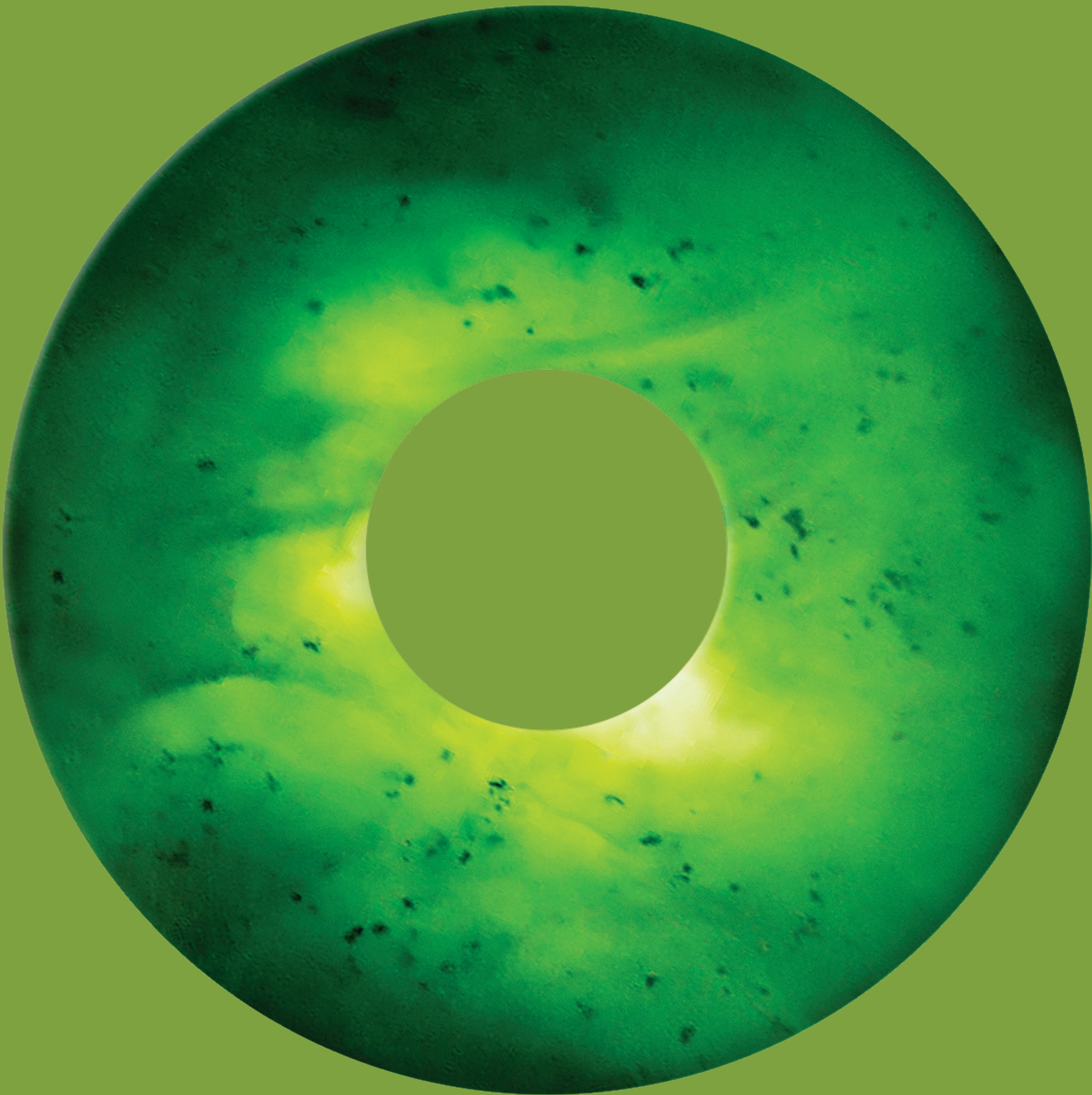
The Aotearoa Circle

Mā te Kaitiakitanga ko te Tōnuitanga
Prosperity Through Guardianship



Climate-related risk scenarios for the 2050s

Exploring plausible futures for aquaculture and fisheries in New Zealand

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Contents

Abbreviations and Acronyms

ACE	Annual Catch Entitlement
BEC	BusinessNZ Energy Council
CDSB	Climate Disclosure Standards Board
EC	European Commission
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organisation of the United Nations
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GHG	Greenhouse Gases
ICES	International Council for the Exploration of the Sea
IIED	International Institute for Environment and Development
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IMTA	Integrated Multi-Trophic Aquaculture
ISO	International Standards Organisation
MBIE	Ministry of Business, Innovation & Employment
MfE	Ministry for the Environment
MPA	Marine Protected Area
MPI	Ministry for Primary Industries
QMA	Quota Management Area
QMS	Quota Management System
RAS	Recirculating Aquaculture Systems
RCP	Representative Concentration Pathway
SASB	Sustainability Accounting Standards Board
SLR	Sea Level Rise
SPA	Shared Policy Assumptions
SPANZ	Shared Policy Assumptions for New Zealand
SSP	Shared Socioeconomic Pathway
SST	Sea Surface Temperature
TAC	Total Allowable Catch
TACC	Total Allowable Commercial Catch
TCFD	Taskforce on Climate-related Financial Disclosure
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
WMO	World Meteorological Organization

List of Figures and Tables

Key Conclusions

1. Key Conclusions

While based on best available science and the wisdom of The Aotearoa Circle's government, iwi, corporate, and civil society partners, some of the insights below are speculative. All are intended to challenge assumptions about the future, stimulate critical thinking, and encourage timely action.

