Ministry for Primary Industries
Manatū Ahu Matua

Support for the National Climate Risk Assessment: Processes for the identification and quantification of climate change risk for the primary sectors

MPI Technical Paper No: 2022/03

Prepared for the Ministry for Primary Industries
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ISBN No: 978-1-99-102640-8 (online)
ISSN No: (online)

March 2022

Te Kāwanatanga o Aotearoa
New Zealand Government

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Support for the National Climate Risk Assessment: Processes for the identification and quantification of climate change risk for the primary sectors

SLMACC 2.5 Final Report

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Report information sheet

Report title	Support for the National Climate Risk Assessment: Processes for the identification and quantification of climate change risk for the primary sectors'
Authors	Andrew Dunningham, Alan Jones, Grace Villamor
Client	MPI
Client contract number	406099
MBIE contract number	N/A
PAD output number	
Signed off by	Peter Clinton
Date	December 2020
Confidentiality requirement	
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Published by: Scion, Private Bag 3020, Rotorua 3046, New Zealand. www.scionresearch.com

Executive summary

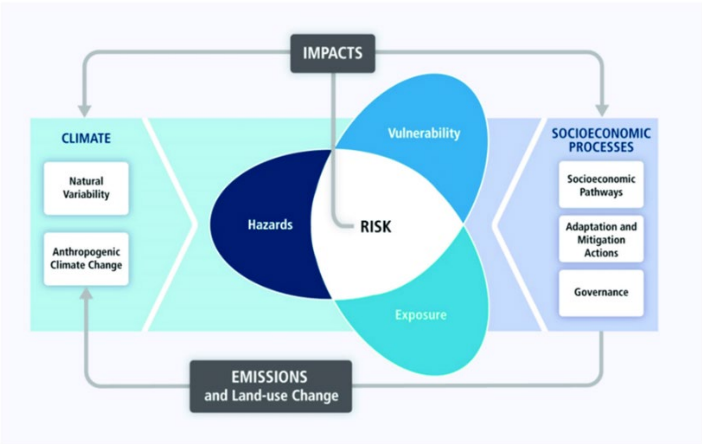
Risk assessment is the core component of risk management (Figure ES-1). However, as climate change is a global problem, risk elimination is beyond the independent ability of national governments. Hence, processes and data for risk assessment must be identified and define drivers of risk and monitor how risks have evolved, how they may change in the future, and understand the progress of risk minimisation across all of society.

This report describes the findings and outcomes of SLMACC 2.5 'Support for the National Climate Risk Assessment: Processes for the identifying and quantifying climate change risk for the primary sectors.

Climate-related risks are complex:

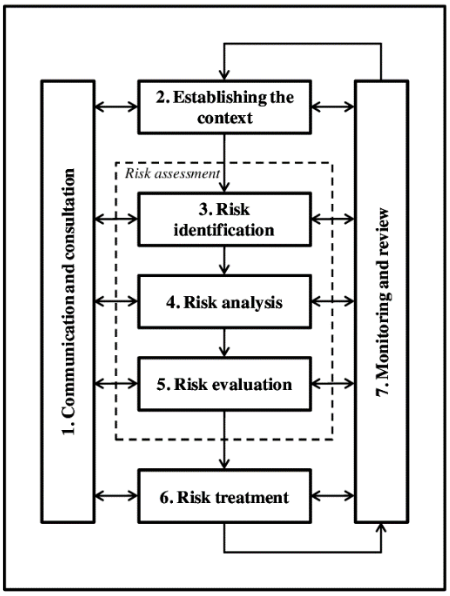
- Climate risk is not definitive nor absolute, but the risk varies and is nuanced as people, communities, businesses have different risk appetites, tolerances, and even understanding of what risk is, and the urgency and priority of varying risk drivers.
- The response to climate-driven risks varies across individuals, families, communities, businesses.
- Drivers of climate change risk can exacerbate existing vulnerabilities.
- Drivers of climate change risk, new and current climate risks and other risks or drivers can combine to increase or magnify the impacts and vulnerabilities.
- Risk arises from climate drivers creating hazards and socio-economic drivers, interacting with vulnerability and exposure of people and ecosystems (Figure 1).

Figure ES 1: IPCC conceptual risk model



This report addresses:
- Expanding risk identification (ISO Step 3) through introducing scenarios and analysing how different futures may impact the primary sector.
- Reviewing different modelling methods that can quantitatively estimate risk impacts and assess costs and benefits of adaptation options (the Risk analysis and Evaluation steps, ISO steps 4 & 5).
- We are identifying methods for monitoring and evaluation (ISO step 7) using both indicators and the models.

Figure ES-2: ISO 31000 risk management (ISO, 2018).



Recommendations and findings

1. Risk assessment should consider all risk drivers including, the physical acute and chronic climate drivers and systemic risk drivers.

Socio-economic drivers are a crucial driver of risk the ultimately impact people's vulnerability and their adaptive capacities and as the socio-economic environment is the source of anthropogenic CO_2 emissions.

2. Indicators are needed to assess progress on achieving climate risk reduction goals and objectives. Implicit is the explicit definition of the goals of an indicator programme.

3. Indicators should have an underpinning conceptual model so that there is the confidence that changes in indicators represent material changes in the underlying drivers.

4. An indicator framework should consider all aspects of understanding the risk environment:
   - Assess the changes in the global climate and the ongoing implications for NZ.
   - Assess the effectiveness of risk reduction policies and actions in reducing vulnerability and building resilience: i.e., reducing the exposure to climate hazards, addressing the adaptive capacity of different elements of society to manage climate-related risks and the governance environment.
   - Provide data and information that allows all of society to undertake effective climate change-related risk management.

The report reviews indicator frameworks used by the US, UK and EU in assessing climate-related risks, adaptation progress and effectiveness, and the underpinning understanding of how indicators represent the system in question.

5. Undertake more research in data and tools and quantitative modelling to improve the understanding of impacts, enabling more informed decision making and monitoring and evaluation.

Adaptation action requires a robust understanding of the risks and potential impacts by those that make risk management decisions. These decision-makers need to understand how risk affects their responsibilities, strategies, goals, and aspirations. Risk needs to be defined and evaluated against their criteria, e.g., Any risk to financial performance, natural capital, cultural capital, service delivery.

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1 Background

1.1 Assessing national climate change risk in productive biological systems

The Government is required under the Zero Carbon Act 2020 to complete an assessment of national climate change risk – the National Climate Change Risk Assessment (NCCRA) (Ministry for the Environment, 2020b). The assessment aims to understand areas of society that are vulnerable to or at risk from climate change impacts.

This report focuses on three components of future risk assessment across the land-based biological productive sectors at a national scale. Three components address:

1. The use of scenarios to further risk assessment
2. The use of indicators to assess, monitor and evaluate mitigation and adaptation responses and progress in minimising risk and risk drivers and vulnerabilities and adaptive capacities
3. Methods for quantifying risk impacts.

This research proposal was developed before the NCCRA methodology, and was undertaken as the NCCRA reports were being completed. Hence, we undertook this research independently and contemporaneously with the NCCRA process.

1.2 Impacts of climate change on the primary sector

Primary industries such as pastoral grazing, arable farming, horticulture, and forestry are susceptible to adverse climate change impacts (Clark et al., 2012). These impacts include declining yields and rising production costs in response to climate hazards of increasing temperatures, decreased rainfall, more frequent droughts and increased probabilities of ex-tropical cyclone events affecting New Zealand within this century (Ministry for the Environment, 2018).

The primary impacts cascade through local, regional, and national scales, creating further adverse consequences for people and the environment due to impacts on economic development, food security and well-being (IPCC, 2007).

1.3 Risk definition used

This research used the definition of risk from IPCC Assessment report 6 (Reisinger et al., 2020).

The concept of risk for the IPCC Sixth Assessment Report (IPCC 2020) is:

> *The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.*
>
> *<u>In the context of climate change impacts</u>, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to*

socio-economic changes and human decision-making (see also risk management, adaptation, mitigation).

In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (see also risk trade-off). Risks can arise for example from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions.

The key points from the definition are:

- *Risks are those with only adverse consequences* for human or ecological systems.
- *Risk is values-based:* recognising the diversity of values and objectives associated with such systems.
- *Risk includes* climate-related *hazards* and the *exposure and vulnerability* of the affected human or ecological system to the hazard.
- *Risk has uncertainty* in magnitude, likelihood, timing, and geography.
- *There are complex interactions:* risk results from dynamic interactions between climate-related hazards.
- *Risks encompass a range of adverse consequences* include those on people, their livelihoods, health and wellbeing; Societal economic, social and cultural assets, and services; and consequences for ecosystems and their services.
- *Risk and impact change according to s*ocio-economic changes and human decision-making.
- *Risk covers maladaptation: i.e., where adaptation does not* achieve the intended outcomes.

The IPCC Assessment Report 5 conceptual model (IPCC, 2014b) depicts how different elements contribute to understanding risk, i.e., the sources or drivers of adverse effects (Figure 1).

Risk arises from the intersection of two sets of drivers: the hazards arising from both natural variability and human-induced climate change (left-hand side, Figure 1) and vulnerability and exposure arising from three socio-economic processes (right-hand side, Figure 1). These three processes also either increase or decrease emissions and land-use change, changing anthropogenic GHG's. Realised risk creates direct impacts and amplifies indirect impacts through feeding backs changing the climate and hazards, and changing socio-economic processes such as policy, adaptation, and mitigation actions.

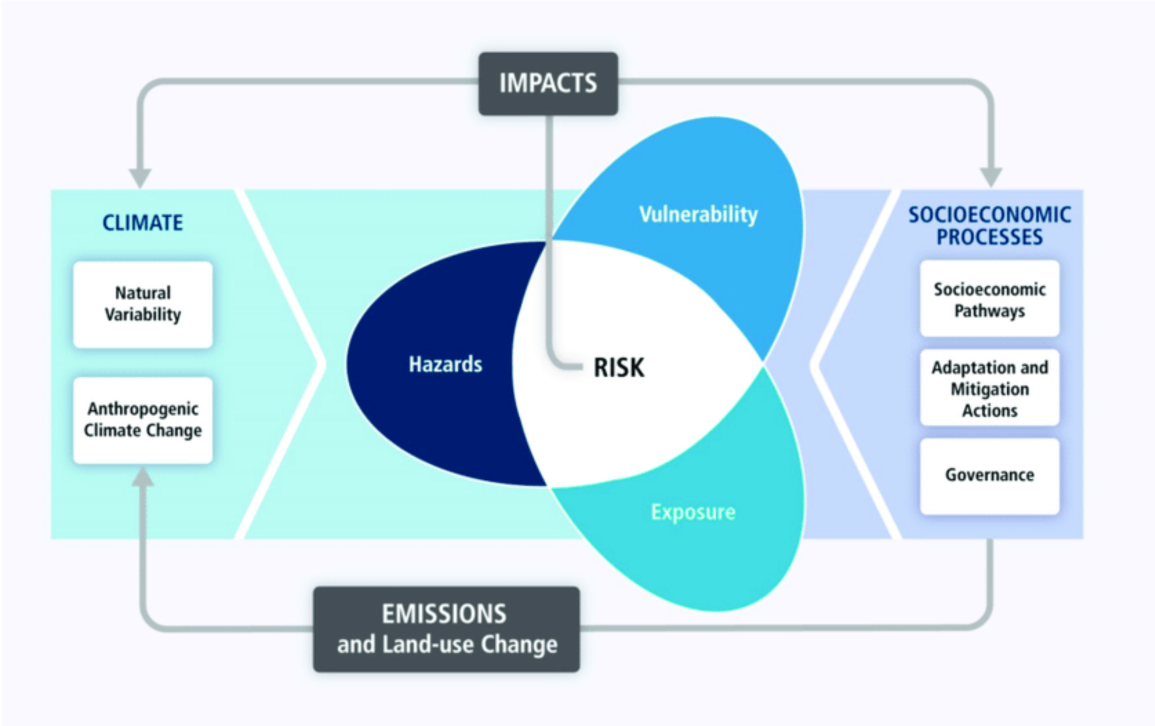

Figure 1: IPCC Assessment Report 5 Conceptual model (IPCC, 2014b)

Many socioeconomic pathways, mitigation actions, and international governance elements in the conceptual model are global. Hence, the ability to act at the national and local scale is limited to local action and governance components of the socio-economic processes.

Risk management focuses on managing the impact of climate change on society (right-hand side) from sources that cannot be controlled and addressing the impact from physical climate (left-hand side) through global processes and mitigation engagement.

Our reliance on utilising natural capital to create commodity and high-value products for international markets determines risk exposure. The risks arise from direct climate change impacts on natural capital assets, but risk evaluation is mainly qualitative, e.g., Clark et al. (2012).

In addition, systemic risks arise from other countries' policies and behaviours that could negatively impact supply chains, NZ's ability to export, or restrict access to intellectual, manufactured, or financial capitals and policies that the NZ Government enacts. Over several decades, these socio-economic changes will dictate the operating environment for the primary sector.

As part of the global action on climate change, three integrated systems help understand risk drivers: The Representative Concentration Pathways, Shared Socio-Economic Pathways and the Shared Policy Assumptions.

The Representative Concentration Pathways (RCP's) are scenarios of four different levels of (simplistically understood as[1]) global temperature increase – i.e., as RCP's increase, so does the temperature. The physical risks arise from how temperature affects other climate processes, such as changes in precipitation or sea-level rise.

[1] RCP's represent radiative forcing levels (watts/m^2), RCP 2.6. is 2.6 watts/m^2, of radiative forcing, RCP 8.5 is 8.5 watts/m^2. Energy continuously arrives from the sun, with naturally ~70 percent) being absorbed by the planet, with 30% reflected back into space. Radiative forcing is the amount of the 30% that is retained in the earth by atmospheric GHG's. The difference between outgoing energy and incoming energy is the radiative forcing, and if the number is greater than zero, then some warming is occurring. Planetary climate sensitivity determines the change in temperature for different levels of radiative forcing.

The Shared Socio-Economic Pathways (SSP) are scenarios used to describe potential future socio-economic possibilities at global scales (Kriegler et al., 2012). SSP scenarios are based on quantitative and qualitative assumptions of different societal futures, described in terms of demographics, economics, governance and institutions, culture, energy use, and technology development. The SSPs can be downscaled to address regional, national and sub-national issues and develop implications for different sectors.

The Shared Policy Assumptions (SPA) incorporate policy determinants that will drive societal behaviours, including investment. The policy is detailed separately in SPA's as the RCP's and the SSP's assume no climate change mitigation or adaptation policy interventions, enabling scenarios to model the impacts of different policy interventions; i.e., they are baselines of no specific interventions[2].

1.4 Aims of this research

This project addressing methods, gaps and knowledge requirements that address the understanding of "the effects of global change on the natural environment, agriculture, land and water resources, human welfare, human social systems, and biological diversity" through the two questions based on the UK assessment processes:

1. Can we assess the present-day national vulnerability and current climate-related risks, opportunities and levels of adaptation effectively? What do we know? Where are the gaps?

2. How can NZ understand the future vulnerability and assess how climate and socio-economic change may alter climate-related risks and opportunities.

1.4.1 Overarching methodological approach

To determine priorities for adaptation that protects and enhances the primary sector in the face of a range of possible uncertain futures, we propose developing a framework that utilises scenario planning for risk identification and evaluation.

Primary sector businesses are largely privately owned. Hence risk management and risk treatment are private actions, largely determined and funded (or not) by the individual entities.

ISO 31000 defines the risk management process as a series of risk assessment steps and then treating the risk, supported by cross-cutting work on communication, monitoring, and review (ISO, 2018). Critically, risk evaluation is based on an organisation's risk appetite, which will vary between organisations.

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[2]This can be somewhat confusing, as an RCP 2.6, or lower projection of climate change temperature (c. 2C or lower) can only be achieved by government action – typically decarbonisation of energy production. The SSP's or RCP's don't define how that occurs, but only that it does occur. In the modelling, assumptions of a range of GHG drivers are made to define, and identify credible pathways to the scenario goals, such as energy transition to renewables, but don't explicitly identify the policy frameworks. Other scenarios such as the Shell Sky 1.5 identify what needs to happen to achieve certain goals, or with IEA CPS, identify the probably outcomes (of not meeting Paris) on emissions under current policy settings. These types of scenarios also help define the transition risk to fossil fuel dependant business.
Shell Sky 1.5: https://www.shell.com/promos/energy-and-innovation/download-full-report/_jcr_content.stream/1612814283728/d14d37b7dd060d78b65bfee3c7654520e10381aa/shell-energy-transformation-scenarios-report.pdf)

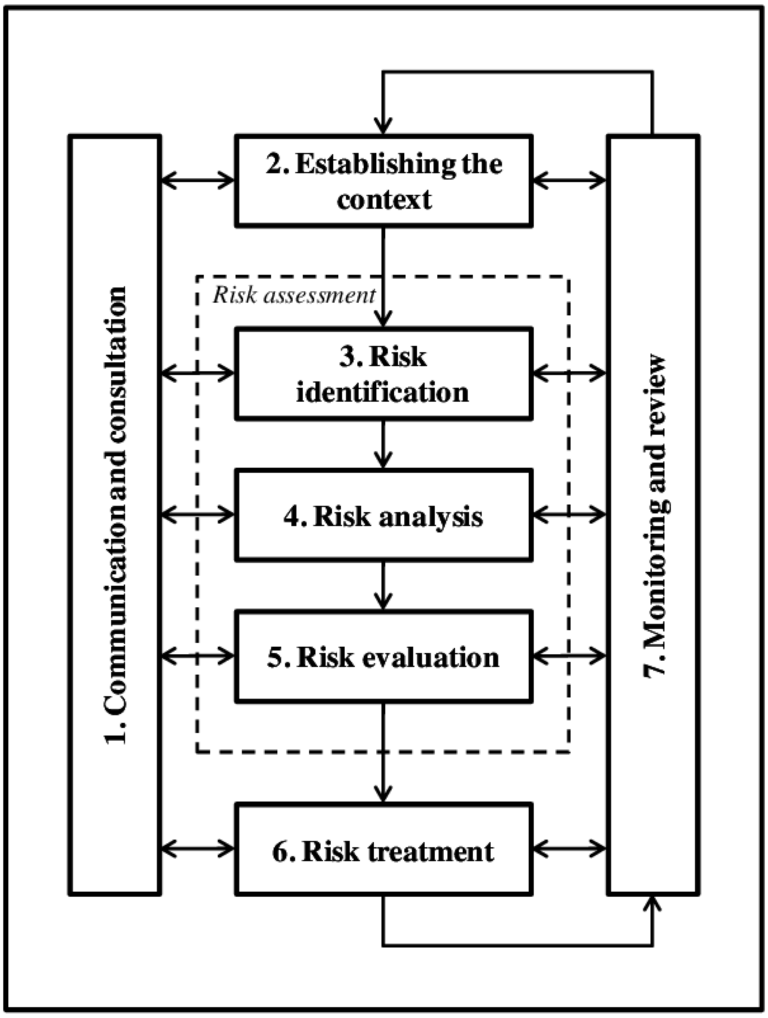


Figure 2: ISO 31000 Risk Management Process (ISO, 2018).

2 OBJECTIVE 1: DEVELOPING / ADAPTING CLIMATE CHANGE SCENARIOS.

We address scenarios and methods for downscaling the global scenarios to a national scale using the Actor-Sector-Factor (Absar & Preston, 2015) methodology and other research.

This section focuses on risk assessment from future socio-economic using scenarios of possible future worlds. The TCFD recommends using scenarios to assess risk: "Scenarios are a well-established method for developing strategic plans that are more flexible or robust to a range of plausible future states" (Task Force on Climate-Related Financial Disclosures, 2017).

While all scenarios are hypothetical and do not fully describe the future, they identify critical elements influencing future success. Their strength is that they encourage critical strategic thinking and explore alternatives challenging business assumptions and thinking. Scenarios are used: (i) to help determine adaptation options (Santos, Pagsuyoin, Herrera, Tan, & Yu, 2014), (ii) for policy interpretation (iii) to understand climate change risk vulnerability and management and progress in adaptation (EU-Impressions 2019), and strategic asset allocation (Guyatt, 2011)

Understanding risk response – potential typologies of primary industry decision-makers

We hypothesise that future climate change and shared socio-economic changes will impact the primary sector's land use and profitability. Companies or owners driven by their behaviours will determine these outcomes. We have evaluated the potential typologies of primary industry decision-makers to investigate how these can predict adaptation behaviour in response to a simplified set of locally relevant future scenarios covering both climate and socio-economic risks.

3 OBJECTIVE 2: UNDERSTANDING KEY RISKS AND EVALUATING KEY INDICATORS OF NATIONAL SCALE RISK.

Indicators of national risk will be needed for the NZ Climate Change Commission to assign priorities for adaption. For example, the UK 2017 evidence report (Kovats & Osborn, 2016) identifies risks and impacts on production, trade, people, communities, and the environment and includes new and emergent risks such as pests and diseases.

Indicators of risk provide the ability to determine risks and progress in mitigating the risk. Representative indicator frameworks from the US, UK, and EU are reviewed to provide insight into the different programmes' scope, conceptual underpinning, aims, and goals.

The US Global Climate Research Programme goal is to develop and coordinate "*a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change*." A key activity is to "*Analyse the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity*"[3].

The UK Climate Change Committee is required to address the requirement: "*Based on the latest understanding of current, and future, climate risks/opportunities, vulnerability and adaptation, what should the priorities be for the next UK National Adaptation Programme and adaptation programmes of the devolved administrations*?"[4]

Hence, the UK committee focuses its efforts on answering two questions (UKCCC., 2017):

1. Understanding present-day vulnerability and assessing current climate-related risks, opportunities and levels of adaptation; and

2. Understanding future vulnerability and adaptation and assessing how climate and socio-economic change may alter climate-related risks and opportunities in the 2020s, 2050s and 2080s.

[4] UK Climate Change Risk Assessment Evidence Report 2017 .... https://d423d1558e1d71897434.b-cdn.net/wp-content/uploads/2016/07/CCRA-Introduction-fact-sheet.pdf

[3] https://www.globalchange.gov/nca4
[4] https://www.theccc.org.uk/uk-climate-change-risk-assessment-2017/introduction-to-the-ccra/

4 OBJECTIVE 3: QUANTITATIVE METHODS FOR ASSESSING RISKS

We identify methods and models that quantitatively frame risk and impacts, then develop the pros and cons and the data requirements for each method.

4.1 National Climate Change Risk Assessment

The Government outlined a framework (Ministry for the Environment, 2019) for enhanced leadership on adaptation that consists of (p 7):

- A National Climate Change Risk Assessment (NCCRA) improves our understanding of the climate risks Aotearoa New Zealand faces.
- A National Adaptation Plan that will outline the Government's approach to improving New Zealand's resilience to the effects of climate change.
- Monitoring and reporting on the implementation of the National Adaptation Plan to ensure accountability.

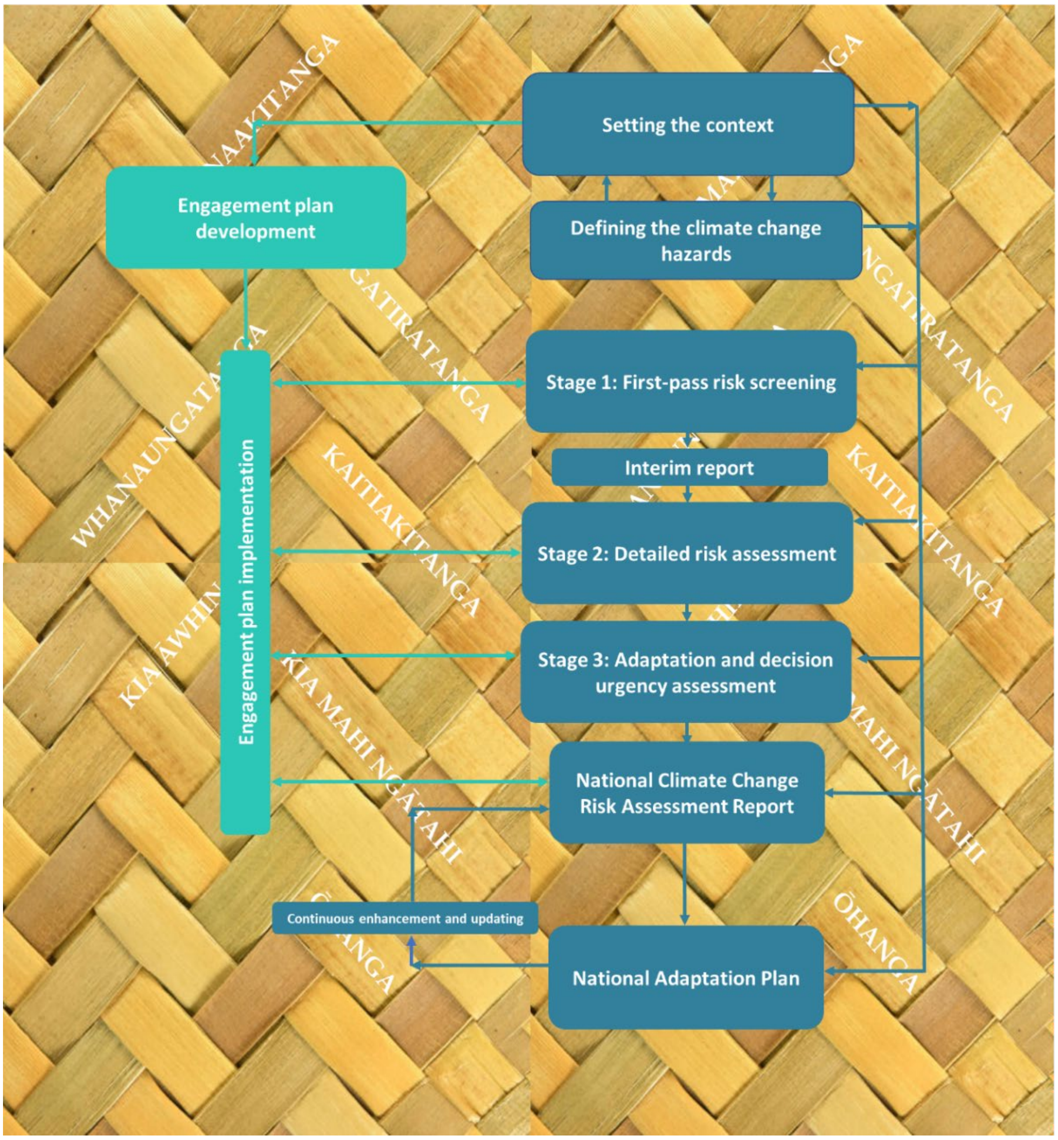


Figure 3: Overview of the National Climate Change Risk Assessment framework methodology, including the three-stage assessment approach.

The first risk assessment was completed in three reports (Ministry for the Environment, 2020a, 2020b, 2020c).

The NCCRA has the following key objectives:

- provide a national overview of how New Zealand may be affected by various hazards and threats that are caused, exacerbated or influenced by climate change, and the risks and opportunities this brings, as well as any gaps in evidence;
- support decision-makers to better understand the wide range of risks that New Zealand will face, and which risks to address most urgently; and
- provide the best available evidence, information and assessment of risks to inform a NAP directly.

Th NCCRA provides:

- The first national picture of the risk New Zealand faces from climate change.
- Forty-three priority risks covering each of the five value domains from our ecosystems and communities to buildings and the financial system.
- A grouping of risks according to five value domains: natural environment, human, economy, built environment, and governance.
- The ten most significant risks that require urgent action in the next six years to reduce their impacts
- The foundation for a national adaptation plan outlining the Government's response to climate change risk.

The most significant risks are the top two risks in each of the value domains and are listed (Table 1)

Table 1: New Zealand's ten most significant climate change risks, based on urgency (Ministry for the Environment, 2020a):

Domain	Risk	Rating	
		Consequence	Urgency (44–94)
Natural environment	Risks to coastal ecosystems, including the intertidal zone, estuaries, dunes, coastal lakes and wetlands, due to ongoing sea-level rise and extreme weather events.	Major	78
	Risks to indigenous ecosystems and species from the enhanced spread, survival and establishment of invasive species due to climate change.	Major	73
Human	Risks to social cohesion and community wellbeing from displacement of individuals,	Extreme	88

	families and communities due to climate change impacts.		
	Risks of exacerbating existing inequities and creating new and additional inequities due to differential distribution of climate change impacts.	Extreme	85
Economy	Risks to governments from economic costs associated with lost productivity, disaster relief expenditure and unfunded contingent liabilities due to extreme events and ongoing, gradual changes.	Extreme	90
	Risks to the financial system from instability due to extreme weather events and ongoing, gradual changes.	Major	83
Built environment	Risk to potable water supplies (availability and quality) due to changes in rainfall, temperature, drought, extreme weather events, and ongoing sea-level rise.	Extreme	93
	Risks to buildings due to extreme weather events, drought, increased fire weather, and ongoing sea-level rise.	Extreme	90
Governance	Risk of maladaptation across all domains due to practices, processes, and tools that do not account for uncertainty and change over long timeframes.	Extreme	83
	Risk that climate change impacts across all domains will be exacerbated because current institutional arrangements are not fit for adaptation. Institutional arrangements include legislative and decision-making frameworks, coordination within and across levels of government, and funding mechanisms.	Extreme	80

4.2 Role of this research with respect to the NCCRA

This research was contracted before the NCCRA framework was published and was undertaken as the NCCRA was being developed. As a result, the authors participated as much as possible in the NCCRA workshops.

