, and it does not account for endogenous technological development. The model was used to consider several scenarios, all of which addressed hypothetical ideas about the future. While detailed, the data on climate change and the primary sector depends on other simplified models and the judgment of other researchers. If we made other assumptions or used other methods, we would likely obtain different results. We have approached the work professionally and with due regard for relevance and accuracy; however, it should not be used for any purpose other than as indicated in the project scope.

Given that it is impossible to predict the future, the scenarios outline the implications of some plausible future pathways that can help inform thinking about the range of issues we might face and the different types of adaptation we may need to undertake. Scenario building also allows researchers to tap into stakeholder consensus about those future pathways.

1.3 Scope and contents of this report

The remainder of this report describes the research and presents its results. First, it provides background on potential climate change futures. The discussion is organised around scenario-building that is already foundational for international research on climate change. One consideration is the amount of warming that might occur, which is specified as the Representative Concentration Pathway (RCP) for the amount of greenhouse gas (GHG) emissions and the associated warming in watts per square metre.

Typical scenarios are RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. Another consideration is the Shared Socioeconomic Pathway (SSP), which describes how populations, societies, technologies and economies might change. Five SSPs have been developed to capture a range of possibilities for mitigating (curtailing emissions and preventing warming) and adaptation (changing to cope with a warming planet). The final piece of context concerns economic modelling and, in particular, how economists have discussed and modelled uncertainty and intertemporal considerations of welfare.

Next, the report turns to the analysis and modelling for this research programme. It describes the information and data that form the basis for the modelling. It explains how the modelling for the Climate Change Commission has been used to inform the present work. It also describes the process for generating the modelled scenarios and how they were informed by expert judgment and quantitative data.

Finally, the report provides results from the modelling. Results are presented for all the scenarios, disaggregated by region and industry. We focus on a few key economic metrics to facilitate the comparison of results across scenarios and locations. We then discuss the implications of the results to highlight important lessons and causal relationships.

Throughout this report, we have attempted to do three things:

- transparently explain what we have done so that the factual basis and limitations are clear
- place this specific piece of work in the wider context to recognise the complexity, uncertainty and controversy of the topic
- draw the lessons we can from our work while recognising the limitations and context.

The rest of the report contains the following sections, which are organised into three groups and summarised below to guide the reader:

Sections laying out the international research context for this modelling

- Potential future scenarios for climate change – reviews the major international frameworks for developing scenarios about the future under different possibilities regarding climate change and society.
- Important elements for future scenarios – identifies the key elements of scenarios that should be specified to create coherent descriptions of the future for the kind of economic analysis undertaken in this project: first, the climate; next, agriculture; and finally, the economy.
- Details on macroeconomic modelling for climate change – turns specifically to macroeconomic modelling and reviews some types of models and several examples of models relevant to New Zealand.

Sections describing the modelling itself

- Developing a baseline for 2050 – uses work by the Climate Change Commission to create a baseline scenario for the economy in 2050, taking into account international frameworks, key elements of scenarios and prior macroeconomic modelling from the earlier chapters of the report.
- How are we modelling different climate change scenarios? – presents more technical information about the modelling, both for the baseline and the scenario development.
- Scenario development – describes the process we followed to create future scenarios by working with stakeholders to specify the important inputs for scenario development, as well as the resulting scenarios and their economic logic.

Sections providing results, discussion and interpretation

- Scenario results – presents the results of the analysis of the specified scenarios.
- Discussion and conclusion – provides a discussion of the modelling results and the wider lessons that can be drawn from them, as well as the limitations of the modelling and topics for future work.

2 Potential future scenarios for climate change

2.1 Scenarios – to make sense of the 'could be'

In 2022, the concentration of GHGs in the atmosphere reached 477 parts per million (ppm) CO_2 equivalents (European Environment Agency 2025). This is close to the maximum concentration that would limit global warming to 1.5°C by 2100, a target set by the 2015 Paris Climate Agreement (European Environment Agency 2025). Higher peak concentrations or slower action to reduce GHGs could limit warming to 2.0°C by 2100 (European Environment Agency 2025). The less that is done, or the later it is done, the higher the average global temperature in 2100. Experts have written about the current state of the climate: "*We are on the brink of an irreversible climate disaster. This is a global emergency beyond any doubt. Much of the very fabric of life on Earth is imperiled*" (Ripple et al. 2024).

Global climate change is a complex issue, and therefore, it is challenging for policy-making and modelling. First, concerns about climate change are largely concerns about the future. Researchers cannot measure, for example, that the world will be 5°C warmer in 2100, because that year has not yet occurred. Policymakers must rely on projections of what could happen, which involve estimating the impacts and the likelihood of these events occurring. Second, climate change affects not only global warming – the average temperature across the world being higher – but also the consequences of more energy in weather systems. With increased energy comes increased rainfall but also greater variability and larger storms. Third, the changes in temperature and consequent impacts on rainfall, drought and adverse weather events will not be distributed evenly around the world. Finally, once all of that is understood – how much average warming will be created, the impacts on weather and climate, and the distribution of those impacts – there is still the matter of the impacts on human systems such as agriculture and transportation. Those impacts depend on additional variables, such as changes in population, technological development, and the social and physical ability to adapt.

To bring some order to the complexity, researchers have developed sets of scenarios (Dellink et al. 2017; Intergovernmental Panel on Climate Change 2019; 2022; 2023). By having a commonly agreed-upon and well-researched set of scenarios, experts can focus on understanding the relationships among the various variables, the likelihood of certain outcomes, and the associated policy implications or recommendations. The scenarios are currently described in relation to two main aspects: the expected warming (RCPs) and the social, economic, technological and political pathways (SSPs) (Intergovernmental Panel on Climate Change 2022, 7). The energy or warming potential is described by the RCP. The common RCPs (e.g. Ministry for the Environment, 2018) are:

- RCP 2.6, in which warming would be limited to 2°C, in keeping with commitments for the 2015 Paris Agreement
- RCP 4.5, which is essentially the current track without additional efforts to reduce GHG emissions, or the business-as-usual scenario (BAU) (Intergovernmental Panel on Climate Change 2023) and would entail a warming of 3°C
- RCP 6 and RCP 7, which involve larger amounts of warming and are intermediate scenarios between RCP 4.5 and RCP 8.5
- RCP 8.5, the highest warming potential and worst-case scenario in the IPCC set.

The potential futures are also described by SSPs, which provide storylines for consistent scenarios of economic growth trajectories (Dellink et al. 2017; O'Neill et al. 2014). These pathways involve different assumptions about population growth, technological development and energy sources. Larger populations tend to produce greater GHG emissions. Technological development can increase the options for low-emissions economic activity and technology substitutions: better technology could lead to lower emissions. The energy source is important because continued reliance on fossil fuels would increase emissions, whereas more renewable energy could help reduce them. These factors work together: a smaller population with more efficient technology and greater use of renewables, for example, would have much lower emissions.

These two groupings can be combined to produce more detailed scenarios, with some RCPs fitting more logically with certain SSPs. For example, Fujimori et al. (2017) reported modelling based on scenarios that combined climate conditions defined by RCPs with socio-economic conditions defined by SSPs. Similarly, the Working Groups for the Sixth Assessment Report (AR6) considered the scenarios in the table below.

Table 1 Example of SSPs and RCPs in scenario development

Category in Working Group III	Category description	Combined SSP and RCP in Working Groups I and II	RCP in Working Groups I and II
C1	Limit warming to 1.5°C with no or limited overshoot	Very low (SSP 1-1.9)	
C2	Return warming to 1.5°C after a high overshoot		
C3	Limit warming to 2°C	Low (SSP 1-2.6)	RCP 2.6
C4	Limit warming to 2°C		
C5	Limit warming to 2.5°C		
C6	Limit warming to 3°C	Intermediate (SSP 2-4.5)	RCP 4.5
C7	Limit warming to 4°C	High (SSP 3-7.0)	
C8	Exceed warming of 4°C	Very high (SSP 5-8.5)	RCP 8.5

Source: Intergovernmental Panel on Climate Change (2023)

These scenarios enable researchers to examine the effects of a set of assumptions about society and the economy. The details of the SSPs are available in the literature (Dellink et al. 2017; KC et al. 2024; KC and Lutz 2017; Kriegler et al. 2017; Riahi et al. 2017).

Table 2 Descriptions of the five Shared Socioeconomic Pathways

	SSP 1 – Sustainability	SSP 2 – Middle of the road	SSP 3 – High challenges	SSP 4 – Adaptation challenges	SSP 5 – Fossil-fuelled development
Demographics	Low population growth, falling by 2100	Medium population growth	High population growth	Low to high, depending on country	Low population growth
Economy	Growth, with low material consumption and low meat diets	Medium growth, but uneven and resource-intensive	Slower growth, low education levels	Divergence between high and low growth countries	High growth with consumerism and the use of fossil fuels
Technology	Rapid growth in renewables	Medium and uneven growth in technology	Slow progress	Rapid technological growth	Rapid technological growth
Environment and resources	Strong regulations, and productivity improvement in agriculture	Medium regulations, medium pace of change in agriculture	High emissions because of slow technological change	Medium use of fossil fuels	Medium regulations; resource-intensive rapid productivity growth in agriculture
Policies	Local and global policy with tighter regulation	Weak international collaboration, some success with local pollutants	Weak international collaboration, poorer countries struggle	Barriers to trade, divergence that limits global growth	Focus on economic development and local environment

Source: NZIER

Different researchers combine different RCPs and SSPs in various ways. For example, Kriegler et al. (2017) focus their analysis on SSP 5, a low-population, high-consumption pathway supported by fossil fuels and high technological innovation. While their baseline does not incorporate an RCP, the results are consistent with other modelling of RCP 8.5. Kriegler et al. (2017) also consider SSP 5 alongside RCP 4.5 and RCP 2.6. For the various scenarios, they estimate energy use, sources of energy, land-use changes, and emissions throughout the century for different regions of the world.

Turning to New Zealand, according to the Ministry for the Environment (2018), temperatures are expected to increase between 0.7°C (RCP 2.6) and 1.0°C (RCP 8.5) nationally by 2040, depending on the RCP. There is slightly more warming in the northern part of the country compared to the southern part. Temperature increases are projected to be 0.7°C (RCP 2.6) to 3.0°C (RCP 8.5) by 2090. More warming is expected in summer and autumn than in winter and spring. The daily maximum temperature is expected to increase more rapidly than the overnight minimum temperature, thereby widening the daily temperature range. Air temperatures in New Zealand are expected to increase at about 75 percent of the global rate of increase.

3 Important ingredients for developing scenarios

3.1 Introduction

This research exercise is based on scenarios. Scenarios must contain specific types of information. In this section, we describe the information necessary. Our modelling is focused on the New Zealand economy, disaggregated by regions. We are particularly interested in the impacts of changes in agriculture and forestry, as well as their implications for regional economies. These changes are expected to be driven by climate change, specifically changes in temperature and rainfall. Thus, we are interested in accessible descriptions of climate changes that describe impacts on food and fibre production across sectors and regions.

3.2 Climate

For our modelling, we would like to identify the expected changes in climate. The Ministry for the Environment and Stats NZ (2020) describe New Zealand's climate, past and future trends. It provides some qualitative background but not the data required for our modelling. The New Zealand Climate Change Centre (2014) provides a link to global climate modelling efforts. It provides a short piece that downscales one of the earlier climate scenarios, AR5, to New Zealand and shows where a place may be drier or wetter. However, the climate information has not been translated into the impacts on agriculture or agricultural production.

For this modelling to 2050, we have focused on RCP 4.5, a scenario in which global warming is not limited to 1.5 degrees or 2.0 degrees, but some action is taken to mitigate GHG emissions. Focusing on just one scenario is likely to be sufficient for 2050. Long-term modelling suggested that climate change in the short term is likely already determined by past emissions (Kotz, Levermann, and Wenz 2024), so impacts on the primary sector in 2050 are likely to be similar under most scenarios.

The Ministry for the Environment provides a summary of projected temperature changes:

> *The mid-range estimate for projected New Zealand temperature change is for an expected increase of about 0.8°C by 2040, 1.4°C by 2090, and 1.6°C by 2110, relative to the 1986–2005 period. Owing to the different possible pathways for the concentrations of greenhouse gases in the atmosphere, however, as well as the differences in climate model response to those pathways, the possible projections for future warming span a wide range: 0.2–1.7°C by 2040, 0.1–4.6°C by 2090, and 0.3–5.0°C by 2110.* (Ministry for the Environment 2018, 13)

The impacts of climate change will also affect rainfall patterns, with changes varying by season and location. There is expected to be increased rainfall in winter in the west of Te Ika a Māui/the North Island and Te Waipounamu/the South Island, while there will be less in the east and north. In summer, it is expected to be wetter in the east of both islands but drier in the western and central North Island. In addition, extreme rainfall events are likely to increase in frequency, and drought severity is expected to increaseAdditionally, extreme rainfall events are likely to become more frequent, and drought severity is expected to intensify. These projections were produced by downscaling results from global climate models (GCMs), using between 18 and 41 GCMs, depending on the scenario.

3.3 Agriculture

Climate change is expected to impact agriculture in several ways. Three key areas include temperature, rainfall and adverse events.

Temperature affects plant growth and farming issues like chilling requirements for certain crops. The impacts of higher temperatures are not limited to plants; labour is also affected. Labour performance and labour participation in the economy decline at higher temperatures (Burke, Hsiang, and Miguel 2015).

Adverse events are possibly the hardest of the three impacts to quantify. They are not explicitly included in the modelling for this project. Developing acceptable scenarios of adverse events requires considerable data and consensus building among stakeholders. Nevertheless, it is important to include them in the discussion of impacts on agriculture. One measure of the potential for disruption is the impact of storms, droughts and other adverse events that New Zealand has already experienced. For example, estimates of economic damages have been made for Hawke's Bay after Cyclone Gabrielle (Boston Consulting Group 2023). Gabrielle affected approximately 35 percent of the local crop value, or about $500 million. Critical response and replanting would cost $920 million; expected losses without intervention would be $3.5 billion over the 2024–2030 period. The analysis noted that growers would be capital-constrained, so government spending would play a role in enabling faster recovery and reducing economic losses. The impacts of the cyclone, and presumably other adverse events in the future, were:

- reduced economic activity
- reduced regional development because development funds were diverted to rebuilding
- increased unemployment and beneficiaries
- increased social costs in terms of mental health, alcohol abuse and domestic violence
- reduced investment in productivity and sustainability.

Changes in international food prices will impact New Zealand agriculture. Estimated impacts on agriculture depend on both the level of warming and the choice of RCP, as well as assumptions about demographics, innovation, and policy, and the choice of SSP. For example, the modelling of SSP 5, a low-population, high-consumption scenario, produced per-capita gross domestic product (GDP) growth in the OECD of 1.8 percent per year to 2100 (Kriegler et al. 2017). Per-capita food consumption increased to 3250 kcal per day and was accompanied by high animal product consumption and food waste. In that baseline scenario, the share of GDP expenditure on food fell from about 4.5 percent in 2020 to less than 1 percent by 2100. The food price index was essentially flat to 2050 and then fell 15 to 20 percent by 2100. In SSP 5 coupled with RCP 4.5, the expenditure share of food was about 2.5 percent in 2050 (Kriegler et al. 2017, Figure 12). In that case, food prices were estimated to increase by about 10 percent by 2050 and 25 percent by 2100.

Earlier modelling examined the impact of climate change on agriculture, including production and prices. The modelling included "*climate scenarios, agroecological zoning information, demographic and socio-economic drivers, as well as production, consumption and world food trade dynamics*" (Fischer 2009, 47). The research was one of the few studies to provide information about future prices. In the baseline, livestock product prices were expected to increase by 11.2 percent between 2020 and 2050 without climate change or biofuels, and agriculture prices as a whole by 17.3 percent.[1] Impacts on prices from climate change depended on the model and the assumption about CO_2 fertilisation, but the author summarised the results as follows: "*there is only a small impact resulting on world market prices from climate change yield impacts in the decades until about mid-century. In fact, the CO2 fertilization effect and assumed autonomous adaptation to climate change more than compensate for negative yield impacts*" (Fischer 2009, 16). The conclusions were the following:

- Aggregated modelling projected small changes to prices, production, and consumption.
- Technology plays an important role, so future technology pathways are an important variable in projections.
- The impacts of climate change could become severe in the second half of this century.

3.4 Economy

3.4.1 Key economic concepts and metrics

Climate change is complex. Climate models include many parameters and equations to simulate spatially detailed changes in temperature, rainfall and other weather phenomena. However, these complexities are often summarised with a number: a 2°C change in average global temperatures versus a 4.5°C change.

Economies are also complex. They involve different types of people, businesses and industries, and they include production, consumption, investment, trade and government spending. However, we often simplify them into a single metric: gross domestic product. It is a measure of total economic output, whether it is counted as all production in a particular place and time or all of consumption. It is understood to be a useful but imperfect measure. Nevertheless, it can be used consistently across models, places, time periods, and research projects, making it especially useful for understanding their differences.

It is also useful to consider GDP per capita. As a population grows, it will likely have more working-age people and, therefore, more production. Growth in GDP can be achieved either with more workers or with increasing the output per worker. This increasing productivity (output per input) creates the possibility of increased economic welfare per person.

When analysing economic impacts over time, it is important to consider two issues. The first is the impact of inflation. Generally, with economic analysis, we are concerned with 'real' dollars – after the effects of inflation have been removed. Most climate change research appears to use real dollars (e.g. Barrage & Nordhaus, 2024; Bilal & Kanzig, 2024; Casey et al., 2023; Hänsel et al., 2020; Kahn et al., 2019). That approach allows economists to estimate the real impact of growth or the real cost of actions. However, some past data and some projections use nominal dollars, in which inflation is still included. It is important to understand which metric – real or nominal dollars – is being used.

