Westpac NZ

Climate Change Impact Report

April 2018

Building a better working world

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1. Executive summary

Westpac Group is committed to operating in a manner consistent with a two-degree future.[1] Against this backdrop, Westpac NZ engaged EY to assess the climate change implications facing the New Zealand economy through to the middle of the century. This analysis comprised modelling the transitionary impacts of climate change under different 'two-degree aligned' scenarios, and conducting a literature review to develop an assessment of potential physical risks posed to different economic sectors under a range of climate scenarios. This report aims to provide long-term insights to inform Westpac NZ of the impact of climate change from a transition to a two-degree future and from the physical changes expected as climate change eventuates.

Two types of climate change implications are referenced in this report:

- **Transition implications:** reflecting the risks and opportunities associated with changes in the economy, including growth impacts, sector re-weighting, and other macro-economic factors.
- **Physical implications:** reflecting the changes in the physical climate (e.g. altered rainfall amounts, intensities and timing) that may impact future business activities.

The approach to the analysis is described in Appendix B.

Transition Scenario Analysis Results

Two scenarios, each consistent with achieving a 'two-degree future', were modelled and analysed. Each scenario represented key economic, policy, and technology factors. The *central scenario* modelled earlier and smoother phased action to tackle climate change, whilst the *shock scenario* modelled delays in action for over a decade followed by a shock event which drove more rapid action to meet NZ's targets. These are described in further detail on page 3.

Key findings:

- New Zealand can transition to a net zero emissions economy, under either scenario, while continuing economic growth.
- Taking earlier, planned action on climate change under the *central scenario* is modelled to save NZ$30 billion in GDP growth by 2050 compared with the *shock scenario,* and results in a 32% lower carbon price by 2050.
- Economic growth is not projected to be evenly distributed across sectors of the economy.
- A sector's ability to decarbonise is positively correlated with its potential for economic growth.
- Agriculture faces decarbonisation challenges under both scenarios, but it benefits from an early and phased introduction into the New Zealand Emissions Trading Scheme (NZ ETS).
- Technology and greenhouse gas (GHG) emissions constraints drive significant changes in the electricity sector.

[1] The UN Paris Accord established a consensus view to seek to keep global temperature rises to within two degrees Celsius of the pre-industrial era. New Zealand is a signatory to the agreement.

Central Scenario	Shock Scenario
The world takes strong action to limit global warming to within two degrees Celsius. Globally, technology investment increases, creating significant early decarbonisation, including the electrification of passenger and freight vehicles, enabling industries to reduce the emissions intensity of their operations. Early action is mirrored in New Zealand, with the NZ ETS capping international trading to 20% of national gross GHG emissions from 2022, resulting in significant domestic effort to achieve net zero GHG emissions in the second half of the century.[2] New Zealand takes early and planned action to deliver its climate commitments, a key component of this being the phased introduction of agriculture into the NZ ETS from 2020 through 2030. Following this path, New Zealand meets and likely exceeds its Nationally Determined Contribution (NDC) target by 2030. This policy platform provides for changes in land-use towards GHG abatement activities, increasing the decarbonisation potential of New Zealand.	The world takes action to limit global warming to within two degrees Celsius. However in New Zealand, prior to 2030, there is slower uptake of low-carbon (or alternative) technologies domestically, including only a gradual electrification of passenger vehicles. The included sectors in the NZ ETS remains consistent with today, meaning there are less significant changes in land use, delaying a shift towards land-based GHG abatement. New Zealand activities to decarbonise the economy just meets the country's 2030 NDC commitments. In 2030, a significant 'shock event' occurs, requiring rapid decarbonisation to meet global temperature goals, which necessitates the inclusion of agriculture in the NZ ETS, compelling a shorter phase-in period of just 2-5 years. This swift corrective action re-aligns New Zealand's GHG emissions trajectory in line with a two-degree trajectory of net zero emissions in the second half of the century. From 2030, international carbon markets become accessible, with a cap on international trading of 20% of national gross GHG emissions.

Physical Implications Analysis Results

Physical impacts from climate change that pose significant risk were analysed for five sectors:

- Agriculture
- Tourism
- Forestry
- Transport
- Electricity

A range of probable climate scenarios were considered in this analysis, to provide insights into the physical implications of a future world that is not two-degree aligned.[3]

[2] Each of the two scenarios likely represents less of an emissions reduction than New Zealand would achieve if the Government were to attain its net zero emissions by 2050 target.

[3] The results of our physical implications analysis rely on the information available from New Zealand sources and highlight climate issues that were consistent across the sources. The sources range from government reports to climate change research, which use various climate scenarios that do not directly align with the *central* and *shock scenarios* used in the transitional analysis. Several sources refer to the Intergovernmental Panel on Climate Change's Representative Concentration Pathways (RCPs), which are global GHG concentration scenarios. Because climate scenarios vary across sources, the physical impact data consistent across most sources has been discussed to provide a high level summary of physical impacts relevant to each sector.

Key findings:

- The physical implications of climate change are not evenly distributed across New Zealand's economic sectors, as transport, electricity, and agriculture are particularly likely to be impacted.
- Climate change's physical implications could further adversely affect sectors already impacted by competitive pressures from New Zealand's transition to a two-degree aligned economy.
- Increased frequency of droughts and extreme high temperatures would likely have the most significant impacts on New Zealand's agriculture sector.
- The transport sector's most significant climate vulnerabilities are from higher temperatures, more frequent, short duration, extreme precipitation events, flooding, and sea level rise.
- The electricity sector – generation, transmission, distribution and retail – could experience its most significant impacts from temperature and sea level rise, whilst storms and wind are amongst climate variables of medium significance to the sector.
- New Zealand's forestry sector could be most significantly impacted from increased bushfires.
- New Zealand's tourism sector could be affected by sea level rise, more extreme temperatures and precipitation, although no single physical implication of climate change is forecasted to be of high significance to tourism.

2. Drivers for modelling a two-degree world

There are a range of reasons for improving a business's understanding of the financial risks posed from climate change.

International commitments

The international community has recognised climate change as one of the most pressing collective challenges the world currently faces. At the 21st Conference of Parties to the United Nations Framework Convention on Climate Change (COP21), New Zealand – along with 194 other countries – agreed to limit global warming to within two degrees Celsius above the long-term global average. Known as the Paris Accord, this included signatories' commitments to near-term actions, as well as longer-term ambitions. It has since been the major driving force of both government and private sector actions to address climate change.

Risks to the finance sector

For the finance sector, the Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD) released its *Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures* in July 2017. The TCFD was established by the G20 to determine the aspects of climate change-related disclosures expected to be issued in companies' future financial filings. While the adoption of the report's recommendations remains voluntary, some large institutional investors and regulators are requesting its adoption through direct engagement. The TCFD's Recommendations for the banking sector focus on the credit implication of climate risk, aligning with the approach on how other financial risks are currently incorporated.

Political motivation for action

In October 2017, New Zealand's government changed, bringing about expected policy changes to increase action on climate change, including a framework for a net zero emissions economy by 2050. In December 2017, Climate Minister James Shaw, together with Prime Minister Jacinda Ardern, announced plans to introduce a Zero Carbon Bill into Parliament by October 2018 following public consultation and the establishment of an Interim Climate Change Committee.

New Zealand's unique economy

Almost half of New Zealand's national GHG emissions are generated from agricultural and other land-use activities. Agriculture is not currently in the NZ ETS, which is akin to other schemes internationally, however the New Zealand Government is assessing whether to phase agriculture into the NZ ETS over a transition period.

3. Transition analysis - Key insights

New Zealand can transition to a net zero GHG emissions economy, under either scenario, while continuing economic growth

The modelling indicated that New Zealand can achieve decarbonisation of its emissions-intensive sectors in line with a two-degree target while continuing to achieve overall economic growth. Compounded annual growth of gross domestic product (GDP) to 2050 was predicted from the modelling to be 2.015% for the *central scenario* and 2.005% for the *shock scenario* respectively. The baseline economic growth rate, absent any additional climate-based policy, is 2.04%, in line with the assumptions used in MBIE's forecasts[4].

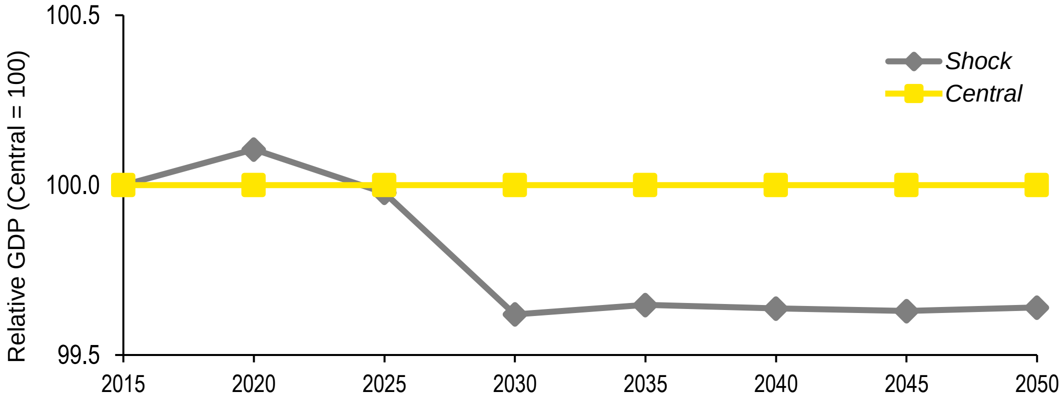

Figure 1: GDP growth (modelled at 5 year intervals) is steadier in the *central scenario* than the *shock scenario*

Source: Vivid Economics with EY analysis from ViEW CGE model outputs

Figure 1 shows the relative performance of the *shock scenario* compared with the *central scenario*. Delays to curbing GHG emissions in the *shock scenario* resulted in a higher economic growth outcome than the *central scenario* in the short-term. The costs of these delays, however, become evident in later years, when the pressures of a faster transition slow the GDP growth rate in the *shock scenario* to below 2% after the 2030 shock event. This correlation has been demonstrated in other international markets, indicating the value from early action at a national level – with the corresponding pressure to forego value created today for improved overall future value.