The NCCRA framework and risk priorities excluded socio-economic drivers of risk, vulnerability and exposure, and socioeconomics' role in enhancing or reducing hazards (sec. 2.2, p 27), excluding risks from systemic privilege, deprivation, lack of access to resources, impacts from trade and economic transition (to a low carbon economy) inequalities and inequity.

The NCCRA is necessarily at a high level, noting that primary production is part of the larger economy value domain. The risks to primary production did not make the top 10 (the risk of disaster and lost productivity to government finances did). Most of the physical risks to the primary sector are in the third priority of the economy domain: "*Risks to land-based primary sector productivity and output due to changing precipitation and water availability, temperature, seasonality, climate extremes and the distribution of invasive species*." (Ministry for the Environment, 2020a)

4.3 This report

This report investigates future scenarios of different worlds in Section 2 and understands the role of behaviour in adaptation decision making. Section 3 addresses how indicators can be used to monitor and evaluate adaptation actions and plans and identify gaps in risk assessment and risk management, including process and governance. Finally, section 4 summarises tools and methods for quantitatively assessing risk.

5 OBJECTIVE 1: DEVELOPING / ADAPTING CLIMATE CHANGE SCENARIOS

5.1 Introduction

The impacts of and vulnerability to the effects of climate change arise from the physical climate changes that result in global warming. Climate change is anthropogenic, meaning that socio-economic factors drive increased atmospheric CO_2. The socio-economic environment is also impacted by climate change, creating reinforcing and balancing feedback loops - creating, enhancing, or reducing the harm from climate change. (IPCC, 2012).

Socio-economic pathways (SSP) scenarios are a set of widely different and plausible futures that provide pictures of societal changes that could influence potential risks and impacts of climate change. Scenarios help understand sources of risk, the impacts that may occur and provide the basis for developing risk responses – mitigation and adaptation options (B. O'Neill et al., 2017). Within the ISO 31000 framework. SSP's and RCP's provide information for risk identification, analysis, and evaluation.

Scenarios are quantitative and qualitative descriptions (storylines) that provide data and assumptions. The storylines explain changes to institutions, political stability, changes in understanding – political awareness, environmental awareness (see Appendix: SSP Narratives).

SSP's help explore the interactions between human societies and the natural environment (Shinichiro Fujimori et al., 2017).

This research identifies key drivers of SSP's based on the method used by Daigneault et al. (2019) and the Factor-Actor-Sector framework (Kok, Rothman, & Patel, 2006), when the authors defined forest sector pathways based on the specification of key forest sector factors, including:

1. Land-use regulation.
2. Forest productivity growth.
3. Environmental impact of forestry activities.
4. International trade of forest products.
5. Forest-specific mitigation policies.
6. The efficiency of timber processing and wood use.
7. Consumption of primary and secondary forest products.
8. Forest carbon pricing and mitigation.

This review focused on socio-economic factors relevant to the broader agricultural sectors: Landuse, Trade, Population, and Consumption.

The drivers of socio-economics impact on forestry are further developed in other research, including end-user engagement. Further factors that could be included are the Treaty, social license, and the ETS.

For NZ, the role of the Treaty, the impacts on environment management on social license, and the impacts of carbon pricing are largely dependent on the policy environment in NZ, namely the replacement of the RMA, the changes to the ETS, the recommendations from the Climate Change Commission, and the Government's response to the NZCCC budgets, and the National Adaptation Plan.

5.2 Socio-economic processes of climate change risk

The IPCC has moved from vulnerability conceptualisation to a risk-based conception of climate change adaptation that integrates climate risk assessment as just one risk affecting stakeholders (including non-human stakeholders).

This new framing is important as it allows other questions, and the enabling or governance environment will react to how risk and vulnerability are defined and bounded. The new risk approach focuses on the nexus of hazards, exposure, and vulnerability requiring data on all three. Vulnerability and exposure arise from socio-economic processes, including crucial socio-economic pathways, governance and mitigation and adaptation actions, and vulnerability and exposure need to be considered when developing risk assessment, adaptation plans and indicator frameworks.

The socio-economic system comprises society, the economy, the environment, and energy and technology. Interacting with all of these are landscape-level policies and institutions that provide governance (or not). Demographic trends and population dynamics affect the economic activity undertaken by persons, firms and other agents in society. The effects are transmitted through the environment, the energy sector, the use of land and persist over time (UK-SSP Consortium, 2020).

5.3 Results

The interpretation and implications are developed from team knowledge, information from the academic and the grey literature. Unfortunately, participatory scenario development is very complicated; hence it was well beyond the resources of this project.

The Factor-Actor-Sector framework (Kok et al., 2006) is a method used to downscale the global SSP's, identifying critical aspects of an extended storyline. In the Factor-Actor-Sector framework, a sector is a part of a national system; actors are organisations or individuals who critically can *act* or *influence* change. The factor represents an aspect of a social or natural system with broad policy issues or particular interests. Factors are present in the global storylines, but national factors are added to national or sub-national versions of storylines (Absar & Preston, 2015).

Scenario interpretations were undertaken by analysing the extended global storylines with local understanding of specific factors, considering work completed within CCII[5] and the literature.

We have used a one-to-one storyline development process, noting that this approach is constraining, as downscaling global SSP's can result in multiple storylines based on the uncertainties associated with SSP elements and how they play out at a national scale. The alternative has many national storylines which could become unmanageable.

Absar and Preston (2015) commented on the lack of information about storyline elements such as sectors and the inclusion of other actors at the sub-national level and how they could be articulated. In this case, there is limited to no literature that can be used to develop storylines specific to the different businesses that make up the primary sector.

The storyline articulated here are word sketches or 'straw person' allowing others to discuss what is important and the assumptions made. Much of what happens in the future, e.g. SSP 4 and SSP 5, depends on GDP and population, based on land utilisation, land ownership and consolidation, and access to technology and global markets.

The scenario development is cyclic and iterative; we expect subsequent research to add and refine the factors and the impact assumptions.

Table 2 gives the interpretation and sector implications for SSP's 1,3,4,5) (SSP2 is a middle-of-the-road scenario and hence not used).

[5] Climate Change Impacts and Implications MBIE project. www.ccii.org.nz

Table 2: SSP interpretations and the implications for the primary sectors (Storylines are in Appendix 5).

SSP's	Interpretation	Implications for Primary Sector
SSP 1	• The SSP 1 marker scenario is a coherent storyline for sustainable development, with ambitious improvement in resource efficiency, human development, and preferences regarding consumption and production systems within energy- and land-system (van Vuuren et al., 2017). • The developments in technology and governance provide no barriers to effective mitigation and adaptation. • SSP 1 emphasises the use of environmentally friendly technologies, less resource-intensive lifestyles, an increasing GDP coupled with a decline in population post-2050. • Technology improvement and efficacies drive down the cost of technologies such as PV and electric batteries.	• SSP 1 is a utopian vision, with an expectation of increasing prosperity driven by strong demand for agricultural products increasing GDP, allowing social and economic life improvements. • SSP1 is a prosperous and highly technology-led rural sector that focuses on sustainability and efficiencies.
SSP 3	• SSP 3 describes a world of fragmentation, resulting in low economic growth and low technology development, so when combined with an increasing population, mitigation and adaptation are difficult (van Vuuren et al., 2017). • SSP 3 has a high degree of challenge that consists of factors that lead to high emissions in the absence of climate policy and factors that tend to reduce society's ability to mitigate climate change. SSP 3 is a word of regional rivalry (Shinichiro Fujimori et al., 2017). • Countries develop policies that are identity-based and focused on national security. • The lack of international collaboration with weakened international organisations limit economic growth; provides	• This scenario is dystopian, with potential negative impacts for the primary sector. • The emphasis is on production in a world that could have high CO_2 concentrations with resultant high warming. • Impacts from increased atmospheric CO_2 and temperature will significantly impact production systems, water quality and land use. As a result, some production systems may not be viable. • Prosperity in NZ is uneven; it is expected that regions will suffer. • Technology improvements are limited, leading to low growth in land production efficiencies, and there is a lack of access to new technologies due to rigorous and enforced IP management.

	for low investment in education and low technological development. • Economic growth is resource-intensive with low increases in energy efficiency and agricultural production efficiencies. • Growth can be pursued through increasing land in production, increasing deforestation. • The growth agenda depreciates environment policies and protection and limits investment in resource efficiencies and agriculture system efficiencies. • Trade barriers are strengthened, with a reliance on in-country resources. • SSP 3 is a high fossil fuel dependant world and sees more coal used and with carbon intensity increasing. The transition from traditional energy sources is slower. • Land use is driven by food demand, with the trends in population and welfare increasing food demand. Yield improvements are limited due to low technology developments. • The marker scenario shows warming of 4C by 2100 (Shinichiro Fujimori et al., 2017; van Vuuren et al., 2017).	• Land use in agriculture expands to overcome/address the increasing demand for food and lower efficiencies. • Those that have land in food production will be well off compared to others. • New Zealand as a trade food producer, in a more competitive world, would be competing against producers that would have significant state support and less labour, environmental protections. This may lead to policies that offer subsidies, remove environmental constraints to production, and increase productive land use. • Decision-making is expected to serve the privileged, addressing their predominantly business/economic interests. • Environmental protection will be for areas that are for the elite and probably near population centres, i.e. their recreational areas or restricted to national icons. • Protections could be reduced. • Consultation for social, environmental, and cultural aspirations and values is limited to those immediately affected and is inequitable, benefiting those with economic resources. • Treaty of Waitangi institutions' role are limited and depreciated under the national [economic] security focus. • There is limited investment in people, in health and education and opportunities.
SSP 4: Inequality – A Road Divided	• The SSP4 world is one characterised by global and within nations inequality and stratification between haves and have-nots. It is entrenched through high levels of unequal investment in human capital, increased disparities in economic opportunities and political power (B. O'Neill et al., 2017)	• New Zealand is a high-income earning country. Hence impacts will be lessened when compared to poorer countries. • NZ role as a food producer is emphasised. Two opposing national scenarios can be developed based on the equitable (or not) distribution of wealth and land.

	• Society splits into those who are: well educated, internationally connected, and who drive and develop knowledge and have access to capital or those who are: low income, poorly educated working in labour-intensive and low technology economies. • The elite holds power even in democratic societies where the 'poor' have limited representation nor the capacity to achieve it. Globally, 'extreme poverty, income inequality, and lack of opportunity lead to environment ills especially for the poor' (Calvin et al., 2017). • The elite segment can invest in mitigation, and technologies 'should the will to do so materialise' (Calvin et al., 2017, p. 285). Poverty and lack of access to technologies make it hard for the 'poor' to adapt to climate change. • The marker scenario shows that the population decreases for high- and middle-income regions (HIR, MIR). HIR's become more prosperous. The opposite is for low-income regions with no means for increasing income. These differences between the different strata will drive other demands for food, energy and how demand is met. • This plays out for NZ depends on whether the regions benefit from a world that requires food, provides economic returns to agriculture, or whether cities dominate economic growth and trade.	• Farms, forests, and other primary enterprises part of the agri-industrialised sector will prosper, along with their owners/investors and potentially their workers, due to investment, access to technology, assistance with necessary and costly adaptations such as water supply and access to trade and overseas markets. However, whether the towns will benefit will depend on where large companies purchase goods and services. • Farms that are not part of the elite will struggle as they will have to face the severe impacts of climate change in an environment of inequality, limited access to technology and information, and probably will have poorer returns. • Extreme events will impact production and profitability, and resilience and adaptive capacity could be low, especially for extreme events that are close together. • Inequality rules this world. Hence the impacts of climate change, especially at high RCP's will have detrimental effects on local communities.
SSP 5	• SSP 5 is a world that is energy and resource-intensive, derived from very high fossil fuel usage, high food usage, a tripling of energy requirements. • Under this scenario, CO_2 will increase with a resultant challenge to decrease it.	• Pursuing a low CO_2 would mean that the focus is similar to the current focus, emphasising production, but not at the expense of the environment. Agriculture still dominates in a medium CO_2 world but with policy options to manage down agriculture emissions as part of NZ international commitments.

	• The population will increase then decline; there is rapid human development and growth in income convergence, coupled with an inclusive and globalised economy. • The high challenge to adaptation means that adaptive capacity is high and continues to grow. • This world is somewhat like the world over the last 30-50 years, with international collaborations, trade-dominated economies, with some focus on sustainable development. • Depending on attitudes to climate change mitigation and appropriate technologies, there could be limited CO_2 increases. • To some degree, adaptation and mitigation are driven by technological solutions or afforestation and policy-emission payments.	• Primary production will prosper, land-based export sectors are protected and valued, and enjoy good returns. • Agriculture, forestry, horticulture etc., are major export earners and are protected and enhanced. • Exporting opportunities and the effects of climate change on primary production supply chains are managed to ensure production. • Changes in climate-related risks would require adaptive measures to prevent or react to, requiring capital and cash. In addition, impacts can affect infrastructure, e.g., roads, or land and community and private assets, e.g. sea-level rise. • Where there are economic benefits, adaptation measures are well funded, though land-use is market-driven. • Overtime (decadal), the climate could limit some land-use practises, either requiring a refocus or some transformational changes. • Climate change may increase opportunities for other production systems to thrive. • Water supply is expected to be a valuable commodity, with limitations on supply and restricted access. • There is no restriction for using mitigative energy sources. At least agriculture is not part of any emission trading scheme. • Sector inclusion in any ETS is driven by trade requirements and limited competitive disadvantages with trade competitors. • Institutions and governance are focused on both production and strong investments in health, education, and institutions to enhance human and social capital.

		• Adaptation funding protects production and includes welfare issues, especially for more wealthy neighbourhoods/communities. • Economic activity rules. • Environmental and ecological protection is still a component of NZ but can be exploited. • Marginal lands are used for production; irrigation has priority.

The primary sector-specific Actors, Factors and Sectors (Table 3) have been developed from analysis and categorisations from Absar and Preston (2015) and, with reference to Kok et al. (2006), and national-level factors have been included. The key elements that affect the primary sectors are given in bold.

Table 3: Factors, Actors, and Sectors that contribute to global and national storyline development from Absar and Preston (2015), with other National Actors, Primary Sectors and Factors identified in the research (n italics).

		Global	National
Factors			
	Population	Y	Y
	Globalisation	Y	Y
	Economy / GDP	Y	Y
	Consumptive behaviour	Y	Y
	Technology	Y	Y
	Land Use	Y	Y
	Biodiversity / Conservation	Y	Y
	Equity	Y	Y
	Millennium Development Goals	Y	-
	Emissions	Y	Y
	Production	-	Y
Actor	Public Institutions	Y	Y
	Private Institutions	Y	Y
	Civil Society	Y	Y
	Iwi	-	Y
	Treaty of Waitangi	-	Y
Sectors			
	Water	Y	Y
	Agriculture	Y	Y

	Forestry	Y	Y
	Transport	Y	Y
	Service	Y	Y
	Telecom	Y	Y
	Manufacturing	Y	Y
	Banking / Finance	Y	Y

5.4 Four socio-economic factors affecting the primary sector

5.4.1 Population

The population is at the core of anthropogenic climate change. The Kaya identity (Kaya, 1990) summaries succinctly the role people have in greenhouse gas emissions. It states that the total emissions are expressed as the product of four factors: human population, GDP per capita, energy intensity (per unit of GDP), and carbon intensity (emissions per unit of energy consumed)[6].

The implications for changes in risk are:

- Population growth drives consumption.
- Every added person increases carbon emissions.
- Population growth globally affects deforestation as land is converted for agricultural use to feed a growing human population.
- More people mean more demand for energy, e.g., oil, gas, coal and other fuels and more demand for products.

5.5 Land-use change

The land is critical as it provides the principal basis for human livelihoods and well-being, including the supply of food, feed, fibre, fresh water, timber, energy and other ecosystem services essential to humanity's existence. Consequently, the land is both a source and a sink of GHG's and is vulnerable to climate change impacts. Landuse change is mainly unregulated in NZ, though restrictions are based on the RMA (e.g. nitrate limits). Currently, there are several National Policy Statements (NPS) on [protecting] highly productive land, [protecting] biodiversity in development as well as recently enacted NPS's on fresh water and forestry as well as the replacement for the RMA.

The expected financial returns drive change in land use. Conversion to agriculture increases emissions; agriculture accounts for around 45% of eCO_2 emissions. Pressures from future worlds that prioritise food production will exacerbate risks to forests and forestry business and increase pressure on forests, vegetation, and freshwater systems providing key ecosystem services (Table 4).

[6] Kaya identity - Wikipedia. https://en.wikipedia.org/wiki/Kaya_identity

Land Use	SSP 1	SSP 3	SSP 4	SSP 5
	• Strong environmental regulation • Emissions pricing • Strong role for sustainable production • Sustainable landscapes • Recognition of multiple benefits from land • Circular/bio economic models • Local processing	• Less regulation • Production emphasis and priority • Low technology improvements	• Primary sector business will be exposed to more risk from a lack of adaptation • NZ primary producers should prosper in a trading world that demands food and fibre • In NZ, technological improvements drive productivity gains	• A competitive world that rewards producers that are innovative, manage costs. • Strong trade creates a positive feedback loop with more investment in technology and IP
Forestry	• Environmental regulation will protect species, soil, and water. • Forestry will have a large sequestration role • There will be alternative harvest and silvicultural systems, potentially reducing clear-felling and increasing cost • Forests will be established and maintained for multiple benefits and products (fibre, timber, bioplastics, bioenergy) • Potential for payment of ecosystem services • Timber is a green product • Afforestation rates increase	• Established only on marginal lands • Land use is prioritised to profitable sectors. Hence afforestation rates are low • There is limited consideration of other forest benefits. • Harvesting on erosion-prone soils will create land and water degradation • Forest land area will decrease • Forest sequestration will decrease	• Forestry as a whole will prosper. Though its mitigation role will mean that land-use change decisions will come with surrender costs • Forests will continue to have a strong mitigation role • Forests are exposed to increased risks, where the sector meets the costs of adaptation (including planning) • Demand for wood products as well as sequestration payments means that forestry can compete for land	• There is a role for forests in global mitigation policy

	• With more land in forestry (from agriculture), water quality will improve as inputs are cut.	• Forest land decrease and conversion to agriculture will have positive impacts on water quality		
Agriculture	• Regulations will protect waterways, on-farm biodiversity will be protected and managed, with lower land-use efficiencies (though this may be mitigated with technology) • Alternative farm animal systems (with animal welfare prominent) • Land will be in demand • Global niche products with sustainability	• Agriculture will continue to utilise the best land • Agriculture will still be an intensive industry with probable land and water degradation	• There will be strong regulation on on-farm CO_2 efficiencies • Agriculture emissions will be priced • Under medium and extreme climate change, there will be water availability pressures	• High demand leads to marginal land conversions

Table 4: Landuse implications for each of the SSP's

5.6 Trade

International trade has increased dramatically over the last 60-70 years, where most NZ wealth comes from export earnings. The export of goods (June 2019) was $59.3 billion: Dairy: $16.1b; Meat: $8b and Wood: $5b.

Trade has three effects on emissions:

1. The scale effect: GHG emission increases may result from increased economic activity.
2. The composition effect: Trade may affect the relative size of the various sectors that make up a country's production, leading to the expansion of some sectors and the contraction of others. The changes in country emissions depend on whether energy-intensive industries or high emitting sectors are expanding or contracting, depending on policies that price or restrict carbon-intensive sectors. The effect of international differences in climate change policies raises the likelihood of "carbon leakage", where measures taken by countries to limit their emissions at a national scale may result in emission-intensive businesses relocating to countries with poor emissions management, resulting in no global CO_2 reduction.

3. <u>The technique effect</u> is where technological improvements reduce the emission intensity of the production of goods and services (Grossman & Krueger, 1991).

Impacts on trade arise from how other countries respond to climate change. Future world (Table 5) scenarios include those where competition for scarce resources, protection of local economies, and lack of environmental regulation in markets can develop trade barriers, behaviours that increase the competitiveness of local industries (e.g., race to the bottom in social and ecological protections).

Rampant climate changes that impact people's ability to earn or changes household budget relativities (e.g., cost of food as a proportion of income) may affect demand for housing, higher valued food products, meat, or wool.

Table 5: Story points for Trade under different SSP's

Trade	SSP 1	SSP 3	SSP 4	SSP 5
	• Demand for sustainable and well-priced products	• Highly competitive world • Commodity products are a price taker • Limited technological improvements to production efficiencies • Regional international trading partners limits trade		
Forestry	• There is demand for forest products as green or low CO_2 intensive product • Demand will be strong for traditional products but also engineered and modified products that can substitute for concrete	• Ongoing competition from harvesting of global native forest • No real growth in productivity or product improvements • No bioenergy to speak of in NZ • High demand in construction, paper, and newsprint (i.e., traditional products) • Low demand for alternatives such as biofuels, bioplastics, and other non-timber products	• Low forest product demand • Some demand for new forest products from high-income countries	• High demand for construction • Low demand for paper and newsprint • Medium demand in packages • Limited demand for bioenergy

		• Scale effect: Forestry is medium but doesn't grow		
Agriculture	• Externalities are included in costs • Trade costs are higher • Agriculture is the backbone of the primary sectors • Builds on decades of farming improvements	• Competition drives opposition to strong environmental (including climate change) regulation • No technology improvements in methane or nitrous oxide production • The scale effect is strong. More overseas population drives more demand, especially from countries with a new middle class • The composition effect drives more land into agriculture, increasing that sector • Limited investment in technology, especially strategic or transformational, means that the carbon intensity remains high • Trade is generally constrained globally, NZ's ability to enter markets will depend on its specialisations and price	• Moderate trading environment	• High • Specialisations

5.7 Consumption

Changing consumer preferences can impact primary production, where food-specific trends drive agricultural future demand. Eight megatrends have been identified (Mathijs, Deckers, Kopainsky, Nitzko., & Spiller, 2018): health and well-being, slimness and body shape, diversity, sustainability, origin, convenience, pleasure, and naturalness. These eight megatrends, the central drivers, and resulting environmental changes are proved in Table 6.

Forest products are used in value and supply chains for packaging, secondary production, housing, and commercial real estate, particularly in environmentally aware demography. Simplistically, an increased population and an increased middle class will drive demand and consumption of timber products. Key story points across the SSPs are given in Table 6.

Table 6: Identified megatrends with their associated central drivers and environmental changes (Mathijs et al., 2018)

Driver / Cause	Environmental Change	Megatrend
Improved health care system Demographic change	Increased life expectancy Higher proportion of seniors	**Health**
Ubiquitous availability Decreasing relative prices Genetic predisposition	Obesity	**Slimness**
Failed states Globalisation Variety seeking	Global disparities Migration flows	**Diversity**
Industrialisation Greenhouse gases	Climate change Biodiversity Loss	**Sustainability**
Convenience Food crises Concerns re GMO	Countertrend to industrialisation Desire for health Labelling requirements	**Naturalness**
Changed professional development Increased “work” involved with consumption	Lack of time Female employment Need for labour saving methods	**Convenience**
Increased polarisation Status consumption / Distinction	Countertrend to convenience Wider ange of products	**Pleasure**

Individualisation		
Sustainability Globalisation	Climate change Countertrends to diversity	**Origin**

The impact of these megatrends on EU-farming is given pictorially in Figure 5. The push towards healthy foods (e.g., vegetarianism, alternative proteins) and low carbs and fruit developed sustainably should have no surprise. Of interest is the origin, though this encompasses traditional production, produce and purchaser common values, primary production, but can include local production.

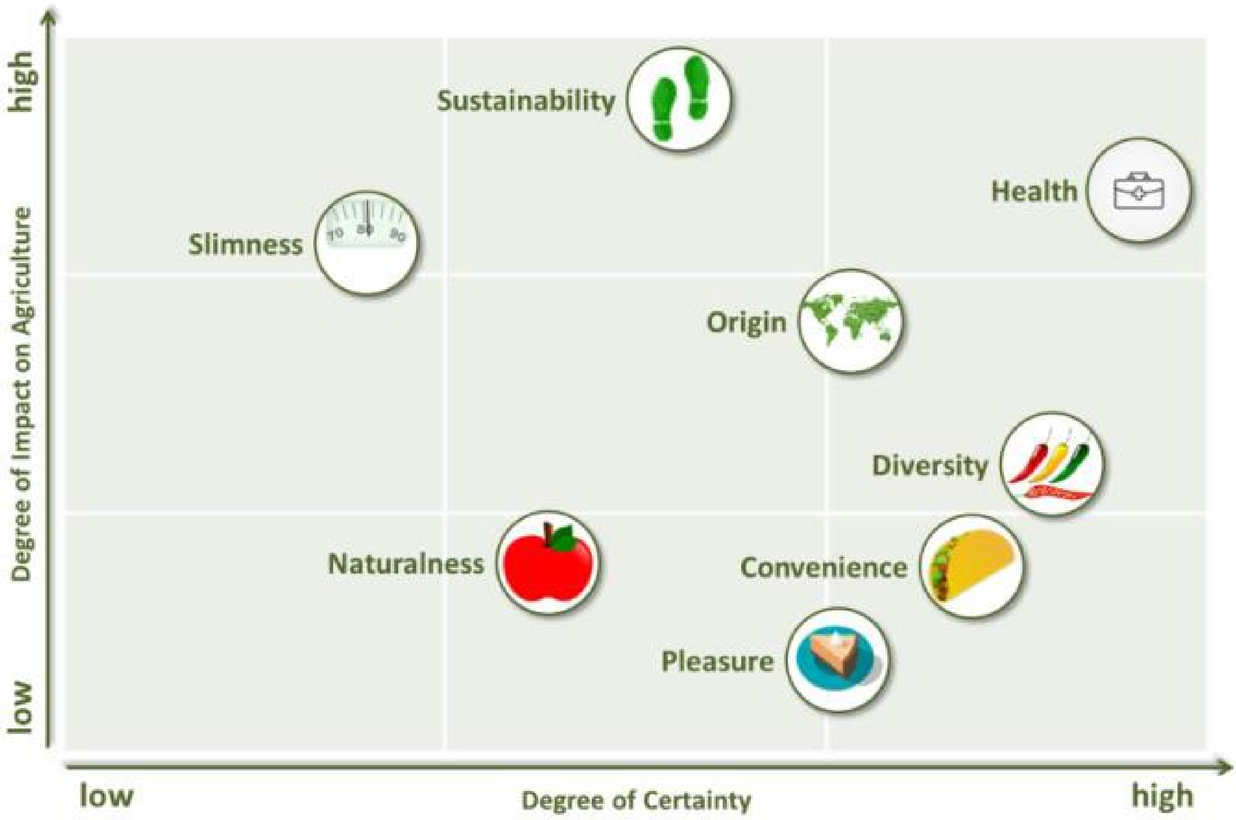


Figure 4: Degree of impact of the megatrends on agriculture and degree of certainty (Mathijs et al., 2018).

Table 7: Story points for Consumption under different SSP's

Consumption	SSP 1	SSP 3	SSP 4	SSP 5
	• NZ is a respected supplier of primary produce	• NZ is a small but important provider of high-end products that return high yields. Demand for milk powder still dominates, especially in the new middle and upper classes. • Costs of exporting logs and increased demand for timber products shift NZ to more processed product exports than round wood. • Limited consumer barriers to products based on NZ environmental standards		
Agriculture	• Demand for traditional products will decrease, e.g. less meat is eaten internationally • Demand for plant-based products will increase • Consumers will continue to purchase green and sustainable products • Purchase decisions become more values-based • Non-sustainable producers abandoned by purchasers • Alternative foods, products based on shared values that are free from anything deemed harmful, are preferred (and potentially short-lived in a competitive market) • Trade is ethics based	• Traditional products continue to dominate, though with an emphasis on convenience • There are high food prices due to poor production efficiencies and a lack of technological innovation • Trade rivalry will be limiting for dairy production	• Trade in products to the wealthy ('elites') internationally dominates NZ • Can innovate to meet elite demand • Dairy is reliant on imported feedstocks, especially in drought and production limited areas of NZ • Meat and dairy consumption is high • In international markets, their local environmental factors dominate, not as concerned for NZ environmental standards	• Strong meat demand and meat diets • Open trade allows NZ to target those that want our products, probably can be exclusive • Prices are low due to technological efficiencies • Production is consolidated and dominated globally by international corporates • Carbon pricing
Forestry	• Has a very positive environmental credential – sequestration, biodiversity, cement substitution • Multiple fibre use – Biofuels, timber, pulp, bioplastics	• There is a low demand for forest products • Commodity products • Limited investment in onshore processing	• Opportunities for high value timber products	• High demand for forest products

	• More niche/high-value products in smart packaging and multi-story buildings			

5.8 Example: Finland's extended SSP narratives for agriculture

Finland co-developed SSP narratives for the agriculture and food sector (Lehtonen et al., 2021). Discussions focused on five themes – Diet, Food industry, Agriculture and Horticulture, Technology, and Environment, from the perspectives of consumers, producers, and policymakers.