[1] Prices are presented in Table 3.4 as indices (1990=100). For Livestock products, 2020=107 and 2050=119; for Agriculture, 2020=98 and2050=115 (Fischer 2009).

The second concern with economic impacts over time is discount rates. They have been an important topic in the literature on the economics of climate change. Stern, for example, has argued for very low discount rates, while Nordhaus has argued for higher ones. Discount rates are important because they compare the value of economic outputs and costs now with their value in the future. Also, through the impact of compounding, seemingly small differences year to year accumulate into large differences over decades. The New Zealand Treasury has recently changed its advice about discount rates, suggesting a higher rate for short-term, commercial investments and a lower rate for long-term, environmentally-focused investments.

3.4.2 Impacts on economic composition

When we build scenarios, we must be aware that climate change impacts and responses will affect the economic composition. Work by the IPCC indicates the economic sectors that might change due to efforts to address climate change (Intergovernmental Panel on Climate Change 2023):

- Coal, oil and gas would be reduced.
- Hydropower would be increased.
- Carbon Capture and Storage could increase as technology develops.
- Agriculture, forestry and food changes are complex. For example, reducing food waste to reduce emissions would also entail additional costs – because it is extra to current economic activity – but should also have benefits.
- Electric vehicles (EVs), public transport and bicycling would all increase as part of the effort to decarbonise transportation.
- Efficient buildings and transport should lead to increased costs and produce larger benefits, but the net impact is uncertain.

Overall, the IPCC has found that mitigation activities should be beneficial: *"Even without accounting for all the benefits of avoiding potential damages, the global economic and social benefit of limiting global warming to 2°C exceeds the cost of mitigation in most of the assessed literature (medium confidence)"* (Intergovernmental Panel on Climate Change 2023, 26). The New Zealand Climate Change Commission stated a similar finding: *"We are confident that if the country took the actions in the EB4 demonstration path the overall effect would be economic and social gains*" (Climate Change Commission 2024a, 111). Some modelling also reaches the same conclusion: Bilal & Kanzig (2024) assembled a new database on the climate and the economy and estimated larger economic impacts than previous work. They estimated a much higher social cost of carbon – a measure of the potential benefits of avoiding climate-related damages in the future – and demonstrated that this high value justified substantial investment in mitigation.

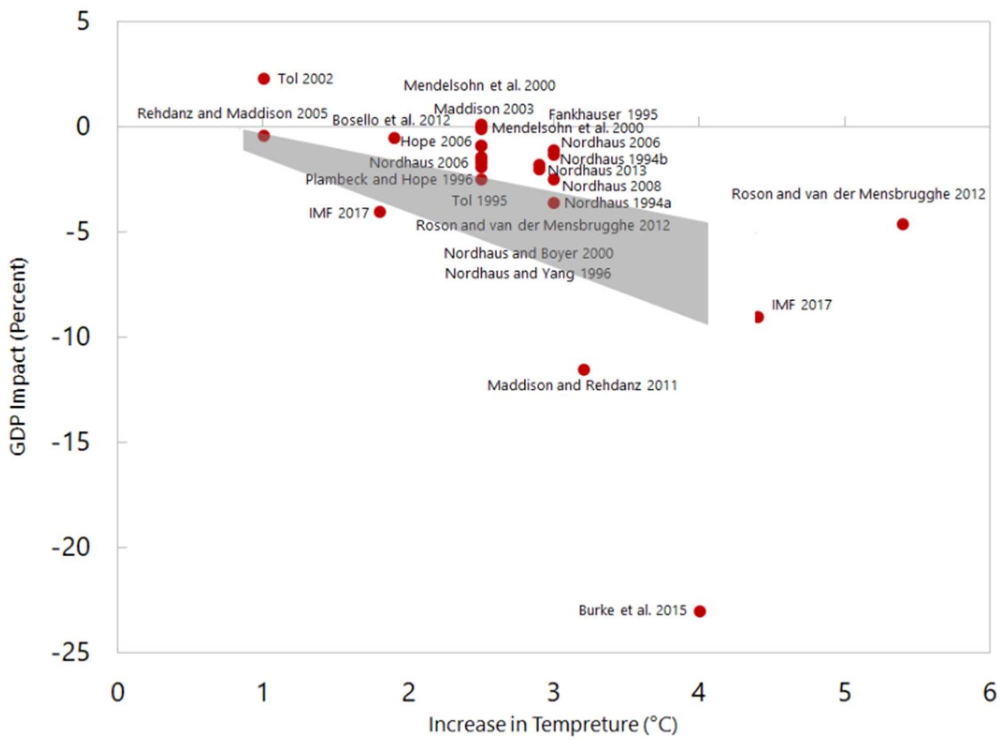
Another economic issue is the availability of productive resources to make the changes envisioned under alternatives to business as usual. According to the IPCC, there is sufficient capital to invest in the necessary changes; however, this would require redirecting existing capital (Intergovernmental Panel on Climate Change 2023).

3.4.3 Overall macroeconomic impacts

Potential impacts on the economy have also been studied without reference to underlying mechanisms. Kahn et al. (2019) analysed a panel data set of 174 countries over the period 1960–2014 to estimate the relationship between temperature and macroeconomic output (Figure 1). This research used data from the past to estimate the economic impact of higher temperatures, providing an empirical basis for projections. Then, they projected the relationships estimated forward.

They found that an increase in global temperature of 0.04°C per year would reduce world GDP by more than 7 percent by 2100. An increase in global temperature of 0.01°C per year, consistent with the Paris Agreement, would reduce GDP by only about 1 percent in 2100. Considering the impacts in 2050, Kahn et al. (2019) found that RCP 8.5 would create economic losses of 1.53 to 3.77 percent. They also compared their findings to those of previous research. For comparison, Hänsel et al. (2020) referenced damage functions that resulted in a 6.7 percent loss at 3°C of warming, which is consistent with RCP 4.5 (Intergovernmental Panel on Climate Change 2023).

Figure 1 Prior estimates of global GDP impact by global temperature



Note: The grey area shows the results from their analysis; the dots indicate estimates from prior research.

Source: Kahn et al. (2019).

Other researchers have found similar results. Casey et al. (2023) also conducted an econometric analysis of panel data to estimate relationships between GDP and temperature, as well as precipitation. The focus was understanding the impact on total factor productivity, which is the efficiency with which the factors of production (land, labour and capital) produce economic output.

This analysis was again at the country level, so it did not provide disaggregation by industrial sector. The researchers then projected those estimates forward to 2100 using RCP 8.5. They find output losses due to climate change: a 0.78 percent decline in GDP in 2050 and a 3.4 percent decline in 2100. The confidence interval spans 'virtually no impact to a 6.5 percent decrease in global GDP per capita' in 2100 (p. 712), showing the difficulty of producing precise estimates for policy development.

3.4.4 Factors affecting economic impacts

The impact of higher temperatures depends not only on the size of the change but also on the baseline climate. Burke et al. (2015) found that the relationship between temperature and economic production is non-linear. They found that economic production or GDP by country is concave in relation to annual average temperature and roughly symmetrical, with a peak at 13° C. The US, Japan, and China are close to the peak temperature, while Germany, the UK, and France are below it. The relationship between future temperatures and economic production is thus complex. Even under the RCP 8.5 scenario, there is a wide range of impacts on economic production:

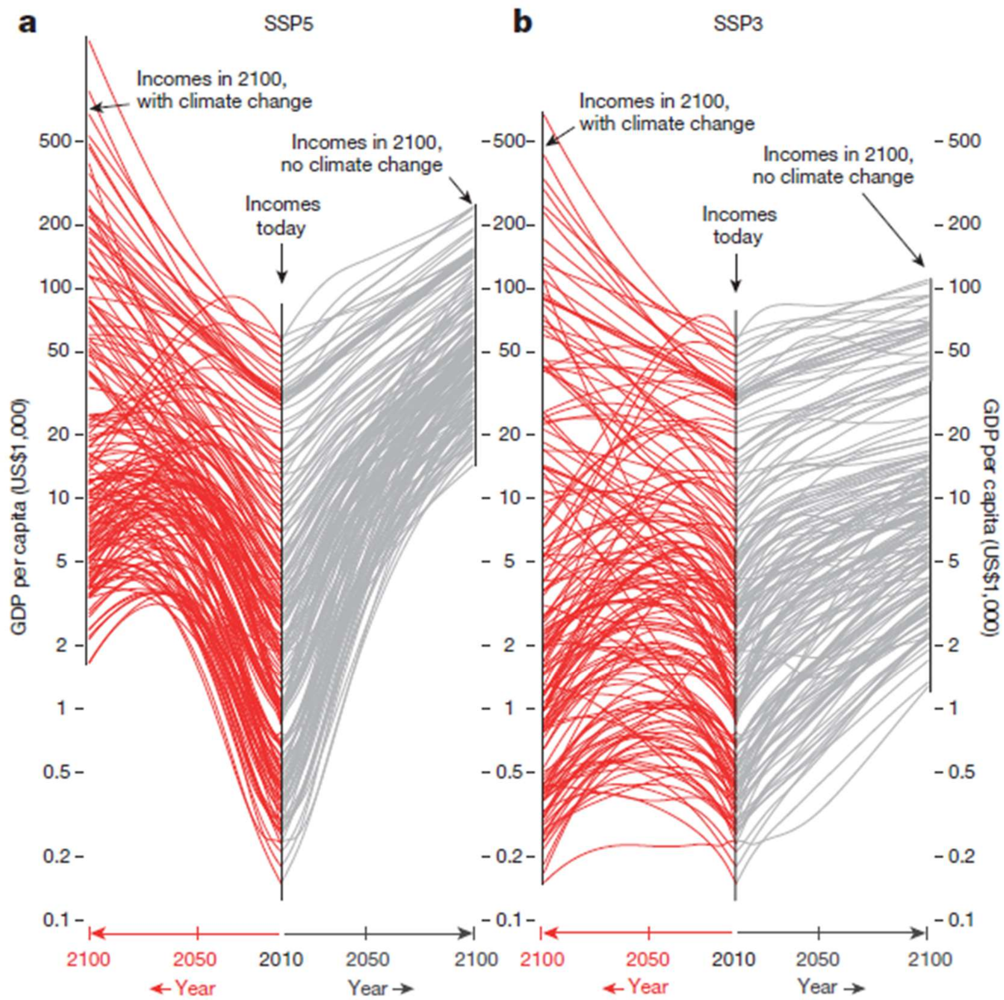
> *The impact of warming on global economic production is a population-weighted average of country-level impacts in Fig. 4a. Using our benchmark model (Fig. 2a), climate change reduces projected global output by 23% in 2100 (best estimate, SSP5) relative to a world without climate change, although statistical uncertainty allows for positive impacts with probability 0.29.* (Burke, Hsiang, and Miguel 2015, 238)

The complexity and detail of the results are evident in Figure 2 below from Burke et al. (2015, 237). It presents results from SSP 5 (panel a) and SSP 3 (panel b). Each line to the left or right indicates the GDP path for a single country. The red lines to the left indicate country-level income growth over the 21st century to 2100, including the impacts of climate change. The grey lines to the right in each panel indicate incomes over time without the impact of climate change. As indicated above, the average for the world is 23 percent lower in SSP 5 with climate change than without. However, as the figure shows, the country-level impacts are spread widely so that some countries are better off while others are worse off (note the logarithmic scale for GDP per capita).

Modelling of the different SSP scenarios also shows the variability in potential future economic performance depending on assumptions about population, technology, education, and international institutions (Dellink et al. 2017). SSP 5, which assumes low population growth with a high focus on economic production and technology, leads to high GDP and GDP per capita. SSP 3 is expected to produce the worst results by 2100 as it involves low growth in productivity and education. The other three – SSP 1, SSP 2 and SSP 4 (not shown in Figure 2) – are intermediate in both GDP and GDP per capita. However, the low-population, strong-regulation, high-focus-on-renewables SSP 1 does the best of those three. In particular, SSP 4 is dragged down by the divergence between rich and poor countries.

Overall, the figure demonstrates three conclusions from the modelling. First, future incomes depend on socioeconomic variables as well as climate change. Technology, population and international relations all help determine future economic paths. Second, future incomes are higher on average and less variable (have a smaller distribution) without climate change. Third, the impact of climate change is spatially inconsistent. Some countries have higher GDPs with climate change, while others are markedly poorer (note the logarithmic scale for GDP per capita). This sort of modelling and fine-grained detail are important for understanding the potential impacts of climate change and were used to help inform the approach to modelling in this project.

Figure 2 Country-level income projections with and without temperature effects of climate change



These are projections to 2100 for two socioeconomic scenarios consistent with RCP 8.5. Panel a provides results for SSP 5, which assumes high baseline growth and fast income convergence between countries. Panel b provides results for SSP 3, which assumes low baseline growth and slow convergence. The centre in both panels is 2010, and each line is a projection of national income. Right (grey) lines are incomes under the baseline SSP assumptions, and left (red) lines are incomes accounting for non-linear effects of projected warming.

Source: Burke et al. (2015, 237)

3.4.5 Economic impacts in New Zealand

Finally, researchers have produced results for New Zealand. Kahn et al. (2019) estimate the economic loss for New Zealand for RCP 2.6 and RCP 8.5 for three time periods: 2030, 2050 and 2100. The per capita GDP losses for 2050 are 1.17 percent for RCP 2.6, which involves little warming, and 3.18 percent for RCP 8.5, which is a pathway with more warming. Casey et al. (2023) provide country-level results graphically rather than numerically, but the economic losses in New Zealand for 2100 under RCP 8.5 are relatively small (around 1 to 2 percent). This result is similar but slightly better than those of Australia, China, and the US. Research on the non-linear impacts of temperature on GDP suggests that New Zealand would experience little economic impact, positive or negative, for temperature changes in RCP 8.5 and SSP 5 (Burke, Hsiang, and Miguel 2015, 238 Figure 4).

3.4.6 Uncertainty regarding economic impacts

Finally, when discussing the impacts on the macroeconomy, we also need to be cognisant of the critique by Stern, Stiglitz, and Taylor (2022). Two criticisms are first that some models handle climate risk poorly and second that they are sensitive assumptions. The careful analysis by economists that estimates damages of a few percent is remarkably different from the warning of other climate change researchers:

> *We need bold, transformative change: drastically reducing overconsumption and waste, especially by the affluent, stabilizing and gradually reducing the human population through empowering education and rights for girls and women, reforming food production systems to support more plant-based eating, and adopting an ecological and post-growth economics framework that ensures social justice.* (Ripple et al. 2024)

Such impacts are outside the bounds of our usual tools for economic analysis and would require a different approach to assess.

4 Details on macroeconomic modelling for climate change

The purpose of this section is to describe the different modelling approaches to climate change used in the past. A good summary reference for macroeconomic climate modelling in New Zealand is White et al. (2018). The range of economic models they review includes two dynamic computable general equilibrium (CGE) models (CliMAT-DGE and NZIER's Monash-New Zealand-Green), a static CGE (ESSAM), and a few models with unspecified techniques. The CGE models described do not appear to offer disaggregated results for New Zealand, only national-level outputs. However, some ancillary models use partial equilibrium techniques to find regional results for agriculture and forestry.

4.1 CGE is standard for macroeconomic modelling

CGE (Computable General Equilibrium) modelling is a quantitative method used to analyse the complex interconnections within an economy. Our tool for modelling in this project was TERM-NZ, a CGE model of the New Zealand economy maintained by NZIER.

CGE modelling has been used internationally to investigate the potential impacts of climate change. For example, Fujimori et al. (2017) considered scenarios built on combinations of RCPs and SSPs and modelled them with the AIM/CGE model. AIM is a dynamic CGE model that separates the world economy into 17 regions and 42 sectors and includes detailed modelling of energy and air pollutant gases. The modelling showed that mitigation costs, such as lost GDP, varied considerably across the scenarios. The research focused on SSP 3, which included international rivalry and slow technological development and was associated with high costs. This sort of information guides the likely trajectory of the economy under different assumptions about the future.

4.2 CGE models are a map of the economy

A CGE model consists of equations which describe model variables. It also uses detailed data on the structure of the economy that is consistent with these model equations.

This data provides a snapshot of the economy in a particular year, which is used as a starting point for a baseline (or business as usual (BAU)) against which to compare policy simulations or economic changes.

The model data is linked together through a set of equations which capture how the economy evolves over time in response to a shock. These equations, which are based on the economic theory of general equilibrium, ensure that supply and demand for goods, services and factors of production in the economy are balanced and determine how firms and households react in response to changes in incentives.

In any CGE model, we must choose what is to be determined within the model (the endogenous variables) and what is to be considered external to the model (the exogenous variables). A CGE model is just a way of explaining the endogenous variables in terms of the exogenous variables.

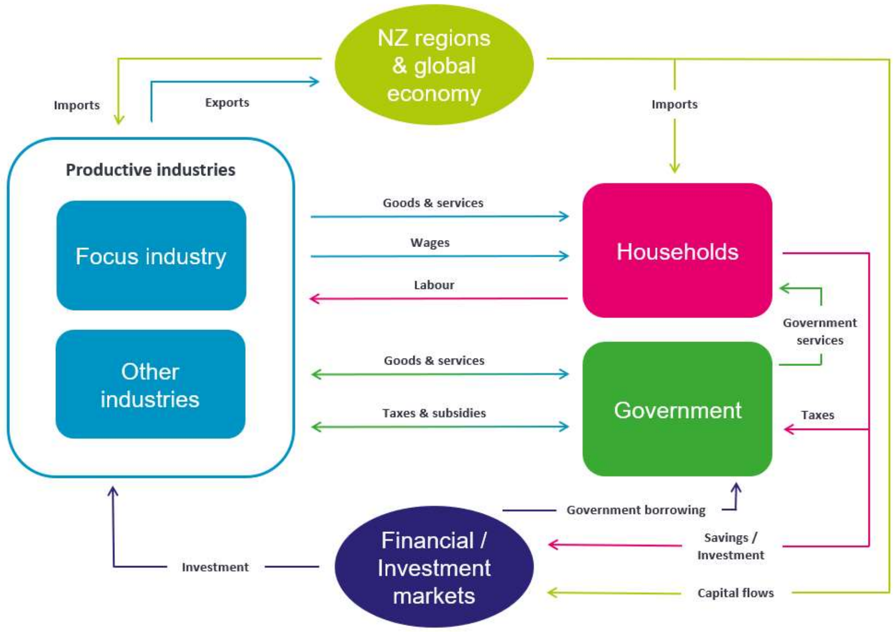
Where we draw the line between endogenous and exogenous variables and which ones can vary or have to remain fixed depends on a number of factors, including the purpose for which the model simulations are to be used. The choice that we make is called the model closure.