The GDP trends of each scenario reflect the amount of abatement modelled in the scenarios (Figure 2). The *shock scenario*'s emissions are temporarily allowed to increase, and its GDP is initially higher than the *central scenario*'s. Then the 2030 shock event requires a sharper retraction in emissions, dropping the *shock scenario*'s emissions below the *central scenario*'s, so that both scenarios remain on track to meet their two-degree carbon budgets.

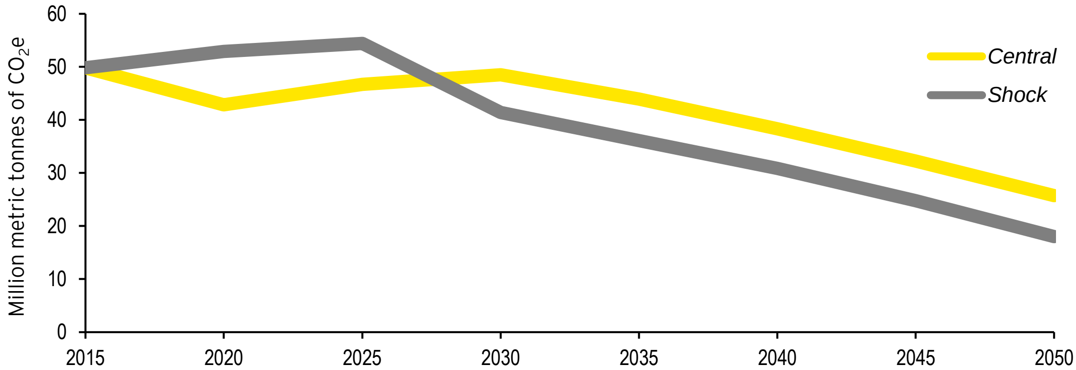

Figure 2: The scenarios differ according to their profiles of domestic emissions (modelled at 5 year intervals) and when agriculture is subjected to an emissions constraint.

Source: Vivid Economics; EY analysis from ViEW CGE model outputs

[4] Aligned to *Net Zero in New Zealand* report and Ministry of Business, Innovation and Employment projections.

Taking faster action on climate change under the *central scenario* is projected to save NZ$30 billion in GDP by 2050 compared with the *shock scenario* and results in a 32% lower carbon price

Compared with the *shock scenario*, a more managed transition to a two-degree economy in the *central scenario* creates an additional NZ$30 billion of GDP through to 2050. Figure 3 shows the relative performance of the *shock scenario* compared with the *central scenario*. A smooth, early transition through mitigation policy and technology investment will be better for New Zealand's economy as a whole. Such a transition will have fewer impacts at the micro-level on individuals and businesses at the economy's margins, providing greater protection than would be offered under the more abrupt policy and economic shifts of the *shock scenario*.

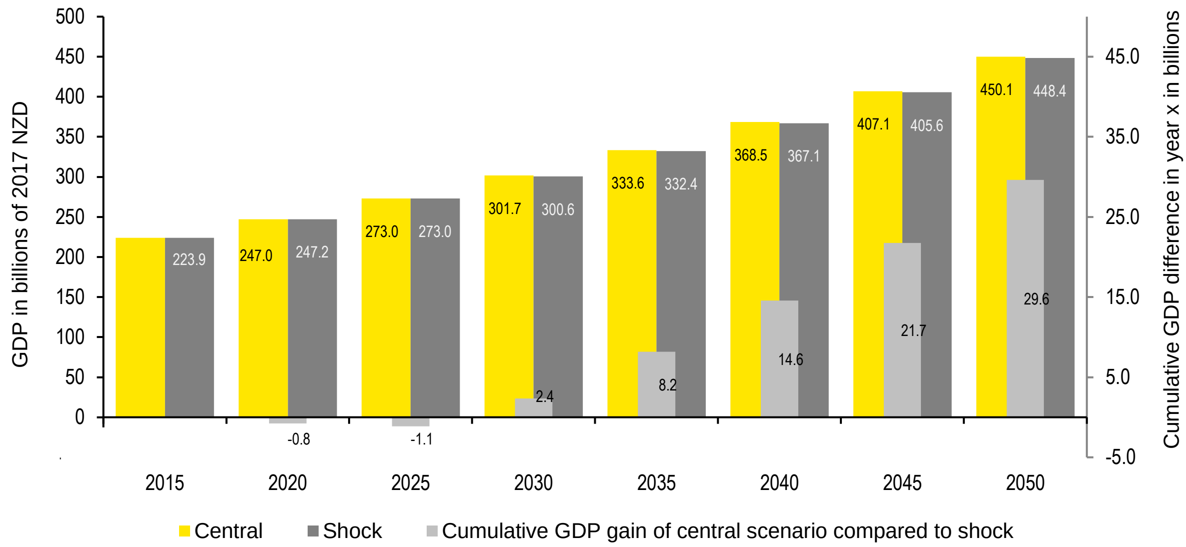

Figure 3: GDP in the *central* and *shock* scenarios and the cumulative difference

Early and more distributed action in the *central scenario* is projected to allow the economy-wide price of emissions to be lower, in the long term, than in the *shock scenario* (Figure 4). The *shock scenario* implies less climate action economy-wide before the 'shock' event of abruptly regulating the agricultural sectors' emissions, starting from 2030. However, as that climate action is carried out by a smaller percentage of New Zealand's economy than under the *central scenario*, it results in a higher carbon price under the *shock scenario*.

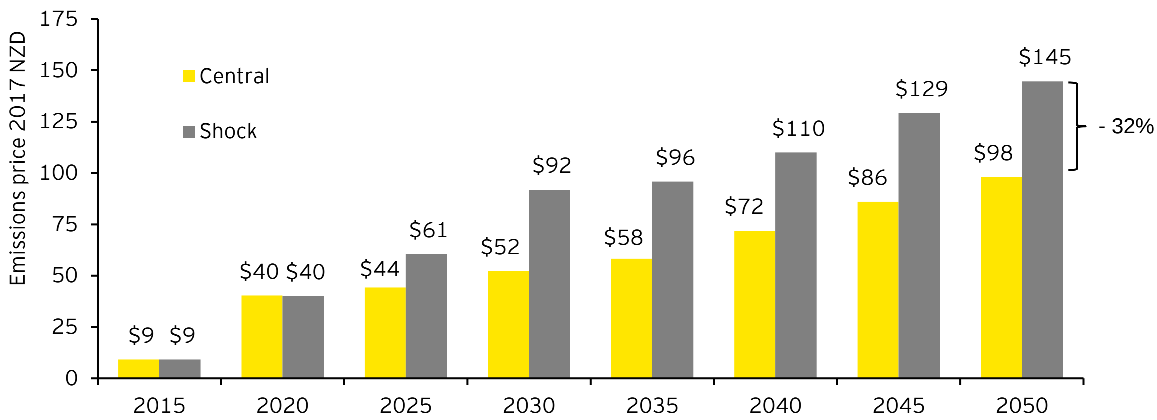

Figure 4: The emissions price in the *central scenario* is around 32% lower than in the *shock scenario* in 2050

Source: Vivid Economics with EY analysis from ViEW CGE model outputs

Economic growth is not projected to be evenly distributed across sectors of the economy

Projected growth is not even across New Zealand's economy. Manufacturing and production of non-ferrous metals[5], wind generation, fishing, solar, geothermal and other electricity generation sectors experience the most growth in both modelled scenarios, with sectoral compounded average growth rates of gross value added (see Box 1) in excess of 5%[6] per annum to 2050. Full sectoral results from the transition modelling can be found in Appendix A.

Box 1: Use of GVA as a proxy for GDP in sectoral level analysis

Gross value added (GVA) is the measure of the value of goods and services produced in an area, industry or sector of an economy. Throughout the report, GVA is used as an indicator of sector growth and can be seen as indicative of GDP growth for a sector.

GVA is used as the total aggregates of tax and subsidies on products (which factor into GDP) are only available at the economy level and not by sector. The relationship between the two can be expressed as: GVA + taxes on products – subsidies on products = GDP.

Directed action on climate change will cause a structural readjustment of the New Zealand economy (see Figure 5). Over a timeframe that extends through to 2050, the *shock scenario* – despite its comparative lack of climate action and low emissions prices for the first decade – would be likely to expose emissions-intensive sectors to greater economic impacts than the *central scenario*. Raw milk (dairy farming) and dairy products (processing) sectors decline in terms of their overall percentage of GVA in the *shock scenario* and coal and gas as electricity generation sources are modelled to exit the generation mix. The refined oil, coal and gas sectors experienced negative growth in both scenarios out to 2050.

Domestic trade and services (not included in the graphic), including transport and construction, continue to dominate the economic landscape in terms of relative GVA, contributing 77% of total GVA consistently through to 2050.

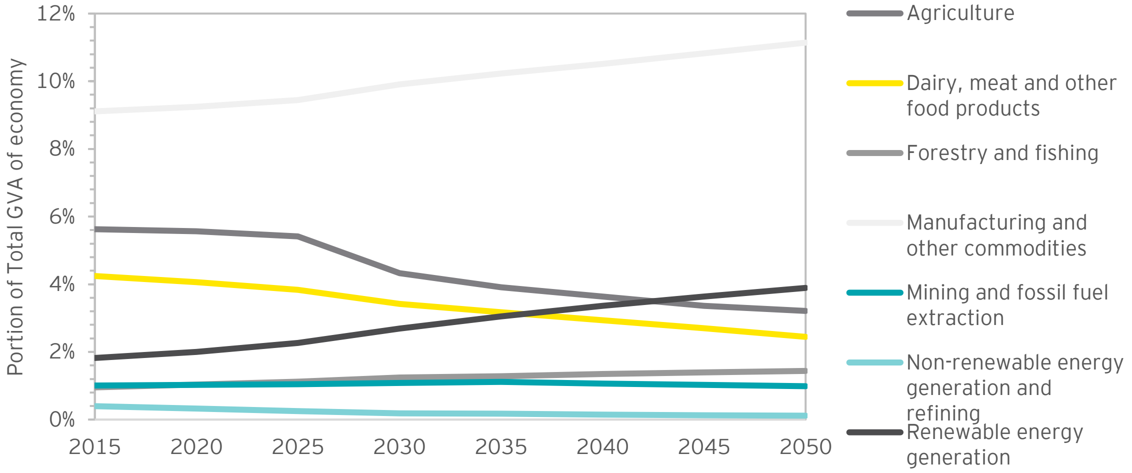

Figure 5: Relative change in certain sectors' (excluding Trade and Services) GVA as proportion of national GVA for *shock scenario*

Source: Vivid Economics with EY analysis from ViEW CGE model outputs

[5] Non-ferrous metals includes copper, aluminium, zinc, lead, gold and silver.