	2018 situation[a]	SSP1: Taking the green road	SSP3: A rocky road	SSP4: A road divided	SSP5: Taking the highway
A. Diet					
Meat and dairy-based	M	↘	↗	↗	→
Plant-based	M	↗	↘	→	→
Health concerns	M	↗	→	↘	→
Sustainability concerns	M	↗	↘	↘	↘
B. Food industry					
Trade liberalisation	M	↗	↘	↗	↗
Foreign ownership	L	→	→	↗	↗
Market power	L	→	↗	↗	→
Export orientation	L	→	↘	↗	↗
C. Agriculture and horticulture					
Role of large farms	M	→	→	↗	↗
Role of small farms	M	→	→	↘	↘
Output prices	M	→	↗	→	↘
Input prices	M	→	↗	→	↘
Coupled subsidies[b]	H	↘	→	↘	↘
Decoupled subsidies[c]	H	↘	↘	↘	↘
Effectiveness of A-E policy	M	↗	↘	→	→
D. Technology					
Productivity[d]	M	↗	↘	↗	↗
IT utilisation	L	↗	→	↗	↗
New products and methods	M	↗	↗	↘	↗
E. Environment					
Agricultural GHG emissions	H	↘	→	↘	→
Water pollution	H	↘	→	→	↘
Biodiversity	M	↗	↘	↘	↘

Table 8: Summary of selected developments in the Finnish agriculture and food sector out to 2050 and beyond, organised by themes (with respect to 2018). L = low; M = medium; H = high. Arrows show the direction of change from 2018. (Source: (Lehtonen et al., 2021))

Factors, drivers, concerns within each theme are given in Table 7, along with a visual interpretation on how they may change under different climate scenarios, e.g., meat consumption is projected to decline under SSP 1, increase under SSP 3 and SSP 4, and stay on the same track in SSP 5. The transition risk to meat producers under a world that addresses climate change increase, either requiring (among other things) a pushback response or a response that reduces emissions from agricultural practices. Trade liberalisation increases under SSP's 1, 4, 5 but declines under the more internally focused SSP 3. Companies that see growth from exporting need to understand risks in the trading environment – access, barriers and tariffs, protectionism, returns)

5.9 Example: Shared Socioeconomic Pathways for European agriculture and food systems: The Eur-Agri-SSP's

Mitter et al. (2020) SSP's provide regional and sectoral detail for European agriculture and food systems. The five Eur-Agri-SSP's are: (1) Agriculture on sustainable paths, (2) Agriculture on established paths, (3) Agriculture on separated paths, (4) Agriculture on unequal paths, and (5) Agriculture on high-tech paths.

The Eur-Agri SSP's describe alternative plausible qualitative evolutions of multiple drivers of particular importance and high uncertainty for European agriculture and food systems. The SSP development used the following drivers of socio-economic risk (no. of indicators in brackets):

- Population and urbanisation (11)
- Economy (22 in 4 categories)
- Policies and institutions (13)
- Technology (3)
- Environment and natural resources (3).

5.10 Behavioural understanding of risk and adaptation

To understand how climate change adaptation may affect the primary sectors, we piloted a segmentation of the sector based on climate change risk and adaptation behaviours in farmers.

The aim was to elucidate information about:

- Risk profiles, Environmental orientation, Farming background and education; Reactive vs proactive decision-making preferences; Innovator level and sources of learning; Farming sector; Farm attributes, including the composition of activities; and Farming motivations (Table 3, Appendices 1-3),
- Ontological information about these stakeholders: their membership of professional groups or organisations, farm location, and neighbourhood farming connections.
- Behavioural responses to the scenarios were evaluated in questions about economic, governance, management, capability impacts. The survey questions were asked in a small group workshop setting or individually by primary industry decision-makers who, for example, took the survey home to complete.
- The decision-maker responses to the elements of future risk described in the scenarios.
- The decision-maker expectations of, e.g., profitability, ownership changes, land-use options and capability.

We identified primary industry decision-maker type or segments using an adapted set of survey questions taken from the Survey of Rural Decision Makers (Brown et al. 2013) and using a refined set of future scenarios.

5.10.1 Primary sector simplified scenario development

Three socioeconomic scenarios were developed: 'High-constraints,' 'Low constraints,' 'Innovative NZ.' In the 'High constraints' scenario policy, market-driven outcomes drive high costs of carbon emissions and other regulatory mechanisms, potentially constraining certain types of primary industry activity. The 'Low constraints' scenario describes a situation where these impacts are considerably reduced. 'Innovative NZ' describes a world where technological fixes (e.g., zero-carbon transport) can mitigate some economic constraints under the 'high constraints' scenario, inferring that both scenarios develop within a similar future space. We do not consider it likely that the 'innovative NZ' socio-economic scenario would be contiguous with a 'low constraints' future because the intensive technological investment required to reduce emissions will only occur alongside policies that highly constrain those emissions.

Four scenarios were selected for the survey and the workshop setting (Table 8). The period 2040 was considered the most immediately policy-relevant and meaningful period for understanding adaptation responses. The survey method and description are given in appendix 6.

Table 9: The four combined scenarios of climate and socio-economic change used in our survey with decision-makers

Combined scenario	Combination 2040
1	'LOW' + 'Low constraints'
2	'LOW' + 'High constraints'
3	'HIGH' + 'Low constraints'
4	'HIGH' + 'High constraints'

5.10.2 Results

Sixteen primary industry decision-makers were engaged in Waikato, Bay of Plenty, and Hawkes Bay The mean farm size of this group was 356 (±128 s.e.) hectares and had a 66/33 male: female ratio. The mean age of our study group was 51 (±2.9) years, and the mean duration of their careers was 26 (±3.6) years. The majority managed land is held in a family trust (31%), with others (25%) being owner-operators. The main primary industry activity on each of these farms was dairying (56%), with sheep and beef (19%), forestry (19%), and arable (6%) making up the main activity on other farms.

The principal component analysis identified four decision-maker typologies:

- Environmentally aware diverse-grazing farms: Farms involved in a range of diverse activities (e.g., sheep and beef grazing, pigs, goats, chickens, with horticulture or forestry) had stronger tendencies towards environmental awareness
- Large sheep-beef, risk-takers: Farms with a primary focus on sheep and beef activity only tended to be characterised by having a larger overall size, and this sub-set of decision-makers also tended more towards risk-taking behavioural preferences
- Large, well-connected dairy farms: Dairy farms were characterised by a tendency towards valuing being 'highly-productive' with a sub-set of this group also tending to have stronger connections to other farmers while also being larger.
- Highly productive dairy farms: Dairy farms were characterised by a tendency towards valuing being 'highly-productive'.

5.10.3 Analysis of behaviour around risk

A principal component analysis (PCA) was used to evaluate the behavioural responses by decision-makers to the information contained in our four scenarios of 2030 to 2040 future operating conditions.

The initial assessment determined that only behavioural responses to scenario 4, the most severe combined scenario, were identified as meaningful to develop a response. We interpret this as an indication that our study group had a potentially low level of sensitivity to the information in the moderate scenarios, with behavioural responses only provoked when potential future conditions were described as highly unfavourable.

In using the percentage area by farming activity as a measure of changes in individual decision-maker preference, the analysis found very strong distinctions between three groups under the most severe combined scenarios:

- ‘Environmentally aware sheep and beef farms’ which were associated with a shift to ‘Forestry’;
- ‘Pigs and goats’ grazing farms with a shift to ‘Arable’; and
- ‘Dairy’ farms with shifts to a range of activities including ‘Sheep and beef’, ‘Deer’, ‘Horticulture’ and ‘Pigs and goats’.

‘Dairy’ remained one of the future land-use options, even under the most severe combined scenario, suggesting that some existing dairy farmers in our study group would maintain the same land-use preferences even under the most severe projected future conditions.

5.10.4 Discussion

6 Segmentation

The segmentation analysis indicates that farming activity is a strong predictor of individual decision-maker typology grouping. Secondary, farm size, farm connectedness, and environmental motivations have contributing roles in defining groupings. These outcomes suggest that a survey could be simplified by targeting a subset of these questions in future work. This rationale would be more efficient and faster to implement with study groups.

7 Use of scenarios

The scenario development process showed that to work effectively with primary industry decision-makers, potentially complex scenario narratives of future conditions require simplification so that they are meaningful for rapid engagement with stakeholders in a workshop setting. Climate change and socio-economic scenarios are themselves simplified narratives of possible futures. However, to determine differing behavioural responses in our study group, our analysis required several permutations of these in simplified form, derived from a range of combined biophysical and socio-economic futures using an analysis of scenario literature. Our work demonstrated that only the most severe of these combined scenarios for the period 2030 - 2040 (combined scenario 4) effectively elicited a meaningful behavioural response in our study group.

8 Caveats

Our analysis of activity type by land area suggests that the study group was more weighted towards decision-makers whose main activities are dairy or arable farming. Forestry decision-makers were under-represented in the study group. Such potential biases and the limited size of our study may have influenced our results and interpretation. e.g., the findings that dairy activity was a favoured land-use decision, even under the most severe combined scenario describing conditions highly adverse for dairy farming.

A more representative selection of primary industry decision-makers from our study region would be needed to develop this work further. We anticipate that a full investigation covering a similar regional area would require between 100 and 300 survey responses in total.

8.1 Findings

The clusters for the most severe combined scenario of future conditions (combined scenario 4) demonstrated that present-day farming activity was also the best individual predictor of future decision-making behaviour.

Decision-makers whose current primary activity was sheep and beef grazing and a tendency for greater levels of environmental awareness expressed a greater preference for forestry as an adaptation response to the more difficult biophysical and economic conditions presented in combined scenario 4. This finding suggests that levels of environmental awareness combined with present-day farming activity inform a tendency for forestry to be chosen as a future land-use option under the more challenging conditions described in our scenario.

Potential shifts characterised decision-makers whose main activity was pig and goat grazing to arable farming under these conditions.

However, the greatest difference in potential responses arose with dairy farming decision-makers, who strongly preferred to remain in dairy under combined scenario 4. This group also indicated potential decision-making preference for future shifts to sheep and beef grazing, deer, horticulture, and pig and goat grazing.

Overall, this supports our previous interpretation that the dairy farm decision-makers in our study group were relatively resistant to land-use change shifts away from dairying. However, the decision-making preferences evident in this group include a range of other grazing options (sheep and beef, deer, pigs and goats) and horticulture. Thus, a range of possible land-use options are potentially involved in future decision-making with this group. Still, our study poorly characterises these responses due to the low sample numbers involved.

The research determined that behavioural responses to perceived future risk were only apparent alongside the most severe combined scenario of future conditions.

We determined that the strongest overall predictor of both decision-maker typologies and behavioural responses to future risk was primary-industry activity, with dairying having the greatest overall influence in this.

We evidenced large potential changes in future land use according to decision-making around perceptions of risk. These suggest that adaptation to future climatic, biophysical and socio-economic conditions will result in land-use changes for these regions.

Our findings suggest that arable farming, together with forestry, will increase in land cover. However, practitioners specialising in dairy may have a low behavioural preference or personal capacity to change farming activity, even under the most severe risk conditions.

8.1.1 Acknowledgements

AgFirst, Waikato helped connect our study with primary industry decision-makers in their network.

9 OBJECTIVE 2: UNDERSTANDING KEY RISKS AND EVALUATING KEY INDICATORS OF NATIONAL SCALE RISK

9.1 Introduction

Climate change is unequivocal, with anthropogenic emissions the key driver. Equally unequivocal are the risks that a changing climate creates or enhances for people (communities and societies), ecosystems, and economies. Understanding the nature, extent, and severity of impacts from risks is a critical step in mitigation and adaptation planning. Decision-makers need to understand risk occurrence and change over time. Outcome probabilities as climate change increases, noting that risk is subjective, and both temporally and geographically variable, as well as context-specific.

Risks are derived, exacerbated and mitigated from both physical and socio-economic drivers. The severity of potential harm (risk) and impact is determined by society's and the environment's vulnerability and exposure. The previous section has discussed the role of SSPs in defining a range of plausible different futures from which novel sources of risk can be explored. Previous SLMACC research has detailed at least a qualitative understanding of climate change's physical hazards and impacts. A summary developed from the 2012 SLMACC review (Clark et al., 2012) is provided in appendix 2.

The IPCC also identifies governance as a source of risk (Figure 1), which enables people/organisations to undertake risk management or adaptation planning, including understanding behavioural responses of primary sector managers to different risk scenarios.

As the UK CCC notes, "*risk assessment needs to be made on a regular and consistent basis, so that areas of uncertainty, any changes or trends in expert judgement are clearly visible over time. This could be facilitated by the identification and use of a consistent set of metrics or indicators*." (Committee on Climate Change and China Expert Panel on Climate Change, 2018) (Author emphasis).

Indicators inform whether adaptation is working to reduce climate change risk and provide information on the effectiveness of adaptation actions, hence, developing efficiencies with more targeted and cost-effective options. In addition, indicators can simplify understanding of complex systems where it is impossible to know everything about the system where indicators provide indications of state, extent and change within the system.

Indicators are widely used in environmental reporting, e.g. Montreal Process – Sustainable Forestry, Ecosystems, Sustainable development goals, and Economic Performance (United Nations Statistical Commission, 2017) and Environmental Indicators[7] that provide data for environmental reporting.

9.2 Introduction to indicators

This section reviews how indicators from the US, UK, and EU support climate change risk reduction.

The main aim of this initial research was to identify what indicators systems are being used, what were they trying to achieve (goals), and how were they constructed.

9.3 UK Experience – Climate Adaptation Indicators

The UK Climate Change Commission (King, Schrag, Zhou, Ye, & Ghosh, 2015) identifies three categories of risk to assess:

1. The future pathway of global emissions.
2. The direct risks arising from the climate's response to those emissions.

[7] https://www.stats.govt.nz/tools/environmental-indicators

3. The risks to complex human systems.

9.3.1 Adaptation Indicator Framework (UK)

The adaptation indicator framework used by the Adaptation Committee is given in Figure 6. Adaptation is focused on reducing components of risk: reducing exposure, increasing adaptive capacity, reducing vulnerability.

The goals of the Adaptation Committee indicators are (Committee on Climate Change, 2019):

- To understand the extent to which adaptation is reducing exposure and vulnerability to climate change impacts.
- To understand the trends in exposure and vulnerability to climate change and understand the actions underway and the impacts those are having, and
- Whether progress is being made in managing risk.

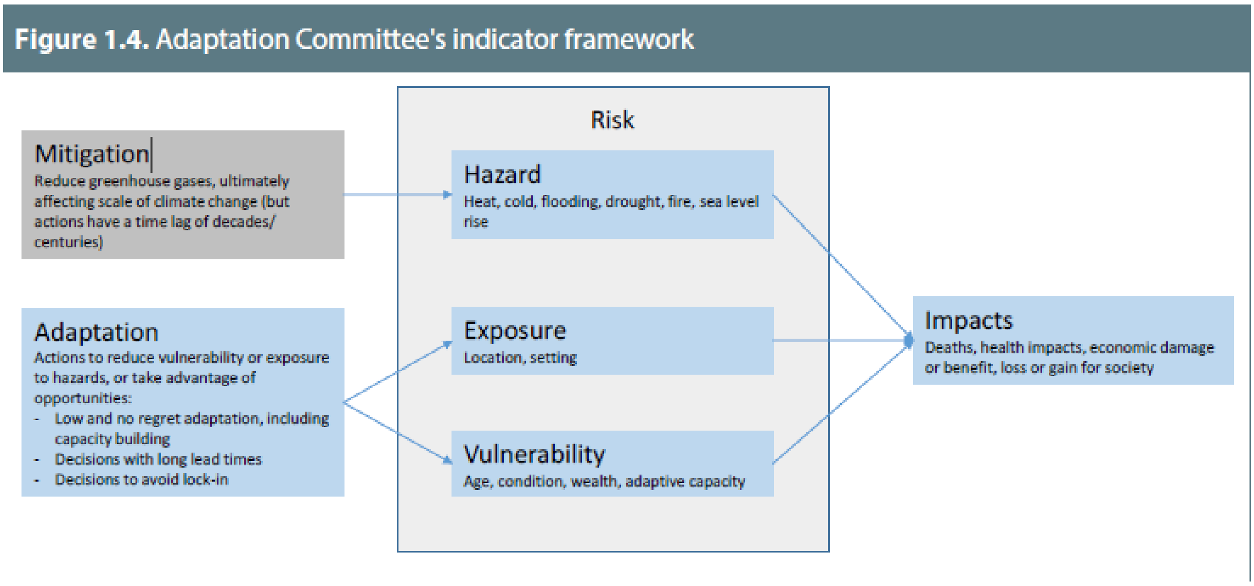


Figure 5: UK CCC ASC Indicator Framework. (Committee on Climate Change, 2019).

The UK CCC collaborated with China in developing indicators of climate risk (Committee on Climate Change and China Expert Panel on Climate Change, 2018).

Three categories of risk are identified, providing a focus for indicators.

1. Emissions risk – the chance that the world is on a high emissions pathway. Indicators monitor emissions; the proof of concept focused on the energy sector and CO_2 emissions. While not as relevant to NZ, a set of 12 indicators focused on the international effect for energy decarbonisation.
2. Direct impact risk – relating to the climate impact on services and sectors of interest. Indicators for hazards, exposure, and impact have been developed for eight subcategories for both a low- and high-emission pathway (aka RCP2.6/IEA Sustainable development; RCP8.5/IEA Current Policy Scenarios). Indicators are used to compare the impacts from a low or high pathway.
3. Systemic risk – where direct climate impacts propagate through complex systems. Risks are presented in narrative form and as a cascade, i.e. primary impact, 1st order impact, 2nd order

impact etc. Points in the chain that propagate the effects are identified, with indicators for exposure and vulnerability developed.

These risk categories are embedded in the current reality, where:

- *Global reductions in CO_2 emissions are dangerously off-track,* so the risk of not achieving a 2°C maximum global warming target is high, and the resultant high emissions pathway provide material risk.
- *There is a very high risk to social, economic, and environmental systems with a high emission pathway*. Cascading impacts in economic and environmental systems will have major disruptions to global human systems – food supply, security, health, finances and infrastructure. Critical tipping points could result in extreme social disruption at large scales.
- At the global scale, even with a low emissions pathway, *systemic risks are expected to increase***,** again with impacts to human systems, increasing vulnerabilities. Source of risk includes poor responses to impact, inequities in vulnerability and adaptive capacities, and governance and economic policy changes.

The recent parliamentary report (Committee on Climate Change, 2021) identified inadequacies in the current indicator set:

- Indicators are not necessarily aligned with the need to identify tangible reductions in climate risk or resilience improvement.
- The indicator framework needs to be aligned with a Theory of Change, i.e., links between inputs, outputs, outcomes, and impacts (see also the USGCRP conceptual modelling framework).
- There are significant gaps in indicators, from a lack of impact indicators, lack of data, and the reliance on potential unrepresentative self-reported data
- Many entities have indicator sets that could be brought together
- There is a lack of funding for indicator development that would support the comprehensive assessment of adaptation progress

9.4 U.S. Global Change Research Program (USGCRP) Impact Indicators

U.S. Global Change Research Program indicator programme has the following goals (Kenney, Janetos, & Gerst, 2018; Reidmiller et al., 2018):

- Are multi-stressor impacts related to climate change getting larger, more frequent, more damaging, or less so?
- As the USA plans and implements adaptation actions, is it becoming more or less resilient to a variable climate system and other related environmental stresses?
- Given sub-national, national, and international climate plans and commitments, is the nation making progress on greenhouse gas emissions reductions?

The indicators represent reliable baselines from which change and vulnerability can be measured, assessed, and used with the conceptual model to assess improvement in resilience.

The design criteria for indicators are:

1. Focus on impact indicators for national-to-regional sectors and resources of concern.

2. Indicators need to be justified by a transparent model of how each system is structured and functions, using a conceptual modelling framework that articulates the current understanding of the system's complex state and dynamics and includes indicators that reflect these elements (National Research Council, 2000). Hence, indicators are built on an interdisciplinary understanding of the system.

3. The indicators must address the aims of the program – a documented relationship to climate change and variability.

4. Indicators must be related to phenomena that are of national importance.

5. Indictors selected are boundary objects, i.e. designed and selected to be used by different individual and decision specific uses (Wiggins, Young, & Kenney, 2018).

The DPSIR and ecosystem frameworks were used to develop the indicators and conceptual models to explore human-natural system interactions.

DPSIR conceptualises environmental change through a series of causal relationships (Smeets & Weterings, 1999). Social and economic development drivers initiate environmental change; these exert *pressure* on ecosystems, which may change the *state* of ecosystems. Changes in *states* may lead to *impacts* on functioning, which may be reduced by societal and political *responses*, specifically mitigation and adaptation, which affect earlier parts of the system directly or indirectly. Mitigation acts on pressures, and adaptation improves human-natural system resilience.

Ecosystem services are benefits that society recognises as directly or indirectly coming from ecosystems (Millennium Ecosystem Assessment 2003). They are categorised as product provisioning, ecosystem process regulating, supporting services, or non-material cultural benefits.

A change in ecosystem states may lead to change in service provision and impacts (Rounsevell, Dawson, & Harrison, 2010). Hence, indicators can track trends in services and not just impacts (Kenney et al., 2018).

The overall conceptual model is given in Figure 7.

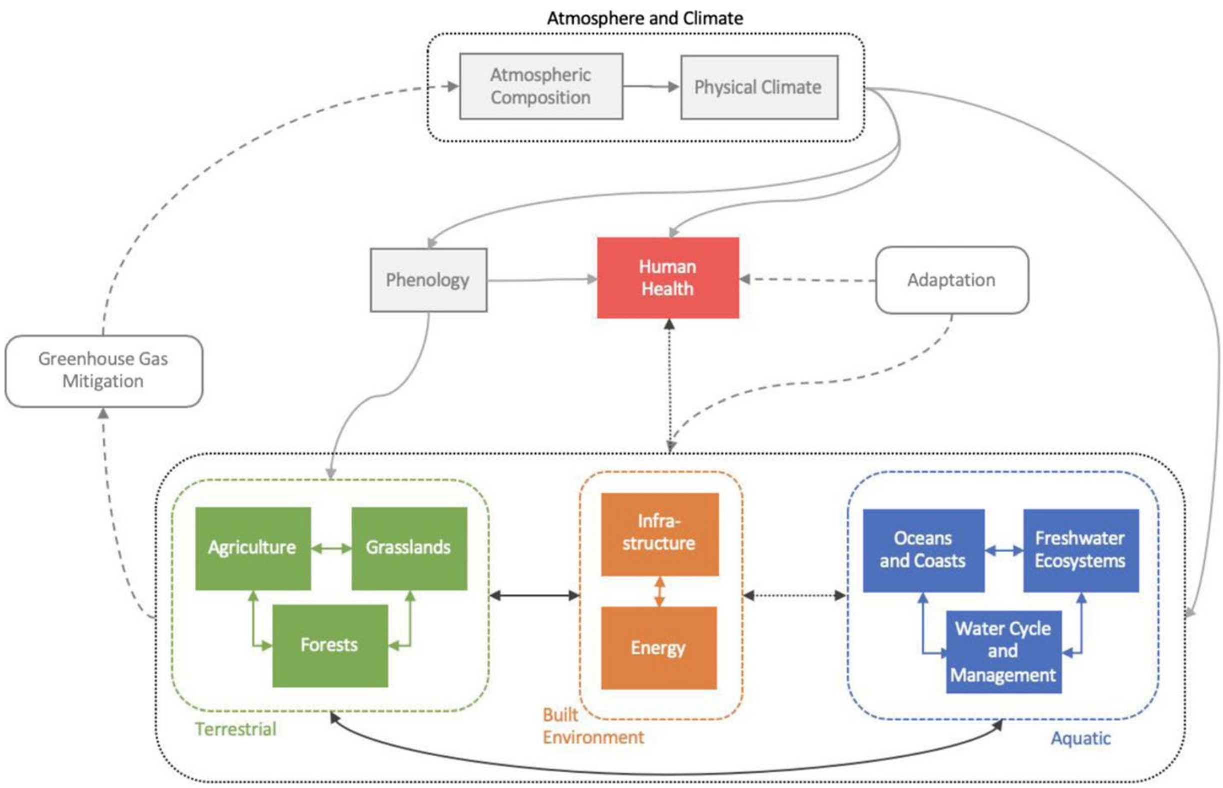


Figure 6: Overarching Conceptual Model of relationships among expert team systems (Kenney et al., 2018). The coloured boxes are areas of importance that have their conceptual models.

Indicators are developed, with links back to the ecosystem services and the conceptual model, with metrics and data sources.

9.4.1 Europe (EEA) – Adaptation indicators

There is a need to integrate adaptation into climate change responses. Indicators that focus on adaptation are oriented to understating the effectiveness and efficiencies of adaptation policies, institutions and programmes., i.e. focused on the Monitoring, Reporting and Evaluation component of a standard adaptation planning cycle.

The Climate Change Expert Group categorised EU national adaptation monitoring and evaluation systems, classified the indicators included in their reports into three broad categories:

1. Climate risks: which embrace climate hazards, climate impacts, exposure, adaptive capacity;
2. Adaptation processes, which look more at the implementation of strategies and plans and the allocation of resources; and
3. Adaptation outcomes look at the actual results of adaptation policies and plans (Vallejo, 2017).

Indictors focus on two broad categories: policy and adaptation. The adaptation policy process has four indicator categories focusing on evaluating the effectiveness of policy and its implementation:

- **Input indicator** – an indicator that provides a measure of resources, both human and financial, devoted to a particular adaptation activity, programme or intervention.
- **Process indicator** – an indicator that tracks progress in adaptation policy processes and actions.

- **Output indicator –** an indicator that relates to the direct results of an adaptation policy or action without assessing if these results lead to better adaptation outcomes.
- **Outcome indicator** – an indicator defines an explicit outcome or a result of adaptation action. Outcome indicators may also assess the level of success of specific adaptation measures, indicating, e.g. a reduction in vulnerability or improved adaptive capacity.

There is four ‘adaptation in general’ categories that focus on the components of the makeup of vulnerability:

- **Exposure indicator** – an indicator of the exposure of people, livelihoods, species or ecosystems, environmental functions, services, and resources; infrastructure, economic, social, or cultural assets in places and settings that could be adversely affected.
- **Adaptive capacity indicator** – an indicator of the ability of systems, institutions, humans and other organisms to adjust to potential damage, or take advantage of opportunities or respond to consequences.
- **Sensitivity indicator** indicates the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect. In the Disaster Risk Reduction (DRR) policy domain and knowledge communities, this is called ‘vulnerability’ (EEA, 2017a, section 1.4 and Box 1.3).
- **Composite vulnerability indicator** – an indicator that provides a metric characterising the vulnerability of a system by combining, with or without weighting, several indicators assumed to represent vulnerability, including indicators that combine two or more exposure, sensitivity, and/or adaptive capacity indicators. In some cases, this has been described as a ‘vulnerability index indicator’.

Source Mäkinen et al. (2018)

9.4.2 EEA Climate change impacts and vulnerability in Europe 2016. An indicator-based report (European Environment Agency (EEA), 2017).

This state and trends report identifies the key observed and projected climate change and impacts for the regions in Europe using indicators to identify state and trends for:

- Changes in the climate system (11 indicators)
- Climate change impacts on environmental systems (12 indicators)
- Climate change impacts on society (14)
- Multi-sectoral vulnerability and risks (7 indicators).

(Within each indicator, there can be multiple variables).

The indicators are used to support the objectives of:

- Present past and projected climate change, as well as selected impacts on ecosystems and society.
- Identify the regions and sectors most at risk from climate change impacts.
- Discuss the main sources of uncertainty in observations and projections.
- Report on key adaptation policy developments at European, transnational and national levels.
- highlight the need for further adaptation actions; and

- demonstrate how monitoring, information sharing, and research can improve the knowledge base for adaptation.

The indicators describe the observed and projected climate change and its impacts in Europe. Information for each indicator comprises 'Key messages', an explanation of its policy relevance, and an analysis of past trends and future projections, where available. In addition, data quality issues and the main uncertainties are generally discussed jointly for a group of indicators with specific policy objectives (Table 9).

Table 10: Type of indicator and policy objective

Type of indicator	Policy objective	Examples
Global climate change	Monitoring the main changes in the global climate system, which will provide the background for assessing regional climate change and its impacts	• Global mean temperature • Ocean heat content • Arctic sea ice
Regional climate change	Tracing regional climate hazards to inform regional assessment and management of climate-sensitive risks	• Heavy precipitation • Regional sea level
Climate change impacts on environmental systems and society	Assessing the sensitivity of ecosystems and society to observed climate change, estimating future impacts of climate change and the resulting adaptation needs	• River floods • Species distribution • Forest fires • Damages from extreme events

9.5 Indicators for Agricultural Systems

Climate change will increase vulnerabilities within different agricultural systems. Food, feed, and fibre systems are at risk and require the ability and knowledge to adapt to anticipate disruptions in the world's ability to feed itself.

