WESTPAC NZ AGRIBUSINESS CLIMATE CHANGE REPORT

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LINCOLN UNIVERSITY

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TE WHARE WĀNAKA O AORAKI

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Executive Summary

Climate change is an increasingly important concern, both globally and in Aotearoa New Zealand. Changes are already being felt in the natural environment, the economy, and communities. The agricultural sector faces risks both from a changing climate, as well as through efforts to reduce its contribution to climate change through greenhouse gas (GHG) emissions.

This report presents the summarised findings of research commissioned by Westpac and carried out by the Agribusiness and Economics Research Unit (AERU) at Lincoln University (New Zealand), examining the physical and transition risks and opportunities presented by climate change to New Zealand's primary sector (focusing on dairy, sheep/beef, and horticulture) to the middle of the century, as well as the sector's vulnerabilities and potential actions to address the effects of climate change.

Physical risk from climate change arises from the interaction of the changing climate (the hazard), the exposure of the property or sector of interest, and its vulnerability.

Hazard: Aotearoa New Zealand can expect ongoing warming throughout the 21st century, as well as changes to extreme temperatures. Extreme warm temperatures and heatwaves are likely to be more common in the future, while extreme cold temperatures and frosts are likely to decrease. Rainfall patterns may change, with the west and south of Aotearoa New Zealand becoming wetter and the north and east of the North Island becoming drier. Some areas may not experience much change in total annual rainfall, but the times of the year when rainfall occurs may change (e.g. summers may become drier and winters may become wetter). The intensity of extreme rainfall is likely to increase in a warmer climate. Winds are also likely to increase across central New Zealand, particularly in winter.

The dairy sector may experience some benefits resulting from a potential increase in pasture growth and changing seasonality (providing sufficient changes in timing of operations to adjust to the changed seasonality). However, increased heat stress and the likely increases in extremes such as drought, mean that some regions are likely to experience challenges to their systems during the next 30 years.

The sheep and beef sector will experience similar changes to pasture growth as the dairy sector, however they are less able to rely on irrigation to cope with water variability and drought.

The effects in the horticulture and arable sectors are likely to be mixed depending on crop type and region. Changes to the growing season and seasonality will affect crop yields both positively and negatively, with some potential increases in quality, offset by decreased winter chilling and increased rainfall intensity and hail.

Vulnerability: Properties across the country will be affected in different ways by the same risks due to their differing physical characteristics and the social and economic circumstances of the farmers and growers. This reflects the vulnerability of the system.

Physical risks will affect farm profitability

Increasing frequency and intensity of extreme weather events alongside gradual shifts in temperature and rainfall will create disruption that may result in some farms becoming unprofitable without effective adaptations. Through four examples we demonstrate the implications of drought on farm profits for the dairy and sheep/beef sectors, and changing seasonality on kiwifruit production:

- A moderate drought could reduce the operating profit of a dairy system by almost 30 per cent
- One year of drought on sheep and beef systems would result in a mild reduction in profit, but a second year of drought could result in 46 per cent reduction in profit for an extensive North Island system
- A second consecutive year of drought could result in a reduction of almost 65 per cent in an intensive South Island Sheep/ Beef system
- Transitioning to other irrigated land-uses, such as pipfruit or viticulture production, would represent a 58 per cent decrease in per hectare gross margins for kiwifruit producers

Adaptation can reduce physical risk

Farmers and growers have a range of options available to reduce the risk and remain viable despite the changes already being experienced and those expected in future. While adaptation cannot eliminate climate risks, it can help to reduce their impact on farm systems, and as a result, support their long-term viability. Uncertainty regarding the precise nature of future changes can complicate decisions, so adaptation that is flexible is likely to be more resilient.

The majority of adaptations identified in this report are based on changes to the management of the system, with only a few requiring an initial investment of capital. However, management changes may require significant increases in labour and skills, so a key feature of supporting farmers to adapt to climate change will be in extension work and knowledge exchange.

The move to a low-carbon economy can create transition risks

Transition risks refer to both the governance and policy ('upstream') and market and trade access ('downstream') risks. Emerging government policy regarding primary sector GHG emissions means that farmers and growers in New Zealand will be required to reduce emissions from their production activities.

A range of GHG mitigation options are available to producers, including feed, pasture, stock and effluent management for pastoral producers, as well as crop and soil management and technology investment for all sectors. A further case study in this report shows that while a reduction in stocking rates can reduce GHG emissions as well as maintain profitability, it needs to be accompanied by an improvement in per animal productivity. As with adaptation to physical risk, management ability will be essential to ensure profitability is not lost.

New Zealand's 2030 methane reduction target of ten per cent below 2017 levels will be achievable with currently available mitigation options in existing systems. Achieving reductions above that will require a combination of improved technologies and land use change.

Conversion or diversification from pastoral to horticultural/arable production could lead to potentially significant decreases in GHG emissions and increases in farm profitability. Including trees on marginal land can also reduce emissions while generating other benefits (e.g. improved soil and water quality, increased biodiversity, natural flood management). More diverse systems are also likely to be more resilient to the physical risks from climate change.

New Zealand's agricultural producers may also face market and trade access risks from failing to decarbonise, although currently the country is a leader in beginning to regulate agricultural emissions.

Opportunities may arise from the transition to low-carbon agriculture in New Zealand, including:

1. Reduced on-farm production costs through resource efficiency and low-emission energy sources/ farming equipment;
2. Increased productivity through the adoption of climate smart farming techniques (e.g. precision agriculture);
3. Increased farm profitability through conversion/diversification of farming systems (e.g livestock conversion to cropping/arable; implementation of on-farm agroforestry systems);
4. Increased producer returns and improved competitive advantage through differentiating products to target shifting consumer preferences towards credence attributes in food;
5. Increased producer returns through a changing trade environment (e.g. better market access to existing markets and/ or access to new export markets);
6. Creating intellectual property and a competitive advantage through expertise from the transition of the agricultural sector to a low carbon industry;
7. Possible sector productivity opportunities from warmer temperatures, allowing for an extended growth season, faster maturation, more optimal growing environments for some crops and allowing new species to become viable;
8. Higher market prices resulting from climate-related disruption in global markets;

Farm management skills are critical in managing risks

Improved farm management practices and skills are critical for avoiding profit loss, for physical as well as transition risks. This is a key area for further investment, both in research for developing more detailed understanding of effective adaptation practices that will endure under a changing climate, as well as in the training of rural professionals and supporting extension programmes for farmers and growers.

A comprehensive understanding of the risks – including the wider determinants of vulnerability – is an important first step in addressing the physical risk from climate change. But understanding the options available to adapt to the risks, and developing comprehensive, locally specific, and achievable plans to implement adaptation will be essential to ensure a thriving agricultural sector into the future.

1 Introduction

Climate change represents a significant challenge to the success and sustainability of New Zealand's primary sector, which is both dependent on the climate for its productivity and contributes to emissions of greenhouse gases (GHG). The effects of climate change are likely to disrupt New Zealand's primary sector, making it increasingly difficult for agricultural operators to continue without adjustments to their production systems. This is what is referred to in this report as *physical risk*.

Agricultural production also sits within New Zealand's legislation and policy. In addition to New Zealand's nationally determined contribution (NDC) to the Paris Agreement of 50 per cent reduction below 2005 levels by 2030, the Climate Change Response (Zero Carbon) Amendment Act 2019 sets targets to:

- Reduce all GHGs (except biogenic methane) to net zero by 2050;
- Reduce emissions of biogenic methane by 10 per cent below 2017 levels by 2030 and between 24-47 per cent below 2017 levels by 2050.

Agriculture makes up 48 per cent of New Zealand's GHG emissions, and will be required to achieve emissions reductions in line with these targets. Aotearoa New Zealand has taken the approach of pricing emissions to achieve these changes, and the Government will report at the end of 2022 on how agricultural emissions will be priced in future.

The Task Force on Climate-Related Financial Disclosures (TCFD) has recommended the identification and disclosure of climate related financial risks – including the physical risks arising from a changing climate, and the risks associated with transitioning to a low carbon economy, as well as any potential opportunities. Aotearoa New Zealand is in the process of introducing the Financial Sector (Climate-related Disclosures and Other Matters) Amendment Bill to broaden non-financial reporting by requiring and supporting the making of climate-related disclosures.

This report presents the summarised findings of research commissioned by Westpac and carried out by the Agribusiness and Economics Research Unit (AERU) at Lincoln University (New Zealand) examining the risks and opportunities presented by climate change to New Zealand's primary sector, as well as the sector's vulnerabilities and potential actions to address the effects of climate change.

In summary, climate change presents two main kinds of risks to New Zealand's primary sector as illustrated in Figure 1. Together, these risks may lead to declining profitability for the agricultural sector, as well as reduced well-being for farmers and growers, without changes to current practices.

This report focuses primarily on the farm-level risks and opportunities. Climate change can also create risks and opportunities through the supply chain, and at a sectoral and industry level as well. These risks are not considered in this report. The time period considered in this analysis is out to 2050.

Figure 1 Physical and transition risks arising from climate change

This report proceeds in Section 2 by identifying physical risk through the lenses of hazard, exposure and vulnerability. Case studies of the effects of selected climate impacts on farm profitability are provided, as well as a discussion of adaptation options and processes to avoid or reduce the risks. Transition risks are identified and discussed in Section 3, including a case study of a farm in Southland, examining a series of mitigation options and their effect on farm profits and GHG emissions. Opportunities are discussed in Section 4, and Section 5 concludes.

2 Physical Risks

2.1 Defining climate change risk

Risk in the context of a changing climate refers to much more than the climate hazards alone. Figure 2 illustrates the risk analysis framework first proposed by the Intergovernmental Panel on Climate Change (IPCC) in 2014 and still widely used. Risk is defined as the intersection of hazards, exposure and vulnerability, and this is the approach taken in this report.

Climate-related hazards include physical events or trends, such as drought or seasonal climate changes. Exposure measures the extent to which people, assets or taonga might experience the hazard (proximity to a river, for example). Vulnerability is embedded within the political, economic, environmental and social context, and includes both the sensitivity of the system to the climate hazard as well as the capacity to adapt. Recognising the multiple components of risk is critical for making an informed risk assessment. In this report we review the available hazard, exposure and vulnerability evidence for the main risks of climate change facing New Zealand.