Determining the closure is a key part of any modelling exercise, and it is very important that the modeller be transparent about what the result of the modelling is and what has been imposed by assumption via the closure.

The difference between the initial and the new equilibrium can then be analysed to determine the effect of the shock on a range of economic indicators, such as GDP, employment, wages and living standards.

Figure 3 provides a stylistic representation of the relationships between different parts of the model.

Figure 3 Our CGE model represents the circular flows in the economy



Source: NZIER

4.3 CGE examples for New Zealand

The following subsections provide further information about previous modelling efforts as well as comments on their strengths and weaknesses.

4.3.1 C-PLAN

Economic impacts reported by the Climate Change Commission relied on modelling using the C-PLAN model (Climate Change Commission 2021a; Winchester and White 2022). C-PLAN is a dynamic CGE model explicitly developed to assess climate change impacts in New Zealand. It models the whole New Zealand economy and is connected to other models for detailed analysis of key inputs such as energy to provide national-level results. C-PLAN modelling provides a baseline: it quantifies the economy in each year from 2014 to 2050 (Winchester and White 2022), which provides a view of the future from the perspective of the Commission. C-PLAN does not provide results at a regional level.

The focus in these scenarios appears to be the impact of technological change, such as reduced-methane agricultural practices or a shift in the source of electricity generation. The extensive research and modelling – including an energy-focused model (ENZ), research into methane-reducing technologies by The Agribusiness Group, and research into process heat decarbonisation by DETA – indicate this focus (Climate Change Commission 2024b). The analysis does not model climate change directly, i.e. the direct impacts of temperature, changes in rainfall, and adverse events on the New Zealand economy: *"C-PLAN does not consider the expected effects of the physical impacts of climate change (such as droughts, floods, forest fires, changing weather patterns) on economic output"* (Climate Change Commission 2024b, 8).

Instead, it is focused on potential changes in production and their implications for both GHG emissions and the value of economic production. The Commission demonstrated the potential to achieve emissions reductions with minimal costs to the economy. That scenario is consistent with a world in which New Zealand and presumably other countries are meeting Paris targets, which would be consistent with lower levels of global warming. That scenario was compared to a baseline to measure economic costs. That baseline is the Current Policy Reference, which is thus likely to represent a world with more global warming. Input and output data for C-PLAN modelling is publicly available at the sectoral level for the Commission's 2021 draft advice (Climate Change Commission 2021c) but not the 2021 final advice (Climate Change Commission 2021b).

4.3.2 Monash-New Zealand-Green

Prior NZIER climate change modelling examined economic growth between 2017 and 2050 using the Monash-New Zealand-Green model (NZIER 2018). The analysis also used a dynamic CGE model and considered several scenarios with different policies and technological changes. However, it again did not consider the potential impacts of climate change on temperature, rainfall, adverse events, and the economic costs of inaction. The report thus presents climate policies as costs without associated benefits. In the Baseline, the average economic growth from 2017 to 2050 is 2.2 percent; this scenario involves then-current policy settings, exclusion of biological emissions, a low domestic carbon price, and "*strong rest of world action on climate change*" (NZIER 2018, 2).

The report also focuses on a scenario with widespread innovation across the agriculture and energy sectors and policy changes that enable the country to reach 50 percent of zero net carbon emissions by 2050. In this scenario, the economy would be 2.4 percent smaller in 2050 than in the Baseline. There are at least two possible ways to conceptualise the differences between these two scenarios. One possibility is to recognise that climate change is a global phenomenon and adopt the stance that whatever happens in the future will have little connection with New Zealand's actions. New Zealand policy should thus be analysed against a constant climate background. Another possibility is to treat New Zealand's actions as part of international efforts so that New Zealand policies are reflected in the climate due to international cooperation. Otherwise, New Zealand's inaction would be classed economically as 'free riding' on the good behaviours of other countries.

The results of the modelling have two key implications:

- Having wide possibilities for innovations and emission-reducing technologies leads to lower economic costs of change because there are more possibilities for identifying low-cost options.
- The total economic cost of achieving lower emissions is small relative to the economy and projected growth. For example, in scenarios with wide possibilities for innovation, reaching zero net emissions rather than 50 percent of the target leads to 1.9 percent less economic activity. However, the modelling assumes a growth rate of 2.2 percent per year, so the difference is less than a single year's growth. That is the same as needing until 2050 to reach the level of GDP originally forecast for 2049.

4.3.3 ESSAM

ESSAM is a static national-level CGE model that has been used for decades in New Zealand for commercial and policy-related analysis (White et al. 2018). It takes a standard CGE approach to model the entire economy, including imports and exports. It includes four types of energy: coal, oil, gas and electricity, and it includes more details about households than other New Zealand models.

4.3.4 CliMAT-DGE

Other CGE modelling used:

> *an integrated assessment modelling (IAM) methodology using the New Zealand Integrated Assessment Modelling System (NZIAMS). A bulk of the assessment is conducted with Landcare Research's computable general equilibrium (CGE) model Climate Mitigation and Trade in Dynamic General Equilibrium (CliMAT-DGE).* (Daigneault 2015, 1)

CliMAT-DGE treats New Zealand as a single region (one of six in this case: New Zealand, Australia, North America, the Rest of the OECD, China, and the Rest of the World (RoW)), and it models the economy using 18 sectors.

This modelling investigated the economic impacts of emissions reduction targets and carbon price paths on New Zealand, considering the period 2021 to 2030 (Daigneault 2015). Agriculture and forestry emissions were not priced. Carbon pricing drove the domestic economy to reduce emissions, and any shortfall was filled with international units purchased.

> *The model estimates that total RGDP is estimated to increase from $201 billion in 2007 to $344 in 2030. For context, the trajectory of RGDP over the modelled period is relatively similar to the long-term projections published by the NZ Treasury.* (Daigneault 2015, 18)

The impact on the economy varied by scenario. In the core policy scenario of a 10 percent reduction in emissions, most sectors declined less than one percent, although some sectors, such as coal, declined by more. The total impact of reducing emissions by 40 percent in 2030 versus 1990 levels was -0.24 percent (one-quarter of one percent). A higher carbon price increased the economic impact, but the GDP in 2030 was just 0.64 percent lower. However, these small impacts on the economy depended on the ability to purchase international carbon units rather than relying solely on domestic abatement.

4.3.5 Comments on New Zealand CGE models

Each of the CGE models has strengths and weaknesses. As Winchester & White (2022, 2) noted regarding CliMAT-DGE, Monash-New Zealand-Green (MNZG), and ESSAM:

> *These tools have been successfully used for policy analysis but are not ideal for informing policies to meet long-term emissions targets as they do not include a detailed representation of advanced technologies (low-carbon technologies that do not currently operate but may be deployed in future years). Specifically, to our knowledge, no advanced technologies are represented in the MNZG and ESSAM models, the representation of new technologies in the CliMAT-DGE model must be simplified so that the model is solvable (Fernandez and Daigneault, 2015), and none of the models include advanced technologies for agricultural production. Additionally, none of these models are open source. The C-PLAN model, documented in this paper, addresses these limitations.*

By contrast, in C-PLAN, the agricultural sectors in the model are focused on livestock, likely because they are major sources of greenhouse gases, but aggregates all horticulture and does not include arable farming. Furthermore, C-PLAN does not have a regional decomposition but presents results only at the national level. However, it has been used as the basis for regional modelling. Monge & McDonald (2023, 3) explained:

> *The CGE model used for this study is based on the C-PLAN model used by the CCC for their draft recommendations (Winchester and White, 2022) and a multi-regional CGE model for Auckland used to assess the potential impacts from volcanic hazards.*

That modelling treated the economy as 36 sectors, based on C-PLAN's 38 sectors. It modelled Target Pathway 2 from the Climate Change Commission: a biogenic methane reduction target of 47 percent and a net zero target for all other sectors. It also modelled Auckland's climate action plan. They found that impacts on Auckland were greater than those on the rest of the country, demonstrating the value of regionally disaggregated modelling.

As noted above, the demonstration path means different futures for different sectors. They may grow, shrink, or change composition. Growing and shrinking are simple to include in our modelling to duplicate the scenarios in C-PLAN. Changing composition is more difficult. C-PLAN was designed to consider energy and GHG emissions, and so it includes disaggregated sectors such as transport with internal combustion engines and transport with electric vehicles. The NZIER CGE base database does not include these distinctions. Because this research is focused on the primary sector, we focused our analysis on disaggregated modelling in that sector and not detailed modelling in energy and transport.

Other researchers have also made model comparisons. Daigneault (2015, 7) compared model results between the dynamic CliMAT-DGE and static ESSAM:

> *Both models estimated that there would be negative economic impacts for all policies, but CliMAT-DGE typically estimated that New Zealand would reduce a greater level of GHG emissions at lower costs compared to ESSAM.*
>
> They noted a few differences between the models, saying:
>
> *As a result of these differences, we could expect ESSAM to show relatively higher costs of an emissions reduction policy. That being said, each model has its relative strengths and can provide useful insight on the impacts to various sectors of the New Zealand economy.*

4.4 Integrated assessment models

Integrated assessment models (IAM) models focus on the cost-benefit trade-off concerning climate change and actions to mitigate it: knowing that future climate change is going to create damages, how much should we do or invest now to avoid those damages (Nordhaus 2019; 1993; Stern, Stiglitz, and Taylor 2022)? This question can be assessed with an IAM that integrates modelling about the environment and the economy. One well-known model is the Dynamic Integrated Model of Climate and the Economy (DICE) model (Barrage and Nordhaus 2024). This is a one-sector model, so the whole macroeconomy is treated as a single activity.

Economic output results from a standard economic equation known as the Ramsey model. Output is produced with a combination of capital and labour, which are also affected by a productivity parameter that describes the economy's ability to produce outputs given a level of inputs. In the DICE model, output is reduced by damage from climate change and by measures to reduce or abate those damages. Thus, the model can find a balance between simply incurring future damages and investing now to avoid them.

As with any model, the results depend on the parameters assumed for the modelling. Damages are modelled as quadratic, that is, with a non-linear relationship, and are driven by temperature and some other parameters (Barrage and Nordhaus 2024). Another important factor is the discount rate. The overall discount rate – which regulates the comparison between the value of production and consumption now versus the value in the future – is effectively 4.5 percent (Barrage and Nordhaus 2024). Using a combination of model outputs and 'judgmental adjustment', the researchers found that total output loss (economic damages) would be 3.1 percent for 3°C warming and 7.0 percent for 4.5°C warming.

The parameters and functions of an IAM affect the results. DICE's damage functions have been shown to be central to the outputs produced by the model and consequential for conclusions drawn (Bilal and Kanzig 2024; Hänsel et al. 2020). One extension of the DICE model found that economic damages from climate change would be worse than prior predictions: for a 1°C temperature increase, losses were 12 percent of GDP vs 2 percent of GDP as in previous estimates (Bilal and Kanzig 2024). They stated:

> *Our estimated effect of temperature shocks on world GDP stands in stark contrast to existing estimates of the cost of climate change. Nordhaus (1992), Dell et al. (2012), Burke et al. (2015) and Nath et al. (2023) find that a 1°C temperature shock reduces GDP by at most 1-3% in the medium run.* (Bilal and Kanzig 2024, 3)

Additionally, discount rates are a known issue with any type of investing (Parker 2011). The 4.5 percent reported for DICE (Barrage and Nordhaus 2024) is a higher discount rate than other climate change experts believe is appropriate (Stern 2006; Stern, Stiglitz, and Taylor 2022). Higher discount rates reduce the value of investing now to mitigate future damages.

The importance of these differences for policy was shown by Hänsel et al. (2020). They recalibrated the DICE model to include "*more accurate calibration of the carbon cycle and energy balance model, and updated climate damage estimates*" (p. 781). They also drew on expert opinion regarding intergenerational welfare to inform the model. They concluded that, given certain parameters, the results from DICE were consistent with investing in the economy to keep global warming within the 2°C target. They contrasted that with results from Nordhaus, developer of the DICE model, who concluded that lower targets, such as 1.5°C or 2°C, are either unattainable or not economically optimal.

Challenges to IAMs are not just at the level of individual parameter values. Stern, Stiglitz, and Taylor (2022) suggested that IAMs are flawed as a tool for understanding the economics of climate change. They noted a disconnect between economists and other experts in thinking about responses to climate change (p. 181). For other experts: "*There is a shared understanding that this will involve fundamental structural change in our economies*", but "*This consensus stands at odds with a major stream of thought within the economics profession*".

The key reason is that potentially catastrophic results are assumed away in IAMs:

> *Nordhaus and others supporting the IAM approach are focused on the non-linearity in costs – if one attempts to reduce carbon emissions to achieve 2 degrees, the costs rise so high as to be, for all practical purposes, infeasible. As we*

> *note below, the international community is focused on the nonlinearity in risks – if one doesn't reduce carbon emissions to achieve at least 2 degrees, the risks rise so high as to be intolerable. At the same time, the costs of limiting net emissions (including, if necessary, carbon capture and storage and carbon sequestration) are sufficiently limited that such trajectories are indeed feasible. The fact that there is such disagreement reinforces our emphasis on the importance of risk and uncertainty.* (Stern, Stiglitz, and Taylor 2022, 183)

Despite Stern, Stiglitz, and Taylor (2022) believing that the problem is inherent in IAMs (and specifically DICE), the results in Bilal & Kanzig (2024) suggest that this might not be completely true. They found much larger economic losses than other modelling, using a modified version of DICE. They reported that a 3°C increase by 2100 would lead to a loss of economic welfare of 52 percent versus no temperature increase. Warming of 5°C would lead to a 60 percent welfare loss. These large changes seem to align the economics with the rest of the international community, according to references by Stern, Stiglitz, and Taylor (2022).

Stern, Stiglitz, and Taylor (2022) provided three sets of criticisms of IAMs:

- IAMs cannot account for deep uncertainty and fat-tail risk.
- Progress has been made in some issues with IAMs, but not enough to base policy on them. These issues are political economy, damage functions and cost functions. As a result, estimates of the social cost of carbon (a key metric) range over three orders of magnitude. The difference in policy conclusions highlighted by Hänsel et al. (2020) – that the 2°C target was either appropriate or not, depending on assumptions – shows the policy relevance of this uncertainty.
- There are also issues that IAMs struggle to address: the existence of multiple market failures, complex systems and the economics of technological change. This last issue is particularly important. If technological change is meant to achieve emissions reductions without economic disruption, then the known market failure in research and development needs to be addressed. Investment in innovation for mitigation will not be optimal without government intervention.

These criticisms of IAMs and the attempts to address the criticisms demonstrate the role that models can play. They can organise information and calculate the impact of the information they are given, but they are just one tool for understanding climate change and its impacts.

5 Developing a baseline for 2050

5.1 Building on the work of the Climate Change Commission

For this analysis, we have made a concerted effort to build on prior modelling and analysis, thereby deepening our understanding of existing scenarios. We have taken as our touchstone the analysis in the Climate Change Commission's (CCC) 2021 report, *Ināia tonu nei: a low emissions future for Aotearoa*. That report focused on demonstration paths toward achieving GHG emissions consistent with the 1.5°C global warming target. The report focused on changes to 2035, with long-term scenarios to 2050. The key sectors for CCC were:

- transport
- buildings
- electricity
- industry and heat
- agriculture
- forests
- waste and F-gases.

Thus, agriculture and the primary sector, more generally, were only one of the concerns of the CCC. The narratives that were developed also focused on a range of options, such as energy generation and transportation options. The CCC analysis was based on a **Current Policy Reference (CPR)** case, which was the set of current policies, and the **demonstration path**, which provided policies that would meet New Zealand's commitments and be consistent with RCP 2.6 (Climate Change Commission 2021a, 99, Figure 7.1). The demonstration path amalgamated four scenarios: headwind, tailwind, and two others. The CCC advised that the demonstration path could be achieved with small GDP impacts: the difference between CPR and demonstration path GDP was 1.2 percent (Climate Change Commission 2021a, 138). This impact, in the context of a baseline, was a 75 percent increase in GDP between 2020 and 2050.

Prior research on climate change has been organised around different RCPs. The climate and commodity production analysis conducted by our research partners was explicitly based on RCP scenarios. The CCC reporting does not adopt a specific RCP scenario. The demonstration path focuses on meeting Paris Agreement commitments, which implies RCP 2.6. The CPR, which describes a different future pathway with less mitigation, thus implies it would align with RCP 4.5. To create a consistent basis for our economic analysis across the food and fibre sectors and the other parts of the economy, we assumed that the CCC CPR reflects RCP 4.5, combined that information with the commodity modelling of RCP 4.5, and considered other RCP 4.5 information in the literature. While our modelling focuses on the food and fibre sectors, we are using a model of the whole New Zealand economy. As a result, we need to be aware of changes in other parts of the economy outside the primary sector. To achieve this, we relied on the transition pathway that the CCC developed. A summary of the changes is shown in the table below.