[6] Caution is advised when observing the high growth rates of sectors operating with scarce resources, such as fishing, non-ferrous metals and crude oil. A limitation of the model is that the relationship between scarce resources and increasing demand over time can be oversimplified. This effect can be magnified by the modelled assumption that the trade deficit of New Zealand is held constant to GDP, meaning that growing demand for scarce resources may not be as easily met through low cost imports of goods, thus benefiting local producers in the model.

A sector's ability to decarbonise is positively correlated with its potential for economic growth

The modelling results showed a correlation between a sector's ability to decarbonise and the sector's growth to 2050. This relationship is shown in Figure 6 for the *central scenario*, suggesting sectors that cannot adapt to a low-carbon future could be hindered in terms of their economic growth. Sectors that align better with a low-carbon future generally outperform economy-wide growth.

The largest sectors by GVA in 2015 performed fairly within the modelled improvement in carbon intensity. These sectors, namely Other Services, Trade, Construction, Other Manufacturing and Transport, continued to grow closely alongside the economy growth rates in each scenario to 2050.

Resistance to decarbonisation or the inability to decarbonise will put businesses under financial and reputational pressures that could increase over time. Certainty from policy makers would be important for businesses attempting to adjust to the increasing modelled emissions price.

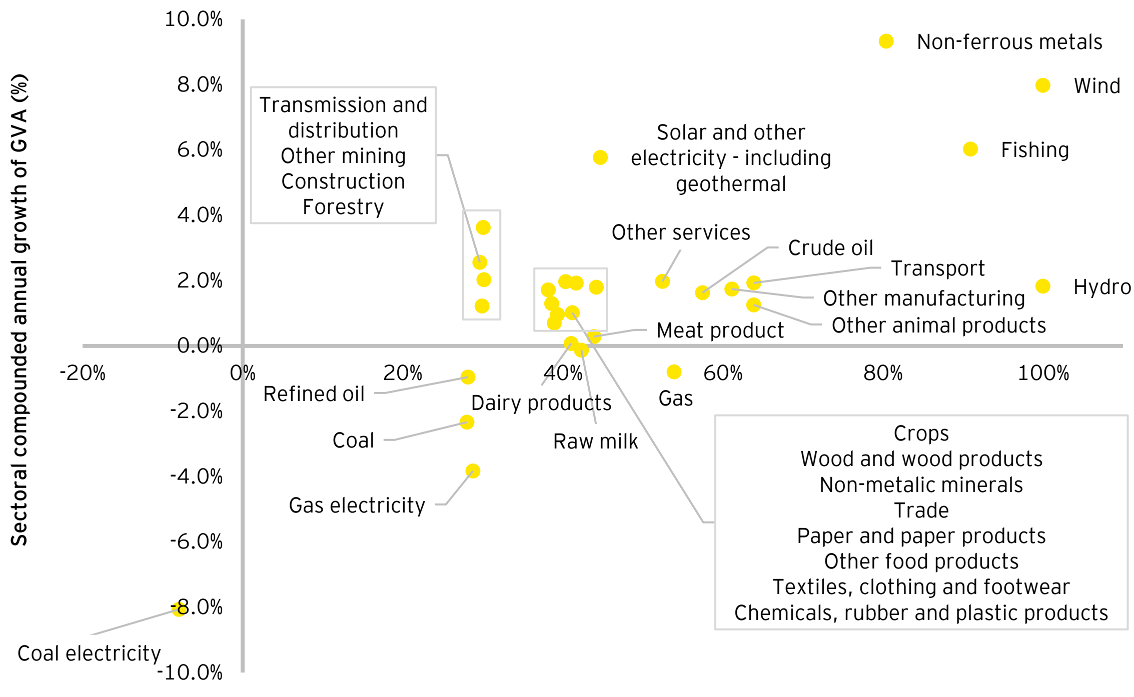

Figure 6: Correlation between sector's growth and its ability to decarbonise shown for *central scenario* to 2050

Source: Vivid Economics with EY analysis from ViEW CGE model outputs

Agriculture faces challenges under both scenarios, but it benefits from an early and phased introduction into the NZ ETS

Agriculture currently contributes nearly half of all New Zealand's gross national GHG emissions and the sector is also supported by other emissions-intensive sectors. Not surprisingly, growth rates of New Zealand's agricultural sectors are forecast to be impacted by GHG emissions constraints. In the short term, the *shock scenario* is intuitively better for agriculture-based sectors as the emissions cost of their operations is effectively concentrated within other sectors through paying the emissions price. In the absence of any emissions policy, agriculture continues to grow, consistent with its performance over the last ten years.

Agriculture's introduction into the NZ ETS has a noted effect on related sectors within the model. As seen in Figure 7, this effect is far more pronounced within the *shock scenario*, in which agriculture is introduced to the NZ ETS with half of the time allowed to phase its introduction. The GVA of the combined sectors in Figure 7 drops 13.7% between 2025 and 2030 (when agriculture is introduced to the NZ ETS). The rapid transition also generates losses in efficiency during the uptake of other land uses like forestry. Agricultural sectors are ultimately better able to manage their economic impacts through a longer, better signalled transition period within the *central scenario*. By comparison, the *central scenario* only experiences a combined 2.1% reduction in GVA between 2015 and 2020 (when agriculture is introduced to the NZ ETS).

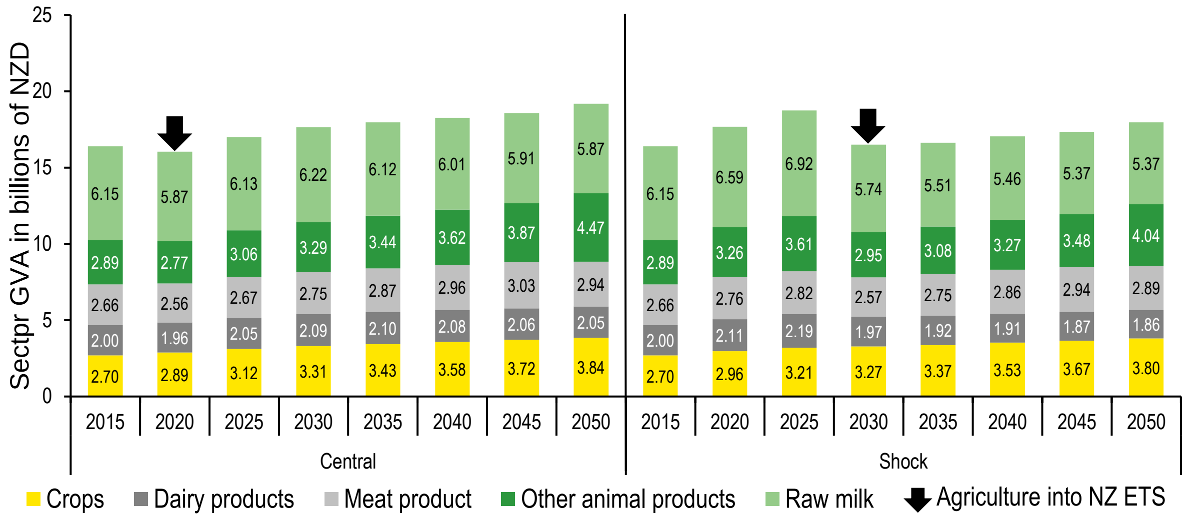

Figure 7: Change in GVA for the agriculture related sectors out to 2050

Source: Vivid Economics with EY analysis from ViEW CGE model outputs

The observed trend from the modelling was that the GVA of agricultural sectors plateaued or regressed, decreasing in relative terms while the economy overall continued to grow. This effect is projected to be felt most by raw milk producers and exporters of dairy products, with Gross Fixed Capital Formation (GFCF)[7] reaching its peak by 2030.

Improvements in technology such as methane reducing activities in grazing species, though not captured within the model, could allow for an improvement in national GHG emissions share over time. Despite this, it could take significant technology breakthroughs, also not captured within the model, to see agriculture continue its high growth in a net zero emissions future. This provides an incentive for New Zealand to continue investment in emissions reducing research and development. See Appendix C for more details on the technology assumptions related to agriculture.

Technology and emissions constraints are likely to drive significant changes in the electricity sector

The modelling results show significant opportunities in the electricity sector. New Zealand's use of energy is projected to double by 2050 due to population growth, the uptake of electric vehicles, a transition away from gas for heating and changing technology. This result is generally consistent with observable trends and international forecasts of international energy demand growth, such as in the International Energy Agency (IEA) World Energy Outlook 2017.

Renewable energy grows strongly under both scenarios, outcompeting non-renewable competitors. A modelled emissions price of over NZ$100 per tonne of carbon dioxide equivalent (tCO_2e) would make electricity generation from non-renewable sources economically unviable. Wind and solar generation have essentially no carbon exposure to their operations and perform better with higher emissions prices.

Figure 8 shows the generation of electricity by generation type for the *shock scenario*.

[7] Gross Fixed Capital Formation refers to the net increase in physical assets for a sector, determined by investment less disposals. It does not include the depreciation of fixed capital or purchases of land. It is used as an indicator of future business activity, business confidence and economic growth.