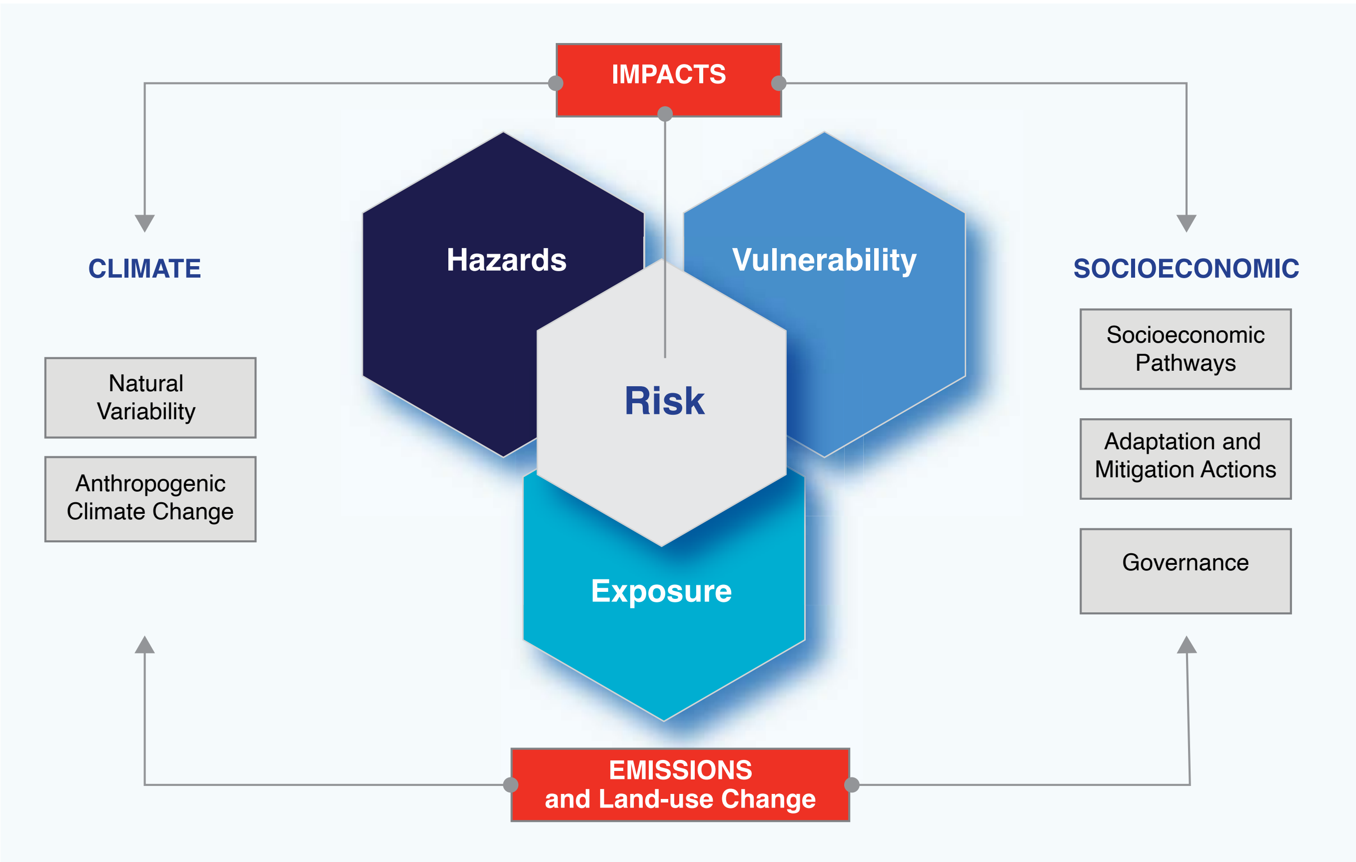

Figure 2 Physical climate change risk as a function of hazard, exposure and vulnerability. Adapted from IPCC (2014).

2.2 Understanding hazards

2.2.1 Climate projections

Our understanding of what a changing climate will look like in Aotearoa New Zealand is informed by internationally developed climate projections. Currently the outputs from a selection of six General Circulation Models (GCMs) out of an ensemble of 41 that were used in the IPCC Fifth Assessment Report (CMIP5) are used. These will be updated over the coming years based on the latest models from the Sixth Assessment Report (CMIP6), and an Aotearoa New Zealand specific Earth System Model, but the analysis in this report uses the CMIP5 data. The outputs are downscaled to provide projections specific for Aotearoa New Zealand[1]. Four Representative Concentration Pathways (RCPs) provide pathways of future emissions concentrations and climate warming by 2100. As the period of focus for this report is mid-Century, the choice of RCP is less critical as the difference between RCPs only begin to increase after 2040.

New Zealand's primary sector faces risks from both:

- Gradual and seasonal change – risks presented by gradual changes in climate important for agricultural production, (e.g. temperature and rainfall) and changes to seasonality (e.g. earlier warming).
- Climate extremes – risks to agricultural production presented by increases in the frequency and intensity of extreme events, (e.g. droughts and floods).

2.2.2 Projected impacts

Risks to land-based primary sector productivity were identified as a priority risk in New Zealand's first National Climate Change Risk Assessment (NCCRA)[2]. These were due to changing precipitation and water availability, temperature, seasonality, climate extremes and the distribution of invasive species.

The main Aotearoa New Zealand primary sectors are likely to experience different impacts from climate change:

Dairy

Increased heat stress and likely increases in extremes such as drought mean that some regions are likely to experience challenges to their systems during the next 30 years. The sector may experience some benefits from a potential increase in pasture growth and changing seasonality (providing sufficient changes in timing of operations to adjust to the changed seasonality). While irrigation water supply is not projected to decline in currently irrigated areas over the next 30 years and may sustain dairy farming during this period, farmers would be wise to consider the projected changes beyond 2050 when making plans for the future.

Sheep and beef

The sheep and beef sector will experience similar changes to pasture growth as the dairy sector, however the sheep and beef sector are less able to rely on irrigation to cope with water variability and drought. Furthermore, the location of many sheep and beef enterprises on steep slopes means they are sensitive to the impacts of heavy rain and increased erosion, resulting in increased land degradation and the loss of productive land. Increases in animal diseases such as facial eczema are also a concern for the sheep and beef sector over the next 30 years.

[1] MfE. (2018). Climate Change Projections for New Zealand. Ministry for the Environment https://environment.govt.nz/publications/climate-change-projections-for-new-zealand/

[2] Ministry for the Environment (MfE) (2020). National Climate Change Risk Assessment for Aotearoa New Zealand. ArotakengaTūraru mō te Huringa Āhurangi o Aotearoa: Pūrongo whakatōpū. Wellington: Ministry for the Environment

Horticulture and arable

The effects in the horticulture and arable sectors are expected to be mixed depending on crop type and region. Changes to the growing season and seasonality will affect crop yields both positively and negatively. Decreased winter chilling will have negative effects on the kiwifruit and viticulture sectors. Increased rainfall intensity and hail can damage crops and waterlog the soil. However, reductions in rainfall can benefit the quality of fruit such as grapes and kiwifruit, depending on the timing of occurrence during the growing cycle. Overall, some regions may lose their current advantage for certain crops (e.g. kiwifruit in Bay of Plenty) but other regions may gain through increased suitability (e.g. kiwifruit in regions such as Waikato, Canterbury and Central Otago). These changes in suitability will intensify later in the century.

2.3 Exposure

Agriculture is highly exposed to a range of climatic hazards through direct impacts to animals, vegetation, and capital assets, as well as indirect impacts to the vast range of interdependent infrastructure, such as electrical networks and water supplies. This exposure means that agricultural properties are extremely vulnerable to the influence of climate change on stressors such as temperature, humidity, soil evapotranspiration, sea-level rise (SLR), and flood severity and frequency.

Agricultural systems are highly exposed to coastal flooding, particularly under a changing climate. The frequency and severity of extreme sea-level rise (ESL) events and associated flooding is increasing globally due to climate change-driven variations in meteorological systems and relative SLR.

Flooding is currently the most frequently occurring and costly hazard in Aotearoa New Zealand, with agricultural activities often concentrated in floodplains. Therefore, it is important to consider the location of these floodplains in any agricultural exposure assessment. Additionally, climate change is projected to increase both the frequency and severity of flood events through rising precipitation intensity coupled with more significant periods of drought increasing runoff.

In addition to coastal and riverine flooding, gradual changes to climatic variables such as temperature and rainfall will also vary across Aotearoa New Zealand. Regions will experience different seasonal patterns, rates and even direction of changes – some regions may experience increases in rainfall while others may experience less rainfall than they would have without climate change. The projected change across regions are also provided in the NCCRA[2]. This variability in climatic changes across the country will have important implications for agriculture, for example through its differentiated effect on pasture growth and persistence, heat stress and pest and diseases.

2.4 Vulnerability

Properties across Aotearoa New Zealand will be affected in different ways by the same risks due to their differing physical characteristics – sometimes referred to as their sensitivity to the hazard. More broadly, vulnerability is determined by a much wider range of factors, all of which can affect the ability of the farmer or grower to adapt to the hazard (adaptive capacity). Together, sensitivity and adaptive capacity make up the vulnerability of the system to the hazard (illustrated in Figure 3), and more detail is provided in Appendix 1.