Table 3 Key transitions along the demonstration path

		Budget 1	Budget 2	Budget 3
Transport	Lower-emissions vehicles	Accelerate uptake of electric and zero-emissions cars, buses and trucks Improve efficiency of vehicles and freight movement		Phase out imports of internal combustion engine light vehicles
	Reducing vehicle trips	Encourage switching to walking, cycling and public transport Reduce demand for travel, for example through smart urban development and increased working from home Increase use of rail and coastal shipping for freight		
	Aviation and shipping	Improve efficiency	Start electrifying ferries and coastal shipping	Start electrifying short-haul flights
	Low carbon liquid fuels		Increase use of biofuels	
Energy, Industry and buildings	Buildings	No new fossil gas heating systems installed after 2025 Improve thermal efficiency		Start phasing out existing fossil gas use in buildings
	Electricity	Phase out fossil base-load generation	Transmission and distribution grid upgrades Expand renewable generation	Achieve ~95% renewable generation
	Industrial process heat	Replace coal with biomass and electricity		Replace fossil gas with biomass and electricity
Land	Agriculture	Adopt low-emissions practices on-farm	Adopt low-emissions breeding for sheep	Encourage new low biogenic methane technologies to be adopted when available
	Native forests	Ramp up establishing new native forests		Establish 25,000 ha per year
	Exotic forests	Average 25,000 ha per year of new exotic forests		Ramp down planting new exotic forests for carbon storage
Waste and F-gases	Waste	Divert organic waste from landfill Improve and extend landfill gas capture		
	F-gases	Increase end-of-life recovery of F-gases		

Source: Climate Change Commission (2021a), Table 7.1.

The table and the report's narrative suggested three aspects to the description of the future. First, there were clear decreases in some sectors, such as a 25 percent reduction in existing commercial buildings' heat demand by 2035 (Climate Change Commission 2021a, 111). Second, some shifts involve substituting one technology for another, such as the shift to electric vehicles. Third, the cost of living would not increase for households. Some things would become cheaper, offsetting higher costs elsewhere (Climate Change Commission 2021a, 138).

As we developed a baseline for 2050, we were uncertain about the net economic impacts of climate change. Some guidance is provided by the CCC (2024a). That report addressed economic impacts in Chapter 5, stating, *"We are confident that if the country took the actions in the EB4 demonstration path the overall effect would be economic and social gains"* (Climate Change Commission 2024a, 111).

The report cited OECD and UK modelling, which also found that higher GDP would result in the future due to climate policy reforms. The intervention logic expressed in the report was that investments now would lead to savings later through improved energy efficiency, lower energy costs and lower maintenance costs. Wider benefits were also anticipated: better health, biodiversity, and soil and water quality. Savings were calculated at $2 billion annually. Nevertheless, economic modelling suggests a 1.6 percent lower GDP by 2050 for the EB4 path versus the reference scenario.

5.1.1 Impacts on agriculture and forestry

The Commission provided details about specific sectors of the economy. Several changes for agriculture to 2050 were included (Climate Change Commission 2021a, 116–19):

- The sector focuses on using current technology and practices.
- New technologies to reduce methane are not required.
- The sector improves per-animal performance, reduces stocking rates, reduces replacement animals, and moves to lower-input systems.
- In the CPR, dairy cattle numbers fall by 8 percent from 2019 to 2030, and milk solid production falls by 4 percent. Sheep/beef numbers fall 8 percent in the same period.
- In the demonstration path, dairy cattle numbers fall 13 percent in total, and milk solid production falls 4 percent. Sheep/beef numbers fall 13 percent in total.
- There is selective breeding of sheep and cattle to reduce emissions.
- There are possibly biogenic methane inhibitors after 2035.
- There are 2,000 ha of land converted annually to horticulture between 2025 and 2035.

Changes for forestry to 2050 were also included (Climate Change Commission 2021a, 120–21):

- New native forests increased: 25,000 hectares annually by 2030, with 300,000 hectares of new native forest between 2021 and 2035.
- The demonstration path and CPR have similar exotic forestry plantings until 2030: around 380,000 hectares planted from 2021 to 2035.
- There would be no further native deforestation after 2025 in the demonstration path.

5.2 Impacts on the Māori economy

We also examined projections regarding the impacts on the Māori economy. Te Puni Kokiri (2024) provided information about the effects on Māori businesses. They looked at three main sectors: construction, agriculture and forestry, and professional services, which include 56 percent of Māori-owned businesses. They considered seven climate hazards: flooding, sea-level rise, wet spells, extreme rainfall, heatwaves, extreme hot days and drought. They showed where the impacts are the greatest by region and calculated the impacts by industry and region. For example, 85 percent of Māori agricultural businesses in Canterbury will be exposed to extremely hot days, and 19 percent of Auckland Māori agricultural businesses will be exposed to coastal inundation.

Some statistics from the report are:

- Sixty-eight percent of Māori-owned businesses are in the primary sector.
- Over 80 percent of Māori land is hilly or mountainous.
- Māori own 40 percent of commercial forestry plantations.
- Māori own a third of the fishing quota by volume.

5.3 Calibrating to the CCC modelling

To estimate the economic impact of different future scenarios, we first need to have a baseline – a version of the 2050 economy without additional changes layered onto it. Because the main focus of this research is the impacts of climate change, we turned to modelling by the Climate Change Commission to inform our baseline modelling. By matching our TERM-NZ modelling to their C-PLAN modelling, we place our work in the same climate and policy context as the Commission's extensive work to understand mid-century New Zealand. Specifically, we looked at the Current Policy Reference (CPR) case (Climate Change Commission 2021a) to describe and quantify our baseline for 2050. The CPR involves a continuation of current policies without assuming considerable adjustment due to climate change or other policies. We also assume that the CPR fits into a future described by RCP 4.5 because neither trajectory includes aggressive actions to reduce greenhouse gas emissions and climate change.

Our analysis is focused on the food and fibre sectors. The sector-level information for C-PLAN modelling was publicly available only for the 2021 draft advice rather than the final advice. There are differences between the two, but they were relatively minor, and the benefits of having sectoral data were greater than any small discrepancy between our results and the Commission's final advice. Therefore, we rely on the published C-PLAN results for 2021 draft advice to motivate our modelling.

To match the Climate Change Commission's assessment of New Zealand in 2050, we calibrated TERM-NZ to the inputs and outputs of C-PLAN. Because these are two different models with distinct sets of variables, equations, and mathematical processes, TERM-NZ cannot replicate C-PLAN exactly. Our calibration process, undertaken with assistance from the Centre of Policy Studies (CoPS) at Victoria University in Melbourne, focused on the main variables of interest and the industries and commodities relevant to this study of the food and fibre sectors.

First, we set the GDP of the economy in TERM-NZ to be equal to the GDP in C-PLAN. The C-PLAN results provided a year-by-year calculation of GDP for the CPR from 2014 to 2050. It projected that GDP in 2020 would be $293 billion and in 2050 would be $512 billion, for a total change of 75 percent.

Next, we adjust three variables to balance this growth in the economy with the source of growth. Economic growth in TERM-NZ can arise from growth in labour (employment), growth in capital (investment), and growth in productivity. This approach fits a standard Solow model of production, which is the basis for CGE modelling. The growth in the quantity of labour is an input to C-PLAN. While it is not specified for the draft advice, it is specified for the 2021 final advice. The labour force grows from 2.774 million people in 2020 to 3.503 million people in 2050, a total growth of 26 percent.

We could not find C-PLAN data for estimating the growth in capital investment. The treatment of capital is as follows:

> *Capital accumulation is equal to investment in the previous period minus depreciation. The C-PLAN model distinguishes between sector specific capital (that can only be used in the sector where it is currently employed) and mobile capital (that can be used in any sector). Changes in capital productivity in the C-PLAN model are specified using a productivity multiplier for each time period. In the baseline scenario, values for capital productivity multipliers are determined endogenously to target external gross domestic product (GDP) projections. Baseline estimates for capital productivity multipliers are then used as exogenous inputs for policy scenarios and GDP is endogenous in these scenarios.* (Winchester and White 2022, 6)

Capital stock is not simply an input into C-PLAN, whereas, in TERM-NZ, it can be specified as an exogenous variable (that is, an assumption for the modelling). We were unable to locate a summary of the capital stock (or capital accumulation) at the level of the whole economy from the public document. Thus, to calibrate TERM-NZ to C-PLAN, we had to find the implicit level of capital stock growth.

The remaining variable in the Solow model is productivity growth. We were unable to find any reporting on total productivity growth for C-PLAN. The above quotation notes that capital productivity is determined in the baseline scenario by targeting GDP. Changes in productivity are then specified for each time period (each year) for the sector-specific and mobile capital. However, the actual rates used, whether exogenous as inputs or outputs from the model as endogenously determined, did not appear to be available. We therefore turned to information on the New Zealand economy.

Stats NZ (2024b) makes several series and indices available regarding capital and labour stocks and productivity over time. In their discussion of the data, they provide the following information:

- Multifactor productivity growth was 0.5 percent annually from 2008 to 2019.
- Multifactor productivity growth was 0.6 percent annually from 2000 to 2008.
- Capital productivity growth was negative in both periods: -0.1 percent from 2008 to 2019 and -0.4 percent from 2000 to 2008.
- For the full-time series (1996 to 2023), capital productivity growth was -0.3 percent and labour productivity 1.2 percent annually.

If we assume for the purpose of calibrating TERM-NZ to C-PLAN that total productivity growth is 0.5 percent annually, then we can include a 16 percent productivity increase in TERM-NZ for the period 2020 to 2050.[2] To create this productivity increase in the model, we have adjusted capital stocks alongside the GDP target (an increase of 75 percent) and growth in labour stocks (26 percent growth) so that the remaining term, productivity, reaches a 16 percent increase. We found that a 75 percent increase in capital stocks,

[2] That is, (1 + 0.005) ^ 30 years = 1.16, or a 16 percent increase.

alongside the GDP and labour changes, produced a 16.6 percent growth in productivity and deemed those figures acceptable for the calibration exercise.

We can provide further context to these figures:

- If we assume a multifactor productivity growth rate of 0.6 percent, this produces total growth of 20 percent over 30 years. Thus, whether the TERM-NZ productivity is set to 16 percent or 20 percent, it is within the range of values experienced in the New Zealand economy this century.
- C-PLAN for 2021 final advice assumed that the labour force grew by 26 percent, as noted above. The labour productivity growth rate was 1 percent per year, which produces growth over the period of 35 percent. These two factors alone produce economic growth of 70 percent.[3] This suggests that only 5 percentage points of the 75 percent growth in GDP in the C-PLAN model are due to changes in capital stock or capital productivity.
- Data on historical capital stocks are available as part of the National Accounts (Stats NZ, 2024a). Considering the *net capital stock by industry, chain-volume series expressed in 2009/10 prices* (series SG07RAC05K90ZZ99), which has data for 1987 to 2023, and taking the total for all industries, we find the following 30-year growth rates.

Period ending (year)	30-year growth rate
2017	105%
2018	105%
2019	106%
2020	107%
2021	109%
2022	115%
2023	120%

  These figures suggest that the growth in capital, as calculated to calibrate TERM-NZ to C-PLAN, is below the capital stock accumulation experienced in the New Zealand economy. Over the past 30 years, capital stocks have more than doubled, but we increased the capital stock in TERM-NZ by only 75 percent.
- Data on historical GDP of New Zealand is also available. Stats NZ series SG00NAC00B01 provides annual GDP in nominal prices for 1972 to 2023 using the production method. We used the Consumers Price Index to adjust the figures to real 2023 dollars, as shown below.

[3] That is, 1.26 * 1.35 = 1.70, or a 70 percent increase.

Period ending (year)	30-year growth rate
2002	96%
2003	86%
2004	84%
2005	98%
2006	110%
2007	100%
2008	115%
2009	107%
2010	111%
2011	109%
2012	105%
2013	107%
2014	102%
2015	111%
2016	116%
2017	122%
2018	128%
2019	128%
2020	138%
2021	142%
2022	150%
2023	152%

These figures, which are 30-year rolling averages, show that New Zealand has more or less doubled its GDP over 30 years, with the average of the rolling averages being 115%. The 75 percent growth in the CPLAN modelling for the Climate Change Commission is thus lower than the recent experience of the New Zealand economy. This projection fits with a lower rate of growth in capital stocks.

5.3.1 Calibrating using C-PLAN

We modified TERM-NZ to reproduce the CPR baseline of C-PLAN used in the 2021 Climate Change Commission advice, mainly using the draft advice but incorporating the final advice where necessary. To calibrate TERM-NZ to C-PLAN, we focused on key economic elements: GDP, labour stocks, capital stocks, and productivity. The key assumptions that we take from the CPLAN model are from the Current Policy Reference scenario:

- GDP will grow by 75 percent between 2020 and 2050. This equates to a 1.88 percent growth rate per year.
- Capital is assumed to grow 75 percent over this period.

- Labour is assumed to grow 26 percent over the period.

While there remain differences between the models for their baselines, calibrating TERM-NZ to C-PLAN puts all of the present research in the climate change and policy context established by the Climate Change Commission. We also target sector growth rates in line with the C-PLAN model. Table 4 below captures the change in output value for each sector in the economy in line with the CPLAN model comparing 2020 to 2050 output values. We let the remaining industries in the model remain endogenous and adjust to the overall GDP target set.

The C-PLAN model draft results provided changes in output by sector at a national level. To use this information in the regional TERM-NZ model, we have to apply the national-level growth rates at a regional level.

Table 4 Sectors modelled and forecasted output growth

Sector	Definition	Growth rate from CPLAN
LivingPlant	Living plants, cut flowers and flower buds, flower seeds	41%
Vegetables	Vegetables (excluding processed vegetables; including dried leguminous vegetables)	41%
Kiwifruit	Kiwifruit	41%
Pipfruit	Pome fruit (apples, pears)	41%
Grapes	Grapes	41%
BerryFruit	Raspberries, blackberries, mulberries, strawberries, loganberries and other berries	41%
StoneFruit	Apricots, cherries, nectarines, peaches and plums, and other stone fruits	41%
CitrusFruit	Lemons and Limes, oranges, tangerines, mandarins, clementines	41%
OthFrtNut	Other fruits and nuts	41%
Forage	Forage	41%
Arable	Cereals	41%
b_s	Beef and sheep farming	-21%
oap	Other animal products, such as swine and poultry	41%
rmk	Dairy farming (existing technologies only)	4%
frs	Forestry, logging and related service activities	112%
fsh	Fishing, fish farming and related services	0%
mtp	Processing of meat	-38%
mil	Processing of raw milk	1%
ofd	Other food processing, such as beverages, fruits and vegetables	26%
w_p	Wood and paper products	162%

Source: NZIER, CCC

6 How are we modelling different climate change scenarios?

The purpose of this section is to provide more information on TERM-NZ and how the CGE method is undertaken.

6.1 TERM-NZ: NZIER's CGE model

TERM-NZ is a CGE model designed by CoPS based on the Stats NZ 2020 input-output tables.[4] CGE models are data-driven and used to capture the effects of new policies, technologies, or other external shocks on economic activity. They capture the economy-wide effects of changes ('shocks' in modelling jargon) directly on the affected industry and indirectly on supplying industries, competing industries, and factor markets (labour and capital). CGE models show the full effect of a change, which includes impacts from indirect effects that aren't immediately obvious. The cumulative impact of indirect effects can outweigh the direct effect of a change.

CGE models also estimate the effect of a shock on macroeconomic variables such as GDP, employment, wages and trade.

CGE models are a powerful tool, enabling economists to empirically explore many issues that would be intractable using econometrics or multiplier analysis. For these reasons, CGE models have become widely used internationally (e.g. by the OECD, IMF, and World Bank) for economic impact analysis.

6.2 What regions and sectors are in the model?

The list below indicates the different regions captured in this model:

- Northland
- Auckland
- Waikato
- Bay of Plenty
- Gisborne
- Hawke's Bay
- Taranaki
- Manawatu
- Wellington
- Tasman/Marlborough (including Nelson)
- Canterbury
- West Coast
- Otago

[4] Input-output tables are a powerful analytical tool for describing the structure of New Zealand's economy. They show the relationships between industries, the goods and services they produce, and who uses them.

- Southland.

The model divides the New Zealand economy into 44 industries, including 16 in the primary sector, 4 in the processing of primary products, and 26 in the remaining sectors of the economy. A full list is available in Table 11 in Appendix C. The model includes one type of labour and one type of household.

6.3 What are our closure conditions?

CGE models require researchers to make a few assumptions about how the economy operates. Essentially, there are too many moving parts for the amount of economic data available, so we must narrow down a few of those parts to allow the model to find a solution. These assumptions are called *closure conditions*. They typically concern labour markets, capital markets, government behaviour, and foreign exchange.

Determining the closure is a key part of any modelling exercise, and the modeller must be transparent about what is a result of the modelling and what has been imposed by assumption via the closure. We investigated several sets of closure conditions to select one that allowed the model to behave in a manner reflecting medium-term adjustments in the economy: sufficient flexibility to represent the choices and changes that businesses and consumers might make, but with some constraints on their options.

The closure conditions used for this modelling are the following:

- Aggregate employment is fixed, but the real wage varies, so changes in the macroeconomy have an impact on the average household.
- Capital is flexible, but the rate of return is fixed, which provides investment capital for changes in business activities as long as the changes are sufficiently profitable.
- Real government consumption follows household consumption so that government spending is constant as a percentage of the whole economy.

6.4 How do we shock the model?

To reach different scenario outcomes, we must 'shock' the model to generate changes in national and regional economies. When we shock the model, we select specific input parameters and change their values. The change in some input parameter values produces further changes throughout the economy. Resources are reallocated to reflect changing conditions. These changes result in increases or decreases in the industries represented in the model, leading to corresponding fluctuations in the commodities produced. There are flow-on effects on markets and supply chains. The model tries to find a mathematical solution that shows how the economy would resettle into a steady state given the new input parameter values. We can then examine the changes by industry and region or at the national level. We can also compare changes across scenarios to identify differences in how the economy responds to various shocks.