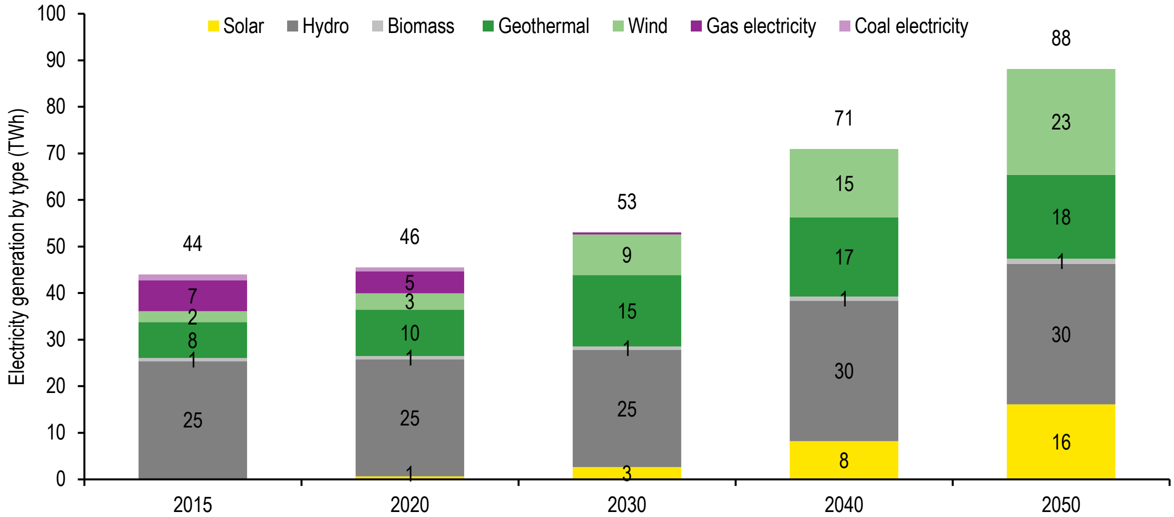

Figure 8: Terawatt hours of electricity production by generation type for the *shock scenario*

Source: Vivid Economics with EY analysis from ViEW CGE model outputs

Table 1 shows the change in the composition of New Zealand's energy generation mix for each source between 2015 and 2050 under each scenario. The projected energy generation mix by 2050 is nearly 100% renewable, with nominal reliance on coal and gas under both scenarios.[8]

Gas currently supports the national grid when there is pressure due to peak demand or climate variables such as drought. New Zealand can get closer to 0% gas by relying on a portfolio of intermittency-mitigating technologies such as increasing distributed generation, industrial demand side response and energy storage.

Table 1: Electricity generation mix by type compared to base year

Metric	*central scenario*		*shock scenario*	
	2015	2050	2015	2050
Coal	2.9%	0.1%	2.9%	0.0%
Gas	15.0%	1.5%	15.0%	0.0%
Hydroelectric	57.1%	34.0%	57.1%	34.2%
Solar	0.5%	17.9%	0.5%	18.3%
Geothermal	17.5%	20.3%	17.5%	20.4%
Biomass	1.6%	1.1%	1.6%	1.2%
Wind	5.4%	25.0%	5.4%	25.8%

Source: Vivid Economics with EY analysis from ViEW CGE model outputs

Wind is modelled to grow to around 25% of the country's total electricity generation in each scenario. However, that level of growth would necessitate a more streamlined regulatory pathway for resource consents. New Zealand has up to 2.3 GW of wind capacity already consented for with more sites under investigation.[9] However, this amount only accounts for around 40% of modelled growth in wind generation.

[8] CGE models, such as ViEW, are generally not built to explicitly capture intraday or intra-seasonal variations in rainfall or equivalent. Therefore, caution should be used when interpreting the modelled result that gas generation will become 0% of generation before 2050.

[9] New Zealand Wind Association. Consented Wind Farms in NZ. Accessed from: http://www.windenergy.org.nz/consented-wind-farms.

Solar is modelled to rapidly increase as costs are driven down and solar photovoltaic (PV) systems can be paired with battery storage, reducing concerns over solar's intermittency. Total generation from small solar PV panels in 2016 was estimated to be 51.7 GWh, up 52% over the year.[10] National Grid operator Transpower found that the existing core transmission network could handle nearly 2 GW of grid-connected solar capacity in addition to current generation and demand.[11]

Hydroelectric generation's ability to expand is limited. Generation increases between 2015 and 2050 from 25 Terawatt-hours (TWh) to 30TWh under both scenarios. Growth is limited by the high cost of increasing capacity. Hydro capacity could be increased through investment in higher transmission capacity from South Island generation and changes to resource consent restrictions. Increased water storage capacity would also allow the current hydro assets to produce more power during the drier months.

Geothermal electricity generation, while producing some GHG emissions, is modelled to play a continuing role due to its reliability and established infrastructure. According to the New Zealand Geothermal Association, there exists a further 800-900 MW-equivalent of geothermal electricity generation currently sitting at varying stages of design, planning and consent.[12] Utilising all this known capacity would result in total geothermal generation of approximately 14-16 TWh annually by 2050.

Coal electricity and **Gas electricity** fared poorly within the model, particularly in the *shock scenario* where the emissions price reaches \$147tCO_2e by 2050. Gas is more resilient than coal due to its lower carbon intensity and increased demand in the short term, where it is used as a transition fuel. Non-renewable electricity generation continued to remain economically viable in the *central scenario*, where the emissions price is 32% lower in 2050. However, it contributed only 1.6% of national electricity generated in 2050 compared with 18% in 2015.

[10] Electricity Authority (2018). Installed distributed generation trends. Accessed from: https://www.emi.ea.govt.nz/Retail/Reports/GUEHMT?FuelType=solar&MarketSegment=All&_si=p|3,v|3.

[11] Transpower (2017). *Solar PV in New Zealand.* Accessed from: https://www.transpower.co.nz/sites/default/files/plain-page/attachments/Solar%20PV%20in%20New%20Zealand.pdf.

[12] New Zealand Geothermal Association (2016). *Geothermal Energy & Electricity Generation.* Accessed from: http://nzgeothermal.org.nz/elec_geo/.

4. Physical analysis - Key insights

Climate change's physical implications are not evenly distributed across New Zealand's economic sectors. These impacts can further affect sectors already impacted by the transition to a two-degree aligned economy. Physical impacts that pose significant risks or opportunities for economic diversification and climate change adaptation were analysed for five sectors. The overall results of the impact to each sector for a range of key climate variables is shown in Figure 9.

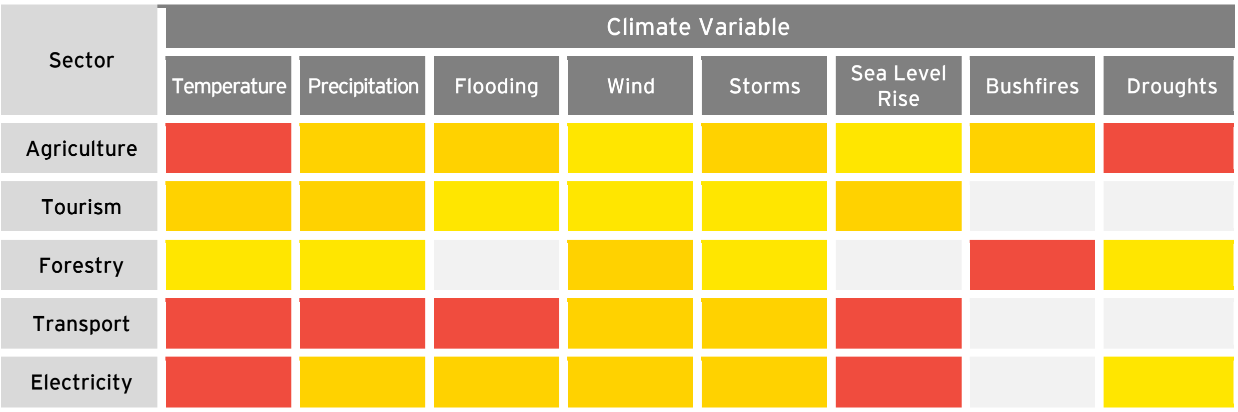

Figure 9: Summary of physical impacts from climate change as reflected in New Zealand literature review

Significance No material impact Low Medium High

Agriculture

Increasingly frequent extreme high temperatures can affect livestock health and production.[13] High temperatures also create favourable conditions for pests and diseases harmful to crops and livestock.[14] Drought frequency could double by the middle of the century under a mid-range scenario and even triple in exposed, already dry regions.[15] The nationwide drought in 2007-2008 cost the sector an estimated NZ$2.8 billion. Increased frequency of storms, rain events and floods will cause hillside slipping, erosion and the loss of topsoil and nutrients through runoff.[16] Sea level rise is associated with erosion and coastal flooding events. Such impacts could infiltrate coastal aquifers, contaminating them with salt water. Most groundwater used for irrigation in New Zealand comes from coastal aquifers, even for inland farms.[17]

Tourism

A changing climate will have implications for resources that New Zealand's tourism industry relies upon, including: infrastructure indirectly relied upon by tourism businesses such as airports and roads affected by sea level rise, precipitation and flooding, temperature extremes, storms and winds.[18] Flooding, heavy rain and wind events also affect infrastructure directly relied upon by tourism businesses, such as walking tracks and campgrounds. Natural attractions such as glaciers and beaches will also be impacted.

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[13] Clark et al. (2012). *Impacts of Climate Change on Land-based Sectors and Adaptation options*. Report prepared for Ministry of Primary Industries. Accessed from: http://www.mpi.govt.nz/dmsdocument/32-impacts-of-climate-change-on-land-based-sectors-and-adaptation-options-stakeholder-report.

[14] MfE. (2016). *New Zealand's Greenhouse Gas Inventory 1990-2014*. Accessed from: http://www.mfe.govt.nz/publications/climate-change/new-zealand-greenhouse-gas-inventory-1990-2014

[15] New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC). (2012). *Impacts of Global Climate Change on New Zealand Agriculture*.