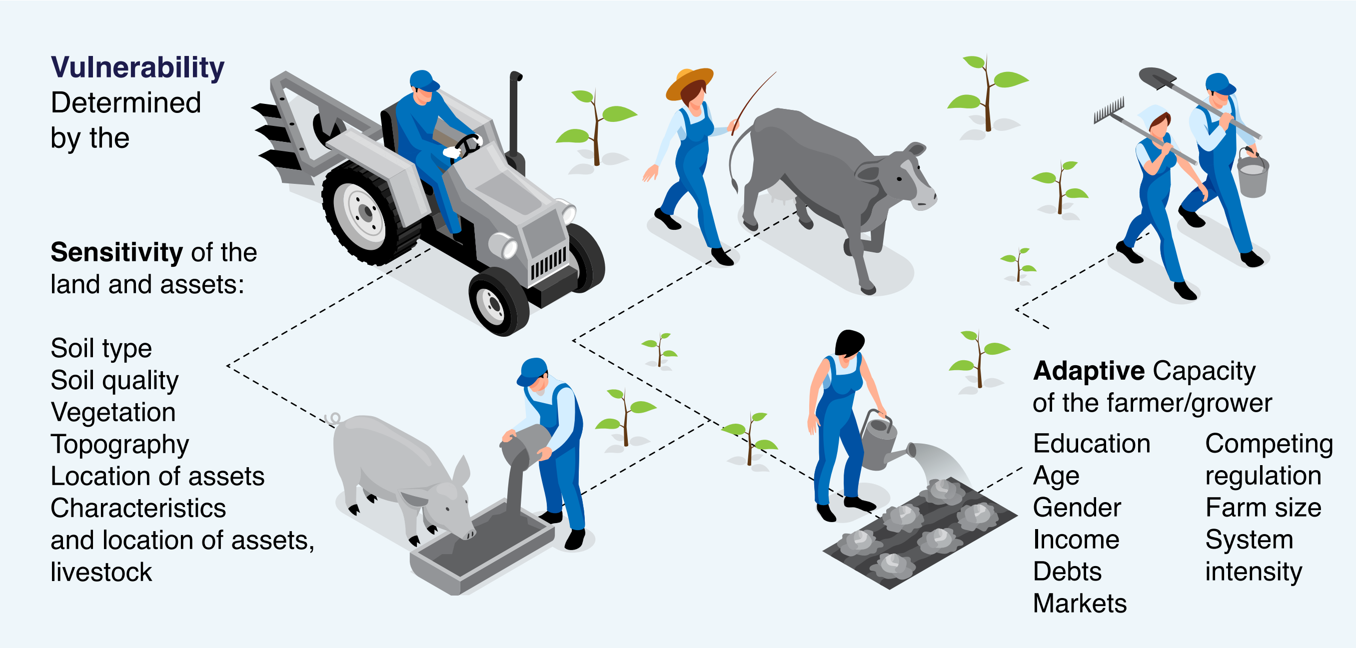

Figure 3 Determinants of vulnerability

2.5 Case Studies – physical risks

In this section we present a series of case studies assessing the financial impact of drought on different production system types and regions in New Zealand, and the impact of changing climate suitability on kiwifruit production in the Bay of Plenty. The case studies are summarised in Table 1, and more detail on the methods used in each is provided within each section.

Table 1 Summary of case studies

	Case	Farm System	Region	Climate change hazard
Physical Risk	1	Dairy	Canterbury	Drought
	2	Sheep & Beef extensive	North Island	Drought
	3	Sheep & Beef finishing	South Island	Drought
	4	Kiwifruit	Bay of Plenty	Changing climate suitability

Case study 1: Region – Canterbury
Climate hazard – drought

This case study examines the potential on-farm financial impact of a drought in the Canterbury region.

Modelling assumptions:

1. Average Canterbury dairy farm, based on the 2019/20 Dairy Statistics and DairyNZ economic data, set up in Farmax[3].
2. 3 scenarios were developed: (1) base no changes, (2) moderate drought, (3) severe drought.
3. The farm is irrigated and water availability will not be limited in the time period under consideration.
4. High temperatures experienced as a result of the drought still have a detrimental effect on farm productivity and profitability due to:
   - Heat stress in animals. High temperatures (>25°C) will induce heat stress in dairy animals, exacerbated if also accompanied by high humidity.
   - Reduction in pasture growth (from Heat stress), in base 16 tonnes DM/ha; Moderate drought 14.2 tonnes DM/ha; severe drought 12.9 tonnes DM/ha.

Further, these adjustments/assumptions were made to pasture growth within Farmax, with the aim of maintaining milk production as much as possible.

Table 2 Assumptions – Canterbury dairy system drought

Scenario	Moderate drought	Severe drought
Feed	Additional feed bought in; 200 tonnes DM baleage, 20 tonnes barley	Additional feed bought in; 300 tonnes DM baleage, 30 tonnes barley
Cull cows	Cull cows were sent off the farm early – January/February, as the farm dried out	Cull cows were sent off the farm early – December/February, as the farm dried out
Cows	Cows were dried off 2.5 weeks earlier than normal and sent out for grazing	Cows were dried off 3 weeks early (1 May) and sent out to graze
Extra feed cost	Additional feed cost = $79,000, additional grazing cost = $36,571	Additional feed cost = $118,500, additional grazing cost = $45,714

[3] FARMAX is commercial farm modelling tool for pastoral farmers initially developed by AgResearch. The model allows pastoral farm set up and the modelling of physical and financial changes in system scenarios.

Table 3 Impact of Drought on Canterbury dairy farm

	Cows	Cows/ ha	kg MS Total	kg MS/ ha	kg MS/ cow	Operating Profit ($/ha)	% Difference	GHG TCO_2e/ ha)	% Difference
Base	809	3.4	349,135	1,498	439	$5,395		13.1	
Moderate Drought	809	3.4	315,556	1,354	397	$3,811	-29.4%	12.2	-6.9%
Severe Drought	809	3.4	292,515	1,255	368	$3,084	-42.8%	11.8	-9.9%

Despite the assumption of irrigation for dairy systems in the Canterbury region, the effect of even a moderate drought could have a large effect on the operating profit of the dairy system of almost 30 per cent, and a severe drought could reduce operating profit of over 42 per cent during a drought year. As the IPCC has stated that droughts are likely to increase in severity and intensity under climate change, this is potentially concerning for the sector. For non-irrigated systems the effects of drought are likely to be even more severe.

Even a moderate drought could have a large effect on the dairy system operating profit (almost 30 per cent), and a severe drought could reduce operating profit of over 42 per cent. With the knowledge that droughts are likely to increase in severity and intensity under climate change, this is potentially concerning for the sector. For non-irrigated systems the effects of drought are likely to be even more severe.

Case study 2: Region – North Island Hill Country systems Climate hazard: drought

The models for both sheep/beef systems were constructed using the statistics from the Beef+Lamb New Zealand's economic survey[4]. The drought conditions used in these models are broadly based on the impacts of the 1997/98 El Niño drought on Sheep and Beef operations (Forbes, 1998) extrapolated over two years, with a third year showing the recovery period due to additional stock sold during the drought years. This farm is assumed to run breeding ewes and breeding cows, finishing most stock (although a proportion is sold to store). The scenario modelled here is for a drought that continues over two years, before returning to normal conditions in the third year.

The model was split into three blocks:

1. Steep (44.5 per cent); pasture production level: 4.6T DM/ha/year.
2. Rolling (45 per cent); pasture production level: 7.6 TDM/ha/year.
3. Flat (10.5 per cent), pasture production level: 10.9 T DM/ha/year.

[4] https://beeflambnz.com/data-tools/sheep-beeffarm-survey

For the drought impact, pasture production was reduced by the following rates:

Table 4 percentage of pasture reduction due to drought

Dec	Jan	Feb	Mar	Apr
10%	20%	40%	40%	10%

Results from the two years of drought are presented in Table 5. While they show a reduction in just over 10 per cent profit in the first year, in the second year profits show a dramatic decrease of almost 46 per cent. Even following a "normal" year in year 3, operating profit is still 16 per cent lower than the base year. This illustrates the potentially devastating effect that consecutive drought years can have on systems like Sheep and Beef, where farmers are unlikely to be able to provide significant supplementary feed (in comparison with a dairy system). This kind of event is likely to take four to five years to recover from, and in a future where droughts may occur more frequently, another drought could occur just as the farm is beginning to recover.

We note that these figures are based on current meat schedule prices that are higher than previous years, so the absolute values may be higher than average, but the relative changes would remain similar.

Table 5 Drought impacts- North Island hill country

	Open Brdng Ewes	Open Brdng Cows	% Sheep	SU/ha	Lamb %	Calving %	Operating Profit ($/ha)	% Difference	GHG (T CO_2e/ha)	% Difference
Base	1,680	194	48	9.6	130	82	$196		3.5	
Year 1 Drought	1,680	194	48	9.6	130	82	$176	-10.2%	3.3	-6.9%
Year 2 Drought	1,530	194	45	8.7	123	80	$106	-45.9%	3.2	-8.9%
Year 3	1,530	194	46	9.2	126	82	$164	-16.3%	3.4	-3.7%

Case study 3: Region – South Island intensive finishing system Climate hazard – drought

This case study looks at the impact of drought on a South Island Intensive Finishing sheep and beef operation (B+L Class 7). This was modelled as one block, producing a total of 8.8 T DM/ha/year, on an effective area of 258ha. The proportional reduction in pasture growth was the same as described above for the North Island extensive system (see Table 5 – refer to the above table on Pasture Reduction due to Drought).

The effect of these droughts on operating profit is presented in Table 6. This presents an even greater loss to operating profit than the North Island extensive system. Again, while the effect after the first year is 31 per cent below the base scenario, the effect on operating profit after the second year of drought is almost 65 per cent. After one "normal" year in year 3, operating profits are still 20 per cent below the base situation, and again this type of drought would take four to five years before profits return to normal. Both droughts result in an associated reduction in GHG emissions as a result of the reduction in animals. But as the stock are lighter, the emissions per unit of product will be higher than in the base year.

Table 6 Drought impacts- South Island intensive

	Open Brdng Ewes	Open Cattle	% Sheep	SU/ha	% Lamb	Operating Profit ($/ha)	% Difference	GHG (T CO_2e/ha)	% Difference
Base	2,554	93	91	13.5	137	$1,140		4.9	
Year 1 Drought	2,554	93	90	12.7	137	$782	-31.4%	4.6	-6.3%
Year 2 Drought	2,427	93	89	11.7	128	$400	-64.9%	4.3	-12.5%
Year 3	2,427	93	91	13.5	134	$912	-20.0%	4.9	0.0%

This analysis underscores the need for effective adaptation to ensure the viability of sheep and beef systems in drought-prone regions. In some cases, adaptation may mean diversification and possible land-use change.