There are several ways to shock the model because there are many input parameters in the model. We have shocked the productivity of economic resources and inputs and then allowed the model to reallocate consumption and production according to prices and market drivers.

Across the three scenarios, we adjusted input parameters in various ways to simulate possible futures, as described with the help of partners and advisors. The next section describes the scenarios and how they were developed.

7 Scenario development

7.1 Co-design of scenarios

NZIER and MWLR worked with MBIE and MPI to co-design scenarios for 2050 that we could model with TERM-NZ. The team held an online workshop to help design the scenarios. The workshop had two purposes: to identify the most important issues to address with the modelling and to collect expert guidance on those issues.

The workshop generated numerous ideas and raised several key issues related to climate change, the primary sector, and regional economics, which are the project's primary focus. The ideas generated in the workshop are provided in Appendix A. During the workshop, these ideas were summarised into themes, which were then narrowed down to select themes as the basis for scenario development. See Table 5 for this list. This process identified four themes that were clearly most important to the participants. Of the four, one theme – modelling around extreme events – had already been designated out of scope for the project. The workshop output was three agreed themes around which to develop scenarios to be modelled with TERM-NZ.

Table 5 Themes identified in scenario workshop

Themes
Themes prioritised by participants
Generalised uncertainty, domestic policy
Market demand
Biophysical – rain, temperature
Extreme events
Additional themes identified by participants
International policy
Climate change as an exacerbator
Stickiness, ability to innovate
Investor sentiment re: climate change
Ethical consumer responses
Adaptation vs lock-in
Feedback impacts on innovation
Mitigation tech and actions
Second order effects
Electricity prices -- up or down

Source: NZIER

The first scenario theme was about physical, financial and human resources used in production and associated uncertainties. Participants were interested in understanding the impact that policies could have on the economy in the context of climate change, as well as the broad range of other factors affecting investment confidence and predictability. These factors could be related to investment and innovation, workforce development and planning, or incentives to producers. Some issues discussed were increased uncertainty, increased caution in the finance sector, impacts on human capital, natural resource investment, and technology-driven productivity increases.

The second scenario theme focused on market demand. Because of the generally export-focused nature of New Zealand's primary sector, this scenario mostly considered international conditions. The participants discussed the impacts of changes in overseas markets from climate change and competition, supply and demand shocks affecting both inputs and product markets, the importance of variations by market and commodity, and risks to 'tier 1' markets.

The third scenario theme focused on the biophysical impacts of climate change on New Zealand's regions and producers. Participants were interested in understanding the impacts of climate change on sector productivity and profitability, with a focus on dairy, sheep and beef, and forestry. In prior work on this project, researchers at Plant and Food Research, Scion and Manaaki Whenua Landcare Research had investigated and modelled the potential impacts of climate change on primary sector production. Participants were aware of this work and were interested in the economic consequences.

7.2 Translating workshopped scenarios into model inputs

The workshop developed the issues and themes for the scenarios. To model them, we turned these issues and themes into quantitative inputs for the TERM-NZ model. The inputs we used and their logic are discussed below.

7.2.1 Scenario one – Productivity growth scenarios

Investment settings will play a crucial role in New Zealand's response to climate change. While policy influences the investment landscape, a broad range of other factors also play a role. Having well-designed investment settings can enhance economic performance by increasing capital and enhancing the acquisition and utilisation of human capital. By improving capital and labour productivity and investing in processes and people, we can mitigate some impacts of climate change.

Scenario one focuses on the productivity of the food and fibre sectors, specifically on the amount of output these sectors can produce with the inputs they use. The underlying perspective is that actions and investments could improve productivity, either as the public sector pursues policies to raise productivity growth or as the private sector pursues efficiency gains. We also considered a variant in which those actions are less effective and productivity grows more slowly. To model the scenario, we change the parameter that regulates the overall productivity of those sectors. We change the underlying sector productivity by enhancing or restricting that input, which simulates changes in the investment in climate change mitigation and adaptation leading up to 2050.

We included a positive and negative scenario to provide information about the potential impact of investment settings. In each of these iterations, we change total factor productivity by 10 percent for the food and fibre sectors, including production and processing.

7.2.2 Scenario two – Changing export demand

Climate change will have impacts across the globe, affecting production, supply chains and consumer demand. In combination, these changes will affect export markets and demand for New Zealand exports. Examples of this may include greater demand for exports of our products, such as increased demand by middle-class consumers for high-quality animal protein, or potential for disruption from synthetic protein, changing consumer preferences and the potential for countries to seek to produce more food domestically and changes to other countries' ability to grow food under different warming scenarios.

Scenario two is focused on changing export demand for meat and dairy products, which account for a large amount of current export revenue. The underlying concern is the international demand for animal products. One perspective is that demand for food and protein will continue to grow in tandem with population and income increases. Another perspective is that the demand for animal products may face headwinds from alternative proteins or concerns about the GHG emissions of ruminant animals. To model the scenario, we adjusted the national export volume for these products. This change simulated an increase or decrease in international demand for animal products. In the model, changes in final demand at the national level are transmitted to changes at the regional and industry levels as the model adjusts to produce the new level of exports.

We included both positive and negative outcomes related to export market demand. In each of these iterations, we change the export quantity demanded for meat and dairy products by 25 percent.

7.2.3 Scenario three – Biophysical impacts of climate change

Climate change will change New Zealand's ability to produce different products. Different regions would be affected differently. The ideal growing locations for some existing crops may move, and the performance of crops in a specific region could change. Under this scenario, we model changes in crop production by commodity and region.

Scenario three is focused on the biophysical impacts of climate change. In this scenario, we utilise the modelling from our research partners on the spatial distribution and impacts of climate change on New Zealand, as well as the consequences for agricultural, horticultural, arable, and forestry production. These impacts were translated into two types of shocks to TERM-NZ. One shock was percentage changes in sector output to simulate changes in per-hectare production by industry and region by changing the primary factors of production to increase or decrease sector output. The other shock was percentage changes to the costs of production by changing the effectiveness of inputs used in production. These detailed changes to the input parameters for production created flow-on effects that the model resolved by reallocating production and consumption across regions and industries.

For each region, we apply shocks for each sector. We relied on information from the wider project team (MWLR, PFR and Scion) to determine the direction of change by region and commodity. Information on each of the shocks can be found in Appendix C.

8 Scenario results

This section contains the results of the three scenarios listed in the previous section.[5] We focus on both national-level and regional impacts, providing an in-depth analysis of their effects. Further information about industry-level impacts can be found in Appendix C.

8.1 Scenario one – Productivity growth scenarios

Scenario one focuses on changing productivity. Table 6 and Table 7 show the main macroeconomic outcomes of an increase and a decrease in productivity, respectively. Each table contains (from left to right) the region of interest (and all of New Zealand) and how real GDP, real household consumption, aggregate employment, and average real wage change in percent terms.[6]

The total impact on New Zealand's real GDP is 3.6 percent for a 10 percent increase in total factor productivity, as well as a 3.8 percent increase in real household consumption and a 4.7 percent increase in the average real wage. GDP impacts are greater in agricultural regions such as Southland (11.0 percent) and Gisborne (13.0 percent), whereas the impacts are quite small in Auckland (0.1 percent) and Wellington (0.3 percent).

Real household consumption and average real wage follow a similar pattern to real GDP at a regional level. For example, in Gisborne, real household consumption increased by 11.1 percent, with higher employment (3.6 percent) and a higher average real wage (8.5 percent). In Southland, real household consumption increases by 10.0 percent, with higher employment (3.1 percent) and a higher average real wage (7.9 percent).

If there is lower productivity in the primary sector, real GDP is expected to fall by 2.9 percent, with real household consumption falling by 3.1 percent and the average real wage by 3.8 percent. As with the positive change in productivity, the impacts are seen more in agricultural areas.

5 In Appendix C5 we compare to the 2050 results to the 2020 model to ensure consistency.

6 As part of closure conditions national aggregate employment is fixed.

Table 6 Results from higher productivity in the primary sector

Percentage change in 2050 versus baseline

Region	Real GDP	Real household consumption	Aggregate employment	Average real wage
Northland	8.4	7.7	2.1	6.8
Auckland	0.1	0.3	-1.5	3.1
Waikato	7.1	6.7	1.6	6.3
Bay of Plenty	8.4	8.5	2.4	7.2
Gisborne	13.0	11.1	3.6	8.5
Hawke's Bay	10.1	8.8	2.6	7.4
Taranaki	4.3	4.5	0.5	5.2
Manawatu	9.2	8.7	2.5	7.3
Wellington	0.3	1.3	-1.0	3.6
Tasman/Marlborough	9.4	7.7	2.0	6.8
Canterbury	4.9	4.6	0.6	5.3
West Coast	6.3	4.1	0.3	5.0
Otago	2.2	1.6	-0.9	3.7
Southland	11.0	10.0	3.1	7.9
New Zealand	3.6	3.8	0.0	4.7

Source: NZIER

Table 7 Results from lower productivity in the primary sector

Percentage change in 2050 versus baseline

Region	Real GDP	Real household consumption	Aggregate employment	Average real wage
Northland	-6.9	-6.3	-1.8	-5.6
Auckland	-0.2	-0.3	1.3	-2.6
Waikato	-5.6	-5.3	-1.3	-5.1
Bay of Plenty	-6.7	-6.8	-2.1	-5.8
Gisborne	-10.9	-9.6	-3.6	-7.2
Hawke's Bay	-8.5	-7.5	-2.5	-6.2
Taranaki	-3.2	-3.6	-0.4	-4.2
Manawatu	-7.2	-6.8	-2.1	-5.8
Wellington	-0.2	-1.0	0.9	-2.9
Tasman/Marlborough	-7.8	-6.6	-2.0	-5.7
Canterbury	-3.9	-3.8	-0.5	-4.3
West Coast	-4.8	-3.2	-0.2	-4.0
Otago	-1.8	-1.3	0.8	-3.1
Southland	-8.7	-8.0	-2.7	-6.4
New Zealand	-2.9	-3.1	0.0	-3.8

Source: NZIER

8.2 Scenario two – Changing export demand

Scenario two focuses on changing export demand. Table 8 and Table 9 show the main macroeconomic outcomes from an increase and a decrease in the national export quantity of milk and meat products, respectively. Each table contains (from left to right) the region of interest (and all of New Zealand) and how real GDP, real household consumption, aggregate employment, and average real wage change in percent terms.

The total impact on New Zealand's real GDP is 0.2 percent for a 25 percent increase in export demand. Real household consumption increases by 0.8 percent, as well as the average real wage by 0.6 percent.

GDP Impacts are greater in agricultural regions such as Southland (3.4 percent) and Manawatu (2.1 percent), whereas the impacts are small (and negative) in Auckland (-0.6 percent) and Wellington (-0.2 percent).

Real household consumption and average real wage follow a similar pattern to real GDP at a regional level. For example, in Southland, real household consumption increases by 5.5 percent, with higher employment (2.4 percent) and a higher average real wage (3.1 percent).

If there is a decrease in export demand in the primary sector, real GDP is expected to fall 0.1 percent, with real household consumption and average real wage falling by 0.6 and 0.5, respectively. As with the scenario of increased export demand, the impacts are more pronounced in agricultural areas.

Table 8 Results from increasing export demand for primary products

Percentage change in 2050 versus baseline

Region	Real GDP	Real household consumption	Aggregate employment	Average real wage
Northland	0.7	1.1	0.3	0.9
Auckland	-0.6	-0.6	-0.6	0.0
Waikato	1.5	3.0	1.2	1.8
Bay of Plenty	0.3	0.1	-0.2	0.4
Gisborne	0.0	-0.1	-0.3	0.3
Hawke's Bay	-0.2	0.0	-0.3	0.3
Taranaki	0.7	2.2	0.8	1.4
Manawatu	2.1	4.2	1.8	2.4
Wellington	-0.2	0.0	-0.3	0.3
Tasman/Marlborough	0.1	0.2	-0.2	0.4
Canterbury	0.8	1.6	0.5	1.1
West Coast	1.6	2.8	1.1	1.7
Otago	0.0	-0.1	-0.3	0.3
Southland	3.4	5.5	2.4	3.1
New Zealand	0.2	0.8	0.0	0.6

Source: NZIER

Table 9 Results from decreasing export demand for primary products

Percentage change in 2050 versus baseline

Region	Real GDP	Real household consumption	Aggregate employment	Average real wage
Northland	-0.6	-0.9	-0.2	-0.8
Auckland	0.6	0.7	0.6	0.0
Waikato	-1.4	-2.6	-1.1	-1.7
Bay of Plenty	-0.2	0.0	0.2	-0.3
Gisborne	0.0	0.2	0.3	-0.2
Hawke's Bay	0.2	0.1	0.3	-0.3
Taranaki	-0.6	-1.9	-0.7	-1.3
Manawatu	-1.9	-3.8	-1.7	-2.2
Wellington	0.3	0.2	0.3	-0.2
Tasman/Marlborough	-0.1	0.0	0.2	-0.3
Canterbury	-0.7	-1.4	-0.5	-1.0
West Coast	-1.4	-2.4	-1.0	-1.5
Otago	0.1	0.2	0.3	-0.2
Southland	-3.1	-4.9	-2.3	-2.8
New Zealand	-0.1	-0.6	0.0	-0.5

Source: NZIER

8.3 Scenario three – Biophysical impacts of climate change

Scenario three focuses on changing production patterns for the primary sector. Table 10 shows the main macroeconomic outcomes of changing per-hectare yields and increasing costs to produce sheep and beef products. The table below contains (from left to right) the region of interest (and of New Zealand) and how much real GDP, real household consumption, aggregate employment, and average real wage change in percent terms.

The total impact on New Zealand's real GDP is 0.6 percent from the changing growing conditions, with real household consumption and the average wage increasing by 0.7 and 1.4 percent, respectively.

GDP impacts are greater in agricultural regions such as Southland (5.2 percent) and Gisborne (4.0 percent), whereas the impacts are small in Auckland (-0.5 percent) and Wellington (0.0 percent).

Real household consumption and average real wage follow a similar pattern to real GDP at a regional level. For example, in Waikato, real household consumption increases by 2.6 percent with higher employment (1.0 percent) and a higher average real wage (2.4 percent).

Table 10 Results from biophysical impacts of climate change

Percentage change in 2050 versus baseline

Region	Real GDP	Real household consumption	Aggregate employment	Average real wage
Northland	1.9	1.4	0.4	1.8
Auckland	-0.5	-0.8	-0.6	0.7
Waikato	2.2	2.6	1.0	2.4
Bay of Plenty	2.0	1.8	0.6	2.0
Gisborne	4.0	3.5	1.5	2.9
Hawke's Bay	1.7	1.4	0.4	1.8
Taranaki	1.4	2.0	0.7	2.1
Manawatu	3.2	4.3	1.8	3.2
Wellington	0.0	0.0	-0.3	1.1
Tasman/Marlborough	2.0	1.3	0.4	1.7
Canterbury	0.4	0.4	-0.1	1.3
West Coast	-0.7	-0.9	-0.7	0.6
Otago	0.3	-0.4	-0.4	0.9
Southland	5.2	5.6	2.5	3.9
New Zealand	0.6	0.7	0.0	1.4

Source: NZIER

9 Discussion and conclusion

9.1 Return to the aim of the research

This research programme aimed to understand better the potential impacts on regional economies resulting from the effects of climate change on the primary sector. For the economic scenarios, MBIE and MPI advised the research team to consider climate change and other economically relevant factors. We, therefore, conducted modelling that started from the baseline macroeconomic modelling from the Climate Change Commission and investigated the impacts on productivity, export markets and primary sector production in 2050, all under conditions assuming GHG emissions and climate change consistent with RCP 4.5.

9.2 Results varied across scenarios, regions and industries

We modelled three scenarios, including variations, which produced the following results:

- Nationally, the impacts of the modelled scenarios amounted to a few percent of GDP or less. The largest impacts were achieved by growing productivity. For a 10 percent increase in productivity in the food and fibre sectors, we observed a 3.6 percent increase in output. The smallest impacts at a national level resulted from changes in primary sector production patterns due to climate change. The relative size of the scenario results is a function of the inputs modelled. The inputs represent the best information we were able to assemble from government experts and scientists, so the results reflect the expected consequences of what those people currently understand about climate change, productivity and export markets.

- Trade impacts had a smaller impact on the economy than productivity impacts, although both were focused on primary sector industries. Increases in export demand produced not just growth but also reallocation of productive resources. Higher export demand led to increased dairy and meat production, partly by reallocating resources from other parts of the food and fibre sectors. A decrease in demand produced the opposite result, with a magnitude roughly equal to the initial increase.
- Climate change impacts on growing environments at a regional level (see Table 16 in Appendix C) generally had a positive effect on the primary sector and the food and fibre sectors as a whole. Dairy and sheep/beef production increased in nearly every region. Horticultural production also increased across regions and industries. Forestry output increased everywhere as well. The increases in production led to higher GDP in most regions. The main exception is the West Coast, where a decline in sheep and beef production led to a decrease in GDP.

The breakdown of results by region provides useful insights. In all scenarios, the modelled shocks were focused on the primary sector or the industries in the food and fibre sectors. The economic impacts were concentrated in the regions where these sectors are based. In all scenarios, Auckland (about one-third of the New Zealand economy) had among the smallest impacts, and Wellington similarly had relatively small impacts. This was especially true of the productivity and export scenarios. The direct impacts of climate change on regional, non-urban economies were largely positive, resulting in higher GDP than the baseline, as well as increased employment and wages. The size of the impact varied by region and industry. The main exception to these positive results was the West Coast, which is expected to be a little worse off due to climate change.