9.5.1 USGCRP Impact Indicators - Agriculture

In the conceptual diagram (Figure 8), climate regulating services, e.g., temperature, carbon dioxide, solar radiation, or precipitation, directly impact grassland, cropping systems, livestock production, and pest dynamics. Precipitation directly affects water supply because of the feedback through the evaporation process, which returns water vapour to the climate system. The water cycle is a critical part of agricultural systems, and variation in precipitation governs the amount of water available to the grassland or cropping system. Variation in water availability is directly related to variability in production and is tempered by variation in temperature (Hatfield et al., 2011; Izaurralde et al., 2011). Linkages and feedbacks among the components in the conceptual diagram encompass the direct effects of climate on production and pests and the indirect effects induced by societal demands on ecosystem services and responses to energy and food production (Hatfield et al., 2018).

USDA Indicators for agriculture are also elaborated in Walsh et al. (2020) see Figure 9. The conceptual storyline is where changing climate and weather conditions affect biological stressors, such as insects, disease, and weeds, that influence agriculture. They also affect the availability and quality of natural resources, such as soil and water, upon which agriculture depends. The USDA Agricultural indicators provide an overview of the influence of climate change on agricultural production and the response of different components of the food system to such influences (Walsh et al., 2020).

Table 11: Indicators for agricultural response to climate change (Hatfield et al., 2018)

Agricultural component	Climate factor	Impact on agricultural system	Indicator
Livestock	Extreme cold/heat events	Lost productivity, mortality	The annual sum of temperature-humidity index values and wind chill index values for a given location
Livestock	Extreme climate events	Lost productivity, mortality	The annual sum of the comprehensive climate index for a given location
Soil	Intense rainfall events	Soil erosion and loss of topsoil, nutrient runoff	Increase in R-value, rainfall intensity
Soil	Carbon sequestration, greenhouse gas exchange	Soil quality, water infiltration, nutrient cycling, soil aggregation, carbon sequestration	Organic carbon changes
Soil	Precipitation	Soil water content and infiltration	Water availability for plant production
Plants	Temperature	Phenological development	Changes in the onset of phenological development, e.g., bud break, the first flower
Plants	Temperature	Chilling hours for perennial plants	Sufficient exposure to temperatures below a species-specific threshold to induce flowering
Plants	Temperature	Growing degree days and plant development, phenology, average annual minimum temperature	Plant hardiness zone map
Plants	Temperature, precipitation, and CO_2	Gross and net primary productivity	

Productivity of ecosystems			
Plants	Temperature, precipitation, and CO_2	Yield, biomass	Productivity and economic return of crop production systems
Pests	Temperature and humidity	Increased insect or diseases pressures	Shifting ranges and populations of insects and diseases
Pests	Temperature and precipitation	Increased weed pressures	Invasive weed distribution
Economics	Extreme events in temperature and precipitation	Loss of productivity, crop, or livestock losses	Crop or Livestock insurance claims and indemnities

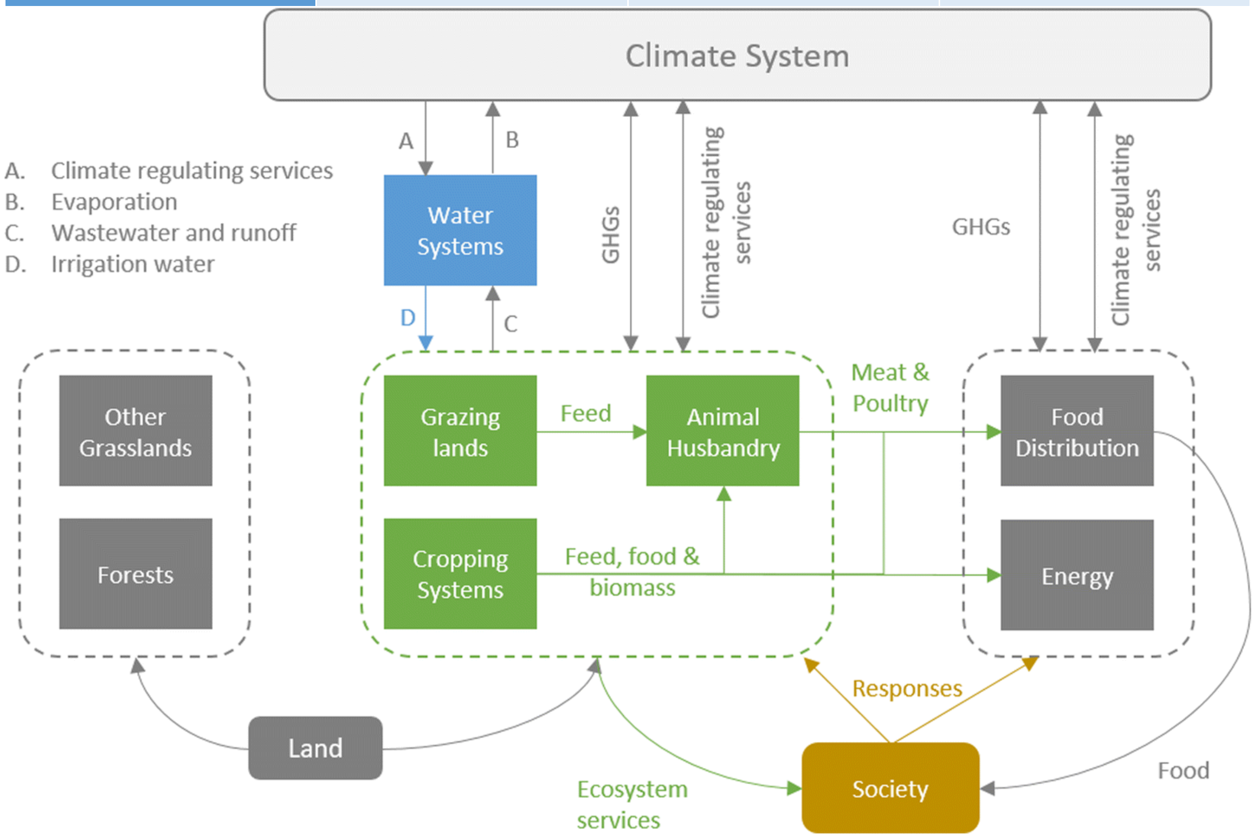


Figure 7: Conceptual diagram of potential indicators of climate impacts on agricultural systems (US) (Hatfield et al., 2018).

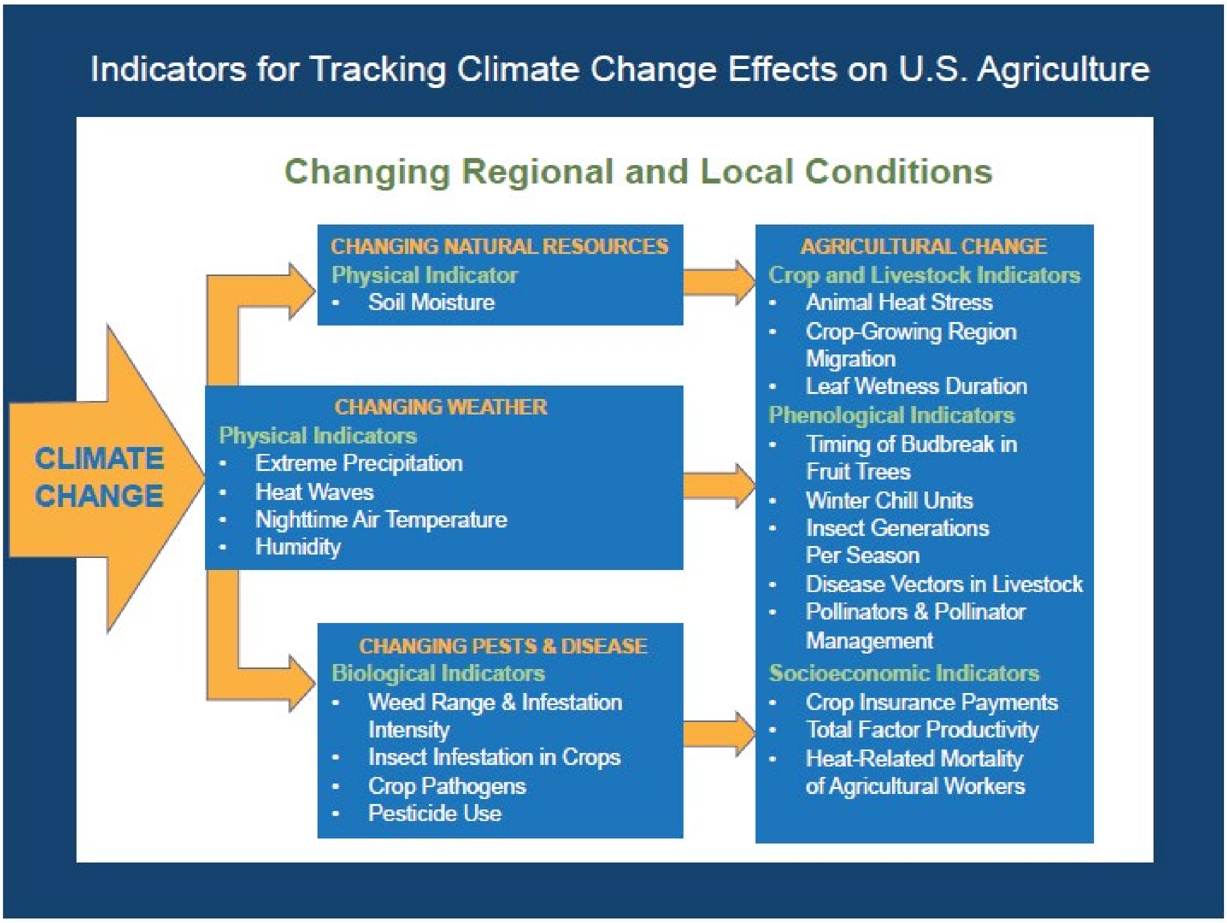


Figure 8: Climate influences on agricultural production and food system indicators (Walsh et al., 2020).

(Forestry indicators from, e.g., the US and EU are focused on natural forest systems which form the basis of their forest economies rather than plantation forests)

9.5.2 UK Indicators for Agriculture and Forestry

The following table (Table 11) provides the complete set of the UK's agricultural and forestry indicators[8].

Table 12: UK Agricultural and Forestry Indicators, with description, type and data availability

Water demand by agriculture			
Indicator No.	**Indicator Description**	**Indicator Type**	**Data availability**
AF1	Total abstraction and consumption of public water supply for agriculture	Vulnerability	
AF2	Total water demand for crop irrigation and livestock	Vulnerability	
AF3	Volume of abstraction for agriculture from catchments at risk of water scarcity	Exposure	

[8] https://www.theccc.org.uk/wp-content/uploads/2015/06/2015-06-25-ASC-indicators-by-adaptation-priority.xlsx

AF4	Amount of crop production in climatically unsuitable areas	Vulnerability	Data only available for two years
AF5	Agricultural losses from drought	Realised impact	
AF6	Total number of farms implementing water efficiency measures	Action	
AF7	Total on-farm water storage capacity	Action	
AF8	Investment in research into water efficiency for cropping/livestock	Action	
Flooding of agricultural land			
AF9	Area of Best and Most Versatile agricultural land reliant on drainage	Vulnerability	
AF10	Proportion of drainage infrastructure in poor condition	Vulnerability	
AF11	Agricultural losses from flooding/waterlogging	Realised impact	
AF12	Investment in drainage infrastructure	Action	
AF13	Proportion of Environment Agency flood asset systems protecting agricultural land in target condition	Action	
Fertility of agricultural soils			
AF14	Area of agricultural land covered by crops at high-risk of soil erosion	Vulnerability	
AF15	Area of agricultural land covered by crops at low-risk of soil erosion	Vulnerability	
AF16	Area of agricultural land losing soil organic carbon, by grade	Vulnerability	
AF17	Area of agricultural land converted to development, by grade	Vulnerability	
AF18	Area of agricultural land under minimum/no tillage, by grade	Action	Wheat only
AF19	Area of agricultural land covered by soil conservation measures	Action	
AF20	Investment in research into soil conservation	Action	

AF21	Agricultural losses from soil erosion	Realised impact	
Prevalence of new and existing pests and diseases			
AF22	Agricultural losses from pests/pathogens	Realised impact	
AF23	Timber losses from pests/pathogens	Realised impact	
Climate suitability of tree species			
AF24	Area of Forest Estate affected by wildfires per year	Realised impact	No time series
AF25	Area of woodland being sustainably managed	Action	
AF25	Proportion of timber trees planted in areas likely to be suitable in 2050	Action	
AF26	Diversity of tree species delivered for planting by the Forestry Commission	Action	
AF27	Proportion of woodland in active management	Action	
Innovation and knowledge transfer			
AF28	Total factor productivity of UK agriculture	Vulnerability	
AF29	Research and development spend on agriculture	Action	
Ecological condition of farmed countryside			
NE15	Area of agricultural land under targeted agri-environment schemes (HLS)	Action	
NE16	Area of agricultural land under non-targeted agri-environment schemes (ELS)	Action	
NE17	Area of agricultural land under ELS options identified as priority for climate change	Action	
NE18	Number of farmland bird species in decline (long-term and short-term)	Vulnerability	
NE19	Number of specialist farmland bird species in decline (long-term and short-term)	Vulnerability	

NE20	Number of farmland butterfly species in decline (long-term and short-term)	Vulnerability	
NE21	Number of farmland bat species in decline (long-term and short-term)	Vulnerability	
NE22	Number of wild bee species in decline (long-term and short-term)	Vulnerability	
Business			
Business impacts from severe weather			
BUS4	Proportion/number of businesses at risk of flooding with business continuity plans in place	Action	
BUS5	Proportion/number of businesses at risk of flooding taking up property-level flood protection measures	Action	
BUS6	Number of businesses with insurance for flooding events (weather damage and business interruption)	Action	
BUS7	Losses to businesses from flooding events (direct and indirect)	Realised impact	Available for some flood events only
BUS8	Insured losses within the UK from extreme weather events	Realised impact	
Supply chain interruptions			
BUS9	Proportion of inputs into goods consumed in the UK from countries at high risk from climate change	Exposure	Data only available for one year
BUS10	Losses to businesses due to disruption to supply chains caused by severe weather events	Realised impact	
BUS11	Proportion of UK-based multi-national companies assessing risks and opportunities to their supply chains from extreme weather and reduced water availability	Action	

The UK CCC undertook a rapid review of existing indicators against a theory of change framework and has produced an indicator wish-list for all sectors. These indicators are in Table 12

Table 13: UK CCC Natural Environment Priority adaptation indicator update[9]

Chapter	Adaptation priority	Adaptation Indicator	Current or wish list	Geospatial scale	What does the indicator measure?			Trend direction to indicate success	High-level goal(s)
					Action	Theory of Change step	Climate risk category		
Natural Environment	Agricultural productivity	UK agricultural R&D funding specifically for adaptation measures (water storage and drainage infra, water efficiency)	Wishlist	National	Yes	Input	Vulnerability	Upward trend	Reliable supply of food and fibre, Thriving Plants and Wildlife
Natural Environment	Agricultural productivity	Soil erosion levels	Wishlist	Regional	Yes	Impact	Hazard	Downward trend	Reliable supply of food and fibre, Mitigation of climate change, Thriving Plants and Wildlife

[9] https://www.theccc.org.uk/wp-content/uploads/2021/06/Cross-sector-adaptation-indicators.xlsx

Natural Environment	Terrestrial habitats and species	Soil organic carbon (SOC) and soil biota levels	Wishlist	Regional	Yes	Outcome	Vulnerability	Upward trend	Cross-cutting
Natural Environment	Agricultural productivity	On-farm water storage capacity	Current	National	Yes	Output	Vulnerability	Upward trend	Reliable supply of food and fibre, Thriving Plants and Wildlife, Reliable supply of clean water
Natural Environment	Agricultural productivity	Volume of water abstracted for agriculture per unit of production.	Current	National	Yes	Output	Vulnerability	Downward trend	Reliable supply of food and fibre, Reliable supply of clean water, Thriving Plants and Wildlife
Natural Environment	Agricultural productivity	Volume of abstraction for agriculture from catchments at risk of water scarcity	Wishlist	Regional	Yes	Outcome	Exposure	Downward trend	Reliable supply of food and fibre, Reliable supply of clean water, Thriving Plants and Wildlife

Natural Environment	Agricultural productivity	Total number of farms implementing water efficiency measures	Wishlist	National	Yes	Outcome	Vulnerability	Upward trend	Reliable supply of food and fibre, Thriving Plants and Wildlife
Natural Environment	Agricultural productivity	Amount of crop production in climatically unsuitable areas	Wishlist	Regional	Yes	Outcome	Exposure	Downward trend	Reliable supply of food and fibre
Natural Environment	Commercial Fisheries & aquaculture	Percentage of UK fish stocks at full reproductive capacity	Current	National	Yes	Outcome	Vulnerability	Upward trend	Reliable supply of food and fibre
Natural Environment	Commercial Fisheries & aquaculture	Percentage of fish stocks at present in UK water that are harvested sustainably	Current	National	Yes	Outcome	Vulnerability	Upward trend	Reliable supply of food and fibre
Natural Environment	Commercial Fisheries & aquaculture	Volume of water abstracted for fish farming	Current		Yes	Output	Vulnerability	Downward trend	Reliable supply of food and fibre, Thriving Plants and Wildlife
Natural Environment	Commercial Fisheries & aquaculture	Number of local fish species extinctions and new species appearing in UK water.	Wishlist	National	Yes	Impact	Vulnerability	Downward trend	Reliable supply of food, Thriving Plants and Wildlife
Natural Environment	Water management	Soil condition for flood-risk management	Wishlist	Regional	Yes	Outcome	Vulnerability	Upward trend	Reliable supply of clean water,

									Thriving Plants and Wildlife
Natural Environment	Water management	Uptake of nature-based solutions for flood-risk management	Wishlist	National	Yes	Output	Vulnerability	Upward trend	Reliable supply of clean water, Thriving Plants and Wildlife
Natural Environment	Commercial forestry	Pest, pathogens & invasive non-native species	Current	National	Yes	Impact	Hazard	Downward trend	Reliable supply of food and fibre, Mitigation of climate change
Natural Environment	Commercial forestry	Proportion of trees planted in areas likely to be suitable in 2050	Wishlist	National	Yes	Output	Vulnerability	Downward trend, Upward trend	Reliable supply of food and fibre, Mitigation of climate change
Natural Environment	Commercial forestry	Geographical spread of different climate-sensitive pests and pathogens	Wishlist	National	Yes	Impact	Exposure	Downward trend	Reliable supply of food and fibre, Mitigation of climate change, Thriving Plants and Wildlife

Natural Environment	Commercial forestry	Percentage species mix of broadleaf/conifer planted	Current	National	Yes	Output	Vulnerability	Upward trend	Reliable supply of food and fibre, Mitigation of climate change
Natural Environment	Commercial forestry	Tree sapling and mature tree losses as a result of extreme weather	Current	National	Yes	Impact	Exposure	Downward trend	Reliable supply of food and fibre, Thriving Plants and Wildlife, Mitigation of climate change
Natural Environment	Terrestrial habitats and species	Condition of terrestrial SSSIs	Current	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife, Reliable supply of clean water, Mitigation of climate change
Natural Environment	Terrestrial habitats and species	Condition of upland peat SSSIs	Current	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife, Reliable supply of clean water, Mitigation of climate change
Natural Environment	Terrestrial habitats and species	Proportion of semi-natural terrestrial	Wishlist	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife, Reliable supply of clean water,

		habitats in favourable condition							Mitigation of climate change
Natural Environment	Terrestrial habitats and species	Measure of woodland resilience (area size and connectivity) to climate change	Current	National	Yes	Outcome	Exposure	Upward trend	Thriving Plants and Wildlife, Mitigation of climate change
Natural Environment	Terrestrial habitats and species	New tree planting, ha, per annum	Current	National	Yes	Output	Vulnerability	Upward trend	Thriving Plants and Wildlife, Mitigation of climate change
Natural Environment	Terrestrial habitats and species	Breeding woodland bird species index	Current	National	Yes	Impact	Vulnerability	Upward trend	Thriving Plants and Wildlife
Natural Environment	Terrestrial habitats and species	Number of wildfire incidents, by land cover	Current	National	Yes	Impact	Hazard	Downward trend	Thriving Plants and Wildlife, Mitigation of climate change
Natural Environment	Terrestrial habitats and species	Area of soil with partly or completely impermeable material	Wishlist	National	Yes	Impact	Exposure	Downward trend	Thriving Plants and Wildlife
Natural Environment	Terrestrial habitats and species	Percentage change in abundance of pest control species?	Wishlist	National	Yes	Impact	Vulnerability	Upward trend	Thriving Plants and Wildlife

Natural Environment	Terrestrial habitats and species	Changes in abundance and distribution of climate sensitive terrestrial species, by type.	Current	National	Yes	Impact	Vulnerability	Upward trend	Thriving Plants and Wildlife
Natural Environment	Farmland habitats and species	Condition of farmland SSSIs	Current	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife
Natural Environment	Farmland habitats and species	Pollinator species occupancy index	Current	National	Yes	Impact	Vulnerability	Upward trend	Thriving Plants and Wildlife, Reliable supply of food
Natural Environment	Farmland habitats and species	Change in hedgerow length	Wishlist	National	Yes	Output	Vulnerability	Upward trend	Thriving Plants and Wildlife
Natural Environment	Farmland habitats and species	Average field size	Wishlist	National	Yes	Impact	Exposure	Downward trend	Thriving Plants and Wildlife
Natural Environment	Farmland habitats and species	Proportion of degraded land area	Wishlist	National	Yes	Outcome	Exposure	Downward trend	Thriving Plants and Wildlife
Natural Environment	Farmland habitats and species	Farmland bird index	Current	National	Yes	Impact	Vulnerability	Upward trend	Thriving Plants and Wildlife

Natural Environment	Freshwater habitats and species	Condition of freshwater SSSIs	Current	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife
Natural Environment	Freshwater habitats and species	Proportion of semi-natural freshwater habitats in favourable condition	Wishlist	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife, Reliable supply of clean water, Mitigation of climate change
Natural Environment	Freshwater habitats and species	Percentage of water bodies in England meeting good status	Current	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife, Reliable supply of clean water
Natural Environment	Freshwater habitats and species	Changes in abundance and distribution of climate sensitive freshwater species, by type.	Wishlist	National	Yes	Impact	Vulnerability	Upward trend	Thriving Plants and Wildlife
Natural Environment	Freshwater habitats and species	Number of low river flow (Q95) incidents	Wishlist	National	No	Impact	Exposure	Downward trend	Thriving Plants and Wildlife
Natural Environment	Freshwater habitats and species	Surface water temperatures	Current	Regional	Yes	Impact	Hazard		Thriving Plants and Wildlife

Natural Environment	Marine and coastal habitats and species	Sea level rise	Wishlist	National	Yes	Impact	Hazard	Downward trend	Thriving Plants and Wildlife
Natural Environment	Marine and coastal habitats and species	Sea surface temperature	Current	National	Yes	Impact	Hazard	Downward trend	Thriving Plants and Wildlife
Natural Environment	Marine and coastal habitats and species	Condition of coastal SSSIs	Current	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife, Reliable supply of food, Reliable supply of food and fibre
Natural Environment	Marine and coastal habitats and species	Proportion of semi-natural coastal habitats in favourable condition	Wishlist	National	Yes	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife, Reliable supply of clean water, Mitigation of climate change
Natural Environment	Marine and coastal habitats and species	Length of coastline realigned per year	Wishlist	National	Yes	Output	Exposure	Upward trend	Thriving Plants and Wildlife
Natural Environment	Marine and coastal	Extent of marine protected area	Current	National	Yes	Output	Vulnerability	Upward trend	Thriving Plants and Wildlife

	habitats and species								
Natural Environment	Marine and coastal habitats and species	Proportion of priority coastal and marine areas in favourable condition	Wishlist	National	No	Outcome	Vulnerability	Upward trend	Thriving Plants and Wildlife
Natural Environment	Marine and coastal habitats and species	Impacts on species occupancy of acidification, temperature and salinity on marine species	Wishlist	National	Yes	Impact	Exposure	Downward trend	Thriving Plants and Wildlife, Reliable supply of food and fibre

9.5.3 Key findings

1. Each set of indicators have specific goals addressing different parts of the risk management process.

Indicator frameworks can focus on risk assessment, adaptation, governance (policy) and processes such as evaluation of vulnerability, sensitivity or adaptive capacity, and the outputs/outcomes expected from mitigative and adaptive actions.

The UK has an indicators system (Committee on Climate Change, 2019) that it reports progress on:

- Understanding the extent to which adaptation is reducing exposure and vulnerability to climate change impacts.
- Understanding the trends in exposure and vulnerability to climate change and understand the actions underway and the impacts those are having, and
- Understanding whether progress is being made in managing risk.

Further research undertaken by the UKCCC as an inter-country project with China develops indicators to consider three categories of risk (Table 13)(Committee on Climate Change and China Expert Panel on Climate Change, 2018).

Table 14: UK-China categories of indicators

Risk category	Definition and scope for indicators
Emissions Risk	Indicators monitor emissions; the proof of concept focused on the energy sector and CO_2 emissions. While not as relevant to NZ, a set of 12 indicators focused on the international effect for energy decarbonisation.
Direct Impact Risks	For hazards, exposure, and impact, indicators have been developed for eight subcategories for both a low- and high emission pathway (RCP2.6/IEA Sustainable development; RCP8.5/IEA Current Policy Scenarios). Indicators are used to compare the impacts from a low or high pathway. The use of IEA scenarios implies a strong energy focus.
Systemic Risks	Risks are presented as a narrative and as a cascade of resultant impacts (theory of change), i.e. primary impact, 1st order, 2nd order, etc. Then, points in the chain that propagate the impacts are identified, with indicators for exposure and vulnerability developed.

The U.S. Global Change Research Program indicator programme has the following goals (Kenney et al., 2018; Reidmiller et al., 2018):

- Are multi-stressor impacts related to climate change getting larger, more frequent, more damaging, or less so?
- As the USA plans and implements adaptation actions, is it becoming more or less resilient to a variable climate system and other related environmental stresses?
- Given sub-national, national, and international climate plans and commitments, is the nation making progress on greenhouse gas emissions reductions?

Within the EEA (European Environment Agency (EEA), 2017), the aims identify the key observed and projected climate change and impacts for the main regions in Europe using indicators to identify state and trends for:

- Changes in the climate system (11 indicators)
- Climate change impacts on environmental systems (12)
- Climate change impacts on society (14)
- Multi-sectoral vulnerability and risks (7).

The indicators are used to support the objectives of:

- The present past and projected climate change, as well as selected impacts on ecosystems and society;
- Identifying the regions and sectors most at risk from climate change impacts;
- Discuss the main sources of uncertainty in observations and projections;
- Report on key adaptation policy developments at European, transnational and national levels;
- Highlight the need for further adaptation actions; and
- Demonstrate how monitoring, information sharing, and research can improve the knowledge base for adaptation.

2. Indicator systems have a different conceptual basis

The US system for indicators has the following design criteria for indicators:

1. A focus on impact indicators for national-to-regional sectors and resources of concern.
2. Indicators need to be justified by a transparent model of how each system is structured and how it functions, using a conceptual modelling framework that articulates the current understanding of the system's complex state and dynamics and includes indicators that reflect these elements (NRC, 2000). Hence, indicators are built on an interdisciplinary understanding of the system.
3. The indicators must address the aims of the programme – a documented relationship to climate change and variability.
4. Indicators must be related to phenomena that are of national importance.
5. Indictors selected are boundary objects, i.e. designed and selected to be used by different individual and decision specific uses (Wiggins et al., 2018).

The indicators are developed from an overall conceptual model (Figure 7) and from theme-specific conceptual models (Figure 8: Agriculture) that address bullets 2 & 3 above, using the DPSIR and ecosystem frameworks to explore human-natural system interactions.

3. Monitoring & Evaluation

The different systems also have strong monitoring and reporting frameworks supported by research and policy development. E.g. the UK CCC reports to Parliament on analysis of trends in indicators (UKCCC, 2019). The EU members are required to report every four years on national adaptation actions. The reporting addresses policy and legal frameworks, information on impacts, vulnerability, adaptation, priority sectors and adaptation action, engaging stakeholders, with an increased requirement from 2021 every two years. A non-mandatory adaptation scoreboard has been developed, focusing on the policy-making process (Preparing for adaptation, Assessment of risks and vulnerabilities, Adaptation options, Implementation of adaptation options, and M&E) (Mäkinen et al., 2018).