Case study 4: Product – Kiwifruit I Region – Bay of Plenty Climate hazard – changing climatic conditions

Higher winter temperature may affect the feasibility of growing green varieties of kiwifruit in the Bay of Plenty areas by 2050. While transitioning to gold is climatically feasible, Zespri, the holders of the licence to the variety, regulate the supply of licences, meaning a wholesale transition from green to gold for growers in the region is unlikely.

There are currently few alternative and equally high-value land-uses identified for green kiwifruit producers if gold licences are unavailable. Kiwifruit is the highest performing land use type in terms of gross margin per hectare, outperforming pipfruit and viticulture by over $15,000 per hectare, and avocados by over $22,000 per hectare. Transitioning to other irrigated land-uses, such as pipfruit or viticulture production, would represent a 58 per cent decrease in per hectare gross margins for kiwifruit producers. However growers are already exploring and implementing ways to adapt and maintain production in a changing climate, and there may also be opportunities for green kiwifruit production to move to new locations, depending on irrigation and land-use constraints.

2.6 Adaptation

Adaptation to climate change broadly means "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities"[5]. Adaptation is critical for the final assessment of climate change risk. If adaptations are available and farmers and growers have the adaptive capacity to implement them, then it may be possible to effectively minimise the risk. Farmers and growers are constantly innovating and adapting to changing conditions, whether they are driven by the market, regulations, or in this case, the climate. It is essential that adaptation is considered as part of a climate change risk assessment.

Adaptation is a continual process and requires consideration of the wider effects and over time. A narrow focus on the immediate risk within the system can lead to unintended consequences (also known as maladaptation) on other considerations and over time. In the context of climate change, the interactions between adapting to the physical risk and transitioning to low emissions systems are particularly important.

Uncertainty regarding the precise nature of future changes can complicate decisions that need to be made now, so adaptation that is robust across a range of climates is likely to be more resilient. This means aiming for:

- Flexibility
- Generating co-benefits with other aims (such as mitigation, or water quality).
- Avoiding irreversible decisions or decisions that close off other options.

Farmers and growers may have different goals from adaptation. Some may want to preserve the current system as it is as much as possible, while others may think about shifting to a different system, or at least introducing aspects of other systems into their current one. Farmers' and growers' goals may change over time and probably will as climate impacts intensify (and they face increasing other pressures). Their goals may also be constrained or influenced by circumstances beyond their own properties and by the actions of other groups, including the wider industry they operate in, or regulations. For the most part, the adaptations identified in this report assume that farmers and growers are aiming to continue with their current systems, although many may be considering changing land use, at least partially.

[5] IPCC, 2022: Annex II: Glossary [Möller, V., R. van Diemen, J.B.R. Matthews, C. Méndez, S. Semenov, J.S. Fuglestvedt, A. Reisinger (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2897–2930, doi:10.1017/9781009325844.02

Farmers and growers can adapt both in advance of the impacts occurring, or after changes have happened. Generally adaptation that occurs in advance and considers longer time frames and wider effects will be more effective than adaptation that occurs reactively after an extreme event. Reactive adaptation may focus on returning to "normal" as quickly as possible without thinking about the future changes to climate and whether a change in the system would build greater resilience over time.

It can also be helpful to think of adaptation in the short, medium and long-term (or against levels of warming and impacts). Adaptations for the short term may help with building resilience to the current climate, generate win-wins across different areas (for example, in also reducing emissions, improving biodiversity, or improving soil health). These are changes that are low-regret options and will benefit the farm regardless of how the climate changes into the future.

Adaptations for the medium term should focus on ensuring that decisions made now consider future climates (e.g. moving into different crops or investing in water storage). This also includes thinking about the future climate for any decision, to avoid stranded-assets or being locked into a system that will not be suitable in future climates.

Considering the long term (beyond mid-century) may focus more on planning, monitoring and gathering information to prepare for future changes. This is likely to be less of a consideration for individual farmers and more for industry and government.

Adaptation approaches to address specific climate risks are summarised in Table 7 for livestock and Table 8 for horticultural systems. The table also identifies whether the changes relate to changes in management, technological adoption or infrastructure investment.

Table 7 Summarised adaptation options for main climate risks (livestock)

	Management	Technology	Infrastructure
Changing seasonality and average conditions	Increase diversity of pasture Pasture and grazing management Change timing of operations Adjust stocking rate	Adopt new varieties	
Drought	Water demand management Reduce stocking rate Supplementary feed Feed import Feed storage Soil management		Water collection and storage Irrigation
Heat stress	Shade and shelter Water and cooling Diet Changing timing of operations	Genetic selection	Animal housing
Heavy rainfall, flooding, storms	Planning Soil management and improved drainage		Shelter Natural Flood Management
Pests and diseases	Livestock management Stocking rate Grazing management		

Table 8 Summarised adaptation options for main climate risks (horticulture)

Climate impact	Adaptation Options			Type	Co-benefits/ trade-offs
	Apples	Grapes	Kiwifruit		
Changing seasonality and average conditions	Winter pruning	Winter pruning	Winter pruning	Management	
	Summer pruning	Summer pruning	Summer pruning	Management	
	Change in timing	Change in timing	Change in timing	Management	
	Sunburn protection		Girdling	Management/ Infrastructure	
	Shade trees	Shade trees	Shade trees	Management	Biodiversity, soil health, natural flood management, GHG mitigation
	Soil management	Soil management	Soil management	Management	Productivity, soil health
Drought	Irrigation	Irrigation	Irrigation	Infrastructure	Potential environmental and social trade-offs
	Enhanced irrigation management	Enhanced irrigation management	Enhanced irrigation management	Management	Ecological
Hail, storms	Over-vine netting	Over-vine netting	Over-vine netting	Infrastructure	Trade-off - waste
	Covered enclosures	Covered enclosures	Covered enclosures	Infrastructure	
	Insurance	Insurance	Insurance	Infrastructure/ Management	
Multiple	Diversification	Diversification	Diversification	Management	

The majority of the adaptations are based on changes to the management of the system, with only a few requiring an initial investment of capital. However, the management changes may require significant increases in labour and skills, so a key feature of supporting farmers to adapt to climate change will be in extension work and knowledge exchange.

While adaptation cannot eliminate climate risks, it can help to reduce their impact on farm or orchard systems, thereby critically influencing the long-term viability. Incremental adaptations that focus on maintaining what is currently the core function of the system may reach the limits of their effectiveness as global temperatures increase and climate impacts intensify. At some stage, farmers and growers may begin to consider transforming to a different type of system. This may be a wholescale shift from dairy to an arable system, for example. Or it may be more gradual and focus on diversifying some parts of the farm, while maintaining some of the original system. This will depend on the extent of the climate impacts, the characteristics of the farm, and the personal circumstances of the farmer.

As Aotearoa New Zealand is a long and narrow country, there is some scope for spatial adaptation – that is, shifting production from one region to another as the climate suitability changes. Regional specialisation has evolved based on a combination of climatic as well as biophysical factors, including geology and soil type, so it may be more complex than shifting production southwards. However, there may be potential opportunities to shift production as well as try new crops that have until now not been able to be grown in New Zealand.

Given the uncertainty of future climate change, making a transformative change in advance of observed impacts may be a risky strategy. However, it is possible and more robust to begin identifying potential options for the future; what would trigger a shift to these options; and putting plans or finance in place so that those options can be implemented when the time comes.

This approach forms the basis of what is known as dynamic adaptive pathways, and has been implemented mostly in the Netherlands in anticipation of sea-level rise, but is becoming more widely used in other countries and contexts.

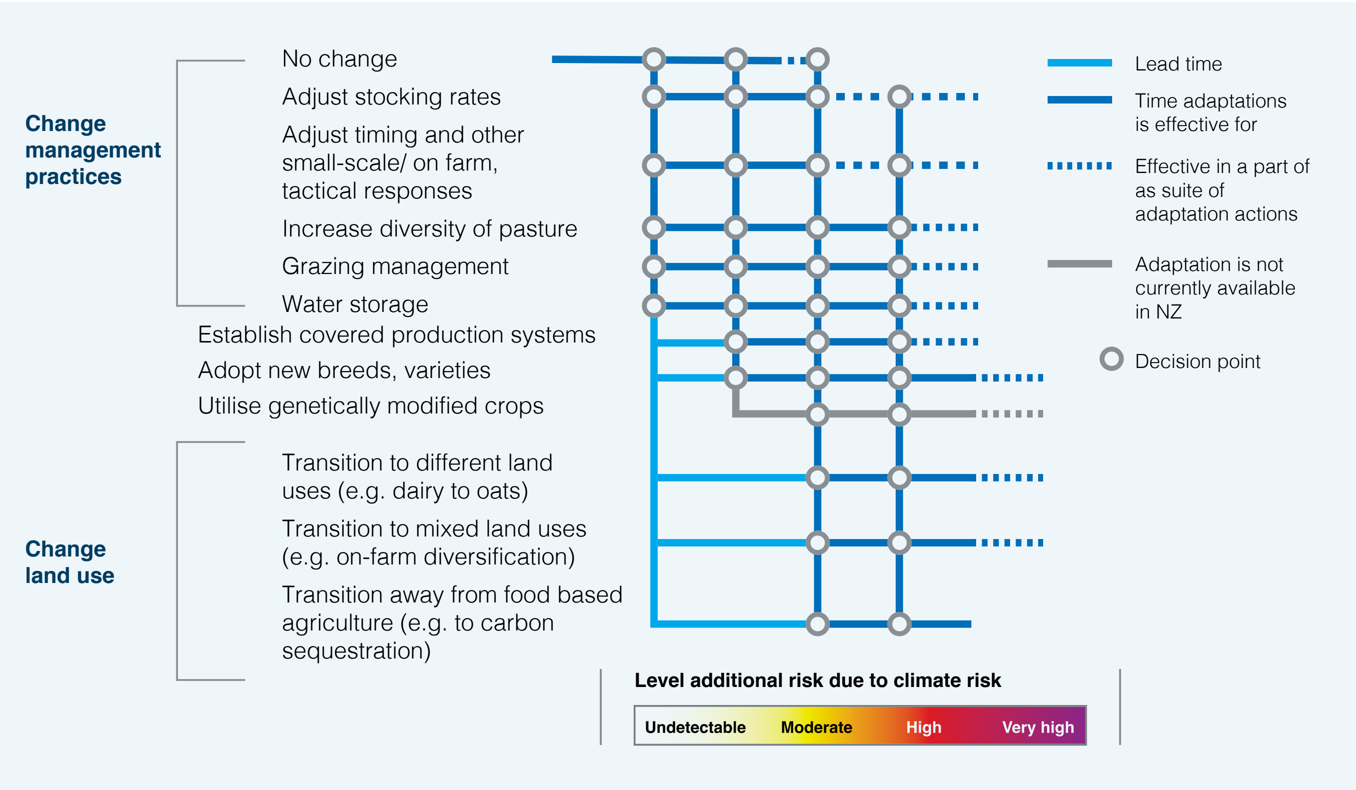

Figure 4 Stylised adaptation pathway for a pastoral system. Adapted from Cradock-Henry et al. (2020)[6]