Overall, the detailed results suggest that regions will vary in their experiences of climate change. The reason for the different results by region can be traced to the industry-level impacts. In Scenario one, the productivity changes apply across the food and fibre sectors. There are some differences across the industries, but they are not as large as in other scenarios. In Scenario two, the changes in export demand affect the meat and milk industries the most. Other parts of the food and fibre sectors, such as horticulture and arable farming, appear to be indirectly affected as resources are reallocated according to the profitability of different industries. As a result, regions with more meat, milk and forestry production tend to have larger impacts. Scenario three is the most complex because the impacts of climate change vary by commodity and region. The West Coast, in particular, is affected differently than other regions. The results suggest that one challenge of climate change for the regions will be increasing processing capacity to capitalise on increased primary sector production.

9.3 Results confirmed earlier findings

This work presents the most detailed economic analysis yet of climate change impacts in New Zealand by region and industry; therefore, so some of the finer points cannot be directly compared to previous findings. However, the aggregated results can be compared to some extent. For example, research by Kahn et al. (2019) estimated the impacts on New

Zealand for RCP 2.6 and RCP 8.5 in 2050, finding losses of 1.17 percent and 3.18 percent, respectively. Although our analysis of RCP 4.5 found a small gain in GDP, the overall magnitude of the impact, just a few percentage points of GDP, is similar to our results. Burke et al. (2015) considered RCP 8.5 and SSP 5, but like our results, they suggested that the economic impact on New Zealand would be small. The findings of Burke et al. (2015) regarding a non-linear response to climate change, with a possibility that cooler countries could benefit, provide an explanation for our Scenario three results.

Previous analyses of the impacts of policy responses have also suggested results of similar sizes. For example, NZIER's analysis of policies to reduce carbon emissions estimated a 2.4 percent reduction in GDP (NZIER 2018). Modelling the economic impacts of emissions reduction targets and carbon price paths to 2030 revealed GDP losses of less than 1 percent (Daigneault 2015). Finally, the C-PLAN modelling and further commentary by the Climate Change Commission suggested that the difference between the baseline projection and greater action to address greenhouse gas emissions could be anything from a 1.6 percent loss in GDP loss to a small economic gain (Climate Change Commission 2024a). All these examples found results of a few percentage points or less, similar to the findings we report here.

9.4 The value of fully developed scenarios

Our review of climate change research highlighted the number of variables that have been considered in prior work. It is not just 'the economy' that will change, but individual sectors within the economy and technologies used within those sectors. Furthermore, the social, political and environmental contexts in which those economies operate are also relevant. The detailed projections of RCPs and SSPs illustrate the number of factors to consider when developing future scenarios. For our modelling, we could only consider a subset of these factors. Further research could more fully incorporate the considerations of prior research to develop a more complete analysis of the potential impacts on the New Zealand economy under the same scenarios that other countries have investigated.

To compensate for a lack of completeness, we focused on building our analysis on the foundations already laid by prior New Zealand research. We used information provided by C-PLAN modelling to update TERM-NZ to a future state. This approach aligned our research with that conducted by the Climate Change Commission, incorporating its insights into industrial and technological development by reference.

As with all CGE modelling, we had to choose macroeconomic closures that reflect assumptions about how the economy operates. Overall, we used closure conditions that reflect moderate flexibility in the economy (Kaye-Blake 2021). Other research has assumed less flexibility in capital markets than we have. For example, Monge and McDonald (2023), building their CGE modelling on C-PLAN, included the restrictive assumption that investment funding was endogenous and a function of savings, which foreclosed the ability to borrow overseas capital. Arguments could be made for more flexibility in the labour market than our modelling due to New Zealand's highly variable net migration. If our research had made more restrictive assumptions about the availability of capital and labour, the results would have been smaller. Had we made less restrictive assumptions, the results would have been larger.

We also recognise the importance of the wider economic, political and environmental context. These results represent a point in time. However, as we were reminded by a workshop participant (Appendix A), a common framework presently is VUCA: Volatility, Uncertainty, Complexity, and Ambiguity. This framework serves as a reminder that any given point in time can include a cyclone such as Cyclone Gabrielle, a COVID-19 pandemic, a war in Europe or sudden changes in trade settings. We have not attempted to include these factors in our modelling, but we recognise that they would affect the results.

9.5 Policy implications of the research

The aim of the research was to consider impacts on regional economies. The results suggest the following implications for policymakers:

- The physical impacts of climate change – temperature and rainfall, but excluding adverse events and other impacts such as pests and disease – could amount to a percentage point or less of the national economy by 2050.
- However, those impacts vary by a factor of ten across regions and industries. Some primary sectors are more affected, which has implications for the regional distribution of impacts. The result is that some regions do better while others do worse. Policy should be sensitive to these details to prepare and plan for the impacts of climate change.
- The impacts of changes in export markets – at least changes of the size modelled here – are of the same order of magnitude as climate change impacts. From a policy perspective, both issues are of similar importance.
- Improving productivity by just 10 percent by 2050 – a 0.3 percent increase per year over the baseline – would more than likely address any losses from climate change or changes in export markets.
- Climate change is forecast to increase the productivity of the primary industries (land-based activities), as shown in Scenario three. An increase in processing capacity would be needed to handle the increased volume of raw product.
- We have confidence in our findings. We developed this analysis based on prior work and in collaboration with MBIE and MPI; the results are broadly consistent with prior modelling.

While we have identified several areas for further research, we also believe that these results provide sufficient guidance for policy development.

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Appendix A Workshop for scenario development

A.1 Workshop plan

Workshop: MWLR/NZIER-facilitated workshop for MBIE project on impacts of climate change on regional economies through primary sectors

Location: Online, with an online whiteboard tool

Participants: from MBIE, MPI and the project team

Purpose: Define three scenarios (possibly more) for primary sector production in 2050 across New Zealand. The scenarios are to take into account climate change for use in an economy-wide ('CGE') model.

Detailed plan:

- Presentation 1: Project summary
- Activity 1: Brainstorm issues facing the primary sector due to climate change
- Presentation 2: Description of NZIER's TERM-NZ model
- Activity 2: Scenario creation in small groups
- Activity 3: Scenario selection and refinement

A.2 Climate change issues identified

The workshop processes identified issues associated with climate change. They are reported below (lightly edited for spelling, punctuation, etc.), organised into clusters of issues.

Adverse events

- Fire risk – e.g. forestry
- Drought increasing
- Storm size and frequency
- Increased frequency and intensity of adverse events – potential change in the role of govt/how the market might respond
- Adverse events
- Adverse events and variability will increase
- Impact of extreme weather events – droughts/floods, reduce land productivity, damage pastures/infrastructure
- Impact of droughts and wildfires. Likely to have the biggest impact on ag/forestry systems
- Forestry fire risk

Biosecurity

- Biosecurity risks change and increase
- Changes in biosecurity risks

- Biosecurity incursion frequency
- Biosecurity changes

Consumer preferences and behaviour

- Changing consumer behaviour
- Changing consumer preferences
- Increases in demand and changes in consumer preferences
- Changes in consumer preferences
- Changing consumer preferences
- Expected consumer/customer expectations

Cross-cutting issues

- Who pays
- The scale of the challenge puts larger firms in a stronger position (potentially). Is this good/bad?
- Variability and Uncertainty – VUCA
- Relativity of differentiated impacts and ability to respond across economies and sectors
- Understanding the impacts of a larger local population and potentially lower reliance on exports
- Impact of market vs policy levers
- Ageing population, which while more wealth to invest, is often less
- Climate change as an exacerbator of existing challenges in the primary sector (low productivity, etc.)

Innovation, adaptation and technology

- Symmetry of information and access to technology
- Tipping points, e.g. vertical farming
- Ensuring incentives and support are fairly provided so early movers who self-invest are not disadvantaged
- Tech adoption and waiting for the silver bullet
- Need to innovate/adopt new technologies
- Speed of adaptation
- Changes in productivity, innovation, technology

International and market issues

- Market access
- Variability with international climate policy
- Where can firms move production to overseas countries

- Responsiveness to market signals
- Impact of global trends and/or protectionist measures
- Trade distortions from governments to address food security for growing populations
- Demand for imports and exports
- Relative competitiveness in international markets
- Conflict – war, etc.
- Policy levers – e.g. impacts of CBAMs
- Changes/disruption to trade and geopolitics
- Population and immigration (forced migration?)
- International policy responses – implications for market access
- Impact of global agriculture production changes and shocks on NZ returns
- Changes in global production patterns – what does this mean for commodity prices? Competition in international markets?

Investment, infrastructure and supply chains

- Investment/policy/market uncertainty
- Infrastructure, e.g. ports, rail, shipping
- The industry structure and the impact this has on investment decisions (e.g. co-ops)
- Off-farm infrastructure
- Investment to adopt and mitigate climate change
- Level of cost effective insurance (physical infrastructure like dams) and financial like insurance policies
- Impacts on infrastructure and supply

New Zealand domestic policy

- Uncertainty in local politics/policy, e.g. councils and consenting
- Political uncertainty and disruption this has on investment/land use decisions
- Domestic policy, e.g. agricultural emissions pricing
- Government policy
- Impact of policy decisions – but a general direction of travel to reduce emissions

Prices for inputs and products

- Input and output prices
- Premiums for reliability of food supply, e.g. Singapore
- Input costs and reliability of supply, e.g. electricity
- Prices, including relative prices, will change
- Changes in costs
- Prices – domestic and international

Production

- On-farm infrastructure
- Encouraging a diversified range of responses at a producer/farmer level while also being clear that we aren't the ambulance at the bottom of the cliff for bad choices
- Demand for land use flexibility
- Impact of competing production methods
- Regional productivity?
- Increasing costs due to risk aversion from investors
- Climate – temperature and rain
- Water availability, changing rainfall patterns and changing viability of irrigation
- Changing rainfall patterns
- Levels of production
- Changes in production
- Impact of elevated CO_2 on plant growth, especially pasture production

Sector development

- Supporting the development of new business models
- Ability to adopt new practices and stickiness in changing land uses
- Infrastructure spend required by each sector over time
- Pathways by sector over time (some will need to move sooner than others)
- Gradual and more abrupt changes in the viability of different land uses due to biophysical effects
- Horticultural production changing
- Regional and international variation – how this will impact relative profitability and competitiveness, etc
- Capabilities – what does NZ have now, and what might it need in the future? How different are the two sets?
- Labour/skills/infrastructure needs to adapt to climate change (management) or changing land use
- Impacts on firm-level resilience, and need to think about impacts pre and post farmgate
- Regional differences in climate change and effect on different land uses (and thus future investment)

Appendix B Modelling decisions and feedback received

B.1 Introduction to this discussion

During the project, we received feedback on our proposed method for modelling climate change impacts on the economy in 2050. We understand that modelling involves choices and judgments that everyone may not endorse. We believe that a detailed discussion of the feedback is warranted so that we can contribute to an informed conversation in New Zealand that develops capability for CGE modelling and policy. Out of discretion and a desire to support a free and frank exchange of ideas, we have not included verbatim feedback. In this section, we discuss how we addressed certain concerns.

B.2 Calibration of TERM-NZ to C-PLAN

We received feedback regarding the calibration of TERM-NZ to C-PLAN. The feedback included detailed suggestions on which variables in TERM-NZ needed to be adjusted to calibrate it to C-PLAN. It also suggested that we provide a detailed explanation of how we did the calibration. We have addressed the second point in the discussion of the main report regarding the calibration process. However, we also underline the other finding from that discussion: there are at least three ways in which the C-PLAN modelling has difficulties with representing New Zealand 30 years in the future:

1. The contribution of capital to economic growth is small, compared to expectations, theory and historical averages.
2. The total amount of growth is small, compared to historical experience.
3. Not discussed above is that the population growth rates and labour force growth rates do not appear to have accounted for the expected ageing of the New Zealand population and the attendant increase in the dependency ratio. The ratio of the labour force to the population in 2014 in C-PLAN is 55.5 percent, and in 2050 is 56.2 percent.

The proposed calibration in this feedback was extensive. We believe that our approach was pragmatic. We started with two different models: TERM-NZ and C-PLAN. There is a continuum to how we make TERM-NZ resemble C-PLAN. At one end of the continuum, there is no effort at all: both models simply do what they do independently of each other. At the other end of the continuum, TERM-NZ has been entirely re-coded and re-parameterised to be a static version of C-PLAN, a dynamic model. In that case, there is essentially nothing of TERM-NZ left. In our actual calibration of TERM-NZ, we had to choose a spot on that continuum, taking into account the issues described above regarding the cost of producing information and the diminishing marginal value of precision. We chose to modify TERM-NZ so that it represented an economy of the same size as C-PLAN (75 percent larger than it is today), and we scaled labour and capital productivity to those of C-PLAN.

In the course of calibrating TERM-NZ, we discovered — and discussed with the Climate Change Commission — that the labour productivity assumptions used in C-PLAN do not align with population projections and anticipated demographic trends. Specifically, while the population is expected to grow, it is also expected to age, and older cohorts (particularly those over 65) tend to have lower labour force participation. C-PLAN does not account for these demographic shifts in its labour productivity forecasts. Our understanding is that this simplification was considered acceptable, given the intended use of the model.

This simplification raises a legitimate question: if C-PLAN's assumptions about labour productivity do not reflect current thinking on the implications of an ageing population, should we calibrate TERM-NZ to it? The answer reflects a broader truth about modelling: all models are simplifications of reality and, as such, none is perfectly 'right'. However, aligning TERM-NZ with C-PLAN allows us to build on an existing body of analysis familiar to decision-makers. In this way, even if both models have limitations, their value lies in fostering continuity, transparency and a shared basis for discussion. We have aimed to make TERM-NZ as relevant and robust as possible within this context.

We can also offer reflections on other details in the feedback:

- The sectoral aggregation differs between the two models (or modelling efforts) because they focus on different things. The C-PLAN model has a greater interest in sources of greenhouse gas emissions, resulting in more complex modelling of the energy sector and low-carbon farming methods. The TERM-NZ modelling focuses on the economic contribution of the primary sectors to regional economies, providing more detailed information about these sectors. It would be possible to create another model that includes detailed modelling from both sources. However, that model would also require a larger number of assumptions, more resources to build and run, and more effort to interpret the results.
- The underlying input-output tables in the two models are likely to be similar. Both are based on data from Stats NZ, which periodically provides an updated table of inter-industry transactions. This is the definitive source of input-output data for any macroeconomic model of the New Zealand economy, whether it is a dynamic, static, or multiplier model. However, although TERM-NZ has been updated to the 2020 data, Winchester and White (2022) only cite the earlier 2013 input-output tables (p. 19).
- Updating either model to account for technological changes or shifts in the economic structure would be a large undertaking. The aim of this work – whether the C-PLAN CPR scenario or the TERM-NZ modelling is to offer a quantitative description of the economy in 25 years. We do not know what that world will look like. Twenty-five years ago, we did not have smartphones or most social media; paper maps, paper cheques, and incandescent lightbulbs were widely used. The country's GDP was roughly one-half its current size. It is an impossible undertaking to predict future changes.
- Even if we were to restrict the problem to changing TERM-NZ to resemble C-PLAN, we would encounter the issue that they are two different models. The more we make certain model values the same, the more other model variables must adjust to compensate for the difference. At some point, those other variables become unreasonable. Importantly, decision-makers using the model's output will never be aware of these unreasonable values deep within the model, as they do not inspect every single number in the model output.

The feedback on calibration set up an impossible position. One option was to rewrite TERM-NZ so that it exactly replicates C-PLAN, and in the process, lose the capability to model the agricultural sectors and incorporate data that is possibly contentious. The other option is that TERM-NZ roughly matches the size of the whole economy and the productivity of its resources in C-PLAN, while leaving ourselves open to criticism that we have not done enough. We have used our experience as advisors to government and our expertise in modelling to select what we believe is the right spot on the continuum. Any criticism of this choice should also demonstrate how much difference another choice makes in the final outcomes of the research.

B.3 Selection of productivity parameters to shock

We received feedback about the method for modelling productivity changes. It discussed that the specific parameters used to shock the model should take into account the details of policy design. For example, policy affecting capital accumulation might be modelled one way, while exogenous changes to returns on investment (for example, with subsidies) would be modelled differently.

This discussion of different methods for accounting for productivity change in the model provided a detailed description of types of investment, their impacts on the economy, and methods for reflecting those changes in a model. They appeared to be driven by a desire to produce better model outputs, i.e. model outputs that more closely reflect behaviours in the real economy and provide better estimates of the economic impacts. This discussion of the appropriate modelling method would suit a methodological investigation of the impact of modelling choices on results or a policy assessment investigating the potential impacts of different policy choices concerning capital investment.

B.4 Timing of the shocks

It was recommended that we consider the timing of shocks because the timing of shocks would affect the pace at which the economy could adapt.

TERM-NZ, as discussed in this report, is a static model. It models two periods: now and then. It is up to the modellers and their interpretation of results to specify the years represented by those two words. Modelling the timing of shocks is typically done with a dynamic model, which explicitly includes a time dimension. As noted above, C-PLAN is a dynamic model, and TERM-NZ is a static model. Investigating the impact of the timing of shocks was outside the project's scope.

B.5 Sectoral differentiation

It was suggested that we consider productivity improvement on a sector-by-sector basis.

Productivity changes are a key driver of economic performance. Across the 44 sectors modelled in TERM-NZ for this project, those with higher productivity would experience more growth. Working at that level of disaggregation requires more assumptions about the level of productivity growth and some justification for all 44 choices. We would need guidance from policymakers about their expectations regarding innovation by sector and capital investment by sector, with some information and evidence to justify the decisions. If we were able to obtain such engagement and information, we would be able to undertake the suggested approach. Otherwise, we risk spurious accuracy: exactly modelling something with no basis in the real economy.

This feedback also raises the general issues discussed above. The cost of producing this information – obtaining sensible estimates for 44 sectors – is much larger than a uniform approach. The value of the additional information produced is unclear, given the marginal value of modelling additional details.