9.6 Recommendations

- Indicators are developed that measure the effectiveness of mitigation and adaptation actions.
- Any indicator set should:
    - have clear aims and goals,
    - be underpinned by a strong conceptual framework, building on research completed in the US and UK,
    - reuse existing data sets, noting that these datasets may be unrepresentative,
    - reuse international indicators, particularly those monitoring global emission trends, piggy-backing on indicators and data from UK and US indicator efforts, and
    - Operate across all aspects of climate change risk assessment and adaptation planning.

10 OBJECTIVE 3: Methods for assessing risk

Decision-makers require information on climate impacts on their areas of concern and responsibility to undertake effective risk management. Within the primary sector, we can define this as understanding impacts on natural capital productivity, resilience, and survival (e.g., forests, animals); impacts on the economy at a business (e.g., Profit & Loss) and regional, national, and international scales (e.g., GDP, Employment); and impacts on other capitals such as infrastructure, human, cultural, social and intellectual. The data sources are from changes in the physical environment derived from the RCP's and understanding the systemic and broader impacts from the SSP and other scenarios.

This objective addresses a perceived shortfall in NZ understanding and knowledge provision that supports comprehensive aspects of the climate change risk management, adaptation planning, and monitoring and evaluation. In much of the previous research, the knowledge of impacts has been qualitative, with quantitative understanding limited to the projected change in physical climate (e.g., temperature and precipitation). While this analysis has been very useful for awareness building of potential impacts, it is not as suitable for company or sector scale strategic planning, forecasting, or adaptation investment decision making.

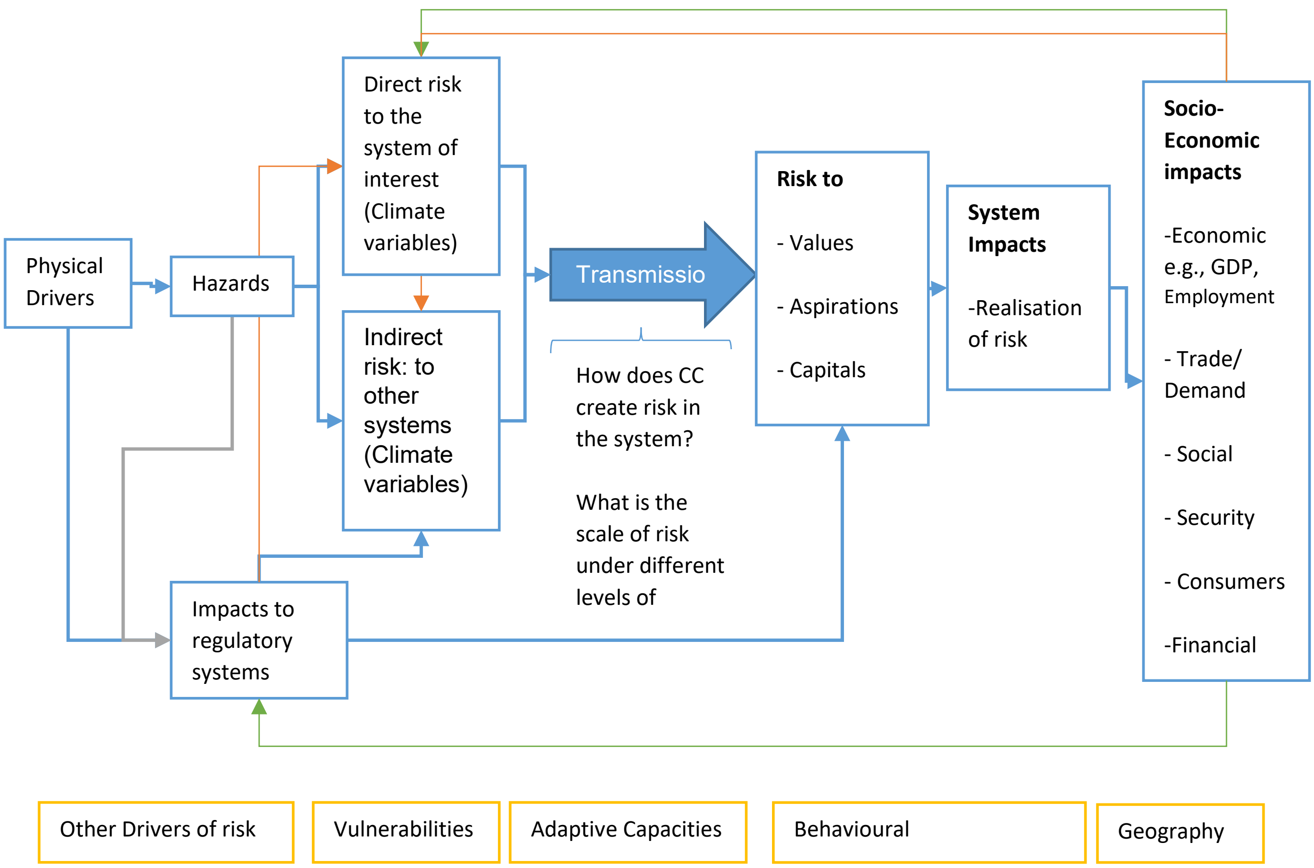


Figure 9: Simplified relationships and feedbacks between physical drivers of climate change and socio-economic impacts. The line widths and colours are for clarity. The purple boxes are other factors that would influence the system impacts and socio-economic impacts.

Using models and tools that identify, measure, and analyse risk and adaptation leads to better and more informed, empowered primary sector business management, a risk reduction, and a respondent increase in resilience. (IPCC, 2014a; Kenny, 2017). Fundamentally, tools and models enable the articulation of impact to stakeholders in terms of variables of importance to them, such as GDP, Employment, and productivity. Just changes in climate physical drivers form which impact can only be inferred but not quantified.

The report identifies standard quantitative tools used for risk management as a potential focus for adaptation research.

All the methods identified have been used in the agricultural sector internationally. In addition, there are some papers (italics) on specific cases in New Zealand.

Each model is summarised in Table 14, with more details of each methodology in the following sections. The last section provides one example from Europe – EU-Impression project that developed an understanding of high-end climate impacts.

An example is given from the EU-Impression project, which "*developed advance understanding of the implications of high-end climate change, involving temperature increases above 2°C, and to help decision-makers apply such knowledge within integrated adaptation and mitigation strategies*"[10].

This project integrates RCP and SSP data and used a suite of impact and adaptation models that simulated adaptation as a process driven by the behaviour of individual decision-makers, firms, and institutions that can learn and interact with each other. The models included interactions between different sectors and regions as they compete for land, water, and energy resources. The models enabled the exploration of synergies and trade-offs between adaptation and mitigation actions, informing planners on Integrated Climate Governance.

[10] http://www.impressions-project.eu/show/project_2731/

Table 15: Advantages and disadvantages of each appraisal methodology Sources:(Checkland & Poulter, 2010; Ruth Dittrich, Wreford, & Moran, 2016; Kenny, 2017; Maani, 2013; Tröltzsch et al., 2016; UNFCCC, 2009) and Authors)

Methodology	Short Description	Advantages	Disadvantages
Productivity and impact models	Models that predict a range of different parameters, such as • Productivity (e.g., trees, horticulture, grassland); • River flow. • Groundwater. • Pest and disease occurrence & Establishment, • Fire, Wind, Extreme events	Allow the impacts of physical changes in climate to be understood in terms of parameters and causation that are more meaningful to end-users • Grass productivity: Keller, Baisden, Timar, Mullan, and Clark (2014) • Crop Productivity: Teixeira et al. (2017) • Landuse: (A. Ausseil et al., 2017; A. G. E. Ausseil, Daigneault, Frame, & Teixeira, 2019) • Pests: Watt, Ganley, Kriticos, and Manning (2011)	The results have variable degrees of uncertainty. Uncertainty arises from model formation and underlying assumptions, from input data such as climate projections; The method can ignore other drivers of harm or mitigation, such as trade or technology.
Soft Systems Methodology	SSM is a framework and methodology for dealing with multi-stakeholder and 'ill-defined' problems. SSM is based on the premise that "human and organisational factors cannot be separated from problem-solving and decision making."	• Help structure complex problems • Wide stakeholder engagement • It can be used to build stakeholder engagement in defining the problem, identifying the affected parties and identifying options. • *Kalaugher, Bornman, Clark, and Beukes (2013)* • Silva Alvarado (2016)	Some limited tool support for some of the stages
Causal loop diagrams	Causal loop diagrams identify key variables in a system and	• Reveals the systemic relationships	• Hard sometimes to identify causal relationships

	indicate the causal relationships via links. By linking together several	• Illuminates the assumptions, values, perceptions of the participants and Decision-makers • Use both hard/soft variables • CLD has been used to understand how risk propagates through systems (e.g. AgriSSP), the causal linkages between climate and socio-economic drivers, and key stakeholder values. • CLD's have been used to develop and ensure internal consistencies of scenarios • Mathijs et al. (2018). • *Lawrence, Blackett, Cradock-Henry, and Nistor (2019*)	• It doesn't include the degree of impact/causality • Time is poorly represented
System Dynamics	A methodology for simulating complex systems to observe and test their dynamic behaviour. SD can be viewed as the casual loop 'quantification' methods	• The ability to integrate interdisciplinary thinking about whole systems • Represents the complex web of interactions between human and natural systems • • Hasselmann (2010). • Nikolaou, Evangelinos, and Leal Filho (2015). • Phan, Bertone, and Stewart (2021).	• Different stakeholders might bring different assumptions with different results • Very complex when using modelling with many variables.
Input-output modelling	The Input-output method estimates economic impacts and traces financial flows. IO assumes that the basic sector is the primary cause of local economic growth; that is,	• Presents an enormous quantity of information in a concise, orderly, and easily understood fashion; • Provides a comprehensive picture of the interindustry structure of the regional economy; • Highlights the strategic importance of various industries and sectors;	• IO models are complex and data-hungry. • Many technical assumptions.

	it is the economic base of the local economy.	• Highlights possible opportunities for strengthening regional income and employment multiplication • Understand the economic impacts of mitigation/adaptation policies and plans on regional economies • Mirzaee (2016) • Garcia-Hernandez and Brouwer (2020) • Wiebe, Bjelle, Többen, and Wood (2018)	
Bayesian belief networks	BBN is a group decision-making tool based on probability theory. Bayesian network algorithm uses conditionals probabilities for each variable to calculate the joint probability distribution for all variables in the network. The main aim of this network is to understand the concept of causality relations. (Maani, 2013)	BBN is effective where expert knowledge is uncertain, ambiguous, or incomplete and where many decision-makers and stakeholders are present • Has the ability to resolve data uncertainties in a transparent fashion • Uses historical, experimental or expert data - a mix of empirical, simulated, and subjective data • Can estimate error • Richards et al. (2013) • Sperotto et al. (2019) • Kaikkonen, Parviainen, Rahikainen, Uusitalo, and Lehikoinen (2021) • de Nijs, Berry, Wells, and Reay (2014)	• There is no universally acknowledged method for constructing networks from data. • The design of Bayesian Networks is hard to make compared to other networks. • Fails to define any cyclic relationships
Agent-based models	ABM models focus on 'agent' behaviours and how that affects land use (amongst other) decisions	• Ability to model heterogeneous populations. • Provides an understanding of the aggregate behaviour of the phenomenon, which could emerge from the rules that are developed by the researcher/modeller	• Computationally expensive • ABM models are limited as they are only useful within the context they are constructed

	• It provides explanatory modelling that does not predict a system's future behaviour but provides a framework in which past observations can be understood as part of an overall process. • They are commonly used for the extrapolation of trends, evaluation of scenarios, and the prediction of a future state. • Changes in initial conditions can be used to evaluate the possible effects on the model outcome. • Predictive models are designed to mimic real-world systems and are particularly useful for scenario development and policy decisions.	• Incorporate randomness into the model since they do not know the patterns to expect • Captures emergent phenomena • Provides a natural environment for the study of certain systems • Micro-behaviour of primary producers, including scepticism and pro-environmental behaviours; • Important in understanding the heterogeneity of primary sector systems. • Use to model decision-maker behavioural impacts on Land Use, Adaptation, Water Use and implications of policy • Kapeller and Jäger (2020) • *Morgan and Daigneault (2015)* • Patt and Siebenhüner (2005) • Taylor, Coll Besa, and Forrester (2016)	• They are sensitive to initial conditions and small variations in interaction rules • Data-intensive
Computable general equilibrium models	General equilibrium models help quantify the wider repercussions from changes in economic systems or as a consequence of policy changes.	• The ability to highlight the importance of linkages between sectors. • The ability to incorporate unique features of an economic system.	• Data requirements of CGE models are substantial. • By covering all sectors in an economy, a CGE model may miss key features of critical sectors. (Gilbert, 2016)

	• General equilibrium approaches and CGE models allow for linkages between all sectors of the economy. • Quantitatively represent and trace through the consequences of inter-linkages between economic sectors and thus the effects from one sector on all others (UNFCCC, 2009).	• The ability to predict values for many economic variables in the system. (Gilbert, 2016) • Provides an understanding of climate change mitigation impacts at the national, regional and global levels. • National and sub-national economic impacts of the transition pathways to low carbon economy, energy access and security, competitiveness and employment, tax, ETS, renewable energy, CC&S. • Macroeconomic impacts, e.g. change in yields, damage functions, adaptation modelling • NB: NZCCC uses three models ENZ, C-PLAN, and DIM, which cover all sectors of the economy • Babatunde, Begum, and Said (2017); • S. Fujimori et al. (2018) • *White et al. (2018)* • *(Daigneault, 2019)*	• It can be diffcult to know what is driving the results.
Value-at-Risk	VAR is a tool for measuring an entity's exposure to market risk. VAR measures the risk of loss for investments, estimating how much investments might lose (with a given probability), given normal market	• Easy to understand. • Can measure and compare VAR of different types of assets. • Assesses the business value that can be a risk from climate change. Has limited use to ate in agricultural, normally focused on investment firms, and their investment portfolio. Monge looked at the VAR impact	• False sense of security: i.e., 99% VAR means that in 1% of cases, the loss is expected to be greater than the VAR amount. • Value-at-Risk does not quantify the size of losses does not say anything about the maximum possible loss. • Different Value-at-Risk methods lead to different results.

	conditions, in a set time period in response to some probabilistic driver. (Wikipedia)	from climate change reduction recreation in forests. • *Monge and McDonald (2020)* • Diaz and Moore (2017) • (MSCI, 2020)	
Catastrophe Models	Catastrophe models simulate potential catastrophic events and quantify the amount of loss due to the events.	• Generates a robust set of simulated events. CM estimates the event's magnitude, intensity, and location to determine the amount of damage before calculating the insured loss resulting from each catastrophic event. • The best method to currently visualise catastrophic risk[11]. • Impact of acute climatic events: floods, fire, storms. • Large insurers normally use them for assessing risk across their insured assets classes. • The robust and accepted mechanism for assessing key NZ risks, such as flooding. • Lloyd's (2014) • (Amendola, Ermolieva, Linnerooth-Bayer, & Mechler, 2013)	• Require significant data checking, processing, and cleansing to enable the model to represent the peril(s) accurately. • Uncertainty is compounded at each subsequent stage of production as the financial component is incumbent on the values expressed in the vulnerability component, which is in turn dependant on how accurate the hazard component is at determining the location of peril[11]
Multi-criteria analysis (MCA)	A qualitative-based approach, where end-users rank options based on a range of different criteria	• Allows the analysis to use a mix of qualitative and quantitative data • Develop an understanding of different stakeholder views, assessing options and	• Only assesses and ranks the relative options • The results are specific to the problem context and cannot be applied to other situations.

[11] https://www.ambientalrisk.com/catastrophe-models-good-bad-ugly/

		priorities for adaptation activities, assessing different views of risk and vulnerability. • Kim and Chung (2013) • Golfam, Ashofteh, Rajaee, and Chu (2019) • Álvarez-Miranda, Garcia-Gonzalo, Ulloa-Fierro, Weintraub, and Barreiro (2018) • Bertilsson et al. (2019) • Maanan et al. (2018)	
Portfolio analysis	Fundamental to PA is that diversification is a significant risk management response. Rather than considering a single intervention, Portfolio analysis attempts to identify the best portfolios according to their performance concerning economic efficiency and risk.	• Emphases that trade-offs that can be expected between risks and benefits of various strategies • PA offers a straightforward way to handle climate uncertainty by selecting options that are effective together over a range of possible future scenarios instead of one best option for one future • Robustly evaluate different adaptation options for primary sector businesses. • Diversification analysis. • It is being used with NZ Forestry to assess different regimes (ongoing). • *R. Dittrich, Wreford, Topp, Eory, and Moran (2017)* • Paut, Sabatier, and Tchamitchian (2019) • Ando et al. (2018)	• PA is resource-intensive
Integrated Assessment Models	IAM's are made up of modules representing the climate, biosphere, energy, and economy.	• Provide policy-relevant insights into environmental change and sustainable development issues by providing a quantitative description of key processes in	• Based on simplified sub-models. The complexity of natural systems cannot be modelled. • Values are difficult to quantify

	The outputs of IAMs are simulations based on assumptions, historical data, and scenario designs. IAMs are widely used in assessing various GHG mitigation policies and climate impacts. IAM's underpins the socio-economic modelling used by IPCC (AR5 used 1134 scenarios from 30 IAM's).	the human and earth systems and their interactions[12].) • IAM are the mainstream methodological approach in climate change research. • IAM's used globally for mitigation policy analysis. • Assessment of how socioeconomic development, technological innovation, and changing climate conditions impact agricultural systems Questions that IAM's can assess: • What are the regional characteristics and opportunities for mitigation and adaptation strategies? • How do changes in mean climate and climate variability affect adaptation and mitigation strategies? • What are the interactions between management decisions and natural processes that contribute to rapid or nonlinear changes in the environment? • Where are such nonlinearities, and how do their consequences contribute to climate feedbacks? • How will adaptation and mitigation strategies interact in the next few decades? • Ruane et al. (2017)	• There is debate about the underlying assumptions (Asefi-Najafabady, Villegas-Ortiz, & Morgan, 2020; Keen, 2020)

[12] https://www.iamcdocumentation.eu/index.php/IAMC_wiki, https://unfccc.int/topics/mitigation/workstreams/response-measures/integrated-assessment-models-iams-and-energy-environment-economy-e3-models#eq-1

Real Options Analysis	Real Options Analysis (ROA) is a Robust Decision-Making tool that incorporates the uncertainty of climate change and the value of flexibility into decision making when appraising policy options ROA extends the principles of cost-benefit analysis to allow for learning based on an uncertain underlying parameter(Wreford, Dittrich, & van der Pol, 2020) .	• ROA is most suited to significant, one-off investment decisions • ROA represents the real-world characteristics of the decision context. • Use in analyses of the investment decision space for adaptation options, e.g. Water storage • *Wreford, Dittrich, Zammit, et al. (2020)* • *Wreford, Dittrich, and van der Pol (2020)*	
Social Cost of Carbon – Integrated Assessment Models – Damage functions	Social Cost of Carbon (SCC) is a financial estimate of the economic damages over time that would result from emitting one additional ton of greenhouse gases into the atmosphere. Underpins the climate regulations is the US and Canada	• Provide policymakers and other decision-makers with the ability to understand the economic impacts of emissions or mitigation decisions, • Evaluating the benefits over mitigation (risk reduction) cost and the benefits compared to other forms of social investment. • Analysis of proposed national/regional investment programmes • SCC is calculated using IAM's (The US government uses DICE, FUND, PAGE models) • The IAM's link four elements[13]: • Socioeconomic projections	• Estimates of the SCC are highly uncertain and variable due to the different assumptions on the sub-models. • SCC incorporates future discounted costs, which strongly affects the social cost of carbon (and also has ethical issues where a high discount rate suggests those alive today are worth more than future generations).

[13] https://www.carbonbrief.org/qa-social-cost-carbon

		• Climate projections • Benefits and damages • Discounting to value future benefits and costs	

10.1 Landuse models

These are the most common approaches to documenting land-use and land-use change, where land cover and land use are mapped over time, allowing an understanding of land-use change dynamics to predict the type of activities best suited for that land. e.g., carbon emissions for different uses, how drivers (e.g., preferences and consumer income) may affect land use and emissions, and the ability of the land to support new activities, e.g. biomass for energy, sequestration. However, their focus is on the physical description of the land; hence any analysis on potential land use can exclude the consideration of other capitals, meaning that there can have limited use in risk and resilience assessment (Kenny, 2017).

NZ examples include Land Cover Database Land Use Map, Vegetation Cover Map and Land Resource Inventory. An application example is the Forest Investment Finder, an NPV based model of forest profitability based on location-specific costs and revenues.

10.2 Productivity and impact models

These are a large number of models that predict:

- growth or productivity of natural systems, water flows, sea-level rise, ecosystem services
- changes in frequency, occurrence, spread, the intensity of secondary impacts, e.g. from pests, disease, fire, drought, extreme storms, etc
- effects on productivity from changes in the secondary impacts.

Table 16: Productivity and impact model in NZ

Model	Type	Who and how used
Cenw	Physiological Radiata growth model.	A Landcare Research model that is used in some SLMACC research to project climate impacts on Radiata productivity.
3 PG	Physiological growth model (range of species)	Scion - Public domain Data for NZ available soon
Cabala	The physiological Radiata growth model	CSIRO, Scion Data Available soon
Forecaster	Model for predicting forest yield tables (no climate)	Commercial model
300 Index	National Radiata growth model. No climate)	Commercial mode (some data is / maybe available on Koordinates)
Apsim	Horticultural physiological model.	Publicly available (NZ parametrisation maybe P&F IP)

		Many horticultural crops have been modelled. Unsure of data availability
Biome / BGE	Physiological growth model	It has been used in NZ by ESR for predicting grassland productivity. Unsure of data availability. Paper has full model parametrisation used.
TopNet	Stream flows	Sophisticated model for modelling stream flows.
Climex	Pest distribution model	Used in NZ to predict suitable sites where some populations (insects, disease, weeds) can establish viable populations (Scion, P&F)
40 "Interoperable Freshwater Models"		The Niwa website[14] provides a list of models.
GCM (RCP)	Global climate change models. Downscaled and bias-corrected for NZ, providing projections on climate change daily data from 2005 to 2100, across and national 5km grid	Niwa. Available for research. Raw data publication (as data or maps is not allowed)

As part of the broader international science response to prediction, the Agricultural Model Inter-comparison and Improvement Project[15] (AgMIP) combines climate, crop, and economic modelling to produce improved crop and economic models and the next generation of climate impact projections for the agricultural sector.

The AgMIP project integrates crop model outputs with regional and global economic models to determine: vulnerabilities, changes in comparative advantage, price effects, and potential adaptation strategies for the agricultural sector that address uncertainty, aggregation and scaling. AgMIP also aids the development of Representative Agricultural Pathways (RAPs) to test climate change adaptations in the context of other regional and global trends.

Adaptation planning requires information on how biophysical processes influence future crop yields and how socio-economic drivers of productivity influence farm management practises such as crop variety or planting date or the impact of pests and diseases (Rosenzweig et al., 2013).

[14] https://teamwork.niwa.co.nz/display/IFM/Compilation+of+models+and+their+attributes
[15] www.agmip.org

10.3 Soft Systems Methodology

Soft systems methodology (SSM) is an action-orientated inquiry process into problematic situations in the everyday world. Users learn from finding out about the situation to defining/taking action to improve it.

The learning emerges via a structured process in which the real situation is explored, using models of purposeful activity built to encapsulate pure, stated worldviews (Checkland, 2000; Checkland & Poulter, 2010).

Maani (2013) identifies seven stages:

1. The problem situation is unstructured.
2. The problem situation is expressed.
3. Root definitions of relevant systems are identified.
4. Conceptual models are developed.
5. The problem situation and the conceptual models are compared.
6. Feasible and desirable changes are considered.
7. Action is taken to improve the problem.

The process starts with a 'vague' problem (stage 1) and is expressed as a rich picture (2) then the root causes are identified (3), and a conceptual model of the problem (4) is developed and validated (5) then solutions are developed (6) agreed on and implemented.

SSM has an affinity with total quality management and the Seven-Step or the Plan-Do-Check-Act methods. In addition, the focus of SSM on root cause definition provides a robust learning process for groups and organisations (Maani & Cavana 2007).

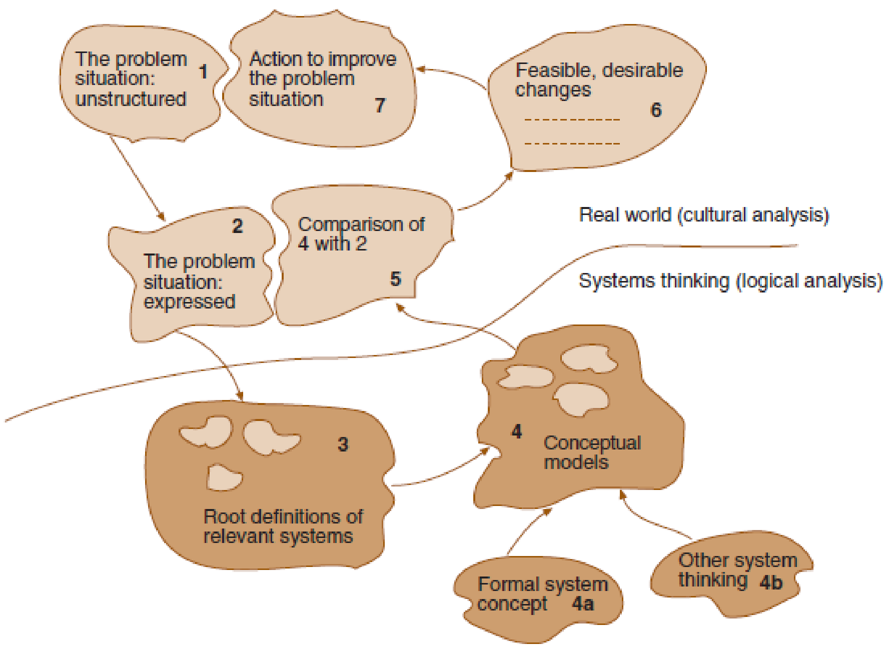


Figure 10: SSM from Maani (2013)

10.4 Causal loop diagrams

Causal loop modelling maps relationships that form a 'system'. The result is a visual representation of the causal links between drivers which affect the system's behaviour or outcomes. Thus, a causal loop diagram (CLD) reveals the systemic relationships underlying a system. Furthermore, the method illuminates the participants' assumptions, values, perceptions, and decision-makers that drive motivations and behaviour (Maani, 2013).

The variables used in a CLD can be quantitative (hard/measurable) or qualitative (soft). While ‘soft’ variables, such as trust, confidence, and collaboration, do not generally lend themselves to direct measurement, nevertheless, their inclusion adds considerable power and realism to the model (Maani, 2013).

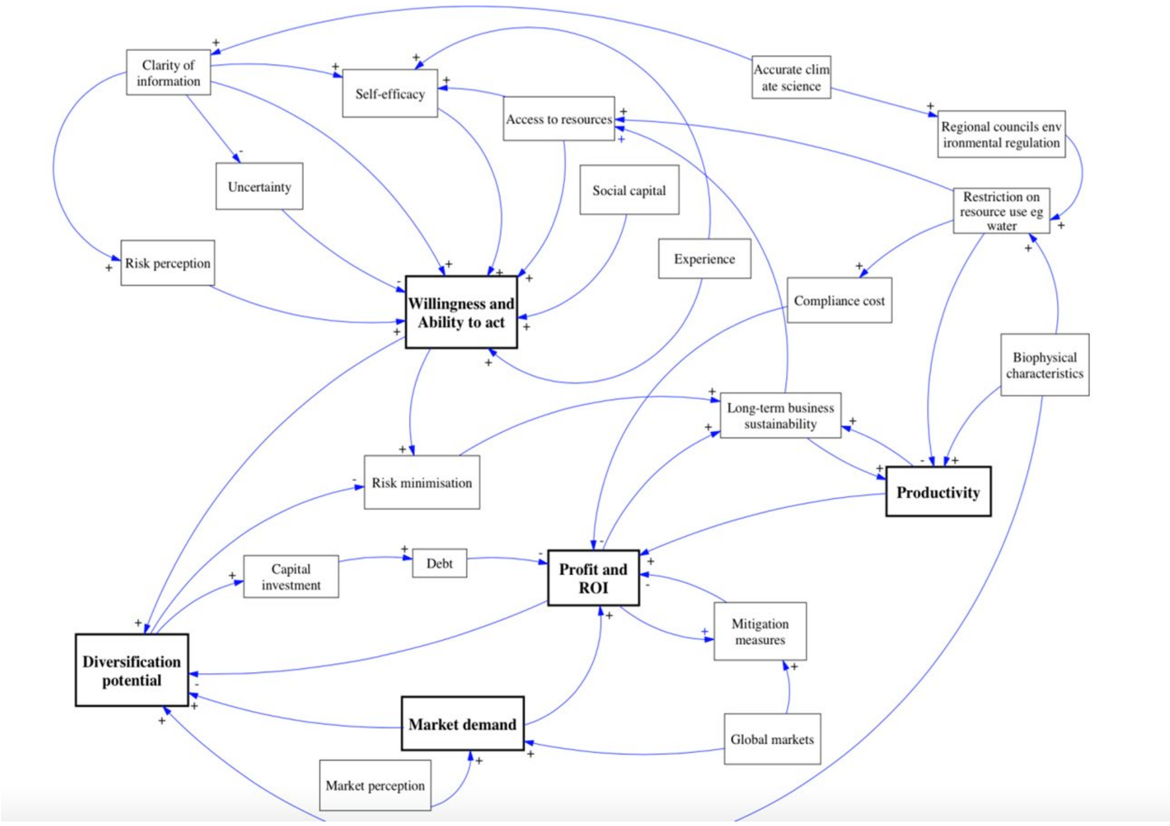


Figure 11: CLD Climate change and adaptation impacts on primary producers - understanding the context for decision making in the primary sector (Dunningham, Bayne, Pizzirani, Blackett, & Cradock-Henry, 2015)

10.5 System Dynamics

System Dynamics (SD) is a methodology for simulating complex systems to observe and test their dynamic behaviour. SD can be viewed as the ‘quantification’ of casual loop models (Maani, 2013). SD provides the ability to integrate interdisciplinary thinking about whole systems, so it is suited for systems with increasing complexity than traditional linear explanatory models. SD focuses on individual components in the context of their relationship to the system and represents the complex web of interactions between human and natural systems. This helps its users identify and explore multiple interconnections and see how individual pieces fit into a larger whole. As such, the method doesn’t seek to reduce complexity to linear casual relationships. System dynamics maps represent trends over time, identify information gaps, enable participatory stakeholders engagement, and identify system nodes for effective interventions (Kenny, 2017).