[16] NIWA. (2012). *Four Degrees of Global Warming: Effects on the New Zealand Primary Sector*. Prepared for the Ministry of Primary Industries Accessed from: http://www.mpi.govt.nz/dmsdocument/6247-four-degrees-of-global-warming-summary

[17] MfE. (2016). *Adapting to Sea Level Rise*. Accessed from: http://www.mfe.govt.nz/climate-change/adapting-climate-Tourismchange/adapting-sea-level-rise.

[18] Becken, S., Wilson, J. & Reisinger, A., (2010). *Weather, Climate and Tourism. A New Zealand Perspective. Land Environment and People Research Report No. 20*.

Forestry

The most serious risk faced by the Forestry sector is the increasing likelihood of bushfires, as days with a fire index of 'very high' and 'extreme' will increase in some New Zealand locations up to 400% by 2040 and 700% by 2090.[19] Wildfires like the 2017 Port Hills fire in Christchurch and the 2015 and 2016 Marlborough fires are expected to occur with increasing frequency and severity. Over the last 70 years, wildfires have cost the forestry industry at least an estimated NZ$300 million and 40,000 hectares of plantations.[20] Furthermore, the combination of high winds, steep sloped plantations and heavy rain events can also result in debris flows, causing damage, particularly to younger plantations.[21] For example, Cyclone Gita created flash floods that washed large logs onto neighboring properties.[22]

Transport

Under mid-range climate scenarios, New Zealand would be likely to experience high water '100 year events' around every 3 years, resulting in more frequent and severe coastal flooding, extreme tidal events, and storm surges. Shipping ports, low-lying airports and coastal railways and roads would be affected. Roads and railways will also be impacted by increasing temperatures and rainfall. Projected growth in 'hot days' around the country would increase rail buckling, and more frequent and severe storm and rainfall events will causing flooding, erosion and landslides that could have costly impacts on roads and rail.[23] The Ministry of Transport has stated that future conditions will amplify extreme weather events' already significant costs and disruptions to transport networks.[24]

Electricity

Risks to electricity transmission and distribution infrastructure are significant, as demonstrated by recent cyclones. Increased precipitation in the west and south of New Zealand is projected to contribute to higher frequencies of landslides, erosion and coastal flooding, which will affect low lying transmission infrastructure.[25] Additionally, a rise in sea levels and a significant increase of coastal flooding events poses risks to coastal infrastructure.[26] Heat waves, storms and extreme winds will also pose risks to transmission infrastructure and increase the frequency of outages due to damaged lines.[27] Another potential impact of climate change to electricity generation will mostly be indirect: drought that can affect hydroelectricity generation through changes to runoff from glaciers and

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[19] New Zealand Climate Change Centre (2014). *IPCC Fifth Assessment Report New Zealand Findings.* Accessed from: https://www.niwa.co.nz/sites/niwa.co.nz/files/NZCCC%20Summary_IPCC%20AR5%20NZ%20Findings_April%202014%20WEB.pdf.

[20] Watt, M.S., Kirschbaum, M.U.F., Paul, T.S.H., Tait, A., Pearce, H.G., Brockerhoff, E.G., Moore, J.R., Bulman, L.S., Kriticos, D.J. (2008). The Effect of Climate Change on New Zealand's Planted Forests Impacts, Risks and Opportunities. Prepared forthe Ministry of Agriculture and Forestry.

[21] Ministry for the Environment (2016). Climate Change Projections for New Zealand. Accessed from: www.mfe.govt.nz/sites/default/files/media/Climate%20Change/nz-climate-change-projections-final.pdf.

[22] Radio New Zealand (2018). Gita forced water, logs towards homes 'like a tsunami'. Available from: https://www.radionz.co.nz/national/programmes/checkpoint/audio/2018633937/gita-forced-water-logs-towards-homes-like-a-tsunami.

[23] D.J., R.S.J. Tol, E. Faust, J.P. Hella, S. Kumar, K.M. Strzepek, F.L. Tóth, and D. Yan, (2014): *Key economic sectors and services. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 659-708. Accessed from: https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/supplementary/WGIIAR5-Chap10_OLSM.pdf

[24] Ministry of Transport (2015). *Ensuring our transport system helps New Zealand thrive; Statement of Intent 2015-2019.* Accessed from: http://www.transport.govt.nz/assets/Uploads/About/Documents/statement-of-intent-2015-2019.pdf.

[25] New Zealand Government. (2010). *New Zealand Coastal Policy Statement 2010*. Wellington. Accessed from: http://www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/new-zealand-coastal-policy-statement-2010/.

[26] D.J., R.S.J. Tol, E. Faust, J.P. Hella, S. Kumar, K.M. Strzepek, F.L. Tóth, and D. Yan (2014). See footnote 23.

[27] Ministry for the Environment (2008*). Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand. 2nd Edition*.

seasonal snow.[28] New Zealand currently lacks adequate research on droughts' impacts on hydroelectricity, although that research is underway.[29]

Implications and opportunities

Transition and physical implications of climate change are, to some extent, inversely correlated. As the world decarbonises, transition implications to economic sectors will increase and, over time, the extent of climate change's physical implications will decrease. Of course, economic sectors are impacted by climate change's transition and physical implications to different extents.

Our analysis attempts to provide insights into the combined transition and physical impacts on each of several key sectors by modelling the sectors' change in growth rate, from the economic average, under a two-degree aligned scenario and against the sector's vulnerability to physical impacts under a range of probable climate scenarios.
Figure 10 identifies certain sectors impacted by a combination of transition and physical implications. It also identifies those sectors for which climate change may present opportunities or be less impacted by either the transition and physical implications.

Sector	Climate Change's Transition Implications	Climate Change's Physical Implications	Implications and Opportunities
Agriculture	High	High	The agricultural sector, as a significant contributor to national GHG emissions, faces both opportunities and risks associated with the physical and transition implications from climate change.
Tourism	Low	Medium	The tourism sector faces moderate impacts from the physical implications of climate change, though opportunities for the sector leading from climate changes may also prevail. Tourism businesses have an opportunity to expand into climate-resilient forms of tourism, capitalising on pressures facing international tourism destinations in competitor markets that will be more extremely impacted by predicted climate changes.
Transport	Medium	High	The transport sector faces moderate transition impacts due to potential decarbonisation and electrification, in addition to higher physical impacts from climate change due to the vulnerability of large-scale infrastructure to more extreme events.
Electricity	Medium	High	The electricity sector will be required to support other industries going through rapid decarbonisation in line with changing policy requirements, creating opportunities if the sector can continue to meet demand. Physical impacts for the electricity sector are likely higher in some regions due to the geographic footprint of transmission and distribution networks in climate-prone zones.
Forestry	Medium[30]	Medium	The forestry sector will likely be a net beneficiary of New Zealand's policy environment, creating economic opportunity for the industry to expand and create value from carbon markets. Physically, the sector remains moderately vulnerable to climate impacts such as water scarcity and soil degradation.

Figure 10: Overlaying the growth potential with physical impacts exposure identifies risks and opportunities

[28] Dunlop R. (30 Jan 2018). *South Island snow 'melt-off' in heat could affect power and irrigation*. New Zealand Herald. Accessed from: www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11984798.

[29] Deep South Challenge. *Snow, ice and glaciers in our changing climate*. Accessed from: www.deepsouthchallenge.co.nz/snow-ice-and-glaciers-our-changing-climate.

[30] A lag on the return on investment in the forestry sector, due to harvest cycles, contributes to the modest growth out to 2050, with additional growth expected over a longer timeframe. This may overestimate the transition implications for this sector.

5. Conclusion

Analysis of the modelling results shows that New Zealand can decarbonise its economic activities, in line with a two-degree target, whilst the economy continues to grow. Climate action towards a two-degree target would lead to a structural readjustment of the New Zealand economy. Through comparing two scenarios, modelling indicates that an early, phased transition to a zero-carbon economy will provide for more positive macroeconomic outcomes in the longer-term than delaying action, therefore requiring a more rapid readjustment beyond 2030. Early action allows the economy-wide emissions price to be lower in the *central scenario* than in the *shock scenario*. Over the longer term, this more gradual adjustment to the structure of the economy will provide greater certainty for business, reducing the efficiencies lost through rapid price driven resource reallocation. Despite the *shock scenario* implying less climate action, and lower emissions prices (in the very near term), the *shock scenario* is likely to expose emissions-intensive sectors to more economic impacts than the *central scenario* from 2030 to 2050.

Besides the transition implications posed by climate change, the physical impacts could be a major disruptor and should be better understood and planned for. Rising temperatures and associated events such as drought and other changes in precipitation, wildfires, and glacial retreat will likely cause economic loss and operational disruption for agriculture and tourism, as evidenced by historic weather events. Forestry will also likely be physically affected by climate change from higher fire risk, but the sector will also play a crucial role in the transition to a two-degree aligned economy. Thus, further economic opportunities created for the sector may balance or likely outweigh the impacts from climate change damage. Similarly, electricity and transport will likely experience physical impacts and disruption to operations because of climate change, but these sectors could become a focus for decarbonisation, and therefore see demand rise during New Zealand's transition to a two-degree aligned economy.

As both transition and physical implications will be experienced to some degree simultaneously, a summary of their impacts to the five key sectors analysed for physical implications are provided in Figure 10.

Appendix A: Sectoral Transition Results

Full sector results from the transition scenario analysis for the *central* and the *shock scenarios* are provided in this Appendix. These results have been calculated in accordance to the Approach set out in Appendix B, and presented in order of highest growth.

Caution is advised when observing the high growth rates of sectors operating with scarce resources, such as non-ferrous metals, fishing and crude oil. A limitation of the model is that the relationship between scarce resources and increasing demand over time can be oversimplified. This effect can be magnified by the modelled assumption that the trade deficit of New Zealand is held constant to GDP, meaning that growing demand for scarce resources may not be as easily met through low cost imports of goods, thus benefiting local producers in the model.