Finally, this feedback also ignores the issues with the capital stock and capital productivity figures in C-PLAN. As discussed above, they seem small in aggregate compared to labour inputs and compared to New Zealand's past performance. It might contribute more to modelling accuracy to explore capital productivity in C-PLAN before using those findings in another model.

B.6 Magnitude of the shock

We were asked to consider the size of the shocks applied to the model. This feedback provided some criteria for making a decision about the size of the shock applied to the model: it should reflect expectations for the future and should not be too large. In other words, the assumed impact should be sensible. However, the feedback did not provide any guidance on what levels of impact would be sensible. It also did not direct us to any source of information that could be used to assess whether a shock is sensible.

In order to run the model, we need numbers. We can choose the numbers, someone else can choose the numbers, or we can work collaboratively to develop acceptable numbers. A suggestion to choose better numbers does not provide enough information about acceptable inputs for the modelling. A good approach would be to engage in a collaborative process to develop recommended magnitudes of the shocks. This process would require the expenditure of resources (refer to the cost to produce information, above) and the value of added precision from the process – the benefit of having a 15 percent shock versus a 20 percent shock in the context of a macroeconomic model of New Zealand in 2050 – is likely to be small (refer to the diminishing marginal value of precision, above).

In general, taking issue with the quantum of a shock brings with it a couple of obligations. First, some basis for a different number should be provided, such as data or information about actual economic shocks. Second, some indication of the impact on research findings should also be offered. If a shock half as large produces a result half as big, then the policy-relevant findings of the modelling still hold.

Appendix C Additional results and modelling information

C.1 Sectors in the economy

Table 11 sectors in the economy

Code	Description
ser	Services
LivingPlant	Living plants
Vegetables	Vegetables
Kiwifruit	Kiwifruit
Pipfruit	Pip fruit
Grapes	Grapes
BerryFruit	Berry fruit
StoneFruit	Stone fruit
CitrusFruit	Citrus fruit
OthFrtNut	Other fruit and nuts
Forage	Forage
Arable	arable
b_s	Beef and sheep farming
oap	Other animal products, such as swine and poultry
rmk	Dairy farming
frs	Forestry, logging and related service activities
fsh	Fishing, fish farming and related services
col	Coal extraction - mining and agglomeration of hard coal, lignite, and peat
cru	Crude oil extraction
gas	Natural gas extraction & distribution
oxt	Mining of ores for iron, copper, gold etc. and gems
mtp	Processing of meat
mil	Processing of raw milk
ofd	Other food processing, such as beverages, fruits and vegetables
w_p	Wood and paper products
oil	Refining of crude oil, and petroleum products
crp	Chemical, rubber, & plastic products including methanol
omf	Fabricated metal products, transport equipment, electrical equipment and machinery
nmm	Cement, plaster, lime, gravel, concrete

Code	Description
i_s	Iron and steel production
mvh	Motor vehicles and parts
ecoa	Coal electricity
egas	Gas electricity
eoth	Geothermal and other electricity
ehyd	Hydroelectricity
ew_s	Wind and solar electricity
tnd	Electricity transmission & distribution
cns	Construction
afs	Accommodation and food services
rtp	Commercial road and rail transport
wtpi	Water transport - international
wtp	Water transport - domestic
atp	Air transport - domestic
atpi	Air transport - international

Source: NZIER

C.2 How to read these results

This section contains additional results from the modelling. The results presented are disaggregated by region and industry. Having some understanding of modelling in general and TERM-NZ in particular is helpful for interpreting the results.

The most important point is that TERM-NZ is a set of mathematical equations, and having non-zero and continuous data and parameters is helpful for allowing the model to find a solution. If we know that, in reality, a crop does not exist in a certain region, it is easier to model the crop as a very small number (0.001) than as a zero (0). When we find a solution, that very small number could double in size and still be small and not economically meaningful. However, when expressed in percentage terms, doubling an insignificant value is still a 100 percent increase, even if that doubling has no impact on the regional or national economy.

C.3 Scenario one

The following tables present the model results for the food and fibre industries in the model, disaggregated by region. Table 12 provides the changes in industry output assuming an increase in investment in productivity. Table 13 provides the results assuming a decrease in investment in productivity.

Table 12 Regional economic impacts as a result of increased investment (percentage change in 2050 vs baseline)

Sector	Northland	Auckland	Waikato	Bay of Plenty	Gisborne	Hawke's Bay	Taranaki	Manawatu	Wellington	Tasman / Marlborough	Canterbury	West Coast	Otago	Southland
LivingPlant	10.3	15.2	9.7	11.7	8.8	9.7	12.0	7.6	12.0	9.8	12.1	16.7	15.6	8.0
Vegetables	9.6	13.5	9.6	10.9	9.8	11.7	11.1	8.2	11.7	9.8	11.1	10.4	11.8	6.6
Kiwifruit	17.7	20.8	17.5	17.6	16.3	17.1	109.5	16.2	112.0	17.4	113.4	103.7	112.0	116.5
Pipfruit	18.7	18.2	16.3	120.1	15.0	15.7	109.5	15.0	18.2	15.6	14.7	103.7	17.4	116.5
Grapes	9.3	11.9	11.0	13.1	10.8	11.8	109.5	7.8	12.0	10.5	9.7	12.8	12.2	116.5
BerryFruit	13.5	14.0	11.0	12.4	13.1	9.7	109.5	7.6	11.2	11.2	9.2	103.7	112.2	7.2
StoneFruit	10.8	12.3	10.1	120.1	12.0	11.2	11.2	114.8	12.1	9.8	9.8	103.7	12.8	8.0
CitrusFruit	11.2	16.3	122.8	17.7	9.9	14.1	109.5	114.8	114.3	120.5	116.4	103.7	112.2	116.5
OthFrtNut	9.9	12.0	10.4	13.3	9.1	10.0	13.0	114.8	14.3	11.3	9.7	103.7	112.2	11.6
Forage	14.5	21.1	16.3	15.5	119.0	16.6	17.2	14.9	17.5	15.5	15.8	17.4	17.3	13.8
Arable	20.9	22.8	19.8	19.7	17.6	19.2	109.5	19.3	21.6	20.2	20.0	103.7	22.8	19.2
b_s	18.0	22.4	19.4	17.7	16.8	18.3	21.9	17.8	19.2	16.8	19.0	19.1	21.4	17.9
oap	21.0	34.6	21.5	20.0	17.3	22.7	22.4	18.7	25.2	18.7	23.8	22.6	25.5	18.2
rmk	23.4	24.9	25.6	23.3	22.4	22.8	26.3	24.4	26.0	23.1	26.2	26.3	27.0	24.1
frs	21.7	17.2	18.8	24.6	23.5	22.7	23.7	9.9	24.1	19.0	15.2	12.4	27.5	15.3
fsh	27.9	34.4	25.3	28.5	25.6	29.0	28.8	25.5	31.2	26.0	26.7	30.7	29.6	23.1
mtp	33.3	36.6	40.6	42.0	32.9	38.8	41.0	35.2	28.6	30.5	32.8	33.7	40.1	30.2
mil	47.3	35.0	45.2	48.1	41.6	40.3	46.5	39.4	40.6	42.0	44.1	45.3	50.3	42.0
ofd	22.2	21.6	15.2	27.9	12.7	17.0	27.5	18.2	13.8	22.5	17.0	7.9	19.0	10.0
w_p	26.2	14.7	19.7	29.9	33.6	22.8	18.3	9.5	20.4	23.8	13.6	20.1	23.1	19.2

Source: NZIER

Table 13 Regional economic impacts as a result of lower investment (percentage change in 2050 vs baseline)

Sector	Northland	Auckland	Waikato	Bay of Plenty	Gisborne	Hawke's Bay	Taranaki	Manawatu	Wellington	Tasman/ Marlborough	Canterbury	West Coast	Otago	Southland
LivingPlant	-9.7	-12.8	-9.2	-11.2	-8.6	-9.2	-10.9	-7.9	-10.7	-9.2	-11.1	-15.1	-13.5	-8.1
Vegetables	-8.5	-11.0	-8.6	-10.2	-8.9	-10.5	-9.7	-7.7	-10.0	-8.7	-9.8	-9.2	-10.0	-6.5
Kiwifruit	-15.4	-16.9	-15.3	-15.7	-14.3	-15.0	-66.8	-14.5	-67.1	-15.0	-68.4	-64.4	-66.4	-69.0
Pipfruit	-15.6	-14.8	-14.1	-68.9	-13.1	-13.7	-66.8	-13.4	-15.2	-13.4	-12.6	-64.4	-14.4	-69.0
Grapes	-8.4	-10.2	-9.7	-12.0	-9.7	-10.7	-66.8	-7.5	-10.3	-9.3	-8.7	-11.1	-10.4	-69.0
BerryFruit	-11.4	-11.6	-9.8	-11.4	-11.2	-8.8	-66.8	-7.5	-9.9	-10.1	-8.5	-64.4	-66.5	-6.8
StoneFruit	-9.3	-10.3	-8.9	-68.9	-10.6	-10.2	-9.8	-70.7	-10.2	-8.8	-8.8	-64.4	-10.9	-7.7
CitrusFruit	-10.1	-13.5	-68.8	-15.7	-9.0	-12.3	-66.8	-70.7	-68.6	-68.6	-70.2	-64.4	-66.5	-69.0
OthFrtNut	-8.9	-10.2	-9.3	-11.9	-8.3	-9.0	-11.1	-70.7	-11.9	-10.2	-8.9	-64.4	-66.5	-10.5
Forage	-12.9	-17.5	-14.6	-13.9	-68.7	-14.6	-15.4	-13.6	-15.2	-13.7	-14.3	-15.5	-15.2	-12.9
Arable	-18.4	-19.4	-17.5	-17.6	-15.8	-17.0	-66.8	-17.4	-18.9	-17.9	-17.8	-64.4	-19.7	-17.4
b_s	-14.8	-18.0	-16.0	-14.9	-13.9	-15.3	-17.8	-14.9	-15.6	-13.9	-15.7	-15.7	-17.3	-14.9
oap	-17.8	-25.4	-18.2	-17.7	-15.1	-19.3	-18.2	-16.7	-20.6	-16.1	-19.9	-18.7	-20.6	-16.4
rmk	-18.3	-18.8	-20.7	-18.5	-17.7	-18.1	-21.1	-20.0	-20.6	-18.2	-21.1	-21.0	-21.4	-19.5
frs	-18.2	-13.5	-15.7	-21.1	-20.1	-19.3	-18.8	-9.5	-19.1	-16.3	-13.1	-11.0	-21.4	-14.6
fsh	-21.2	-24.2	-19.8	-22.6	-20.1	-22.4	-22.1	-20.8	-22.7	-20.0	-20.4	-22.8	-21.5	-18.8
mtp	-23.5	-24.7	-27.7	-29.8	-23.7	-27.3	-27.6	-25.3	-20.3	-22.3	-23.4	-23.5	-26.6	-22.3
mil	-32.1	-23.6	-31.4	-33.4	-29.0	-28.3	-31.8	-28.2	-27.9	-28.9	-30.4	-30.8	-33.1	-29.7
ofd	-18.1	-17.5	-13.9	-22.6	-11.9	-15.2	-21.4	-16.3	-12.6	-18.4	-15.4	-8.4	-15.8	-11.1
w_p	-20.7	-12.4	-16.4	-23.1	-24.9	-18.6	-15.5	-9.5	-16.5	-19.1	-12.4	-16.8	-18.2	-16.7

Source: NZIER

C.4 Scenario two

The following tables present the model results for scenario two for the food and fibre industries in the model, disaggregated by region. Table 14 provides the changes in industry output assuming an increase in export demand for animal products. Table 15 provides the results assuming a decrease in such demand.

Table 14 Regional economic impacts of increasing export demand (percentage change in 2050 vs baseline)

Sector	Northland	Auckland	Waikato	Bay of Plenty	Gisborne	Hawke's Bay	Taranaki	Manawatu	Wellington	Tasman/ Marlborough	Canterbury	West Coast	Otago	Southland
LivingPlant	-1.7	-0.8	-2.9	-1.7	-1.1	-1.3	-2.4	-3.5	-1.0	-1.4	-2.6	-2.3	-1.6	-4.3
Vegetables	-1.6	-0.6	-2.7	-1.6	-1.5	-1.8	-2.1	-3.3	-1.0	-1.1	-2.3	-1.9	-0.9	-3.2
Kiwifruit	-2.5	-1.2	-3.7	-2.3	-2.1	-2.2	20.0	-4.5	16.4	-2.3	18.4	16.7	17.9	24.8
Pipfruit	-2.0	-0.9	-3.5	17.1	-2.0	-2.1	20.0	-4.4	-2.1	-2.1	-2.9	16.7	-2.1	24.8
Grapes	-1.5	-0.6	-2.7	-2.0	-1.6	-1.9	20.0	-3.2	-1.3	-1.6	-2.3	-2.3	-1.5	24.8
BerryFruit	-0.8	-0.1	-2.7	-1.7	-1.0	-1.3	20.0	-3.1	-1.0	-1.6	-2.0	16.7	18.0	-2.5
StoneFruit	-1.0	-0.3	-2.7	17.1	-1.7	-1.9	-2.3	19.9	-0.8	-1.5	-2.4	16.7	-1.6	-4.0
CitrusFruit	-1.6	-0.5	23.3	-2.2	-1.4	-1.3	20.0	19.9	17.6	17.1	20.4	16.7	18.0	24.8
OthFrtNut	-1.6	-0.6	-2.7	-1.8	-1.3	-1.5	-1.8	19.9	-0.8	-1.6	-2.2	16.7	18.0	-4.6
Forage	7.4	0.6	4.3	2.3	15.5	-0.1	7.9	3.0	4.4	3.5	6.8	5.5	6.1	6.7
Arable	0.1	-0.3	-0.8	-0.7	-0.1	-0.6	20.0	-1.5	-0.1	-0.2	-0.6	16.7	0.8	-0.5
b_s	8.1	6.9	8.3	8.5	8.5	7.8	9.1	7.5	8.1	8.8	6.5	8.0	8.1	7.0
oap	-2.5	-2.6	-3.3	-2.2	-1.4	-3.0	-1.0	-4.7	-2.9	-1.3	-3.9	-2.1	-2.1	-5.0
rmk	16.4	15.4	17.1	17.2	17.4	17.2	17.5	16.7	17.9	17.0	17.5	17.6	18.2	16.9
frs	-3.9	0.1	-5.9	-4.0	-3.9	-3.9	-5.3	-6.6	-3.0	-3.4	-4.3	-4.2	-4.0	-8.5
fsh	-2.3	-0.5	-3.9	-2.7	-1.6	-2.8	-4.0	-6.1	-1.7	0.2	-2.9	-1.6	-1.9	-5.9
mtp	12.2	18.0	13.1	24.6	14.9	18.6	12.2	11.4	8.1	22.4	13.1	13.8	13.6	10.0
mil	23.7	16.0	20.6	25.9	22.1	22.0	21.0	18.5	20.5	21.5	19.4	19.3	21.5	17.6
ofd	-2.4	-1.7	-3.9	-3.7	-2.0	-2.7	-4.0	-6.4	-1.4	-2.5	-3.9	-1.8	-1.8	-6.3
w_p	-2.8	-0.4	-4.2	-3.0	-2.5	-2.5	-3.0	-4.2	-1.1	-1.7	-2.0	-3.0	-1.3	-5.5

Source: NZIER

Table 15 Regional economic impacts of decreasing export demand (percentage change in 2050 vs baseline)

Sector	Northland	Auckland	Waikato	Bay of Plenty	Gisborne	Hawke's Bay	Taranaki	Manawatu	Wellington	Tasman/ Marlborough	Canterbury	West Coast	Otago	Southland
LivingPlant	1.4	0.6	2.7	1.5	0.9	1.2	2.2	3.3	0.8	1.2	2.4	2.1	1.4	4.1
Vegetables	1.4	0.5	2.5	1.4	1.3	1.6	1.9	3.1	0.9	1.0	2.1	1.8	0.8	3.0
Kiwifruit	2.2	1.0	3.3	2.0	1.8	2.0	-15.1	4.2	-11.9	2.0	-13.7	-12.4	-13.1	-19.1
Pipfruit	1.8	0.8	3.2	-12.8	1.7	1.8	-15.1	4.0	1.8	1.8	2.6	-12.4	1.8	-19.1
Grapes	1.3	0.5	2.5	1.8	1.5	1.7	-15.1	3.0	1.1	1.4	2.1	2.1	1.3	-19.1
BerryFruit	0.7	0.0	2.5	1.5	0.9	1.1	-15.1	2.9	0.8	1.4	1.8	-12.4	-13.2	2.4
StoneFruit	1.0	0.3	2.5	-12.8	1.5	1.7	2.1	-15.3	0.7	1.3	2.2	-12.4	1.4	3.7
CitrusFruit	1.4	0.4	-18.0	1.9	1.2	1.3	-15.1	-15.3	-12.9	-12.7	-15.3	-12.4	-13.2	-19.1
OthFrtNut	1.4	0.5	2.5	1.6	1.2	1.4	1.7	-15.3	0.8	1.5	2.1	-12.4	-13.2	4.3
Forage	-7.8	-0.6	-4.5	-2.1	-11.4	0.1	-8.6	-3.1	-4.4	-3.4	-7.4	-5.9	-6.4	-7.4
Arable	-0.5	0.0	0.4	0.3	-0.2	0.3	-15.1	1.0	-0.3	-0.2	0.2	-12.4	-1.2	-0.1
b_s	-8.0	-6.3	-8.6	-8.4	-8.5	-7.5	-9.7	-7.8	-8.0	-8.8	-6.3	-8.2	-8.2	-7.4
oap	2.2	2.2	3.1	1.9	1.2	2.7	0.9	4.5	2.5	1.1	3.6	1.9	1.9	4.8
rmk	-15.9	-14.4	-17.5	-17.2	-17.1	-17.2	-17.8	-17.1	-17.9	-16.9	-18.0	-17.9	-18.5	-17.3
frs	3.5	-0.2	5.6	3.6	3.5	3.6	4.9	6.5	2.6	3.0	4.0	3.9	3.6	8.4
fsh	2.0	0.4	3.8	2.5	1.5	2.6	3.7	6.0	1.5	-0.2	2.8	1.4	1.7	5.8
mtp	-12.3	-16.7	-14.0	-23.3	-14.7	-18.4	-12.9	-12.4	-8.2	-20.1	-13.2	-13.7	-13.7	-10.9
mil	-22.8	-15.0	-21.0	-25.0	-21.4	-21.1	-21.0	-18.8	-19.6	-20.7	-19.9	-19.7	-21.6	-18.7
ofd	2.1	1.4	3.8	3.4	1.8	2.5	3.8	6.3	1.2	2.2	3.7	1.7	1.6	6.2
w_p	2.5	0.3	4.0	2.7	2.3	2.3	2.8	4.1	0.9	1.5	1.8	2.8	1.1	5.4

Source: NZIER

C.5 Scenario three

The table below, Table 16, presents the model results for scenario 3 for the food and fibre industries in the model, disaggregated by region. For scenario three, food and fibre industries were subject to detailed changes by industry and region. Results are presented as percentage changes in output.