System Dynamic is defined as:

> *“A methodology for studying and managing complex feedback systems. Feedback refers to the situation where X affecting Y and Y in turn affecting X perhaps through a chain of causes and effects. Only the study of the whole system as a feedback system will lead to correct results.” (www.systemdynamics.org)*

System dynamics modelling is based on stocks and flows. Stocks represent accumulation, while flow denotes the change in the level (state) of a variable. System dynamics can be used for policy design and analysis through changing policy parameters or changing model structure (Maani, 2013).

10.6 Input-Output modelling

Input-Output (IO) modelling tracks the flow of consumption and production across a network of interdependent economic systems, modelling direct and indirect effects. The analysis of economic multipliers from various sector linkages captures ripple effects triggered by demand or supply changes. IO is used in environment and energy IO modelling (Miller & Blair, 2009) and disaster risk analysis (Haimes & Jiang, 2001).

10.7 Bayesian belief networks

Bayesian belief networks (BBN) is a group decision-making tool based on probability theory. Bayesian network algorithm uses conditionals probabilities for each variable to calculate the joint probability distribution for all variables in the network (Maani, 2013).

> *"Bayesian network model is represented at two levels, qualitative and quantitative. At the qualitative level, a directed graph [is used] in which nodes represent variables, and directed arcs describe the conditional independence relations embedded in the model.*
>
> *At the quantitative level, the dependence relations are expressed in terms of conditional probability distributions for each variable in the network. Each variable X has a set of possible values called its state space that consists of mutually exclusive and exhaustive values of the variable. For each variable a table of conditional probability distributions is specified, one for each configuration of states of its parents."* (Nadkarni & Shenoy, 2004) in (Maani, 2013).

BBN models rely heavily on historical, experimental or expert data. Here, a mix of empirical, simulated, and subjective data is derived for each sector. An advantage of the BBN process is its ability to resolve data uncertainties transparently. This includes estimating error terms for alternative trade-off scenarios, making trade-off uncertainties explicit and providing decision-makers with a quantitative framework to resolve catchment level questions and dilemmas. (Maani, 2013; Speigelhalter, Dawid, Lauritzen, & Cowell, 1993).

10.8 Agent-based models

These models focus on 'agent' behaviours and how that affects land use (amongst other) decisions. Agents behave according to prescribed rules, based on the interaction with others and the wider environment and will change behaviour due to the exchanges. Agent-based models (ABM) can predict system-level behaviour from individual-level interactions, i.e., expose characteristics of complex real-world systems (Macal & North, 2017). This modelling method addresses that different people will react differently to drivers; there is a diversity of individuals within a system; and people do not react as an economic 'rational' decision-making in response to self-interest (Kenny, 2017).

ABM has been used previously to address questions of land-use change arising from climate change policy in New Zealand (Morgan & Daigneault, 2015).

ABM requires that: (i) a set of agents are defined; (ii) the attributes and behaviours of these agents are understood; (iii) agent relationships and methods of interaction are defined; (iv) the structure of connectedness of how and with whom agents interact, including their decision making and behaviour, is defined (Kenny, 2017; Macal & North, 2017).

Case study – this research project

The questionnaire requested information that could address

- a set of agents are defined;
- the attributes and behaviours of these agents are understood;

and to test the questionnaire and response rates that are needed to develop information for:

- agent relationships and methods of interaction are defined;
- the structure of connectedness of how and with whom agents interact, including their decision making and behaviour, is defined (Macal & North, 2017)

From the results, a survey would ideally need to reach 100 – 300 participants.

A land-use ABM would be represented as a virtual land surface with simplified real-world characteristics and spatially explicit environmental criteria. The virtual land surface uses current primary industry users, their activity, topographical, hydrological and soil type information. These locations should be idealised to the scale of a ‘land parcel and populated with agents whose decision-making is modelled in time and space to adapt this information within the model.

The ABM model would predict how individual land parcels attributes change over time in response to agent behaviour. The modelling would determine a set of idealised changes in the land surface to anticipate real-world outcomes in response to future perceptions of risk based on the agent’s behaviour. Information from these simulations of human behaviour would project how the land-use change in a region could develop in agent responses to the risks of climate change, socio-economic and policy-driven factors.

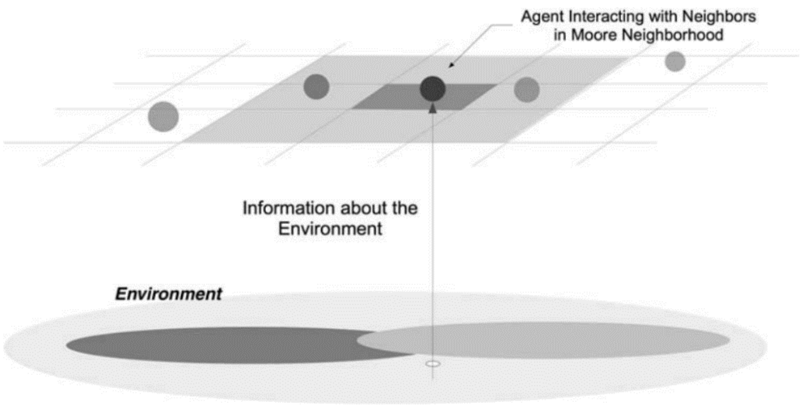


Figure 12: A typical agent-based model's structure shows agents (and their interactions) interpolated over an idealised environmental virtual land surface (Macal & North, 2017).

10.9 Computable general equilibrium models

GCE quantitatively represents and traces the consequences of inter-linkages between economic sectors and, thus, the effects of one sector on all others. Therefore, CGE models the entire economic system to quantify how direct effects of climate change have indirect effects and how these may exacerbate or reduce the size of first-order impacts. They are primarily used to study the economic impacts of climate change, although examples have recently been used to analyse adaptation.

Adaptation is modelled by analysing changes in absolute and relative prices from climate change impacts and the wider economic implications as a form of autonomous adaptation.

The second approach studies the economic impacts of forms of planned adaptation. This approach has been applied to sea-level rise, where hard coastal defences, such as seawalls and dykes, are required. Hard defences are particularly well suited to CGE as costs are easily identified, and any adaptation responses are likely to be sizeable, quantifiable and expressed through changes in market output.

(UNFCCC, 2005)

10.10Value-at-Risk

Value-at-Risk (VAR) is a tool for measuring an entity's exposure to market risk. It is a measure of the risk of loss for investments. It estimates how much a set of investments might lose (with a given probability), given normal market conditions, in a set period in response to some probabilistic driver.

Impacts on financial assets can affect the asset value chain. An asset is where an owner has a contractual claim on income and where the asset is created from a liability that will ultimately be paid off from a flow of output of goods and services, e.g. as part of a production process that in turn utilises intellectual, human, financial, social capital to generate it.

Hence, climate change can destroy or accelerate the depreciation of an asset. It can affect the efficiency of the production process, change the ROI, change knowledge productivity, and labour productivity. VaR quantitatively estimates the size of loss on a portfolio of assets over a given time horizon at a given probability. Estimates of VaR from climate change can be interpreted as the risk for correction in asset price due to climate change. (Dietz, Bowen, Dixon, & Gradwell, 2016)

A probabilistic and system-wide bio-economic model was developed within forestry that measured extreme economic impacts from natural events at a regional scale – windthrow on mountain bike recreation – using the Value at Risk concept (Monge & McDonald, 2020) (Figure 14).

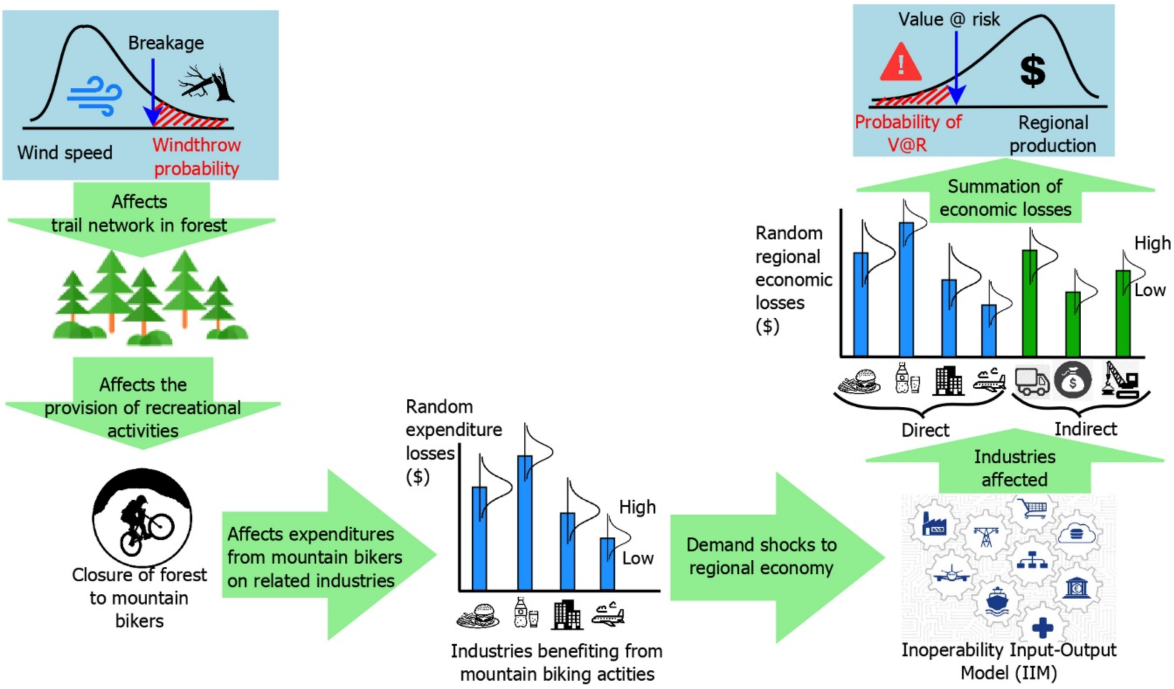


Figure 13: Graphical sequence of the approach developed to assess the economy-wide impacts from an extreme event affecting natural capital using the financial concept of Value-at-Risk. (Monge & McDonald, 2020).

10.11Catastrophe Models

Catastrophe models simulate potential catastrophic events and quantify the amount of loss due to the events.

Catastrophe models model complex scenarios and events, with increasingly accurate risk assessment in extreme weather events and other, informing on where the location of future events and intensity and predicting the estimated probability of loss, and a range of direct, indirect, and residual losses, including the impact from non-financial losses (labour).

Catastrophe models have four modules: Event, hazard/intensity, vulnerability, and financial[16].

- Event Module: The event module generates thousands of possible random event scenarios based on historical data and parameters.
- Hazard or Intensity Module: The intensity module determines the level of physical hazard specific to geographical locations using the location-specific risk characteristics for each simulated event.
- Vulnerability Module: The vulnerability module quantifies the expected damage from an event conditioned upon the exposure characteristics and event intensity.
- Financial Module: The financial module measures monetary loss from the damage estimates. Insured loss estimates are generated for different policy conditions, such as deductibles, limits, and attachment points. Varying financial perspectives, such as primary insurance or reinsurance treaties, are also provided.

Assumptions are made in each module either about specific values of the parameters (deterministic) or the probability distribution of parameters (stochastic).

The key metrics provided by a probabilistic catastrophe model include:

- EP is the likelihood that a loss greater than or equal to a determined amount will occur in the coming year.
- The PML is the annual probability a certain loss threshold is exceeded.
- The AAL is the average loss of the entire loss distribution and is represented as the area under the EP curve. It is frequently used in pricing and ratemaking to evaluate the catastrophic load.

Source: National Association of Insurance Commissioners[16]

Fire Risk Example

RiskFP[17] is a geospatial web-based modelling platform supporting forest managers and forest insurance providers for managing the vulnerability of forests to fire risk. RiskFP includes four main modules that are available for bushfire zones of about 50km x 50km with a spatial resolution of about 10-25m:

- Realistic disaster scenarios and CO_2 release
- Risk mapping
- Seasonal and climate forecast for critical days
- Wild-land-Urban Interface

(Tröltzsch et al., 2016; UNFCCC, 2011)

10.12Multi-criteria decision analysis

Multi-criteria decision-making (MCDM) is a series of independent systematic and analytic tools or methodologies that help compare, evaluate, and rank criteria and alternatives defined by ordinal, quantitative and qualitative attributes. MCDM allows for the examination of user preferences, needs

[16] https://content.naic.org/cipr_topics/topic_catastrophe_models_property.htm
[17] https://oasishub.co/dataset/riskfp-wildfire-hazard-modelling-propagation-forest-fire

and value systems. Furthermore, MCDM formalises the process for making a transparent ranking of criteria that enable decision alternatives to be prioritised (Levy, 2005).

MCDA emphasises the judgment of the decision-making team, establishing objectives and criteria, estimating relative importance weights between options, and, to some extent, judging each option's contribution to each performance criterion. In addition, MCDA allows (independent) ranking of the importance of different criteria that can't be monetised, including social preferences or benefits alongside other decision criteria. (Watkiss, 2015).

MCA is subjective, based on the decision makers' own choices of objectives, criteria, weights and assessments of achieving the objectives. MCA can bring a degree of structure, analysis and openness to classes of decision that lie beyond the practical reach of CBA. (Department for Communities and Local Government, 2009)

The Analytical Hierarchy Process

Analytic hierarchy process (AHP) is an MCDM methodology that allows the decomposition of a decision problem into a hierarchy of subproblems. The top-level is the goal of the problem or decision model. The remaining hierarchies are criteria that influence the opportunities and are refined until a workable or understandable set of sub-criteria is developed.

AHP is a reasonably simple model for users to understand, providing a systematic and transparent approach to setting priorities and identifying trade-offs between goals and factors, and allows the use of quantitative, qualitative or intangible data in the decision-making process. Critical to AHP is the assignment of criteria priorities or weights. AHP uses pairwise relative judgements at each hierarchical level to determine the priority of each criterion with respect to the parent hierarchy. These weights represent subjective understanding by the assessor or relative importance of the criteria with respect to one another. Priority vectors for each level in the hierarchy are determined and propagated to lower levels to retain priority relativities throughout the model. These combine to provide an overall priority of each alternative. Relative pairwise judgments are used as it is easier for users to rank factors than assign absolute priorities to factors. Hence, relativities make the ranking easier for people to evaluate and comprehend (Saaty, 1990).

The priorities obtained from pair-wise comparisons allow the separate evaluation of different sets of criteria. The most effective that focuses judgement is to compare different criteria independently of any other criteria or concern. Each pairwise comparison is evaluated according to a fundamental scale for determining relative importance (Saaty, 1990).

ANP Theory

Analytical network process (ANP) is a generic form of AHP which builds on AHP, addressing some of the structural restrictions in that method. ANP allows for more complex interactions and feedbacks between factors and sub-factors, addressing the assumption of independence between factors at each level and between levels. A network of criteria replaces the hierarchy in AHP. In AHP sub-criteria in separate hierarchies cannot be compared with each other (

The method can be adapted to use pairwise comparisons from groups of subjective actors, and actors themselves can be prioritised so that the opinions from some actors can rank higher than others (Vargas & Saaty, 2013).

10.13Portfolio analysis

Portfolio analysis (PA) is akin to combining shares in a portfolio to reduce risk by diversification. PA helps to examine the value of incorporating a diverse set of options in adaptation strategies instead of relying on a single one (Tröltzsch et al., 2016).

The benefits can be expressed both in monetary and non-monetary terms. The decision-maker can explicitly choose between the average expected value of return and riskiness (standard deviation of the return); the higher the risk, the higher the expected value.

PA allows a trade-off between the return and the uncertainty of the return of different combinations of adaptation options under alternative climate change projections. However, PA still requires assumptions about probabilities of plausible climate change scenarios and associated impacts and is thus still a 'predict-then act' decision-making process.

Fundamental to PA is that diversification is an important risk management response: the benefits of a strategy relying on a portfolio of adaptation options are likely to be higher than for a strategy that relies on a single option. It also aims to minimise the risk of failure on the assumption that a lower performance of one option is compensated by the better performance of another (Tröltzsch et al., 2016).

10.14Robust Decision making

Robust decision making (RDM) seeks to compare the performance of different options across all plausible states of the world. It is designed specifically to conduct appraisals in situations of "*deep uncertainty,*" i.e., *"a decision analysis based on the concept of identifying strategies robust over a wide range of often poorly-characterized uncertainties*" (Groves & Lempert, 2007).

RDM identifies the different parameters that are uncertain and assuming a range of plausible values these could take. All combinations of parameters are created, giving many potential states of the world. No initial assessment is made of the likelihood of these scenarios. However, care must be taken when deciding the upper and lower bounds of possible states of the world. If the analysis goes beyond plausible states of the world and considers implausible states, this may cause results to tip in the wrong direction.

RDM assesses how each of the management initiatives performs under each scenario. The goal is to search for the states where the proposed management initiatives outperform against a particular benchmark. A standard cost-benefit measure is used for this process. The costs and benefits are calculated using a value function. (Frontier Economics, IRBARIS., & ECOFYS., 2013)

10.14.1 Real Options Analysis

Real Options Analysis (ROA) is a RDM tool that incorporates the uncertainty of climate change and the value of flexibility into decision making when appraising policy options. ROA extends the principles of cost-benefit analysis to allow for learning based on an uncertain underlying parameter (Frontier Economics et al., 2013).

ROA manages deep uncertainty by allowing for learning about climate change over time, enabling flexible and reversible approaches that can be adjusted or reversed when additional information becomes available. ROA is one of the several ways to formalise policies that adapt over time in response to new information. e.g., A climate variable, such as rainfall, is the uncertainty parameter. ROA analyses whether it is worth waiting for more information, evaluating the trade-off between obtaining the potential pay-off in the present or waiting for further scientific information in the future (Gollier & Treich, 2003).

Fundamentally, uncertainty is dynamic and can be resolved over time as knowledge in impacts increases.

ROA evaluates postponing part or all of a large irreversible investment over extended time periods that have climate sensitivities and, potential for over- or under-investing and where there is an opportunity cost to waiting (Ruth Dittrich et al., 2016).

The suitability of ROA is depicted in Figure 15.

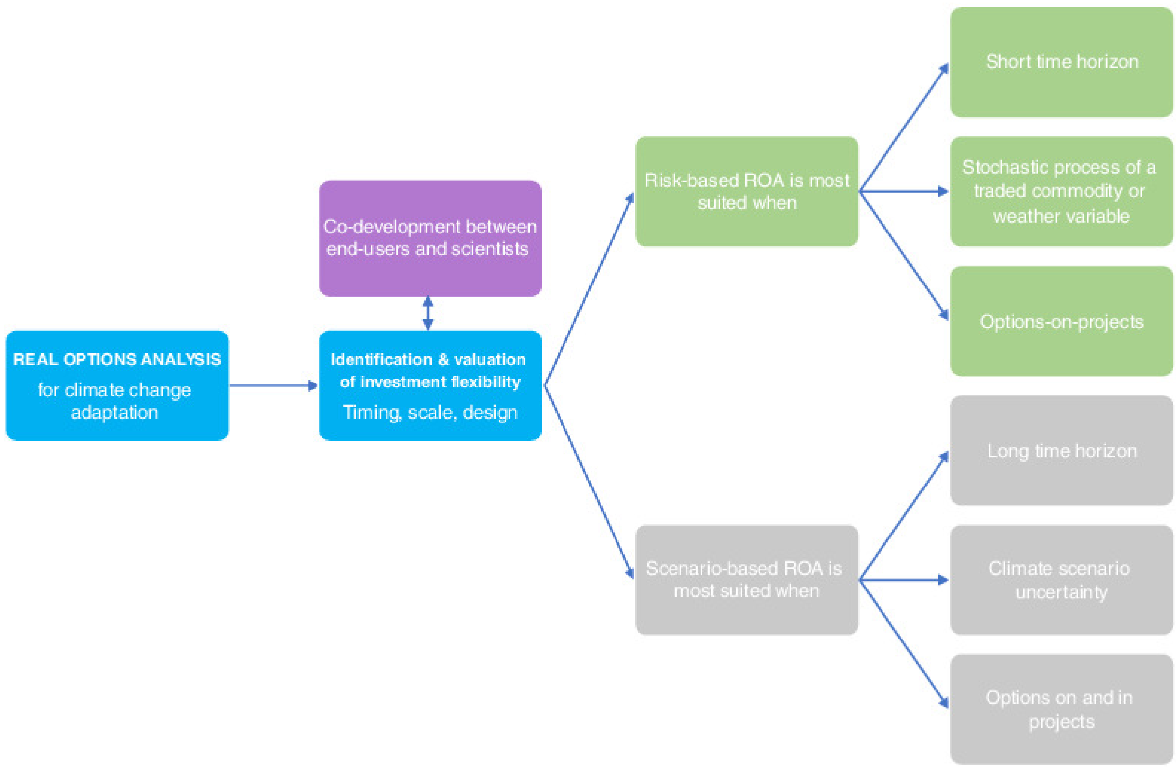


Figure 14: Role of Real Options Analysis in climate change adaptation (Wreford, Dittrich, & van der Pol, 2020).

10.15Integrated Assessment Models

Integrated assessment integrates different models, methods or sectors within a single analysis or analytical model.

Integrated assessment models (IAM) combine the scientific and economic aspects of climate change within a single analytical framework. The framework links economy, emissions, climate, and economic costs together, including feedbacks. Simplified climate projections and impact relationships that link climate changes to very highly aggregated economic damage estimates facilitate the analysis of economic costs.

IAMs mitigation modules analyse the costs and benefits of climate policy. Some IAMs have adaptation modules or functions where adaptation is represented by parameterised functions, reducing the severity of economic costs up to a certain level of temperature change.

It is possible to compare the benefits of adaptation with the costs, but IAMs cannot optimise adaptation and mitigation

(UNFCCC, 2009).

10.16Social Cost of Carbon – Integrated Assessment Models – Damage functions

Fundamentally the proposition is that GHG increases impact the physical and socio-economic system, which impact economic welfare. Social Cost of Carbon (SCC) is a financial estimate of the economic damages over time that would result from emitting one additional ton of greenhouse gases into the atmosphere. The impacts include market impacts, energy costs, infrastructure damage, health and ecosystems.

Having a financial cost for carbon provides policymakers and other decision-makers with the ability to understand the economic impacts of emissions or mitigation decisions, evaluating the benefits over mitigation (risk reduction) cost and the benefits compared to other forms of social investment.

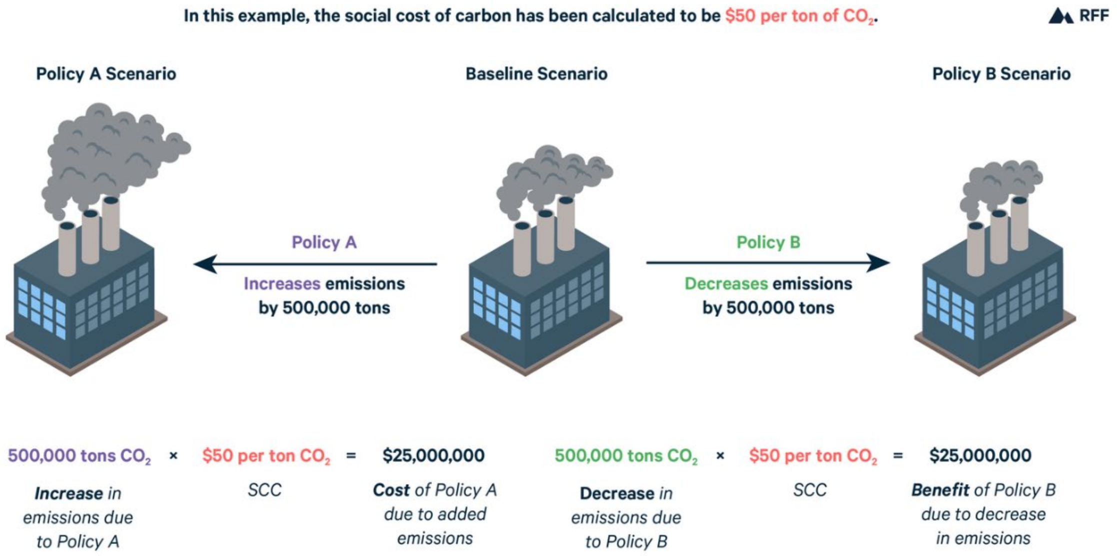


Figure 15: Using the SCC to calculate costs and benefits of changing emission.
Source: https://www.rff.org/publications/explainers/social-cost-carbon-101/

In the US, SCC is mandatory as part of the benefit-cost analysis of significant regulations and other actions.

SCC is calculated using Integrated Assessment models, with simplified representations of the economy, climate and impact mechanisms. The specific method of understanding the impact is through damage functions- in a complex series of physical and socio-economic relationships.

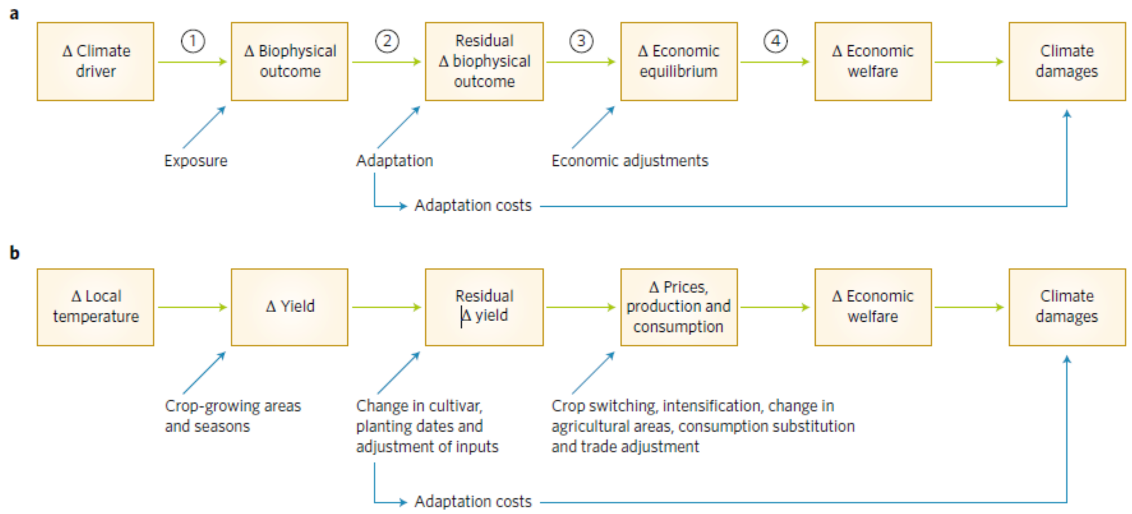


Figure 16: The representation of the complex series of physical and socio-economic processes and relationships encompassed by a damage function. A. Generalised stages (1) biophysical sensitivity to climate driver, (2) adaptation effectiveness, (3) general-equilibrium effects, and (4) economic preferences. b. an agricultural sector example (Diaz & Moore, 2017).

10.17Example – EU-Impressions

The EU-Impression project, 'developed advance understanding of the implications of high-end climate change, involving temperature increases above 2°C, and to help decision-makers apply such knowledge within integrated adaptation and mitigation strategies".