Central scenario

Table 2: Financial metric sectoral results for *central scenario* to 2050

Sector	Compounded Annual Growth of GVA	Unmitigated Carbon Exposure of Operations	Modelled Improvement in Carbon Intensity
Non-ferrous metals	9.33%	3%	80%
Wind	7.98%	0%	*
Fishing	6.03%	6%	91%
Solar, geothermal and other electricity	5.77%	2%	45%
Other mining	3.63%	5%	30%
Transmission and distribution	2.56%	0%	30%
Construction	2.03%	0%	30%
Other services	1.98%	0%	52%
Trade	1.97%	0%	40%
Transport	1.93%	20%	64%
Wood and wood products	1.92%	1%	42%
Hydro	1.83%	0%	*
Non-metalic minerals	1.80%	3%	44%
Other manufacturing	1.74%	1%	61%
Paper and paper products	1.72%	1%	38%
Crude oil	1.63%	1%	57%
Chemicals, rubber and plastic products	1.30%	4%	39%
Other animal products	1.26%	67%	64%
Forestry	1.22%	-142%	*
Crops	1.02%	3%	41%
Textiles, clothing and footwear	0.96%	0%	39%
Other food products	0.70%	1%	39%
Meat product	0.29%	2%	44%
Dairy products	0.07%	5%	41%
Raw milk	-0.13%	29%	42%
Gas	-0.79%	21%	54%
Refined oil	-0.95%	72%	28%
Coal	-2.33%	14%	28%
Gas electricity	-3.83%	441%	29%
Coal electricity	-8.07%	279%	-8%

* Inability to improve because no material net positive emissions. Top score assigned.

Shock scenario

Table 3: Financial metric sectoral results for *shock scenario* to 2050

Sector	Compounded Annual Growth of GVA	Unmitigated Carbon Exposure of Operations	Modelled Improvement in Carbon Intensity
Non-ferrous metals	9.38%	4%	81%
Wind	8.10%	0%	*
Fishing	5.99%	8%	91%
Solar, geothermal and other electricity	5.84%	2%	46%
Other mining	3.65%	8%	33%
Transmission and distribution	2.54%	0%	30%
Construction	2.01%	0%	33%
Other services	1.96%	0%	54%
Trade	1.95%	0%	44%
Wood and wood products	1.94%	1%	48%
Transport	1.88%	29%	66%
Hydro	1.87%	0%	*
Non-metalic minerals	1.79%	5%	53%
Other manufacturing	1.74%	1%	64%
Paper and paper products	1.71%	1%	43%
Crude oil	1.55%	1%	56%
Chemicals, rubber and plastic products	1.26%	5%	42%
Forestry	1.23%	-209%	*
Crops	0.99%	4%	42%
Other animal products	0.96%	99%	61%
Textiles, clothing and footwear	0.95%	1%	45%
Other food products	0.68%	2%	45%
Meat product	0.24%	2%	52%
Dairy products	-0.20%	8%	49%
Raw milk	-0.39%	42%	42%
Refined oil	-1.02%	106%	30%
Gas	-1.29%	32%	54%
Coal	-2.86%	21%	28%
Coal electricity	**	411%	**
Gas electricity	**	649%	**

* Inability to improve because no material net positive emissions. Top score assigned.

** Exit from economy due to inability to decarbonise. Lowest score assigned as no sector GVA in 2050.

Appendix B: Approach

Analysis of Transition Implication scenarios

1. Scenario development

The approach of the transition analysis was to conduct scenario analysis of different scenarios that met the following criteria:

- Align with a two-degree climate future consistent with the Paris Agreement
- Provide insights into a range of possible pathways to achieve this outcome to account for uncertainty
- Consistent with the scenario analysis recommendations of the TCFD Report
- Supported by available data

Two scenarios were selected, defined as the *central scenario* and the *shock scenario*. A description of the economic, policy and technology characteristics that each scenario represents is provided in the Executive Summary. A more detailed explanation of the assumptions underpinning each scenario is provided in Appendix C.

2. Scenario modelling

Scenario modelling was carried out by Vivid Economics, using its recursive dynamic general equilibrium model, called "ViEW". The model considers economic activity, energy production, and GHG emissions (including biological emissions), adapted to represent New Zealand's economy. It is calibrated using data from Version 9 of the Global Trade Analysis Project (GTAP) database. As a general equilibrium model, ViEW is able to evaluate how economic implications arising from decarbonisation policies impact across the economy, at a sector level. The model assumes a set carbon budget for New Zealand. The model also implicitly assumes that 'equivalent' action is taken so that, for each commodity, the price of New Zealand products relevant to the world price remains constant. More detail on the ViEW model is provided within the Appendix C.

3. Setting of carbon budget parameters

The GHG emissions profiles of each scenario vary significantly out to 2030, based on their respective narratives, particularly in relation to agriculture's inclusion in the NZ ETS. The application of a set emissions budget for New Zealand creates an implied emissions price, with ViEW simulating the impact of profit maximising firms responding to that emission price in the context of New Zealand's carbon budget. This emissions price is the marginal cost associated with removing the last tonne needed to hit the emissions target in that year, and represents the economy-wide emissions price expected to prevail under each scenario. In order to allow for the movement of the emissions price implied by the ViEW model, the policy maker will have to lift the NZ$25 tCO_2e cap that currently exists in the New Zealand market. Figure 2 shows the emissions profiles set under each scenario.

4. Developing financial climate metrics

Three metrics were defined and used to estimate the potential financial impact of a two-degree pathway for a given sector, shown in Table 4.

Table 4: Financial climate metrics

Financial Metric	Explanation
Compounded Annual Growth Rate of GVA	This metric models the growth in the sectoral value added, smoothed to 2050. This represents the financial compatibility of the sector with a two-degree scenario.
Unmitigated Carbon Exposure of Operations	This metric shows the proportion of the sectors' total added value at risk if the sector fails to mitigate its emissions (measured as the 2015 emissions with a 2050 cost of emissions, as a percentage of sector value add in 2015).
Modelled Improvement in Carbon Intensity	This metric shows the potential to mitigate carbon emissions through the modelled change in carbon intensity of operations, by reducing emissions relative to gross value add (% improvement in carbon intensity in 2050 compared to 2015).

Physical implications scenario analysis

Scope of literature review

Five New Zealand industry sectors were identified for assessment to consider physical risks, based on available literature, which included **Agriculture**, **Tourism, Forestry, Transport,** and the **Electricity** sector.

A range of potential climate scenarios, including two-degree scenarios and scenarios that do not constrain climate change to two-degrees were considered, in order to identify climate variables that posed a significant risk to each sector. This report includes analysis of research up until January 2018 (and limited research on the effects of Cyclone Gita in February 2018) from a range of sources[31].

For each of these five sectors, the factors the analysis covered considered:

- Leading practices in climate change adaptation.
- Industry level support for action on climate change.
- How leaders within the industry group have responded and are responding to climate change.
- A high-level analysis of the sector's supply chain.
- Key events that have demonstrated the sector's vulnerability to climate change.

Combined transition and physical implications results

Transition and physical impacts from climate change are inversely correlated in magnitude, however both will occur to some degree simultaneously. To demonstrate a combined view of the overall risk to these five sectors, sector growth rates from the transition scenario analysis were considered against the levels of physical impacts identified from the physical implications literature review. Notably, the tourism sector was not captured in isolation with the transition model, as tourism's economic contribution spread across a range of sectors. Subsequently, the growth categorisation for tourism in this report is informed by MBIE's forecasts.[32]

[31] Literature includes sources from New Zealand's Ministry for the Environment, Ministry of Business Innovation & Employment and Ministry of Primary Industries, The Parliamentary Commissioner for the Environment, Key research institutions such as National Institute of Water and Atmospheric Research, The Intergovernmental Panel on Climate Change, New Zealand Agricultural Greenhouse Gas Research Centre and New Zealand academics.

[32] MBIE (2017). *New Zealand Tourism Forecasts 2017-2023*. Accessed from: http://www.mbie.govt.nz/info-services/sectors-industries/tourism/tourism-research-data/international-tourism-forecasts/documents-image-library/forecasts-2017-report-final.pdf.

Appendix C: Technical Method

Overview of the ViEW model:

Climate scenarios were simulated by Vivid Economics using the Vivid Economy-Wide model (ViEW). ViEW is formulated and solved as a mixed complementarity problem using the Mathematical Programming Subsystem for General Equilibrium analysis (MPSGE). It solves each period recursively to the year 2050. Maximisation problems are solved in the first year based on the assumptions and policies active today. This determines investment patterns which, in turn, governs the allocation of production factors, such as labour and capital, across sectors in the following year. The maximisation problems are then solved for the following year based on these allocations and the assumptions and policies that are active in that year. This process continues until the optimal allocations are calculated for all years under consideration. Final results are presented in five year intervals starting in 2020 and proceeding to 2050.

Figure 11 presents an overview of the features of the ViEW model and their relationships.