Table 16 Regional economic impacts of changing growing conditions (percentage change in 2050 vs baseline)

Sector	Northland	Auckland	Waikato	Bay of Plenty	Gisborne	Hawke's Bay	Taranaki	Manawatu	Wellington	Tasman/ Marlborough	Canterbury	West Coast	Otago	Southland
LivingPlant	2.1	0.4	0.5	0.9	3.3	0.9	0.5	0.1	1.6	2.0	0.3	2.3	1.6	-1.0
Vegetables	15.0	18.0	12.0	11.0	11.0	15.0	14.0	20.0	16.0	20.0	33.0	22.0	47.0	66.0
Kiwifruit	22.0	26.0	21.0	20.0	19.0	27.0	41.0	39.0	40.0	45.0	49.0	41.0	55.0	68.0
Pipfruit	20.0	25.0	7.0	6.0	7.0	7.0	2.0	9.0	7.0	6.0	24.0	10.0	36.0	75.0
Grapes	20.0	25.0	7.0	6.0	7.0	7.0	2.0	9.0	7.0	6.0	24.0	10.0	36.0	75.0
BerryFruit	20.0	25.0	7.0	6.0	7.0	7.0	2.0	9.0	7.0	6.0	24.0	10.0	36.0	75.0
StoneFruit	20.0	25.0	7.0	6.0	7.0	7.0	2.0	9.0	7.0	6.0	24.0	10.0	36.0	75.0
CitrusFruit	9.0	8.0	7.0	6.0	6.0	8.0	5.0	12.0	5.0	12.0	30.0	16.0	49.0	59.0
OthFrtNut	13.0	15.0	9.0	8.0	8.0	10.0	8.0	14.0	9.0	13.0	29.0	17.0	45.0	65.0
Forage	8.2	3.2	7.0	3.3	-15.6	1.8	13.4	7.4	9.8	5.8	4.9	3.9	4.4	11.9
Arable	-	-1.0	-	1.0	1.0	3.0	-	1.0	3.0	2.0	4.0	-	1.0	1.0
b_s	14.0	19.0	23.0	21.0	33.0	12.0	34.0	27.0	42.0	23.0	8.0	-7.0	-15.0	46.0
oap	-3.2	2.7	-2.6	-2.9	-3.9	-0.4	-0.5	-2.7	0.7	-2.8	-0.4	-0.9	-0.9	-2.6
rmk	12.0	15.0	18.0	9.0	24.0	11.0	25.0	20.0	30.0	17.0	7.0	-5.0	-	23.0
frs	19.0	25.0	27.0	26.0	27.0	29.0	27.0	32.0	34.0	26.0	38.0	19.0	37.0	26.0
fsh	-3.4	-1.1	-4.2	-4.8	-5.4	-4.8	-3.5	-6.9	-3.0	-3.5	-2.3	-0.9	-1.8	-6.1
mtp	12.5	11.3	20.0	10.1	15.6	15.2	23.6	19.2	17.3	-1.4	10.1	6.4	9.6	16.8
mil	16.4	12.2	18.3	15.3	20.9	14.2	24.8	16.0	17.9	17.4	11.1	9.1	7.2	19.6
ofd	-2.3	0.6	-1.2	-3.7	-5.0	-3.3	-2.8	-0.3	-1.5	-2.0	-1.1	-1.0	-0.1	-1.4
w_p	0.6	1.3	-1.1	-0.1	-1.0	-1.2	0.4	-1.9	2.0	1.7	1.8	2.8	2.5	-0.8

Source: NZIER

C.5.1 Scenario three shock parameters

For scenario three, we have been provided information from Manaaki Whenua Landcare Research about how agricultural production processes will change in 2050 under RCP 4.5.

Pasture production is influenced by several factors. Factors such as heat stress, animal health, disease and pest spread, and other potential climate change impacts on livestock are not considered. Crop yields are driven by climate impacts, such as temperature and photoperiod effects on the timing of key crop development stages.

We have been provided with the change in per hectare production for the following commodities by region:

- forestry
- sheep and beef – this includes the average change in cost per hectare
- dairy
- arable – we use wheat values
- avocado
- lemons
- macadamia
- grapes.

The horticultural categories were originally designed to reflect new commodities. We have matched them in the following way:

- For vegetables, we use the average of Avocados, grapes, lemons, and macadamias
- Stone fruit, other berries, and apples use the same growth rate as grapes
- Kiwifruit uses avocado growth rates
- Other fruit and nuts are an average of grapes and macadamias.

The production per hectare for pasture-based industries was provided by Manaaki Whenua Landcare Research and based on pasture production modelling, using the simulation model APSIM, conducted in the Whitiwhiti Ora Land Use Opportunities programme in the Our Land and Water National Science Challenge (Data supermarket 2023). We have been made aware of other research that might suggest other possible scenarios for pasture production in 2050:

- analysis that found a slow-down in the rate of increase in pasture productivity in New Zealand after 2002 (Chapman et al. 2024)
- analysis that projected losses due to climate-change induced drought out to 2100 (Bell et al. 2021)
- experimental evidence of a loss of effectiveness for phosphorus fertiliser under increased CO_2, although with no indication of an impact on pasture phosphorus concentration or uptake (Beechey-Gradwell et al. 2025).

Assessing this research is outside our expertise as economists. We note these sources and suggest that additional biophysical scenarios could be developed with the assistance of the appropriate experts.

Table 17 Pine yield

Region	2020 m3/ha	2050 m3/ha	% change in Timber production
Auckland Region	770	963	25.1%
Bay of Plenty Region	866	1,088	25.6%
Canterbury Region	608	840	38.1%
Gisborne Region	859	1,095	27.4%
Hawke's Bay Region	812	1,051	29.4%
Manawatu-Wanganui Region	779	1,029	32.1%
Marlborough Region	692	902	30.4%
Nelson Region	884	1,084	22.6%
Northland Region	921	1,094	18.7%
Otago Region	573	782	36.6%
Southland Region	612	774	26.5%
Taranaki Region	872	1,106	26.8%
Tasman Region	795	969	21.9%
Waikato Region	837	1,061	26.7%
Wellington Region	813	1,086	33.5%
West Coast Region	790	936	18.5%
Weighted Upper South Island	744	937	26.0%

Source: NZIER and MWLR

Table 18 Sheep and beef yield

Region	2020 kg/ha	2020 $/ha	2050 kg/ha	2050 $/ha	% change kg/ha	% change $/ha
Auckland Region	313	1,008	371	1,049	18.6%	**4.1%**
Bay of Plenty Region	377	1,028	456	1,082	21.1%	**5.3%**
Canterbury Region	181	462	196	478	8.3%	**3.3%**
Gisborne Region	301	846	401	975	33.4%	**15.2%**
Hawke's Bay Region	349	974	392	1,012	12.4%	**3.9%**
Manawatu-Wanganui Region	326	952	413	1,031	26.8%	**8.3%**
Marlborough Region	210	458	236	485	12.3%	**5.9%**
Nelson Region	225	700	312	787	38.7%	**12.4%**
Northland Region	365	1,029	415	1,069	13.6%	**3.9%**
Otago Region	191	415	162	383	-15.2%	**-7.6%**
Southland Region	131	719	191	786	45.7%	**9.4%**
Taranaki Region	329	997	440	1,097	33.7%	**10.1%**
Tasman Region	143	511	197	567	37.8%	**10.8%**
Waikato Region	372	1,043	458	1,103	23.2%	**5.8%**
Wellington Region	291	953	412	1,059	41.5%	**11.1%**
West Coast Region	186	970	173	958	-6.9%	**-1.3%**
Weighted Upper South island	179	488	219	530	22.6%	8.5%

Source: NZIER and MWLR

Table 19 Dairy yields

Region	2020 Milk solids (kg/ha)	2050 Milk solids (kg/ha)	% change in Milk solids produced
Auckland Region	698	801	14.8%
Bay of Plenty Region	944	1,031	9.2%
Canterbury Region	935	1,003	7.3%
Gisborne Region	937	1,164	24.2%
Hawke's Bay Region	897	995	10.9%
Manawatu-Wanganui Region	865	1,033	19.5%
Marlborough Region	655	718	9.7%
Nelson Region	641	843	31.5%
Northland Region	814	908	11.5%
Otago Region	765	762	-0.4%
Southland Region	556	686	23.2%
Taranaki Region	864	1,082	25.2%
Tasman Region	468	596	27.4%
Waikato Region	915	1,079	17.8%
Wellington Region	775	1,009	30.2%
West Coast Region	480	455	-5.3%
Auckland Region	698	801	14.8%

Source: NZIER and MWLR

Table 20 Arable production yield

Region	2020 (t/ha)	2050 (t/ha)	% change in yield
Auckland Region	11.24	11.12	-1.0%
Bay of Plenty Region	12.18	12.33	1.2%
Canterbury Region	10.30	10.69	3.8%
Gisborne Region	12.61	12.79	1.4%
Hawke's Bay Region	11.99	12.38	3.3%
Manawatu-Wanganui Region	12.59	12.71	1.0%
Marlborough Region	11.59	12.01	3.7%
Nelson Region	12.57	12.79	1.7%
Northland Region	11.20	11.18	-0.2%
Otago Region	9.82	9.91	0.9%
Southland Region	12.11	12.19	0.7%
Taranaki Region	12.58	12.59	0.1%
Tasman Region	12.53	12.64	0.9%
Waikato Region	11.74	11.77	0.3%
Wellington Region	11.47	11.77	2.6%
West Coast Region	12.13	12.17	0.3%
Weighted Upper South Island	12.05	12.32	2.3%

Source: NZIER and MWLR

Table 21 Avocado production yield

Region	2020 (t/ha)	2050 (t/ha)	% change in yield
Auckland Region	17.63	22.22	26.0%
Bay of Plenty Region	18.09	21.77	20.4%
Canterbury Region	5.86	8.73	48.9%
Gisborne Region	16.00	19.06	19.1%
Hawke's Bay Region	13.82	17.53	26.8%
Manawatu-Wanganui Region	11.99	16.67	39.0%
Marlborough Region	10.60	14.91	40.6%
Nelson Region	10.79	16.74	55.1%
Northland Region	18.48	22.55	22.0%
Otago Region	5.52	8.54	54.7%
Southland Region	3.11	5.23	68.1%
Taranaki Region	10.56	14.89	40.9%
Tasman Region	11.63	17.23	48.1%
Waikato Region	17.87	21.65	21.1%
Wellington Region	10.95	15.30	39.8%
West Coast Region	9.70	13.70	41.3%
Weighted Upper South Island	11.09	16.03	44.6%

Source: NZIER and MWLR

Table 22 Grape production yield

Region	2020 (t/ha)	2050 (t/ha)	% change in yield
Auckland Region	13.04	16.36	25.5%
Bay of Plenty Region	16.22	17.19	6.0%
Canterbury Region	7.43	9.20	23.9%
Gisborne Region	14.40	15.35	6.5%
Hawke's Bay Region	13.12	14.05	7.1%
Manawatu-Wanganui Region	14.83	16.19	9.2%
Marlborough Region	12.84	13.22	2.9%
Nelson Region	16.06	15.38	-4.3%
Northland Region	13.40	16.07	20.0%
Otago Region	7.04	9.57	36.0%
Southland Region	4.61	8.05	74.7%
Taranaki Region	13.55	13.83	2.1%
Tasman Region	15.00	16.49	9.9%
Waikato Region	15.91	16.96	6.6%
Wellington Region	11.57	12.42	7.4%
West Coast Region	13.52	14.94	10.5%
Weighted Upper South Island	13.92	14.79	6.3%

Source: NZIER and MWLR

Table 23 Lemon production yield

Region	2020 (t/ha)	2050 (t/ha)	% change in yield
Auckland Region	24.76	26.81	8.3%
Bay of Plenty Region	26.23	27.69	5.5%
Canterbury Region	14.82	19.21	29.6%
Gisborne Region	24.24	25.61	5.7%
Hawke's Bay Region	23.14	25.02	8.1%
Manawatu-Wanganui Region	23.01	25.81	12.2%
Marlborough Region	23.32	25.80	10.6%
Nelson Region	27.43	28.71	4.6%
Northland Region	25.18	27.34	8.6%
Otago Region	10.69	15.89	48.6%
Southland Region	8.80	13.96	58.6%
Taranaki Region	24.50	25.71	4.9%
Tasman Region	22.98	26.32	14.5%
Waikato Region	25.66	27.49	7.1%
Wellington Region	22.48	23.58	4.9%
West Coast Region	23.08	26.88	16.5%
Weighted Upper South Island	23.24	26.10	12.3%

Source: NZIER and MWLR

Table 24 Macadamia production yield

Region	2020 (t/ha)	2050 (t/ha)	% change in yield
Auckland Region	5.57	6.64	19.3%
Bay of Plenty Region	4.94	6.22	25.9%
Canterbury Region	1.20	1.94	61.9%
Gisborne Region	4.43	5.64	27.3%
Hawke's Bay Region	3.55	4.86	36.8%
Manawatu-Wanganui Region	3.05	4.51	48.2%
Marlborough Region	2.66	4.03	51.9%
Nelson Region	3.12	4.61	47.7%
Northland Region	5.57	6.31	13.3%
Otago Region	1.11	1.83	65.0%
Southland Region	0.53	1.05	96.5%
Taranaki Region	3.08	4.69	52.5%
Tasman Region	3.00	4.48	49.3%
Waikato Region	4.71	6.00	27.4%
Wellington Region	2.81	4.30	52.9%
West Coast Region	2.56	3.86	50.8%
Weighted Upper South Island	2.83	4.26	50.5%

Source: NZIER and MWLR

Table 25 Vegetables production yield

Region	2020 (t/ha)	2050 (t/ha)	% change in yield
Auckland Region	60.99	72.03	18.1%
Bay of Plenty Region	65.48	72.86	11.3%
Canterbury Region	29.30	39.08	33.4%
Gisborne Region	59.08	65.66	11.1%
Hawke's Bay Region	53.64	61.45	14.6%
Manawatu-Wanganui Region	52.87	63.18	19.5%
Marlborough Region	49.41	57.95	17.3%
Nelson Region	57.41	65.44	14.0%
Northland Region	62.63	72.27	15.4%
Otago Region	24.36	35.83	47.1%
Southland Region	17.06	28.29	65.8%
Taranaki Region	51.69	59.12	14.4%
Tasman Region	52.62	64.52	22.6%
Waikato Region	64.15	72.09	12.4%
Wellington Region	47.80	55.59	16.3%
West Coast Region	48.86	59.38	21.5%
Weighted Upper South Island	51.08	61.19	19.8%

Source: NZIER and MWLR

Table 26 Other fruit and nuts production yield

Region	2020 (t/ha)	2050 (t/ha)	% change in yield
Auckland Region	43.37	49.81	14.9%
Bay of Plenty Region	47.39	51.10	7.8%
Canterbury Region	23.44	30.35	29.5%
Gisborne Region	43.07	46.60	8.2%
Hawke's Bay Region	39.81	43.93	10.3%
Manawatu-Wanganui Region	40.88	46.52	13.8%
Marlborough Region	38.82	43.05	10.9%
Nelson Region	46.62	48.70	4.5%
Northland Region	44.15	49.72	12.6%
Otago Region	18.84	27.29	44.9%
Southland Region	13.95	23.06	65.3%
Taranaki Region	41.13	44.23	7.5%
Tasman Region	40.99	47.29	15.4%
Waikato Region	46.28	50.45	9.0%
Wellington Region	36.85	40.29	9.3%
West Coast Region	39.16	45.68	16.6%
Weighted Upper South Island	40.00	45.15	12.9%

Source: NZIER and MWLR

C.6 How results compare to 2020

To ensure that the model's results align with expectations, we compared the same modelling shocks to both the 2020 database and the 2050 database, with only an increase in real GDP, labour stocks, capital stocks, and households.

We believe that the results are economically consistent in terms of general magnitude and relative impact across scenarios. The results comparing real GDP in 2020 and 2050 can be seen below in Table 27.

The results of this test give us further confidence in our modelling.

Table 27 Comparison of shock results between 2020 and 2050

Percentage changes

Measure	Year	Scenario 1 - positive	Scenario 1 - negative	Scenario 2 - positive	Scenario 2 - negative	Scenario 3
Real GDP	2020	4.83	-3.86	0.45	-0.36	0.95
	2050	3.56	-2.86	0.18	-0.14	0.64

Source: NZIER