The EU-Impressions project integrated the RCP and SSP data and used a suite of existing climate change impact and adaptation and agent-based models to explore synergies and trade-offs between adaptation and mitigation actions under high impact climate change. [18]

The conceptual model is based on an adaption of the DPSIR (Drivers-Pressures-States-Impacts-Responses) framework ((European Environment Agency (EEA), 2005; Rounsevell et al., 2010)).

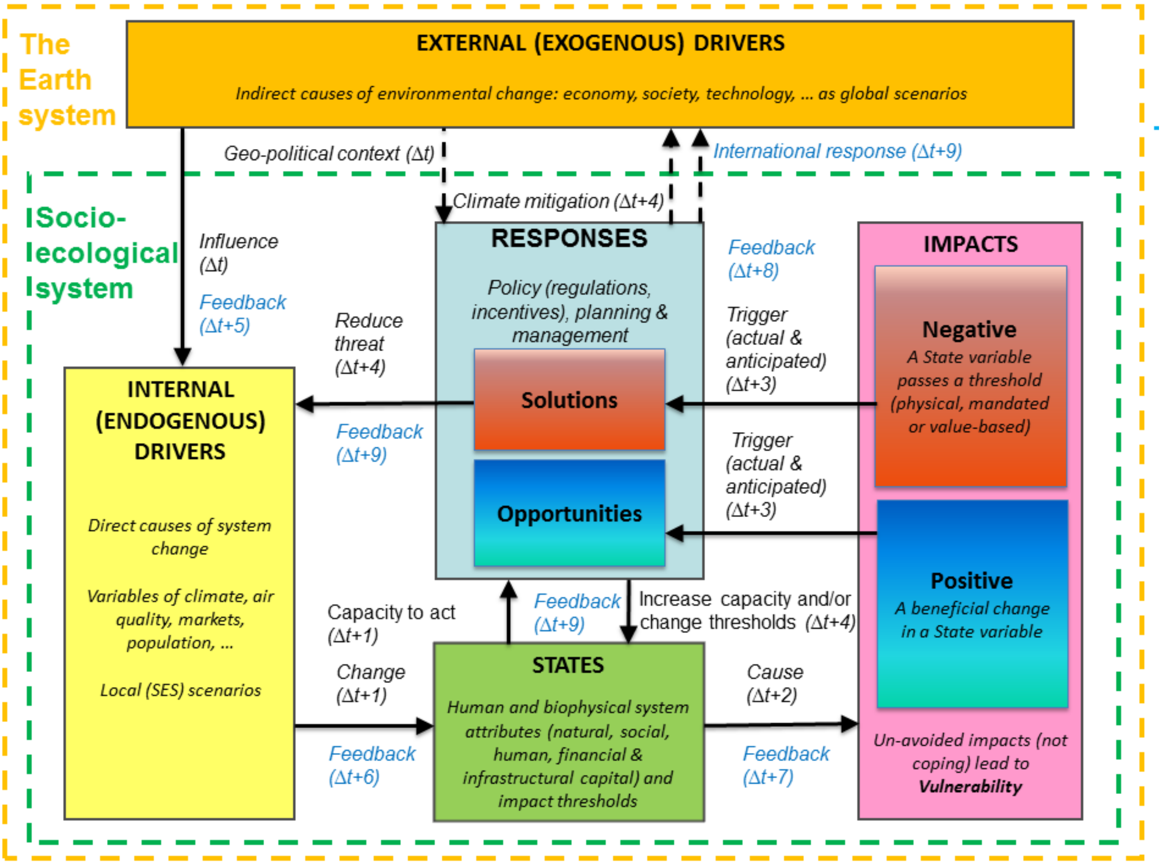


Figure 17: The IMPRESSIONS conceptual framework (Carter et al., 2015)

To identify "environmental change on a socio-ecological system of study" 20+ models were used across a range of case studies. The types of impact models used are given in Figure 19.

[18] http://www.impressions-project.eu/show/project_2731/

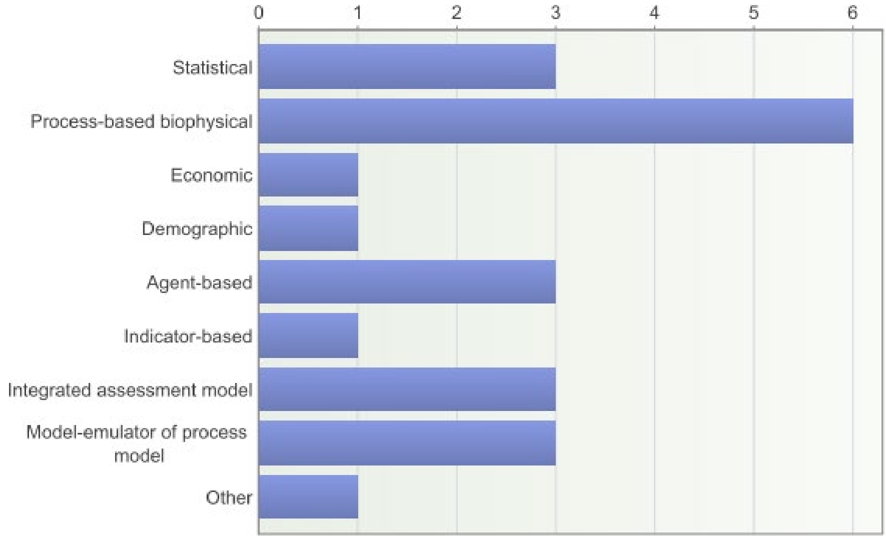


Figure 18: Types of impact models used in EU-IMPRESSIONS

The modelling processes aimed to assess the effectiveness of adaptation pathways to meeting stakeholder visions (Figure 20).

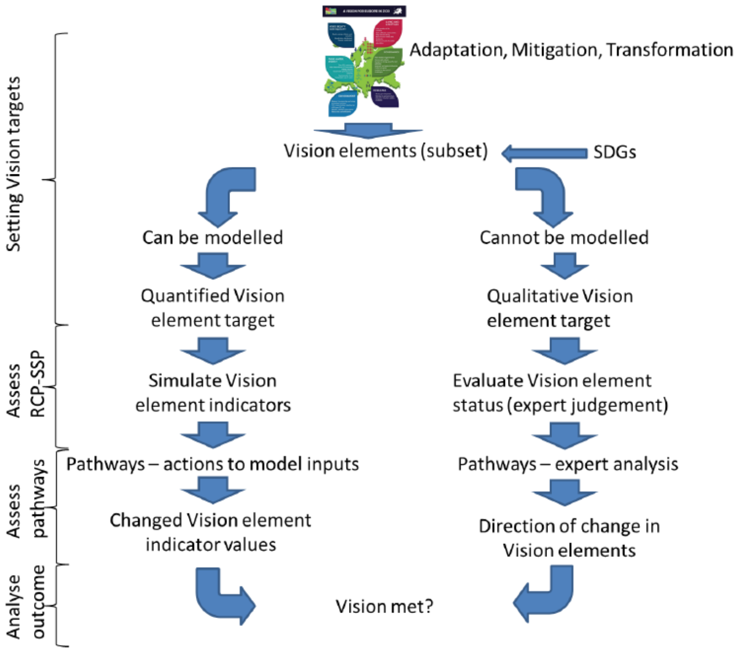
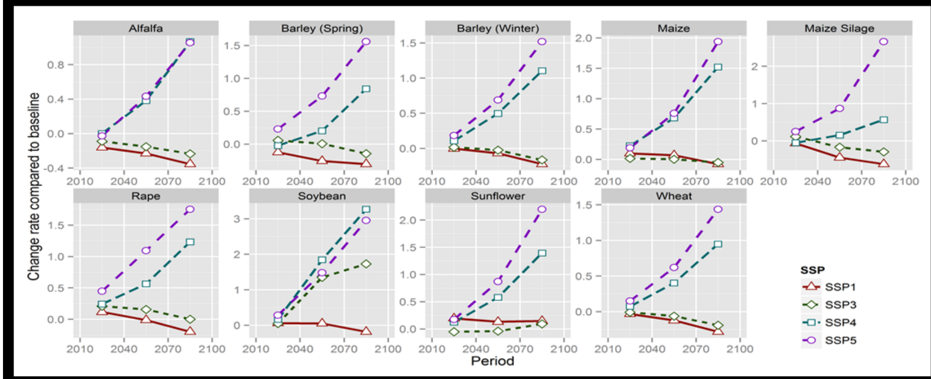
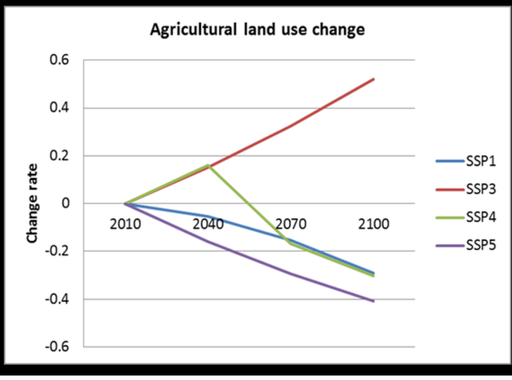


Figure 19: An overview of the methodology used to assess pathway effectiveness (Carter et al., 2015).

Advancement and application of regional/local scale methods and models for quantifying climate change impacts, adaptation and vulnerability (CCIAV) associated with high-end climate and socio-economic scenarios

A range of different modelling approaches was used in the regional and local case studies, including integrated modelling, process-based or physically-based modelling, and agent-based modelling. The models were selected based on the importance of issues to the different case studies, e.g. agricultural land use model for Hungary.





	Time slice	Subsidy	Access to social network	Attitude towards environment
SSP1	2010-2040	+	++	+
SSP1	2040-2070	+	++	+
SSP1	2070-2100	0	++	+
SSP3	2010-2040	0	-	-
SSP3	2040-2070	-	-	-
SSP3	2070-2100	-	-	-
SSP4	2010-2040	-	--	0
SSP4	2040-2070	0	+	+
SSP4	2070-2100	0	0	0
SSP5	2010-2040	0	-	-
SSP5	2040-2070	0	0	0
SSP5	2070-2100	--	+	+

Figure 20: Overview of sources and methods used in scenario quantification for agricultural land use modelling(Carter et al., 2015). The top graph is Crop yields under different SSPs, Lower left: Agricultural land-use change under different SSPs; and Lower right: Socio-economic change assumptions based on qualitative scenarios.

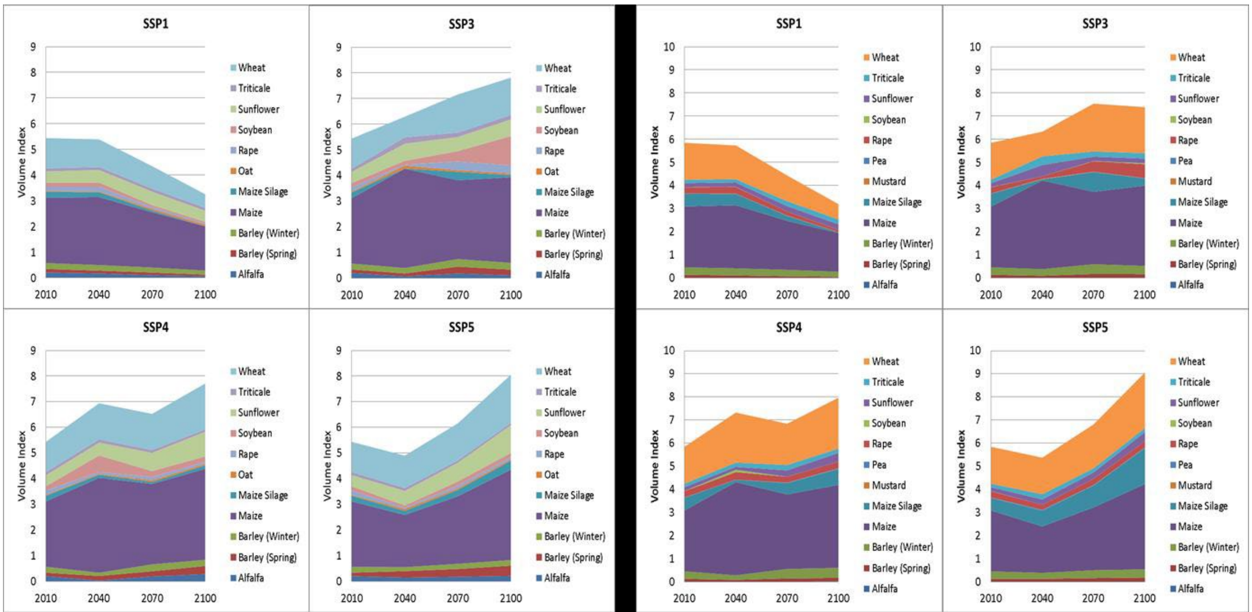


Figure 21: Projected changes in crop production for 2 case study areas for each SSP.

10.18Recommendations

- Further research in adaptation within the primary sector is orientated towards providing freely available quantitative data and models that enable effective analysis of impacts, policy and adaptation options to support adaptation and mitigation planning and investment.
- Further research the development of freely available models and use of models that project changes in biological productivity, socio-economic impacts, behaviours, future economic states, including damage functions; or enable decision making under uncertainty; assist in adaptation planning so that cost of carbon, changes in regional and national economics, business financials, community resilience can be more understood.

11 Appendix 1: SSP Narratives

Narratives are from B. C. O'Neill et al. (2017) and in the 'extra' material associated with the published paper.

11.1 SSP 1 narrative

The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift.

The combination of directed development of environmentally friendly technologies, a favourable outlook for renewable energy, institutions that can facilitate international cooperation, and relatively low energy demand results in relatively low challenges to mitigation. At the same time, the improvements in human well-being, along with strong and flexible global, regional, and national institutions imply low challenges to adaptation. (O'Neil et al 2015, supporting information)

11.2 SSP 3 narrative

A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns.

Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply ***high challenges to mitigation****. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act across regions, implies* ***high challenges to adaptation*** *for many groups in all regions.*

11.3 SSP 4: Inequality – A Road Divided – Low challenges to mitigation and High challenges to adaptation narrative

Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge-and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour intensive, low-tech economy.

Environmental policies focus on local issues around middle and high-income areas. The combination of some development of low carbon supply options and *expertise, and a well-integrated international political and business class capable of acting quickly and decisively, implies **low challenges to mitigation**. Challenges to **adaptation are high** for the substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses. (O'Neil et al, 2015, Supporting Information)*

11.4 SSP 5: Fossil Fuelled Development Narrative

Driven by the economic success of industrialised and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups.

*The strong reliance on fossil fuels and the lack of global environmental concern result in potentially **high challenges to mitigation**. The attainment of human development goals, robust economic growth, and highly engineered infrastructure results in relatively **low challenges to adaptation** to any potential climate change for all but a few.*

12 Appendix 2: Impact chains in primary production systems

Climate Drivers	Changes in climate parameter	Intermediate impacts	Main system Impact	System
Temperature				
	Frost	Phenology changes – delays bud growth	Loss of Productivity	Horticulture
		(extends into spring) Delayed grass production	Loss of Productivity	Dairy; Dry stock;
		Animal health – Lamb mortality	Loss of Productivity	Sheep
	Changes in seasonality: Warming seasons	Pests/Disease	Loss of Productivity	Horticulture; Forestry; Farming
		Fruit set	Loss of productivity	Horticulture
		Water supply	Loss of productivity	Dairy; Dry stock;

	Changes in seasonality: Warmer, dry and mild winters	Invasive species	Loss of productivity	Pastoral
	Changes in seasonality: Warmer and humid Summer/autumn	Facial eczema	Loss of productivity	Sheep & Beef, Dairy
	Hot days	Animal Health (diet, reproduction, heat stress)	Loss of productivity; Death	Sheep & Beef, Dairy
		Milk production	Loss of productivity	Dairy
		Cows stop eating	Subsequent fertility	Dairy
	Changes in seasonality: cold/wet spring	Cow reproduction	Subsequent fertility Replacement of stock	Sheep & Beef, Dairy
		Delayed grass growth	Loss of production (milk solids, meat)	Sheep & Beef, Dairy
	Changes in seasonality: Low temperatures in spring/summer – Growing degree days (GDD)	Fruit growth diminished	Loss of production Inability to export Loss of revenue	Horticulture
		Fruit size, Shape, sweetness, dry matter content	Inability to export Loss of revenue	Horticulture
		Inhibit pollination	Loss of production Loss of revenue	Horticulture
	Cold winter Temperatures	Chilling hrs – Fruit set and bud burst	Loss of production	Horticulture
	Higher Temperatures increased GDD	Increase in weed productivity, competition and spread Increase in pests spread, survivability, breeding	Increase is damage Loss of production Increase in in fire risk	Forestry

		Increase in fire risk, more fuel loading; drier fuel		
Precipitation				
	Increased Precipitation	Pugging	Loss of grass Loss of production	Pastoral
		Water table changes	Wet feet	Kiwifruit
		Erosion/land slips	Loss of production Increase cost	Pastoral
		Diseases; Mastitis	Loss of animals Loss of production Revenue loss	Dairy / Sheep & Beef
		Soil fertility	Loss of production Increase cost More fertiliser Downstream effects	Pastoral
	Heavy Winter Rain	Lower soil temperature	Loss of production	Pastoral
		Delayed warming in spring	Loss of production	Pastoral
	Hail	Product damage	Loss of (all) crop production	Horticulture
		Complete crop loss		Kiwi Fruit
	Drought / Reduction in water availability	Crop/pasture loss or decline;	Loss of production	Pastoral
		Milk Production decline	Loss of production	Dairy
		Loss of livestock (death and divestment)	Loss of production Replacement costs	Animals

			Loss of breeding stock	
		Increased input costs (supplementary feed, other grazing	Cost increases	Animals
		Premature drying off	Loss of production	Dairy
		Reduced water supply; irrigation	Loss of production Loss of grass Increased pressure on water supplies Increased Pressure on Irrigation	Animals
	Extreme Events	Erosion	Loss of trees Loss of soils Loss of production potential Downstream effects RMA breaches	Dairy, Sheep & Beef, Forestry
	Flooding	Crop/pasture loss	Loss of production	Dairy Sheep & Beef
		Asset damage (Farm)	Increased costs	
		Asset damage (Infrastructure)	Increased costs Inability to process Inability to operate machines	Dairy, Sheep & Beef, Horticulture, Forestry
		Asset damage (Transportation)	Inability to transport products Inability to receive supplies	All

		Higher suspended sediment load	Inability to take water Reduced water quality Sedimentation build up - increased risk of floods	All
		Woody debris	Infrastructure damage Damage to downstream properties and assets Legal impacts	Forestry
			Loss of land	Loss of production
		Reduced feeding to stock	Reduction in subsequent calving	Dairy, Beef
	Erosion	Productive land loss	Loss of trees Loss of soils Loss of production potential Downstream effects RMA breaches	All
		Asset damage to roads, rail (Transportation)	Inability to transport products Inability to receive supplies	All
		Siltation of waterways	Inability to take water Reduced water quality Sedimentation build up -	

			increased risk of floods	
	Water table changes	Wet feet – root die off	Loss of production	Kiwi fruit
		Water starvation – lack of roots in previous wet foot zone	Loss of production	Kiwi fruit
Wind	Drying	Increase water loss Increase fire fuel availability	Loss of grass production; loss of grass Increased fire risk	Pastoral
	Damage (extreme)	Loss of plants, food, assets	Loss of production	All
	Damage	Scuffing of fruit	Loss of saleable product	Fruit
Sea level rise	Salt water intrusion (from sea-level rise and extensive pumping of ground water that draws in salt water)	Loss of productive land Loss of ground water (bores)	Loss of land Production losses	
	Salt water flooding	Loss of productive land Loss/damage to assets	Loss of land Production losses Asset replacement and repair costs	Productive land

For more information see : Adapting to Climate change: Information for the New Zealand Food system. https://www.mpi.govt.nz/dmsdocument/28164-Adapting-to-climate-change-Information-for-the-New-Zealand-food-system.

13 Appendix 3: Behavioural Survey

13.1 Questions

Table 17: Themes addressed by questions in the survey

Typology theme	Question number
Risk profile	34
Environmental orientation	45-49
Farming background and education	2-12, 16, 37, 38
Reactive vs proactive decision-making preferences	43,44
Innovator level and sources of learning	39-43
Farming sector	17
Farm attributes, including composition of activities	14, 15, 16, 17-32, 35, 36, 17-32
Farming motivations	37-39
Ontology theme	Question number
Membership of professional groups or organisations	41
Farm location	1
Neighbourhood farming connections	39, 40
Decision-making behaviour in response to scenarios	Question number
Awareness of impact	45-49
Composition of future farming activity	54
Ability to implement changes	55

Table 18: Survey Questions

Number	Question	Notes

1	In which postcode area is your farm located?	
2	Which of the following best describes your farm ownership structure?	Used in typology PCA
3	Which of the following best describes your role on the farm?	Used in typology PCA
4	What is your age now?	Used in typology PCA
5	What is your sex?	Used in typology PCA
6	What is the highest level of education that you have you completed so far?	Used in typology PCA
7	For how many years of your adult life have you made your living as a farmer?	Used in typology PCA
8	On how many farms have you worked during your career?	Used in typology PCA
9	Before starting work on this farm, what types of farms did you work on, if any?	
10	Has a successor to this farm been identified?	
11	Which of the following best describes the successor?	
12	Before starting work on this farm, what types of farms did the successor work on, if any?	
13	How large, in hectares, is the total size of this farming operation?	Used in typology PCA; Used in Scenario PCA
14	Among this, how many hectares are leased?	Used in typology PCA
15	Approximately how far away is the farthest part of your farming operation from your home, in km?	Used in typology PCA
16	In what year did you begin working on this farming operation?	
17	Which of the following activities were undertaken for commercial purposes on this farm in the last year?	
18	How many hectares of this farming operation are primarily used for sheep and beef?	Used in typology PCA; Used in Scenario PCA
19	How many head of sheep are currently on the farm?	
20	How many head of beef cattle are currently on the farm?	

21	How many hectares of this farming operation are primarily used for dairy (only count dairy platform, do not include dairy support)?	Used in typology PCA; Used in Scenario PCA
22	How many head of dairy cattle are currently on the farm?	
23	How many hectares of this farming operation are primarily used for deer?	No positive responses obtained for deer
24	How many head of deer are currently on the farm?	
25	How many hectares of this farming operation are primarily used for pigs, goats, commercial poultry, and other commercial livestock?	Used in typology PCA; Used in Scenario PCA
26	How many pigs raised for commercial purposes are currently on the farm?	
27	How many goats raised for commercial purposes are currently on the farm?	
28	Approximately how many commercial poultry birds are currently on the farm?	
29	How many hectares of this farming operation are primarily used for fruits and vegetables?	Used in typology PCA; Used in Scenario PCA
30	How many hectares of this farming operation are primarily used for growing grapes?	No positive responses obtained for grapes
31	How many hectares of this farming operation are primarily used for growing arable crops?	Used in typology PCA; Used in Scenario PCA
32	How many hectares of this farming operation is planted in forestry?	Used in typology PCA; Used in Scenario PCA
33	Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks?	Used in typology PCA
34	In general, how profitable has this farming enterprise been in recent years?	
35	Which of the following activities have contributed most to the profitability of your farm? Tick all that apply.	
36	In general, what share of your household's income comes from non-farm sources?	Used in typology PCA
37	How important is being a highly productive farmer to your sense of self-identity, i.e., your sense of who you are?	Used in typology PCA

38	How important is being a farmer who takes good care of the environment to your sense of self-identity, i.e., your sense of who you are?	Used in typology PCA
39	With how many other farmers did you discuss farm practises, farm systems change, or practices to improve environmental performance in the last 12 months?	Used in typology PCA
40	How many working farms have you visited in the last 12 months?	Used in typology PCA
41	Please list your memberships of any professional groups or organisations	
42	How important are the following sources of information for making decisions related to farm practices, farm system change, and practices to improve environmental performance?	
a	Newspapers and general interest magazines.	
b	Television and radio.	
c	The Internet.	
d	Organisations that broadly represent primary industries such as Federated Farmers.	
e	Industry groups such as Beef & lamb NZ, HortNZ, DairyNZ and WineNZ.	
f	Cooperatives such as Zespri and Fonterra.	
g	Central government.	
h	Regional councils.	
i	Accountants and financial advisors.	
j	Farm consultants, extension officers, and contractors.	
k	Farmers' forums, agricultural shows, and field days.	
l	Other farmers and farmer discussion groups.	
m	Scientists.	
n	Vets.	
o	Rural retailers and their technical representatives (e.g., seed companies, fertiliser companies).	

43	Please describe your experience with the following technologies and practices on this farm.	
a	reducing stocking rates	
b	reducing N fertiliser	
n	wintering off stock	
d	applying DCDs	
e	employing a nutrient management plan	
f	adding or upgrading the irrigation system	
g	constructing a feed pad	
h	upgrading the effluent system	
i	fencing streams	
j	constructing wetlands and/or sedimentation traps	
k	planting forestry blocks	
l	planting riparian buffers	
m	changing primary crops and/or rotation	
44	How likely do you think the following is to happen in the next 5 years?	
a	part or all of the farm will be sold	
b	part, or all of the farm will be leased out or worked by a share farmer	
c	you will purchase, lease, or share farm additional land	
d	the enterprise mix will be changed to reduce your farm workload	
e	the enterprise mix will be changed to more intensive enterprises	
f	the enterprise mix will be changed due to impending regulations.	
45	How much do you agree with the following statement? I believe that it is important to farm in an environmentally friendly and sustainable manner	This question was not completed correctly by some participants

		and could not be used in the analysis
46	To what extent is the following personally important to you? Sustaining natural habitats that capture carbon and tackle climate change.	This question was not completed correctly by some participants and could not be used in the analysis
48	How much you consider Climate Change is affecting your farming environment now?	On a scale of 0 to 10
49	Do you consider that human activity is contributing to the global climate change above and beyond natural weather cycles?	Used in Typology PCA; Used in Scenario PCA
50	Considering each of these combined scenarios [1-4], how profitable would your farming enterprise be under these conditions?	
a	Combined Scenario 1	
b	Combined Scenario 2	
c	Combined Scenario 3	
d	Combined Scenario 4	
51	Under the combined scenarios [1-4] as described, which of your current farming activities would be affected most severely? Tick all that apply.	
a	Combined Scenario 1	
b	Combined Scenario 2	
c	Combined Scenario 3	
d	Combined Scenario 4	
52	Under the combined scenarios [1-4] described, which of the following activities would you foresee a shift towards, to most protect the profitability of your farm?	
a	Combined Scenario 1	
b	Combined Scenario 2	
c	Combined Scenario 3	
d	Combined Scenario 4	

53	Under the combined scenarios [1-4] described, how likely do you think the following options might be?	On a scale of 0 to 10
a	part or all of the farm will be sold	
i	Combined Scenario 1	
ii	Combined Scenario 2	
ii	Combined Scenario 3	
iv	Combined Scenario 4	
b	part, or all of the farm will be leased out or worked by a share farmer	
i	Combined Scenario 1	
ii	Combined Scenario 2	
ii	Combined Scenario 3	
iv	Combined Scenario 4	
c	you will purchase, lease, or share farm additional land	
i	Combined Scenario 1	
ii	Combined Scenario 2	
ii	Combined Scenario 3	
iv	Combined Scenario 4	
d	the enterprise mix will be changed to reduce your farm workload	
i	Combined Scenario 1	
ii	Combined Scenario 2	
ii	Combined Scenario 3	
iv	Combined Scenario 4	
e	the enterprise mix will be changed to more intensive enterprises	
i	Combined Scenario 1	
ii	Combined Scenario 2	

ii	Combined Scenario 3	
iv	Combined Scenario 4	
f	the enterprise mix will be changed due to impending regulations.	
i	Combined Scenario 1	
ii	Combined Scenario 2	
ii	Combined Scenario 3	
iv	Combined Scenario 4	
54	Under the scenarios [1-4] described, approximately what percentage of your farming operation would you foresee:	On a scale of 0 to 10
a	Combined Scenario 1	Used in Scenario PCA
i	Would be used for sheep and beef?	Used in Scenario PCA
ii	Would be used for dairy?	Used in Scenario PCA
ii	Would be used for deer?	Used in Scenario PCA
iv	Would be used for pigs, goats, commercial poultry, and other commercial livestock?	Used in Scenario PCA
v	Would be used for fruits and vegetables?	Used in Scenario PCA
vi	Would be used for growing arable crops?	Used in Scenario PCA
vii	Would be used for forestry?	Used in Scenario PCA
b	Combined Scenario 2	Used in Scenario PCA
i	Would be used for sheep and beef?	Used in Scenario PCA
ii	Would be used for dairy?	Used in Scenario PCA
ii	Would be used for deer?	Used in Scenario PCA
iv	Would be used for pigs, goats, commercial poultry, and other commercial livestock?	Used in Scenario PCA
v	Would be used for fruits and vegetables?	Used in Scenario PCA
vi	Would be used for growing arable crops?	Used in Scenario PCA
vii	Would be used for forestry?	Used in Scenario PCA

c	Combined Scenario 3	Used in Scenario PCA
i	Would be used for sheep and beef?	Used in Scenario PCA
ii	Would be used for dairy?	Used in Scenario PCA
ii	Would be used for deer?	Used in Scenario PCA
iv	Would be used for pigs, goats, commercial poultry, and other commercial livestock?	Used in Scenario PCA
v	Would be used for fruits and vegetables?	Used in Scenario PCA
vi	Would be used for growing arable crops?	Used in Scenario PCA
vii	Would be used for forestry?	Used in Scenario PCA
d	Combined Scenario 4	Used in Scenario PCA
i	Would be used for sheep and beef?	Used in Scenario PCA
ii	Would be used for dairy?	Used in Scenario PCA
ii	Would be used for deer?	Used in Scenario PCA
iv	Would be used for pigs, goats, commercial poultry, and other commercial livestock?	Used in Scenario PCA
v	Would be used for fruits and vegetables?	Used in Scenario PCA
vi	Would be used for growing arable crops?	Used in Scenario PCA
vii	Would be used for forestry?	Used in Scenario PCA
55	Under all the future shifts you have foreseen in your farming operations, what is your personal capability to potentially make any changes towards new farming operations.	On a scale of 0 to 10
a	Sheep and beef?	
b	Dairying?	
c	Deer?	
d	Pigs, goats, commercial poultry and other commercial livestock?	
e	Fruits and vegetables?	
f	Arable crops?	
g	Forestry?	