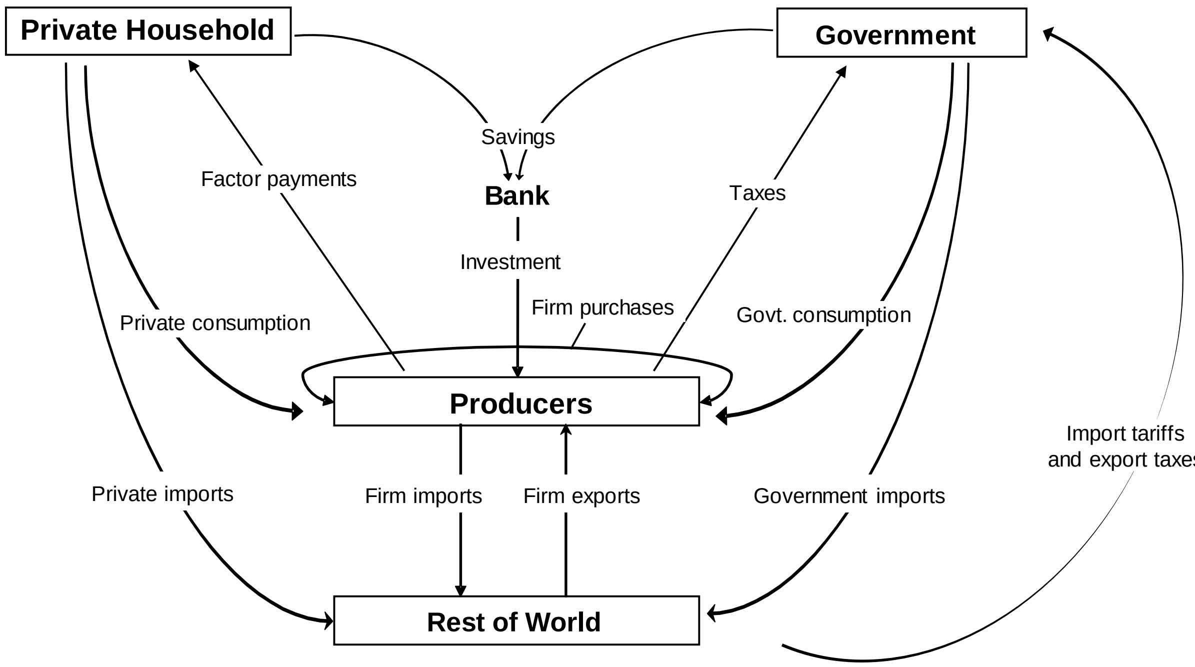

Figure 11: ViEW explicitly models each of the interactions in the circular flow of income
Source: Vivid Economics

ViEW includes a detailed representation of energy, food production, international trade, investment, manufacturing, mining and services. It is calibrated using data from version 9 of the GTAP database.[33] This database's primary purpose is to provide expansive and granular bilateral trade information, transport and trade protection linkages. The current GTAP 9 database features 57 commodity-sectors such as cattle, milk, wool, forestry, dairy products, non-ferrous metals and business services. However, the specific version used to simulate the selected scenarios is calibrated to include the 30 separately modelled sectors presented in Table 5, including definitions of contributing activities. In this way, it models explicitly impacts in the sectors of interest in great detail while aggregating those not of interest together such that the model remains tractable and easy to use.

The GTAP database separably identities "solar electricity" and "other electricity", which includes geothermal and biomass. Solar and other electricity were aggregated together for this analysis into a category called "Solar, geothermal and other electricity". This GTAP categorisation is a limitation in an analysis of New Zealand due to geothermal being significant generator of electricity nationally compared to other countries, where it is a less prominent generation source. To add relevance to the

[33] An overview of the GTAP Database is provided by Aguiar, Narayanan, & McDougall. (2016). Accessed from: https://www.gtap.agecon.purdue.edu/resources/jgea/ojs/index.php/jgea/article/view/23/.

"Solar, geothermal and other electricity" output, the sector has been further disaggregated based on a literature review, and the findings presented alongside the other model outputs in Table 1.

The ViEW model's data is presented in 2011 USD, so outputs from the model were converted into 2017 NZD. The rate of conversion from 2011 USD to 2017 NZD was 0.7521. The conversion factor was determined using the Reserve Bank of New Zealand historical exchange rates and inflation calculator. The exchange rate from 2011 USD to 2011 NZD was 0.804444. The inflation rate to convert 2011 NZD to 2017 NZD was 1.0660.

Table 5: Sector definitions and examples

Sector	Definition	Examples[34]
1. Raw milk	Farming of raw milk	Dairy farming
2. Other animal products	Products of animal origin	Sheep (meat and wool), cattle, swine, poultry, other animals, eggs (in shell, fresh preserved or cooked), natural honey, snails, hides (skins, fur-skins, raw), insect waxes and spermaceti (whether or not refined or coloured)
3. Crops	Edible plant products	Wheat (wheat and meslin), other grains (barley, corn, oats, rye, other cereals) fruits and vegetables (vegetables, fruit-vegetables, fruit and nuts, potatoes, cassava, truffles), rice (husked and not husked), oil seeds and oleaginous fruits, plants used for sugar manufacturing, raw vegetable materials used in textiles, live plants, cut flowers and flower buds, flower seeds and fruit seeds, vegetable seeds, beverage and spice crops, unmanufactured tobacco, cereal straw and husks (unprepared, whether or not chopped, ground, pressed or in the form of pellets), swedes, mangolds, fodder roots, hay, lucerne, clover, sainfoin, forage kale, lupines, vetches and similar forage products (whether or not in the form of pellets), plants used primarily in perfumery/pharmacy/insecticide/fungicide or similar purposes, seeds of forage plants, other raw vegetable materials
4. Forestry	Plantation forestry, logging and related service activities	Forestry, logging
5. Fishing	Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing	Fishing, fish farming, related services
6. Coal	Mining and agglomeration	Hard coal, lignite, peat
7. Oil	Extraction, and service activities incidental to extraction excluding surveying	Crude petroleum
8. Gas	Extraction, and service activities incidental to extraction excluding surveying	Natural gas, manufacture of gas, distribution of gaseous fuels through mains
9. Coal electricity	Production and collection	Coal
10. Gas electricity	Production and collection	Gas
11. Hydroelectricity	Production and collection	Hydro
12. Wind electricity	Production and collection	Wind
13. Solar, geothermal and other electricity	Production and collection	Biomass, solar, geothermal
14. Refined oil	Refining of crude oil	Refined petroleum products, manufacture of coke oven products, processing of nuclear fuel
15. Mining of metal ores	Mining and quarrying	Uranium and thorium ores, other (gold, copper, gems, iron)
16. Dairy products	Processing of raw milk	Dairy products

[34] GTAP Data Bases: Detailed Sectoral List (2013). Accessed from: https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp.

Table 5: Sector definitions and examples		
Sector	**Definition**	**Examples**[34]
17. Meat products	Processing of meat	Cattle meat; fresh, chilled or frozen meat and edible offal of cattle, sheep, goats, horses, mules, and hinnies, raw fats or grease from any animal or bird Other meat; pig meat and offal, preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal; greaves
18. Other food products	Processing of other food, beverages and tobacco	Vegetable Oils; crude and refined oils of soya-bean, corn, olive, sesame, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and canola, mustard, coconut palm, palm kernel, castor, tung and jojoba, babassu and linseed, perhaps partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised. Also margarine and similar preparations, animal or vegetable waxes, fats and oils and their fractions, cotton linters, oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; degras and other residues resulting from the treatment of fatty substances or animal or vegetable waxes, processed rice (rice, semi- or wholly milled) sugar, Other food: prepared and preserved fish or vegetables, fruit juices and vegetable juices, prepared and preserved fruit and nuts, all cereal flours, groats, meal and pellets of wheat, cereal groats, meal and pellets, other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers' wares, starches and starch products; sugars and sugar syrups, preparations used in animal feeding, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, food products, beverage and tobacco products
19. Wood	Manufacture of wood and products of wood and cork	Wood, wood products (excluding furniture), cork products, articles of straw and plaiting materials
20. Paper and paper products	Manufacture, publishing, printing and reproduction	Paper, paper products, record media
21. Textiles, clothing and footwear	Manufacture of textile, clothing and footwear products	Man-made fibres, wearing apparel, dressing and dyeing of fur, tan and dressing of leather, luggage, handbags, saddlery, harness and footwear
22. Chemical, rubber and plastic products	Manufacture of chemical, rubber and plastic products	Basic chemicals, other chemical products, rubber, plastic products
23. Non-metallic minerals	Manufacture of other non-metallic mineral products	Cement, plaster, lime, gravel, concrete
24. Non-ferrous metals	Manufacture, production an casting of basic precious and non-ferrous metals	Copper, aluminium, zinc, lead, gold and silver
25. Other manufacturing	Manufacture of other products	Casting of iron and steel, manufacture of fabricated metal products (except machinery and equipment), motor vehicles, trailers and semi-trailers, other transport equipment, office, accounting and computing machinery, radio, television and communication equipment/apparatus, machinery and equipment, electrical machinery and apparatus, medical, precision and optical instruments, watches and clocks, other manufacturing including recycling
26. Trade	All retail and wholesale trade	Wholesale trade and commission trade; hotels and restaurants; repairs of motor vehicles and personal and household goods; retail sale of automotive fuel, non-specialised retail trade in stores, retail sale of food, beverages and tobacco in specialized stores, other retail trade of new goods in specialized stores, second-hand goods, retail trade not in stores
27. Transportation	All transport and supporting activities	Land, water, air; Supporting and auxiliary transport activities, activities of travel agencies, transport via pipelines
28. Construction	Construction and building activities	Housing, factories, offices, roads, infrastructure
29. Transmission and Distribution	Electricity	Transmission and distribution of coal electricity, gas electricity, hydroelectricity, wind electrify and other electricity (biomass, solar, geothermal)

Table 5: Sector definitions and examples		
Sector	Definition	Examples[34]
30. Other services		Communications (post and telecommunications), other financial intermediation (auxiliary activities), insurance (pension funding, excluding compulsory social security), other business services (real estate, renting and business activities), recreation and other services (recreational, cultural, sporting activities, service activities; private households with employed persons), other government services (public administration and defence, compulsory social security, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organisations, extra-territorial organisations and bodies), dwellings (ownership of dwellings), water (collection, purification and distribution)

Data for the ViEW model is organised using a social accounting matrix. This includes data on the value of all economic transactions that take place within an economy in a specified time frame. Importantly, it imposes an equilibrium within which each sector earns zero profits and expenditure on each good match income from its sale.

ViEW requires estimates of elasticities of substitution to calibrate the consumption and production functions of households and producers respectively. These elasticities provide an estimate of how households and firms change their behaviour in response to a policy shock. In the default version of the model, these are taken from the existing literature, much of which provides econometric estimates using historical data. Furthermore, the design relies on an assumption of optimal market clearing, in both labour and capital markets. In practice, this means that the model assumes no involuntary unemployment or resource waste.

CGE models, such as ViEW, are generally not built to explicitly capture intraday or intra-seasonal variations in rainfall or equivalent, and so have limited ability to capture fine-tuned answers to the intermittency problems from renewable energy generation. EY therefore recommends caution when interpreting the modelled result that gas generation will become 0% of generation before 2050.