[6] Cradock-Henry, N. A., Blackett, P., Hall, M., Johnstone, P., Teixeira, E., & Wreford, A. (2020). Climate adaptation pathways for agriculture: Insights from a participatory process. Environmental Science and Policy, 107, 66–79. https://doi.org/10.1016/j.envsci.2020.02.020

Figure 4 illustrates a conceptual pathway identification process for a pastoral system. It illustrates adjustments to the status quo and best management practices at the top that may be sufficient in the short term. Moving down the figure, the actions become more transformative, including transition to mixed land-uses and away from food production altogether at the bottom. The circles represent decision-points, when the farmer may decide to move from one option to another. The solid darker blue line indicates for how long the adaptation may be effective for (against the levels of risk illustrated along the bottom of the figure). The dashed blue line indicates adaptations that may retain some effectiveness in conjunction with other adaptations. The solid light blue line represents a lead-in time, where farmers will not begin implementing the option, but will need to investigate and put in place actions so they are able to implement it when necessary.

Adaptation is critical for the final assessment of climate change risk. But some adaptations will reach limits to their effectiveness. So while adaptation options exist for most of the climate risks identified, there will come a time at which the current adaptations are no longer effective. Insufficient evidence currently exists for understanding the lifetime of possible adaptation strategies in Aotearoa New Zealand agriculture, but in general as the climate changes intensify, more transformative changes will be required.

The limits to adaptation reinforce the critical importance and urgency of reducing greenhouse gas emissions. Every part of a degree of avoided warming will mean slightly less intense and rapid changes. The difference between keeping warming below 1.5 degrees and going beyond can mean the difference between our current range of experience and adaptation, and moving into unchartered territory. Emissions reduction and transition risks are described and discussed in the following section.

3 Transition Risks

Transition risks in agriculture occur as part of the response to addressing the causes of climate change: the requirement and processes to reduce greenhouse gas (GHG) emissions produced as a result of agricultural activities. In this report we have separated these transition risks into upstream and downstream risks:

- Upstream – those imposed on agricultural operators that directly affect their activities – these often emerge from government policy (e.g pricing mechanisms for New Zealand's agricultural emissions)
- Downstream – those that affect agricultural operators' bottom lines beyond the farm gate – these emerge from market trends (e.g. international consumer shifts away from products with perceived higher GHG emissions) and potential trade access risks (e.g. countries placing restrictions on the import of products with particular GHG emission profiles)

3.1 Upstream risks – greenhouse gas emission reductions

Agriculture was responsible for 48 per cent of New Zealand's greenhouse gas emissions in 2019. A significant majority of these emissions (35.2 per cent of total net emissions, and 73.1 per cent total net agricultural emissions) are biogenic emissions, mostly methane from enteric fermentation (the digestive process of ruminant livestock that breaks down plant matter in the digestive tract under anaerobic conditions), but also from agricultural soils and manure management practices. Nearly half of all New Zealand's agricultural enteric fermentation emissions are from dairy cattle (48.4 per cent in 2019), followed by sheep (29.4 per cent in 2019) and non-dairy beef cattle (20.3 per cent in 2019), with less than two per cent combined emissions from deer and minor livestock. Horticultural emissions comprise approximately less than three per cent of New Zealand's biological emissions.

Under the Climate Change Response (Zero Carbon) Amendment Act 2019 Aotearoa New Zealand must meet the following targets:

- Reduce all GHGs (except biogenic methane) to net zero by 2050
- Reduce emissions of biogenic methane by 10 per cent below 2017 levels by 2030 and between 24-47 per cent below 2017 levels by 2050

Although emissions reductions for most of New Zealand's economic sectors are managed through the New Zealand Emissions Trading Scheme (NZETS), agriculture is not currently part of this. The New Zealand government is currently consulting on what an alternative pricing system for agricultural emissions outside of the NZETS would look like. The New Zealand Climate Change Commission has advised that the best approach to pricing agricultural emissions would be a detailed farm-level pricing system outside the NZETS. This system would be best able to recognise and reward the choices farmers make to reduce their gross emissions in line with the statutory targets. The structure and rules of the pricing mechanism will be important in determining what and how on-farm emissions reductions are rewarded, and the impacts will differ between land-uses.

A range of methods for reducing emissions by farm system and location exist, although they vary in their cost and GHG mitigation potential, and depend on several factors, including farm type, farm size, geographical location, capital availability and the managerial skills of the farmer/grower.

On-farm GHG emissions reduction methods are summarised in Table 9 and grouped into six main categories:

Table 9 Summary of on-farm emissions reduction options

CATEGORY	IMPORTANCE
Feed Management: Adjustments to the frequency and methods of feed type and distribution to animals used within the production system.	As biogenic methane emissions from livestock production are mostly generated through feed types or practices, and there is a direct relationship between food consumed and methane emitted, methods for reducing feed intake can greatly reduce biogenic GHG emissions on-farm.
Pasture, Crop and Soil Management: Adjustments to the growth, rotation and selection of pasture and/or crops within the production system, as well as the application of fertilisers.	The application of different pasture and crop management approaches in the context of New Zealand pastoral production systems can be effective in reducing GHG emissions. However, improvements in pasture and crop production in a pastoral context will only reduce emissions if combined with reduction in total feed consumed on-farm.
Stock Management: Adjustments to stocking rates, productivity, production methods in relation to, as well as the performance and health of, animals used in production systems.	The application of different stock management approaches in the context of New Zealand pastoral production can be effective in reducing GHG emissions.
Effluent Management: Adjustments to methods for capturing, managing and applying effluents from animals used in production systems.	The application of different effluent management approaches in the context of New Zealand pastoral production can be effective in reducing GHG emissions.
Technology Investment: Management decisions relating to the purchase, use and innovation of different forms of technology within the production system.	Investment in and use of existing and novel technologies in the context of New Zealand pastoral production can be effective in reducing GHG emissions. However, many proposed technologies (such as methane vaccines and inhibitors) are not currently commercially available, and may be prohibitively expensive.
Sequestration: Actions and methods for capturing and/or utilising GHG emissions on-farm.	The establishment and use of a number of GHG emissions sequestration activities in the context of New Zealand agricultural production can be effective in capturing, utilising, and thereby reducing, GHG emissions. Increased forestry is the most effective method for sequestering farm emissions – however, this should be considered in relation to potential decreases in profitability in different farming systems.

Extensive analysis has been carried out elsewhere assessing the implications on profit and emissions of different mitigation measures on a range of systems across the country[7]. In this report we provide a case study examining the implications on both profitability and GHG emissions from a range of emissions reduction strategies on a relatively intensive dairy farm in Southland (focused primarily on de-intensification).

[7] Biological Emissions Research Group (BERG) (2018). Report of the Biological Emissions Reference Group (BERG). from https://www.mpi.govt.nz/dmsdocument/32125/direct.
Journeaux, P. and Kingi, T. (2019). Farm Systems Modelling for GHG Reduction on Multiple Enterprise Māori Farms. AgFirst Report prepared for NZAGRC, June 2019. https://www.nzagrc.org.nz/assets/Publications/NZAGRC-Report-Modelling-GHG-Mitigations-on-Multiple-Enterprise-Maori-Farms.pdf.
Journeaux, P. and Kingi, T. (2020a). Mitigation of On-Farm Greenhouse Gas Emissions. In: Nutrient Management in Farmed Landscapes (Ed. C.L. Christensen). http://flrc.massey.ac.nz/publications.html Occasional Report No. 33, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.
Journeaux, P. and Kingi, T. (2020b). Farm Systems Modelling for GHG Reduction on Māori Owned Farms: Achieving the Zero-Carbon Targets. AgFirst Report prepared for NZAGRC, April 2020. https://www.agfirst.co.nz/wp-content/uploads/2020/09/Achieving-Zero-Carbon-Act-Reduction-Targets-on-Farm-AGF.pdf.
Reisinger, A., Clark, H., Journeaux, P., Clark, D. and Lambert, G. (2017). On-farm options to reduce agricultural GHG emissions in New Zealand. New Zealand Agricultural Greenhouse Gas Research Centre. https://ourlandandwater.nz/wp-content/uploads/2019/03/BERG-Current-mitigaiton-potential-FINAL.pdf

3.1.1 Case study 5: Dairy farm emissions reduction through de-intensification

Eight mitigation scenarios were developed including a base scenario; these ranged from reducing stocking rate and supplementary feed, stopping the application of N fertiliser and converting some farmland to forestry.

The key drivers of on-farm biological GHG emissions are:

1. Amount of dry matter (DM) eaten. There is a direct correlation between methane (CH_4) emissions and DM eaten, and a strong correlation with nitrous oxide (N_2O) emissions.
2. Amount of protein in the diet. This is a strong driver of nitrous oxide emissions, with lower protein supplements reducing nitrous oxide emissions.
3. Amount of nitrogen fertiliser used. Nitrogen fertiliser is largely used to increase DM production on-farm, resulting in more being eaten – see point (i). It also results in direct N_2O and carbon dioxide (CO_2) emissions.