56	Which of the following external criteria might limit your capability to make the above changes in future farming operations?	On a scale of 0 to 10
a	Land availability	
b	Capital	
c	Technology and equipment	
d	Water	
e	Expertise and experience	
f	Energy and fuel	
g	Labour	
h	Seed / seedling stocks	
i	Breeding stock	
j	Fertiliser	
k	Other (specify):	

13.2 Data analysis method

The survey responses were analysed using clustering and correlation analysis in R Studio Version 1.3.1093 (R Core Team 2019), including the packages “ggpcorrplot”, "FactoMineR" and “factoextra". To enable categorical data to be used in these analyses, they were converted to whole integers to enable them. Survey data on individual farm activity per hectare were converted to percentage values per farm according to the total farm area. Typology and ontology questions were scanned initially using a correlation matrix to determine the location of any correlations across the questions. This analysis was followed by Principal Components Analysis (PCA), using R packages "FactoMineR" and "factoextra”, which was used to determine the clustering of typology and ontology responses. PCA was further used to determine the clustering of behavioural perceptions of risk from the future narratives in the scenarios themselves. The clustering analysis was used to prioritise the questions used in the PCA, in order to simplify this part of the analysis and make the outputs from this assessment meaningful.

13.3 Details summary statistics

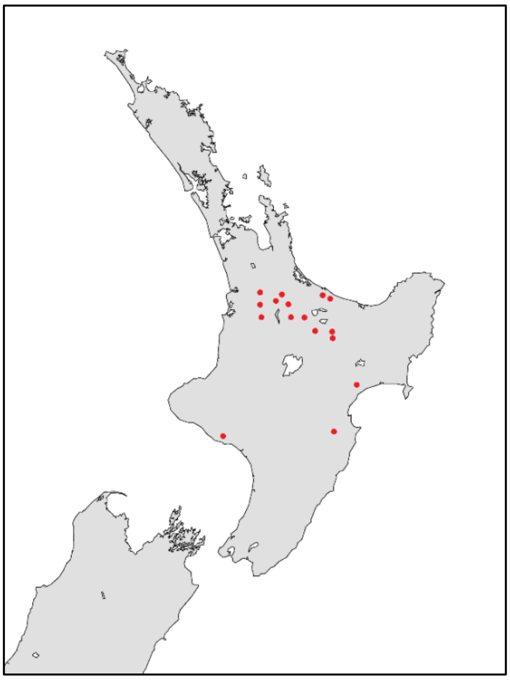


Figure 22: Locations of survey participants

Table 19: Summary statistics from our study group

Category	Value
Survey participants	16
Male	12
Female	4
Age (mean)	51 yr (±2.9 s.e.)
Career length (mean)	26 yr (±3.6 s.e.)
Family trust	31%
Owner-operator	25%
Family partnership	19%
Family cooperative	19%
Farm size (mean)	356 ha (±128 s.e.)
Dairy (main activity)	56%
Sheep & beef (main activity)	19%

Forestry (main activity)	19%
Arable (main activity)	6%

The proportions of farming activity in our study group according to percentage total land area reinforced the predominance of dairying activity (33.8%) in our study group (Figure 2). This is in contrast to the proportions of primary industry activity by land area for 2016 in the Waikato, Bay of Plenty and Hawkes Bay regions (Ministry for the Environment and Stats NZ 2018), showing that sheep and beef predominate (44.4%). Overall, the total land area managed by our study group was more focussed on dairying and arable than is typically expected for this region, together with reduced emphasis on sheep and beef, horticulture and forestry activity.

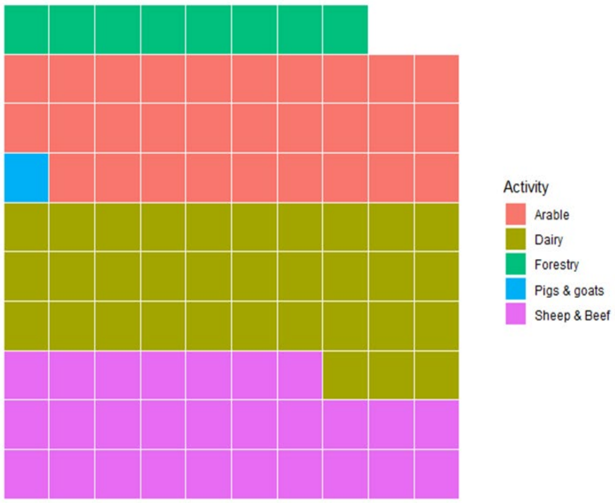


Figure 23 Total proportions of percentage farmed land area by activity in our study group compared with 2016 primary sector land-use cover data for Waikato, Bay of Plenty and Hawkes Bay (Ministry for the Environment and Stats NZ (2018))

- Sheep and beef 27.3%
- Dairy 33.8%
- Pigs & goats 1.1%
- Fruits and vegetables 0%
- Arable 29.6%
- Forestry 8.1%

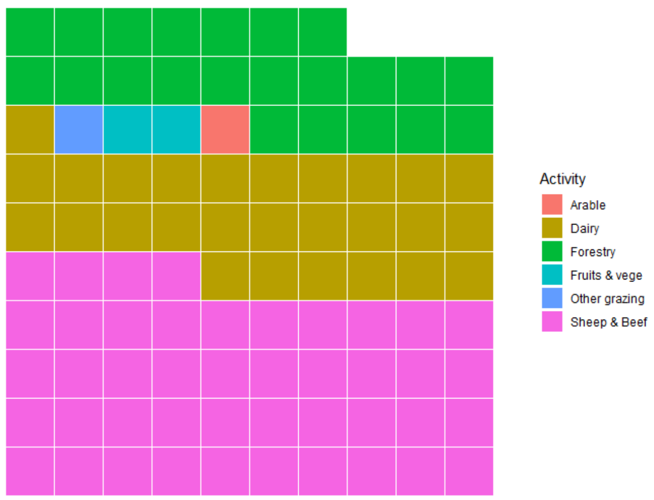


Figure 24: Total proportion of farmed land area in Waikato, Bay of Plenty and Hawkes Bay

- Sheep and beef 44.4%
- Dairy 27.4%
- Other grazing 1.6%
- Fruits and vegetables 2.0%
- Arable 1.9%
- Forestry 22.6%

13.3.1 Analysis of typologies via Principal Components Analysis

Correlation analyses of our typology and ontology survey questions were used to identify potential correlations between these questions (Figure 3, Table 4). The correlation analysis highlighted sets of questions that would be meaningful to analyse with PCA for the typology clustering analysis, indicating potential questions for exclusion if they did not meaningfully contribute to this understanding (these details are presented in Appendix 1). This assessment refined 22 questions for PCA typology clustering, with questions relating to, e.g. ownership structure, education, farming experience, farm size, farming activity, professional memberships and environmental awareness.

Table 20: Questions with the strongest correlations from the analysis shown in Figure 26.

Question	Correlation
Q.38	Q.31
Q.40	Q.38
Q.39	Q.7
Q.33	Q.14
Q.25	Q.32
Q.25	Q.15

Q.13	Q.25
Q.13	Q.5
Q.4	Q.31
Q.37	Q.2
Q.2	Q.21

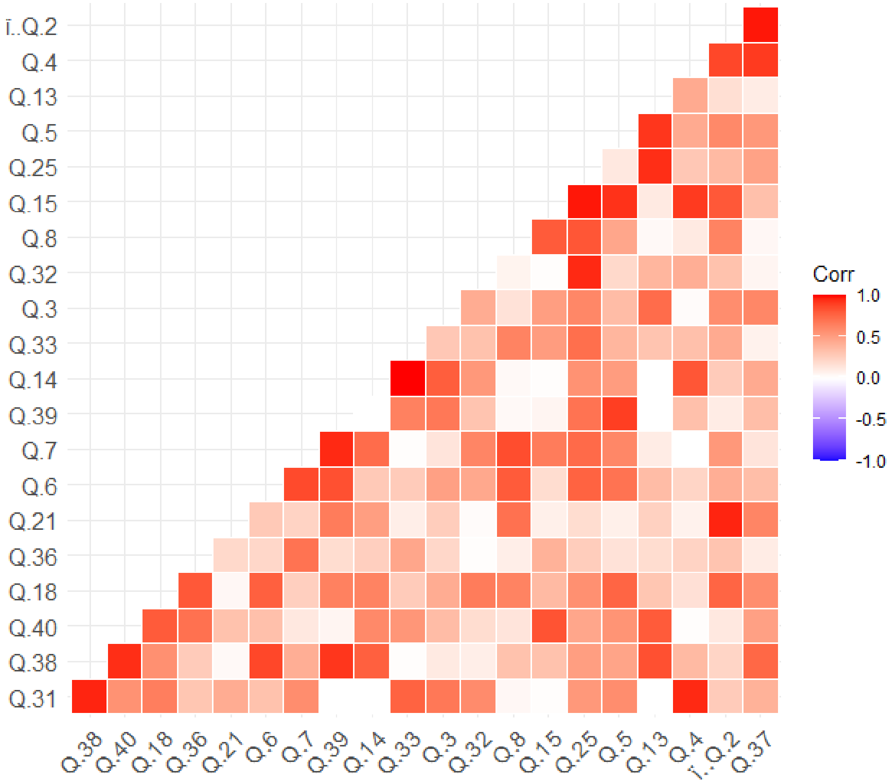


Figure 25: A correlation matrix indicating survey questions with correlating responses in our study group

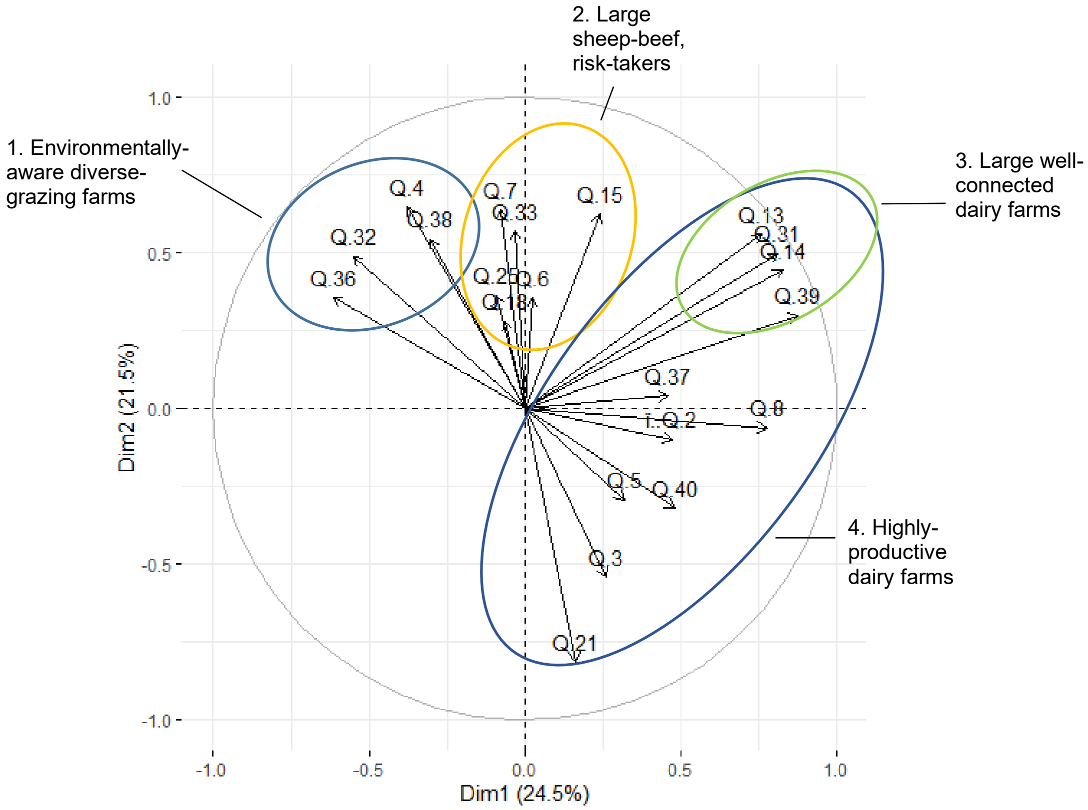


Figure 26: Results of the PCA analysis examining typology clustering in our study group

13.4 Statistical analysis of results

Table 21 Identification of PCA clusters for typologies in relation to the survey questions

Cluster	Questions
1. Environmentally-aware diverse-grazing farms	4, 32, 38, 36
2. Large sheep-beef, risk-takers	6, 7, 15, 18, 25, 33
3. Large well-connected dairy farms	13, 14, 31, 39
4. Highly-productive dairy farms	2, 3, 5, 8, 13, 14, 21, 31, 39, 40

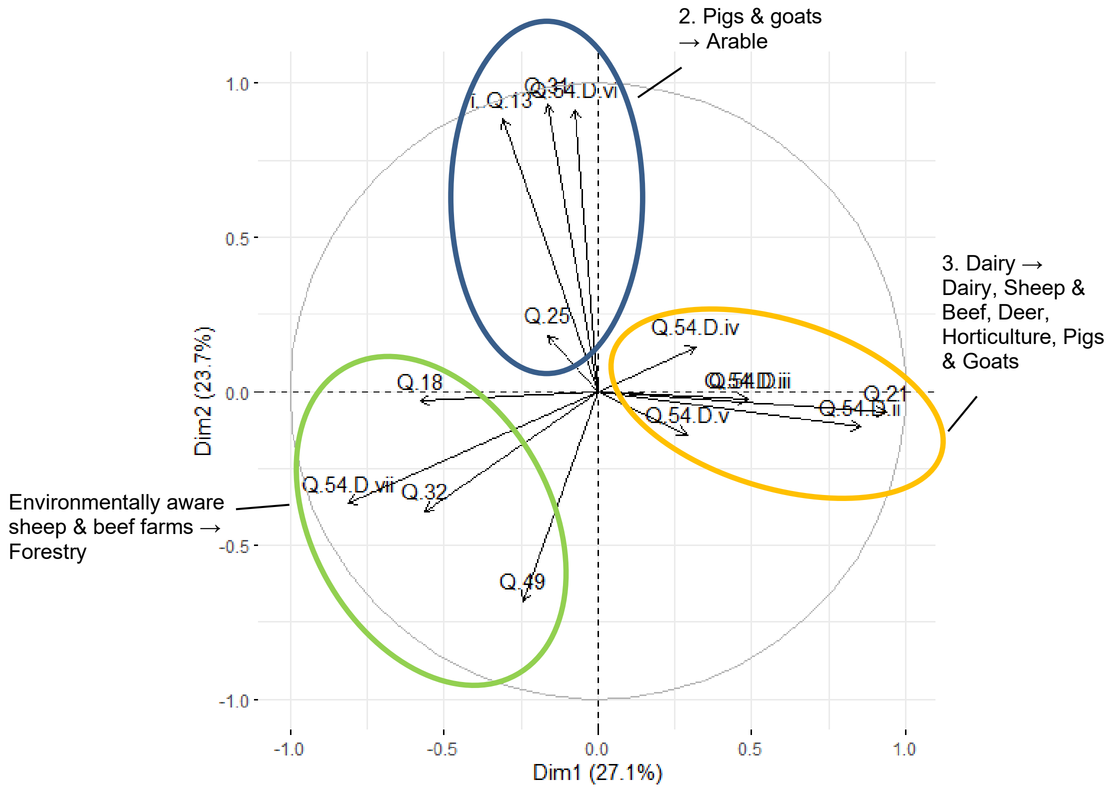


Figure 5: Results of the PCA analysis examining decision-making clustering in response to combined scenario 4.

Table 22: Identification of PCA clusters for decision-making in response to combined scenario 4, in relation to the survey questions

Cluster	Questions
1. Environmentally aware sheep & beef farms → Forestry	18, 32, 54d vii
2. Pigs & goats → Arable	25, 31, 54d vi
3. Dairy → Dairy, Sheep & Beef, Deer, Horticulture, Pigs & Goats	21, 54d i, 54d ii, 54d iii, 54d iv, 54d v,

The analysis of expected changes in farming activity by land area as disclosed by our study group determined some interesting transitions in collective outcomes in terms of land-use change, according to the severity of perceived combined scenario impacts, as shown in Figure 28. The total expected farming land area for (i) forestry and (ii) arable activities increases with the severity of these combined scenarios for the period 2030 to 2040. The total expected land area for (iii) sheep and beef, and (iv) dairy, however, declines according to the severity of the combined scenario (Figure 28). The change in dairy land area was relatively recalcitrant to changes in response to the information in the scenarios, with even the most severe combined scenario 4 revealing little change in the percentage land area accounted for by this land-use preference.

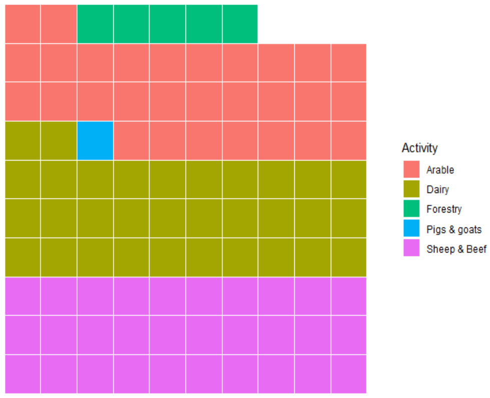
Combined scenario 1 total percentage land-area

Sheep and beef 30.5%

Dairy 32.9%

Pigs & goats 1.1%

Fruits and vegetables 0%



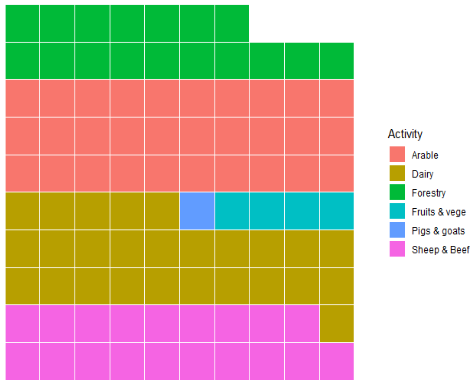
Combined scenario 2 total percentage land-area

Sheep and beef 19.8%

Dairy 26.6%

Pigs & goats 1.1%

Fruits and vegetables 4.8%



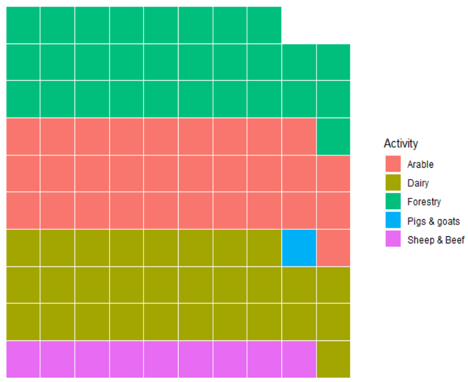
Combined scenario 3 total percentage land-area

Sheep and beef 9.1%

Dairy 29.2%

Pigs & goats 1.2%

Fruits and vegetables 0.4%



Combined scenario 4 total percentage land-area

Sheep and beef 0.1%

Dairy 21.6%

Pigs & goats 1.9%

Fruits and vegetables 2.9%

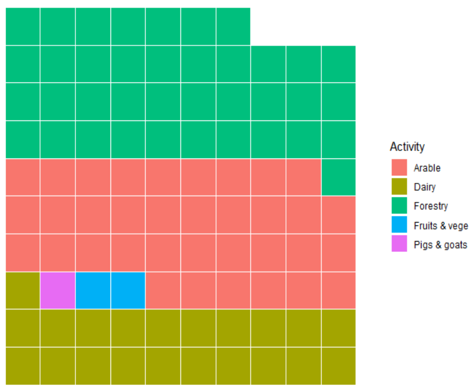


Figure 27 : Total proportions of expected percentage farmed land area by activity in our study group under the different combined scenarios

13.5 Preface of survey to rural decision-makers

These questions relate to the impacts of potential futures, or scenarios. The scenarios describe by a range of environmental, legislative and socio-economic factors that may affect your business in the future. To initially understand your rural decision-maker responses to potential future conditions, we firstly need anonymous information on your business and farming background. The survey then asks you to evaluate responses to a range of probable factors that could affect a business like yours in the period 2030 – 2040. Even if you do not expect to be running your business in 2030 – 2040 – please answer the survey as if you were still involved in its management. This information will allow us to make better predictions about how farming and primary industry sectors may to change in the future – and will help MPI in developing their knowledge-base in this area.

The survey uses sets of 'Combined Scenarios' to describe future conditions, which are referred to on page 7. These combined scenarios integrate sets of (1) climate change risks ('Low' or 'High') with (2) socio-economic pressures (driven by a 'high-constraints' or 'low constraints' world).

This survey supports an MPI-funded project into land-use change, which is led by Dr Alan Jones (Scion, Forest Research).

14 Appendix 4: The logic structure of survey information in relation to an agent-based modelling approach

The below overview details the logic-structure of information obtained by our survey to enable an agent-based modelling approach. This information was obtained in the present study via participatory engagement with stakeholders and the below framework would inform the development of quantitative methods for assessing climate change risk using agent-based modelling.

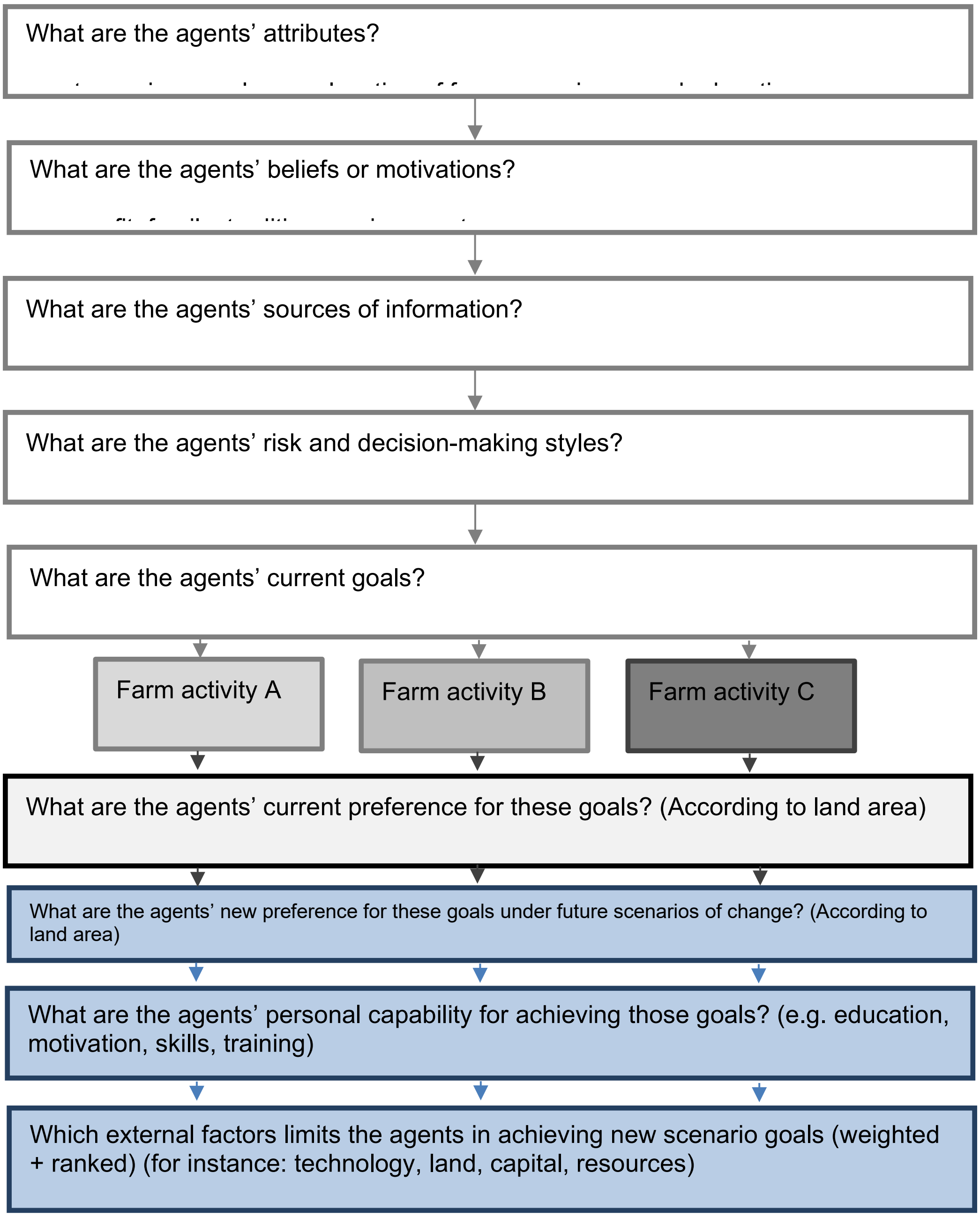


Figure 28: Logic-structure of information obtained by our survey to enable an agent-based modelling approach

15 Appendix 5: Behavioural survey simplified scenarios

Table 23: 2030 – 2040 Simplified regionally-specific physical climate scenarios developed for use with primary industry decision-makers

2030 – 2040 Climate scenario	
"LOW" RCP 2.6 / 4.5	"HIGH" RCP 8.5
• **+0.7°C increase in mean annual temperature** • **30% reduction in frost frequency** • **40% increase in days >25°C**	• +1.0°C increase in mean annual temperature • 50% decrease in frost frequency • 100% increase in days >25°C

• **Minimal change in mean annual precipitation** • **Minimal change in dry days** • **-0.2 % decrease in mean annual humidity** • **+10% CO_2 + climate driven increase in productivity** **+71% increase in wildfire risk**	• Decrease in mid-North Island spring precipitation • Decrease in South Island and Gisborne, Hawkes Bay winter precipitation • Minimal change in dry days • -0.3 % decrease in mean annual humidity •

Table 24 2080 – 2090 Simplified regionally-specific physical climate scenarios developed for use with primary industry decision-makers

2080 – 2090 Climate scenario	
LOW: RCP 2.6 / 4.5	HIGH RCP 8.5
• 0.7°C increase in mean annual temperature • 30% decrease in frost frequency • 40% increase in days >25°C • Minimal change in mean annual precipitation • Minimal change in dry days • -0.6% decrease in mean annual humidity • +20% CO_2 + climate driven increase in productivity • +83% increase in forest fire risk	• +3.0°C increase in mean annual temperature • 90% decrease in frost frequency • 300% increase in days >25°C • Decrease in mid-North Island spring precipitation • Decrease in South Island and Gisborne, Hawkes Bay winter precipitation • 10 or more extra dry days per year • 20% increase in extreme rainfall days • Frequent severe mid-summer droughts in current dry areas • -5% decrease in mean annual humidity • 40% decrease in annual wool yield • Severe annual pest damage to arable crops

Table 25: Simplified regionally specific socio-economic scenarios developed for use with primary industry decision-makers

		"LOW" [RCP 4.5: 2030 – 2040] ↓	**"HIGH" [RCP 8.5: 2030 – 2040]** ↓
Socio-economic scenario 2030 – 2040	High constraints	• $135 / tonne carbon price • National on-farm nutrient emissions admin cost = $11M / yr • Sheep, dairy, beef profits decrease = -80% • Meat and milk demand falls	

		• Export transport costs increase by 4%[19] • Rural land values drop considerably • Afforestation incentives increase
	Low constraints	• $30 / tonne carbon price • National on-farm nutrient emissions admin cost = $0 / yr • Sheep, dairy, beef profits decrease = -9% • Rural land values decline • Afforestation incentives continue
	Innovative NZ	• Increased returns delivered via new high-value primary industry products • New markets created • Transportation electrified • Increased competitive advantage • Methane vaccine: 10-30% reduction in CH3 emissions for grazing animals • Policy incentives for circular bioeconomy initiated

16 References

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