Modelling a two-degree world

In line with the Paris Agreement, the model assumes:

- A set carbon budget for New Zealand, aligned with New Zealand reaching its Nationally Determined Contribution (NDC) commitments and reaching net zero in the second half of the century.
- The application of this carbon budget cap creates an emissions price, with the model simulating the impact of profit maximising firms responding to that emission price.
- Given the policy and technology assumptions, the model calculated the lowest cost abatement path in both scenarios.
- The ViEW model is a single-country model, meaning it does not capture how the New Zealand economy will interact with the rest of the world. In effect, the model assumes that equivalent emissions reduction action is taken by all other countries. The result is that for each commodity, the price of New Zealand products relative to the world price remains constant. Being a single-country model, the ViEW model cannot concurrently model disparate policies in other countries.
- For each product in the model, New Zealand firms' competitiveness relative to the rest of the world is assumed to remain fixed. In reality, global climate change policies might affect New Zealand firms' relative competitiveness in two main ways.
  - First, other countries might adopt different climate change policies to New Zealand. For example, if other countries adopt less stringent climate change targets than New Zealand, some New Zealand firms may become less competitive relative to overseas competitors.
  - Second, even if all counties adopted the same policies, the cost of carbon abatement might differ between countries. This would alter countries' relative competitiveness. For example, if all meat farmers around the world faced the same emissions price, then one might expect any

reduction in global meat production to occur in the countries where meat production is highest in carbon intensity, not in New Zealand where meat production is relatively low in emissions. Similarly, the New Zealand tourism industry may be more heavily affected by a global emissions price than tourism in other countries, since travelling to New Zealand involves travelling such long distances from the world's major population centres.

Key scenario-specific assumptions

Introduction of agricultural sectors into the NZ ETS:

- Agriculture is phased in (2 units for the price of 1) over a 10 year period in the *central scenario* from 2020.
- In the *shock scenario*, the phase in period is shorter (2-5 years) and does not begin until 2030.

The timing of international unit use also differs across the scenarios:

- The *central scenario* assumes that international units can be used up to meet up to 20 percent of economy-wide gross emissions (i.e. before emission removals from forestry sinks) from 2022.
- In contrast, the *shock scenario* assumes that international units can only be used, to the same extent, from 2030.

Technology assumptions echo those used in the *Net Zero in New Zealand* report for the growth of renewables, energy efficiency, uptake of electric vehicles, emissions reductions technology in the agricultural sector and afforestation:

In the *central scenario,* the assumptions are aligned with the Resourceful and Innovative scenarios from 2018:[35]

- Renewable energy continue to grow as a source of power generation;
- Increases in efficiency and the electrification of low and medium-grade heat in commercial and industrial sectors;
- An electric vehicle fleet will be used for light-duty and freight purposes;
- Vaccines to reduce methane in cattle and other agriculture measures are used to some degree; and
- Afforestation occurs to some degree.

In the *shock scenario,* the assumptions are aligned with the Off Track scenario until 2030.[36] Within this climate narrative, some low cost emissions abatement options are utilised from 2018 including:

- Renewable energy continue to grow as a source of power generation;
- Increases in efficiency and the electrification of low and medium-grade heat in commercial and industrial sectors;
- Uptake of electric vehicle use within the light-duty fleet; and

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[35] In Vivid Economics' *Net Zero in New Zealand* report, the Innovative and Resourceful scenarios achieve net zero emissions in the second half of the century, but differ in the way they get to this point. In the Innovative scenario, New Zealand further reduces the emissions intensity of its economic activity through further technological advances, as well as a structural shift away from pastoral agriculture. It relies of technological breakthroughs in the electrification of high grade heat, and non-passenger transport as well as advances in agricultural sector technologies. In the Resourceful scenario, in the absence of the breakthrough technological advances of the Innovative scenario, significant afforestation is required to offset emissions.

[36] In the Off Track scenario, New Zealand focuses on low cost emissions options out to 2050, including focus on renewable energy, electrification of light vehicle transport and low grade heat, and emissions reductions in the agricultural sector from efficiency improvements in areas such as targeted breeding, new feed regimes, and nitrogen and methane inhibitors, as well as process improvement in areas such as precision agriculture. This is accompanied with only modest changes in land-use patterns, and is not sufficiently ambitious to achieve net zero emissions in the second half of the century.

- Vaccines to reduce methane in cattle and other agriculture measures are used to some degree.

From 2030, technology assumptions in the *shock scenario* echo those used in the Innovative and Resourceful scenarios:

- Further growth of renewable energy continue to grow as a source of power generation;
- Further increases in efficiency and the electrification of high-grade heat in commercial and industrial sectors;
- Electric vehicles used for freight purposes;
- Further technological improvements within the agriculture sector; and
- Significant afforestation.

Other general assumptions

- The GDP trajectory is calculated endogenously for every year to 2050. The analysis uses a 2.04 percent growth per year, which is based on the MBIE projections of Q4 2015 growth.
- The trade deficit relative to GDP is held constant in the model. Where exports become less competitive due to an increasing emissions price, this requires an increase in exports of another commodity or for imports to decrease.
- The New Zealand population increases from 4.6 million to 6.1 million by 2050.
- Electricity demand projections were built on MBIE's Mixed Renewables Scenario, with further ambitious uptake of electricity of transport and heating.
- Land productivity increases by 1% each year, in a continuation of recent trends.
- Decreases in agricultural GHG emissions per unit of production of 1.5% each year, reflecting a combination of autonomous improvements and various actions to improve GHG efficiency, including breeding for low emissions, low emissions feeds, methane vaccines and inhibitors, and improved farming processes such as precision agriculture.
- Autonomous decreases in agricultural GHG emissions per unit of production of 1.5% each year.
- A major innovation in this project was to model how policy might change the pattern of land use in New Zealand. For example, a higher emissions price would be expected to lead to a conversion of pastoral agricultural land to forestry. This is a major innovation in New Zealand general equilibrium macroeconomic modelling of emissions policy, with most existing general equilibrium modelling analysis excluding emissions from forestry and land use. This requires a number of simplifying assumptions:
    - Emissions and removals from existing forests will continue to have a major impact on New Zealand's emissions trajectory. The high rates of forest plantings in the 1990's will drive significant net sequestration in coming years, before declining with increased harvests in the 2020's. Given variability in forest carbon stock and emissions over time, the analysis assumes that sequestration from existing forests is accounted for up to the point that forests reach their long run average carbon stock – consistent with emissions accounting specified under New Zealand's NDC[37]. The resulting emissions trajectory was then smoothed, implying that in

[37] When new forests are planted they increase their carbon stock over time, and when they are harvested much, but not all, of this carbon stock is removed and turned into products. Subsequent planting of forests results in carbon stocks increasing and then declining according to the harvest schedule, which results in a 'saw-toothed' emissions profile over time. This saw-toothed profile can have a large impact when measuring year on year changes in emissions. To reduce the variability this introduces to emissions accounting, an averaging approach only accounts for increases in carbon stocks up to the point they reach their long run average value (calculated as the average carbon stock over a period of 100 years), with subsequent changes in carbon stock assumed to cancel out over time.

both scenarios sequestration from existing forests linearly declines from current levels (about 25 Mt in 2015) to reach zero by 2029[38].

- New forests will result in further sequestration. The level and rate of sequestration from new forests is the result of complex species-specific interrelationships between location, climate, age, and forest management regime. For simplicity, the model does not take account of the full variety of factors. Instead, it assumes that sequestration is credited up to the point that new forests reach their long run average carbon stock.[39] These calculations assume radiata pine as the representative species, using sequestration rates and forest yields drawn from MPI[40]. The sequestration rate assumptions also take account of, and are consistent with, the patterns of product end-use and the spatial distribution of new plantations in the Resourceful scenario of the *Net Zero in New Zealand* report.
- The effect of a land use change from agriculture to forestry intuitively reduces the total farming stock of New Zealand, creating a reduction in GHG emissions from agriculture.
- The model calculates land use endogenously. Because there are rising marginal costs of land transitions, opportunities for land use changes will eventually be cut off.
- As forest emissions accounting is complex and challenging to capture in an economy wide model, the model is deliberately conservative regarding its approach to estimating sequestration from existing and new forestry, specifically:
  - Assumptions on sequestration from existing (pre-2015) forestry declines linearly from current levels to 2029, and provides no sequestration from 2030 onward.
  - Estimated sequestration rates for existing and new forestry are based on publicly available ETS look-up tables, which are conservative in sequestration from forestry.

- Renewable energy technology assumptions are expressed as the availability of the technology at a particular cost. The modelling assumes that in both scenarios, renewable energy technologies are available at the same cost across scenarios and that these decline at two percent per year. The extent of penetration is then determined by the model, except for hydropower, which is assumed to be capped at 5 TWh of resource availability, in line with the assumption made in the *Net Zero in New Zealand* report. In addition, the modelling assumes that there are general improvements in the energy productivity of the New Zealand economy of one percent per year.
- Uptake rates are determined by the model rather than by specific pathways. The model's default representation is that the technology assumptions are expressed as the availability of the technologies at a particular cost – with the actual uptake rates determined endogenously in the model depending on the policy assumptions. For example, a higher carbon price – possibly due to the exclusion of agriculture from the NZ ETS – will lead to a greater penetration of renewable power generation. Given the policy and technology assumptions, the model will calculate the lowest cost abatement path, in both scenarios.

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[38] This is calibrated to reflect the model's estimate of net sequestration from existing forests over the period 2015-2050.

[39] After accounting for harvested wood products, we estimate that each hectare of new forestry sequesters on average 415 tCO_2e over the long term with standard harvesting cycles. Reflecting the timeframe of the modelling exercise, we attribute this sequestration equally over a 35 year time period, using a representative sequestration rate of 11.9 tCO_2e/ha per year. This assumption is deliberately conservative and likely underestimates sequestration from new forest plantings in later periods of the modelling.

[40] New Zealand Ministry for Primary Industries. (2015a). *Look-up Tables for Forestry in the Emissions Trading Scheme.* New Zealand Ministry for Primary Industries. (2015b). *National Exotic Forest Description 2015: Yield Tables.*

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