Table 10 shows the modelling results. Reducing stocking rate and improving per cow performance show an improvement in farm profitability, and a reduction in GHG emissions. The reduction in cow numbers reduces DM consumption, with the increase in per cow production increasing DM consumption – in essence, the overall reduction in GHG emissions is largely due to no longer carrying the maintenance feed requirements for additional cows. This scenario is also predicated on an improvement in farm management, particularly grazing management; at a lower stocking rate it becomes even more important to maintain pasture quality. If this is not achieved, then production will drop. Caution is therefore required with this scenario – it is likely that many farmers would take some time to adjust to the new system and would also very likely require advice and information to achieve it.

While all other scenarios also resulted in reduced GHG emissions, they all came at the expense of operating profit. Halving nitrogen use and reducing the stocking rate had no effect on operating profit as well as reducing GHG emissions by 10 per cent. This is likely to also require management skills, so would not necessarily be immediate and/or certain.

The effect of the emissions reductions were priced at different Carbon prices and different levels of free allocation and the effect on operating profit calculated (Appendix 3). At a lower Carbon price and 95 per cent free allocation (as the likely scenario in the short term), the effect of pricing emissions had a modest effect on operating profit (less than 1 per cent in all scenarios). At higher Carbon prices, the effects are more pronounced, as expected.

At lower levels of free allocation, the value of the reduced emissions increases further. In the scenarios that already showed improvements in operating profit, these rise to quite significant increases above the base farm scenario (23 per cent above the base farm at the highest Carbon price and 50 per cent free allocation – however, this scenario would not be expected in the short to medium term).

The improvements in operating profit depend on improved productivity per animal, which require skilled animal and pasture management. For those scenarios that showed a decrease in operating profit from the base farm, even at 50 per cent allocation and the highest Carbon price the operating profits remain negative.

Table 10 Southland Dairy GHG scenario summary results

	Scenario	Cows	Cows/ ha	kg MS Total	kg MS/ ha	kg MS/ cow	Operating Profit ($/ha)	% Difference	GHG (T CO_2e/ ha)	% Difference
1	Base farm	602	2.6	251,608	1,133	433	$3,091		10.2	
2	Reduce SR 10%, improve per cow	542	2.4	250,045	1,126	478	$3,358	8.60%	9.86	-3.3%
3	Reduce SR 15%, improve per cow	512	2.2	248,169	1,118	501	$3,476	12.50%	9.67	-5.20%
4	No N Fertiliser	542	2.4	226,547	1,020	433	$2,833	-8.30%	8.45	-17.20%
5	1/2 N reduce SR 10%	542	2.4	238,462	1,074	456	$3,091	0.00%	9.12	-10.60%
6	No supplementary feed	512	2.2	215,059	969	434	$2,859	-7.50%	8.71	-14.60%
7	1/2 Supplementary feed, reduce SR 9%	548	2.4	229,186	1,032	434	$2,870	-7.10%	9.27	-9.10%
8	5ha native forestry	590	2.6	246,786	1,112	434	$2,961	-4.20%	9.85	-3.40%

Note: SR = Stocking Rate

3.1.2 Emissions reduction discussion

The extent to which agricultural producers will be able to reduce overall emissions or emissions intensity from their operations will likely vary depending on the characteristics of the systems in consideration. Considerable regional differences exist in emissions reduction options – which may mean region-specific mitigation options. The ability of agricultural operators to reduce emissions varies, and several barriers to implementation exist, beyond the purely financial barriers.

Changes in farm systems, stock types, elimination of nitrogen fertiliser and supplementary feed, can all get close to, or achieve, the 2030 methane reduction target (a reduction of 10 per cent). While reduction in stocking rates is a key component of reducing GHG emissions, it has to be accompanied by an improvement in per animal productivity in order to reduce/enhance the impact on farm profitability. While many studies have modelled the possible effects of future technologies for GHG mitigation (e.g. methane vaccine, methane inhibitors), there is currently little information available regarding their speculative cost or time of commercial availability.

Achieving greater than 10 per cent reduction in absolute biological emissions will likely require a combination of on-farm mitigation and land use change. Higher rates of emission reduction would require the widespread adoption of technologies that are not currently available, or proven to be effective in Aotearoa New Zealand systems. While some alternative land uses (e.g. horticulture) may match the profitability of livestock[8], many barriers exist to their adoption and scale. However, when the physical and transition risks of climate change are considered together, land use change, or at least increased diversity within systems, is likely to be essential for the continued viability of agriculture in some regions.

[8] Thomas S, Ausseil A-G, Guo J, Herzig A, Khaembah E, Palmer D, Renwick A, Teixeira E, van der Weerden T, Wakelin SJ (2022) Evaluation of profitability and future potential for low emission productive uses of land that is currently used for livestock SLMACC Project 405422 MPI Technical Paper No: 2021/13

Currently, the only means of achieving the assumed 2030 nitrous oxide reduction (a reduction of 33 per cent), or the 2050 reduction targets (50 per cent), is via forestry carbon credits as an offset[9].

This raises issues for example, around the availability of land for planting, the impact on farm profitability, and the social acceptability of changing landscapes and communities.

3.2 Downstream risks

To address downstream risks (e.g. consumer trends, trade access requirements), farmers and growers may need to adjust or change practices, or provide a point of difference in their products. Many of these risks emerge due to farmers and growers being unable to reduce GHG emissions. Consumers in New Zealand's agricultural export markets are likely to influence the financial success of agricultural operators at the end of the value chain. These risks are summarised in Table 11.

[9] Journeaux and Kingi, (2020). Farm Systems Modelling for GHG Reduction on Māori Owned Farms: Achieving the Zero-Carbon Targets. AgFirst Report prepared for NZAGRC, April 2020. Retrieved 23rd September 2021 from https://www.agfirst.co.nz/wp-content/uploads/2020/09/Achieving-Zero-Carbon-Act-Reduction-Targets-on-Farm-AGF.pdf.

Table 11 Downstream transition risks

CATEGORY	RISKS
Market Trends	**Social license to operate:** International consumers are increasingly aware of the impacts of food production on the natural environment, including GHG emissions, particularly for meat and dairy products. This increased awareness could lead to decreased sales volumes for food producers in favour of those perceived to be more environmentally friendly, driven in part by boycotting and aversion to specific products or product types. Firms that are unable to improve practices may lose out to those who are able to implement the necessary changes to respond to changing consumer preferences, thereby making them more resilient to market disruptions.
	Alternative dietary trends: International consumers are also increasingly shifting from traditional to alternative diets, including vegetarian/vegan/flexitarian diets, as well as increased consumption of alternative protein and milk products. These trends could negatively affect New Zealand's agricultural producers by decreasing the overall market share for meat and dairy products, thereby negatively impacting producers' bottom lines. While evidence suggests high growth rates in these trends, consumer adherence may be limited to specific segments in international markets.
Trade Access	**Risks to food security:** It is likely that climate change will increase the risk of commodity price volatility, and potentially undermine the reliability of supply and distribution of agricultural goods.
	Competitive advantage: New Zealand may be vulnerable to decreased competitive advantage based on the respective policy of competing producer countries. This could include carbon leakage, whereby firms move operations from a country with more stringent and restrictive climate policy to a country with less stringent and restrictive climate policy. This places moving firms in an advantageous position, with relatively fewer costs and restrictions on production, thereby allowing for a greater volume of goods to be produced and sold.
	Carbon border adjustments: Given shifts in international climate policy, countries that import New Zealand's products may apply trade restrictions to products with relatively higher GHG emissions profiles, thereby creating risk for those producers who are unable to reduce their emissions. For example, the EU will implement a Carbon Border Adjustment Mechanism (CBAM) in 2023, initially on a range of products, currently not including agriculture. Other countries (e.g. the UK, US and Canada) are committed to exploring or implementing similar mechanisms in the future. Under these CBAMs, countries that fail to decarbonise will face a carbon levy on their imports. For example, a CBAM would ensure that the carbon emissions of EU imports are charged at the same cost as the EU-produced equivalents. However, imports from a country that already applied a carbon price would usually be exempt from the CBAM – therefore, if New Zealand does progress with pricing agricultural emissions, these would not be subject to this levy. In addition, while CBAMs are the most effective means of reducing carbon leakage (see above), they may create regional inequalities, and due to their trade-distorting nature, may violate WTO rules.

4 Opportunities from a changing climate

Efforts to mitigate and adapt to climate change can also generate opportunities for farmers and growers and the agricultural sector as a whole. Opportunities may arise both through physical as well as transition impacts (although generally more arise in the low-Carbon transition), and have the potential to reduce on-farm production costs, increase farm profitability and productivity, increase producer returns and create and/or improve a competitive advantage for individual farms and the agricultural sector.

Opportunities will vary depending on farming system and region, but farmers that proactively adopt these opportunities may be able to diversify their activities and better position themselves for the transition to resilient and lower-carbon agricultural production systems.

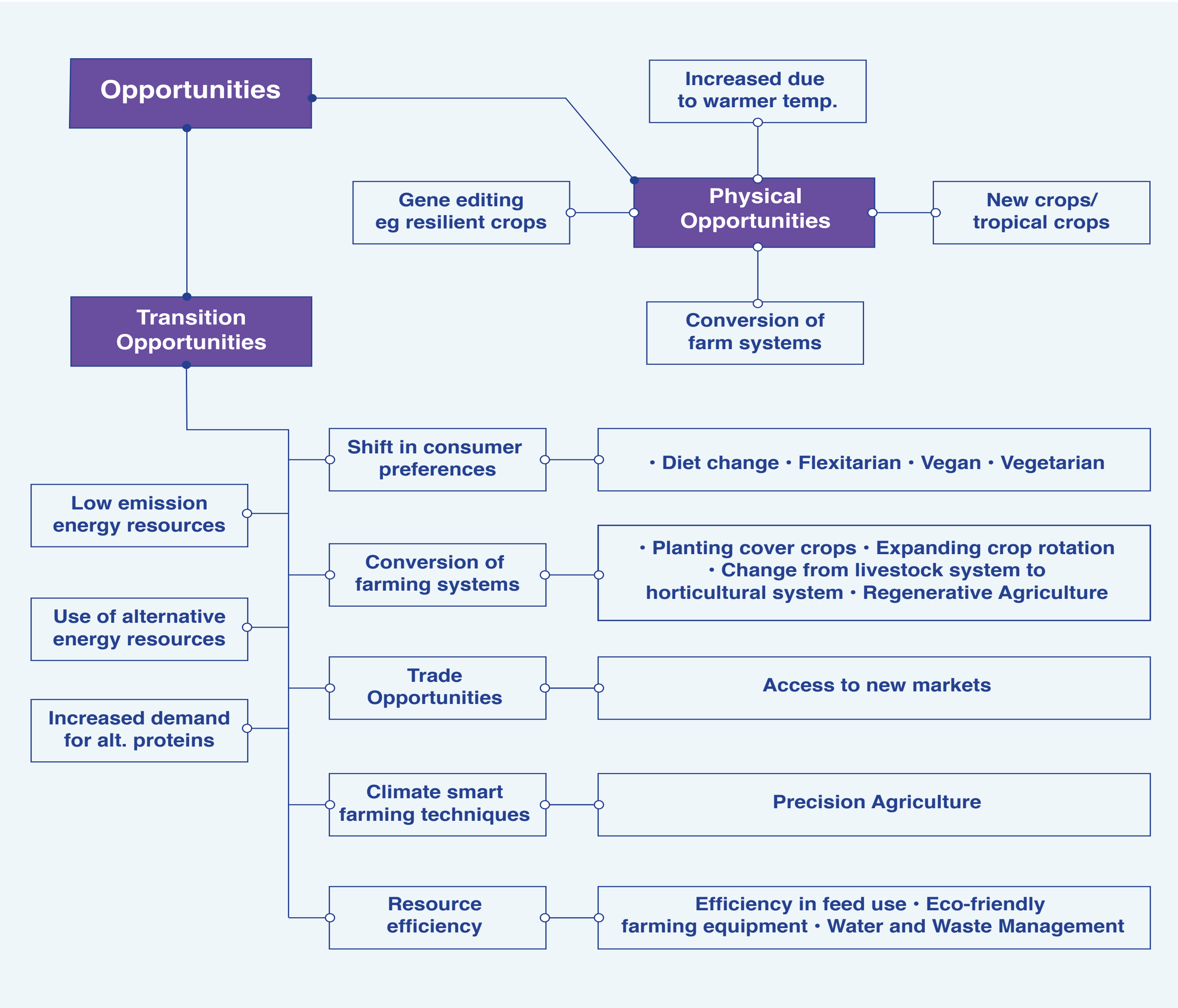

Figure 5 Opportunities through transition and through changing physical conditions

As illustrated in Figure 5, transition opportunities include the adoption of low-emission energy sources and farming equipment (e.g. precision agriculture); diversification/conversion of farming activities (e.g. change from livestock to horticultural operations; implementation of agroforestry systems); access to new markets through a change in consumer preferences towards credence attributes or through trade opportunities; and finally the creation of intellectual property and a competitive advantage from building resilient agricultural systems.

Physical opportunities from climate change have the potential to increase sector productivity. Warmer temperatures may allow for an extended growth season of some crops, faster maturation, and more optimal growing environments for some crops, also allowing new species to become viable (e.g. bananas).

Furthermore, as an exporting country, Aotearoa New Zealand may benefit from global climate change through the market effects of global disruption on commodity prices. For example, a widespread drought affecting international agriculture may lead to higher market prices and therefore higher returns for Aotearoa New Zealand producers.

5 Conclusion

This report has examined the main drivers of climate change risk for New Zealand agricultural producers, both in terms of the physical risk as well as the transition risk.

While there are certainly challenges and risks for New Zealand's agricultural sector arising from climate change, opportunities also arise, particularly for those farmers and growers who are agile enough to take advantage of both a changing climate and a changing regulatory and consumer market.

The journey to lower-Carbon production from agriculture will undoubtedly create challenges, particularly for producers who currently do not possess strong pasture and stock management skills. Opportunities do exist for those who are able to successfully de-intensify and improve productivity at the same time, particularly as the Carbon price increases. However, for those who are unable to make this kind of transition, the requirement to reduce emissions may place extra strain on their business.

A clear message arising from the background analysis for this report is the critical importance of improving farm management practice for avoiding profit loss, both for physical as well as for transition risks. This would be a key area for further investment, both in research for developing more detailed understanding of effective adaptation practices that will endure under a changing climate, as well as in the training of rural professionals and supporting extension programmes for farmers and growers.

A comprehensive understanding of the risks – including the wider determinants of vulnerability – is an important first step in addressing the physical risk from climate change. But understanding the options available to adapt to the risks, and developing robust, locally specific, and achievable plans to implement adaptation will be essential to ensure a thriving agricultural sector into the future.

Appendix One

Table A1-1 Determinants of sensitivity for major climatic hazards

HAZARD	SENSITIVITY DETERMINANTS
Drought	• **Soil type** – Different types of soil have different characteristics that determine their ability to withstand drought • **Soil quality** – Indicators of soil quality (e.g. macroporosity, bulk density, structural condition score, total and mineralizable carbon and nitrogen, and earthworms) can determine soil's ability to hold moisture; intensification can also increase soil compaction, which has implications for pasture production and soil hydrology. • **Vegetation** – In addition to evaporation from the soil, water is also lost from plant transpiration. • **Interactive effects** – The interplay between temperature and precipitation can also affect soil fertility, and therefore pasture growth. Soils with higher organic matter have been shown to increase plant yield in warmer, drier conditions.
Flooding	• **Soil type** – Free-draining soils may recover faster from inundation. • **Topography** – Low-lying areas and valleys may experience greater damage, and farms with access to higher ground may be better able to prevent stock losses. • **Location of assets and infrastructure** – The location of farm assets and infrastructure, including the storage of supplementary feed, for example, the positioning of the milking sheds and their electrical components, and the wider infrastructure such as electricity, play an important role in the final impact of flooding events.
Erosion	• **Soil type, permeability and structure** • **Topography – slope length and steepness, elevation** – For example, elevation can explain up to 50 per cent of the variance in erosion related to rainfall. • **Vegetation** – For example, soil erosion from forage-crop paddocks can be 10 times higher than pastoral grasslands. • **Stock intensity**
Heat stress	• **Livestock breed** – Properties such as an animal's rate of metabolism can determine the effect of heat stress, but can lead to reduced yield and fertility, and even mortality, in animals. Highly productive specialised breeds are often more susceptible to extremes in temperature. • **Stock intensity**
Warming temperatures	• **Crop type, requirements for cold periods**

Examples of what can contribute to vulnerability are shown in Table A1-2, and will vary for each individual farm and context.

Table A1-2 Determinants of vulnerability

CATEGORY	DETERMINANT	DETAILS, EXAMPLES
Social	Education	Including indigenous and local knowledge
	Age, Gender	
	Social capital	Networks
	Health status and services	Including mental health
	Remoteness	
	Awareness and information	
Economic	Income, debt	Income diversification (on- and off-farm), debt, dependency ratio
	Savings, credits, access to loans	
	Inequality	
	Markets	Prices, access, fragility
	Insurance	
Structural	Availability and quality of infrastructure	Transportation, water and sanitation, energy, reservoirs, wells, processing
	Land tenure	Ownership, succession
Governance and institutions	Trust in institutions	
	Participation	Participation in governance, political representation
	Plans and strategies	e.g. Drought planning and investment, water management planning
	Assistance	e.g. Drought recovery
	Competing or concurrent regulatory pressures	Water quality, GHG emissions, etc
Physical environment	Soil type, condition and quality	
	Topography	
	Water availability	Access to irrigation
	Vegetation cover	
Farming system and management	Farm size and composition	
	System intensity	Stocking rate, use of inputs
	Technology use	e.g. Irrigation
	Animal species and breed and composition	Including intra-herd diversity
	Crop type	Resistance, diversification
	Capacity to store feed	

Appendix Two

Actions for transition risks (Mitigation)

Table A2-1 Feed management

CATEGORY	METHOD(S) + DESCRIPTION
Feed management	**Reduce or eliminate bought-in supplementary feed** Eliminating supplementary feed could potentially reduce emissions by 10 per cent, but at significant associated reductions in earnings before interest and tax, depending on location and system type.
	Using low-emissions supplementary feed The use of alternative supplementary feeds, including low-nitrogen forage crops with lower associated GHG emissions in production, such as fodder rape and fodder beet, as well as novel feeds such as seaweed, have been suggested to reduce GHG emissions associated with feed management. While many forms of low-emission supplementary feed sources are currently commercially available (e.g. forage rape, fodder beet, plantain), other novel forms of low-emission feeds are not yet commercially available (e.g. GM ryegrass, seaweed) with very little information currently available.
	Balancing pasture growth with feed demand
	In-shed feeding

Table A2-2 Pasture, crop and soil management

CATEGORY	METHOD(S) + DESCRIPTION
Pasture, crop and soil management	**Removing or limiting nitrogen fertiliser** While in theory reducing nitrogen fertiliser has the potential to both reduce emissions as well as increase profitability (through more efficient use), the available analysis indicates strong emissions reduction, with most scenarios accompanied by a similar decline in profitability. This may be due to New Zealand modelling not accounting for more nuance effects such as timing – more research may be required in this area.
	Using precision nitrogen fertiliser application techniques Carefully managing the timing and placement of nitrogen fertiliser can reduce the total amount of nitrogen applied to land, thereby being an effective means of mitigating N_2O emissions – this could also include the adoption of precision nitrogen fertiliser spreading techniques.
	Improving pasture husbandry and fertility
	Optimising soil pH levels
	Converting more productive land to high-value crops
	Removing summer cropping
	Optimising the use of lime through targeted application
	Using palm kernel alternatives This can reduce emissions with little effect on profit.
	Improving irrigation management Improving the efficiency of irrigation by increasing the uniformity of irrigation application can decrease energy use and associated costs, thereby reducing GHG emissions associated with energy use on-farm.

Table A2-3 Stock management

CATEGORY	METHOD(S) + DESCRIPTION
Stock management	**Reducing stocking rates while improving animal productivity** Many GHG reduction scenarios in relation to stocking rate reductions consider multiple interactions, combining stocking rate reductions with other factors, such as productivity enhancement per animal. These have shown that pastoral producer can achieve emissions reductions of approximately 10 per cent while increasing overall farm profitability. However, this may vary depending on farmer skill, base farm systems, and the degree of productivity improvements possible per animal. The current lack of adoption of this approach may also be an indicator of the difficulty of more widespread adoption.
	Replacing breeding beef cows
	Adjusting finishing intensity
	Converting to alternative livestock options
	Once-a-day milking While this practice may reduce biogenic emissions per animal by reducing overall feed intake, thereby reducing overall emissions from production, this practice has associated negative trade-offs, including a loss of animal productivity.
	Culling less effective stock earlier
	Reducing stock losses and optimising replacement rates
	Selective breeding practices Selective breeding practices that aim to improve livestock performance while decreasing biological emissions in relation to feed consumed could reduce livestock GHG emissions. Genes that allow for lower methane emissions have been discovered, and scientists are now examining methods to select for these genes in cattle and sheep breeding processes. However, many selective breeding and genetically-based practices that have been suggested to greatly improve GHG emissions from ruminant animals are currently in development, and may not be commercially available within the next 2-5 years.
	Managing animal health

Table A2-4 Effluent management

CATEGORY	METHOD(S) + DESCRIPTION
Effluent management	Covering effluent storage for energy recovery
	Keeping effluent aerobic through mixing
	Carrying out solids separation, preventing solids from entering anaerobic ponds
	Biofilter use on effluent pond surface
	Using captured effluent as fertiliser
	Using winter housing and/or stand-off pads

Table A2-5 Technology investment

CATEGORY	METHOD(S) + DESCRIPTION
Technology investment	**Precision agriculture techniques**
	Methane vaccine The use of methane vaccines could be highly effective in mitigating livestock methane emissions. However, methane-inhibiting vaccines for ruminants are not yet commercially available, with the expectation that their development and commercialisation may take 10 years from the time of writing. Despite the expected efficacy of methane vaccines, the combination of a lengthy development process and expected expense may be barriers to widespread implementation in New Zealand pastoral systems.
	Methane inhibitors The administration of methane inhibitors (chemical compounds that suppress the metabolic activities of the microbiota that create methane in the digestive tract of ruminants) has been suggested as a means of reducing total emissions from livestock. Different methane inhibitor compounds can theoretically exhibit different levels of effectiveness in reducing emissions – however, it should be noted that this technology is not yet commercially available, but are expected to become available to New Zealand producers within the next two to five years. There may also be significant regulatory barriers and requirements prior to the successful roll-out of these technologies.
	Nitrification and urease inhibitors The use of nitrification inhibitors (chemical compounds that are spread on pasture and cropland to slow down the nitrification process from ruminant excretion and nitrogen fertiliser application) could potentially reduce GHG emission from New Zealand agricultural production. While commercially available, their use has been discontinued after inhibitor residues were found in milk products. Newer forms of nitrification inhibitors with minimised risk of residual leakage are currently in development, and expected to be available within the next three to five years.
	Reducing fossil fuel use Reducing on-farm fossil fuel use by minimising machinery use, as well as improving the efficiency of existing machinery or other farm technology, may reduce CO_2 and N_2O emissions on-farm. The use of electric farm vehicles and machinery, as well as switching to alternative fuel sources, can reduce GHG emissions associated with farm transportation.
	Reducing electricity use from the grid
	Improve energy efficiency on-farm Multiple energy efficiency improvements in pastoral farming operations, including introducing heat recovery systems from milk vat refrigeration, using a variable speed drive for vacuum pumps, and insulating piping and milk vats, can reduce energy demand and associated GHG emissions.

Table A2-6 Sequestration

CATEGORY	METHOD(S) + DESCRIPTION
Sequestration	**On-farm forestry** The incorporation of forestry activities, including planting vegetation for non-harvested purposes, shows the greatest potential as a means of GHG sequestration in a New Zealand agricultural context. This can include commercial forestry activities, as well as permanent exotic and native forests, as well as non-ETS plantings (e.g. riparian plantings). It is important to note that different types of vegetation (e.g. exotic vs indigenous woodlots vs riparian strips) have different abilities to sequester GHG emissions, which should be considered in line with forestry and other planting-based sequestration options. The efficacy of forestry plantation may vary considerably by region and farm type. Forestry establishment on-farm can be achieved through a range of methods, including: - Converting less productive land into indigenous vegetation or exotic forestry - Planting shelterbelts, with the additional benefit of improving animal welfare and pasture protection - Planting riparian planting setbacks for stock exclusion and ground cover, with the additional benefit of reducing nitrogen leaching - Planting erosion control trees to protect and manage erosion-prone land - Establish wetland forests, restore or create wetlands However, in a dairy context, this is associated with large declines in earnings before interest and tax across most regions of New Zealand, while in a sheep and beef context, there is potential to increase profitability considerably as well as reduce overall GHG emissions by significant volumes.
	Diversification/conversion of some land use from pastoral to horticulture/arable Planting perennial tree crops (e.g. fruit or nut trees) on-farm can partially sequester emissions with the additional benefit of producing a potential commercial crop to supplement main farm activities.
	Organic production methods and applications Conversion to organic production methods, including reductions in nitrogen fertiliser use, riparian setbacks and potential animal productivity improvements may also sequester GHG emissions. Organic amendments (e.g. manure, compost, biochar) may improve soil carbon balances and positively boost soil carbon, thus preventing emissions.
	Minimising periods of bare land
	Retire less productive land from grazing
	Retain and incorporate crop residues
	Diversifying plant species in pasture
	Fencing for pest control
	Optimising water table depth for peat soils
	Soil carbon sequestration
	Using full inversion tillage every 30 years The use of full inversion tillage every 30 years could be effective in sequestering GHG emissions on-farm – however, this is an active area of research in New Zealand with further research needed prior to widespread implementation.

Note on Horticulture: Horticulture and arable production have much lower impacts on land use and associated GHG emissions relative to pastoral farming in New Zealand. While horticultural and arable practice could be seen as a favourable alternative land use options relative to livestock-based operations from a GHG mitigation perspective, there are still GHG emissions associated with horticultural and arable production. Specifically, research has shown that improving the efficiency of horticultural and arable production operations, including improvements in nitrogen fertiliser application efficiency, may reduce GHG emissions in these areas.

Appendix Three

Transition case study with different Carbon prices and allocation levels

We examined what these changes in emissions would be worth if a Carbon price was applied to them. We selected a range of Carbon prices, ($85, $138 and $237/tonne CO2-e). The first two prices are in line with the Climate Change Commission guidance, while the $237 price is the price international analysts have estimated will be required to incentivise transition to net zero by 2050 (reaching that price by the end of this decade (NGFS, 2021). The government has committed to 95 per cent free allocation to agriculture (meaning only five per cent of emissions would be priced). We present the effect on operating profit after the value of Carbon has been accounted for, assuming the 95 per cent free allocation as is currently proposed in Table A3-1. The change in GHG emission was multiplied by the price of Carbon and the price exposure, then subtracted from the operating profit for that scenario, and then divided by the base operating profit, to calculate the percentage gain/loss.

The intention is to reduce this free allocation over time although no details regarding the level or timing of change are currently available. He Waka Eke Noa is assuming there will be a reduction to 90 per cent free allocation by 2030, and as the period under consideration extends to 2050, and by that time we would expect further reduction in free allocation, so we also include 80 per cent and 50 per cent free allocation for comparison in Table A3-2 (percentage change only).

Table A3-1 Operating profit at different levels of Carbon price, assuming 95 per cent free allocation

$/tCO2-e	No C price		85		138		237	
Operating profit		% difference		% difference		% difference		% difference
Base farm	$3,091		$3,048	0.0	$3,021	0.0	$2,970	0.0
Reduce SR 10%, improve per cow	$3,358	8.6	$3,317	8.8	$3,291	9.0	$3,243	9.2
Reduce SR 15%, improve per cow	$3,476	12.5	$3,435	12.7	$3,409	12.9	$3,361	13.2
No N Fertiliser	$2,833	-8.3	$2,797	-8.2	$2,775	-8.1	$2,733	-8.0
1/2 N reduce SR 10%	$3,091	0.0	$3,052	0.2	$3,028	0.2	$2,983	0.4
No supplementary feed	$2,859	-7.5	$2,822	-7.4	$2,799	-7.3	$2,756	-7.2
1/2 Supplementary feed, reduce SR 9%	$2,870	-7.1	$2,831	-7.1	$2,806	-7.1	$2,760	-7.1
5ha native forestry	$2,989	-4.2	$2,947	-3.3	$2,921	-3.3	$2,872	-3.3

Table A3-2 Percentage change in operating profit at 80 and 50 per cent price exposure for three different Carbon prices

	20%			50%		
$/tCO2-e	85	138	237	85	138	237
Reduce SR 10%, improve per cow	9.5	10.0	11.2	10.9	12.7	17.5
Reduce SR 15%, improve per cow	13.5	14.2	15.7	15.3	17.7	23.8
No N Fertiliser	-7.8	-7.5	-6.7	-6.9	-5.7	-2.7
1/2 N reduce SR 10%	0.6	1.1	2.0	1.7	3.1	6.8
No supplementary feed	-7.1	-6.8	-6.2	-6.3	-5.4	-2.9
1/2 Supplementary feed, reduce SR 9%	-7.0	-7.0	-6.8	-6.8	-6.6	-5.9
5ha native forestry	-3.3	-3.3	-3.3	-3.3	-3.3	-3.2

Focusing on the lower Carbon price and the 95 per cent free allocation as the likely impact in the short term, the effect of pricing the GHG emissions has a modest effect on operating profit (less than one per cent in all scenarios). It certainly is not sufficient to off-set any reductions in operating profit. It is sufficient however to lead to a slight increase above the base farm operating profit in the scenario of half N and reducing stocking rate by 10 per cent. At higher Carbon prices the effects are more pronounced, as expected.

At lower levels of free allocation, the value of the reduced emissions increases further. In the scenarios that already showed improvements in operating profit, these rise to quite significant increases above the base farm scenario (23 per cent above the base farm at the highest Carbon price and 50 per cent free allocation – however this scenario would not be expected in the short – medium term). For those scenarios that showed a decrease in operating profit from the base farm, even at 50 per cent allocation and the highest Carbon price the operating profits remain negative.

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