1. Climate-related risks are interdependent and involve more than biophysical change

New Zealand's fisheries and aquaculture sectors face challenging climate-related risks, whether the world continues on a trajectory of high greenhouse gas emissions or abruptly decarbonises in order to meet the Paris Agreement's goal of holding the increase in global average temperature to well below 2°C.

When thinking about climate-related risks to the sector, the biophysical impacts of a high warming scenario intuitively come to mind, but the impacts of rapid decarbonisation also pose threats – as well as opportunities – that demand a strategic response by government, businesses, and other stakeholders.

2. Climate-related risks and opportunities cannot be understood or addressed in isolation

The impact of climate change on natural and human systems will influence, and be influenced by, other risk factors old and new. Disruptive technologies and social attitudes, for instance, may drive comparably profound change. As such, climate-related risks can neither be understood or effectively addressed without considering their dynamic interaction with other risks.

3. Consumer attitudes to seafood, seafood suppliers, and supply chains could shift rapidly

Meeting the UN's Sustainable Development Goals, including ambitious emissions reduction targets, will require a step change in how we feed the planet's people. The ability of food providers to make credible claims about decarbonisation, sustainability, animal welfare and societal equity will become a prerequisite for competitive participation in global marketplaces and may trigger an arms race of 'conspicuous conservation'. Under this scenario, New Zealand's distance to markets grows in significance until innovative solutions to supply chain emissions are developed.

4. Food security concerns could broaden consumer horizons

In a rapidly warming world where climate and conflict-induced scarcity sees low economic growth alongside growing food insecurity, consumers may prize dependable food suppliers above all else. New Zealand's marine resources could play a crucial role in meeting this demand, but peaks and troughs of volatility in fish supplies could drive consumers towards alternative food sources, such as plant-based and synthetic proteins.

5. 'Marine protein' could be the future

The key to a prosperous future in marine food provision may mean moving beyond current commercial concepts and embracing alternatives that range from macroalgae to cultured proteins, multi-trophic marine farms to sub-tropical wild capture species. Indeed, the future of food is likely to require an 'all and' response.

6. New Zealand's geographic location buys time

Compared to most parts of the world, New Zealand's climate will remain relatively benign through to 2050 (and possibly beyond). Our marine 'goldilocks zone', where warm and cold waters meet, should help to preserve New Zealand's commercial catch and aquaculture harvests while others falter. However, this outcome will also depend on increasingly careful resource management. Good science will have a crucial role to play in enabling wise management decisions.

7. Multi-stakeholder collaboration is imperative

Our social, political and economic institutions will need to pivot quickly and collaboratively to avoid the worst effects of climate change. So far, New Zealand's Covid-19 response has demonstrated the value of going hard, going early, and working together to address complex risk under conditions of uncertainty. The 'Māko' and 'Kahawai' scenarios similarly demonstrate how a proactive, flexible, and collaborative approach to mitigation and adaptation, which reflects New Zealand's unique circumstances and Crown-Māori fisheries governance model, could pay dividends.

8. The next decade is crucial

The next 10 years will determine whether our world tracks towards a high warming 'Māko' or strong mitigation 'Kahawai' scenario. If we haven't taken decisive action by then, feedbacks and tipping points in the climate system will choose a perilous path for us.

Insights for key stakeholders

Aquaculture

1. Significant growth in output to meet the needs of a growing global population is a factor in both scenarios for aquaculture, but the nature of growth required may differ substantially. **Effective early collaboration with policy makers at national and local level will be necessary** to establish a sound platform for growth.
2. It is highly likely that **costs will rise** as new locations and methods of production become necessary in response to changing physical conditions and consumer preferences.
3. To be resilient, organisations may not only need **strong R&D capability**, but also the capacity to **connect with domestic and international stakeholders** in new ways in order to navigate the challenges that expansion may bring.

Fisheries

1. The **scope for expansion in volume may be limited** in many fisheries if climatic impacts or changing consumer preferences alter supply or demand side dynamics, but strong consumer demand for safe, secure and sustainable protein could reward **innovative ways of creating value**.
2. Relative to global competitors, **New Zealand's fisheries are favourably placed to meet climate-related risks** because of our mature governance mechanisms under Te Tiriti o Waitangi and the Fisheries Act, and the biophysical advantages of our 'goldilocks' geographical position. Flexible, responsive policy and regulation will be critical to the sector's future success in maximising this comparative advantage.
3. Change in the fisheries sector will likely be swift and profound – **strategic foresight and operational agility** will be key to avoiding risks and maximising opportunities.

Policy makers

1. Climate and socioeconomic change will bring both acute and chronic disruptions to marine social-ecological systems, triggering industry, NGOs and the public to demand immediate action. Early investment in **research and policy options which anticipate disruptive change** will likely pay dividends.
2. Policy makers have taken positive steps to prioritise transparency within the fishing industry. Encouraging **greater transparency across the marine governance system** as a whole will build trust, collaboration and the establishment of shared adaptation objectives, creating the space necessary for innovation and experimentation.
3. Ensuring that **marine governance objectives are firmly embedded within those of Te Tiriti o Waitangi and the Zero Carbon Act** will position New Zealand's fisheries and aquaculture exporters strongly on the world stage.

Science and data providers

1. It will likely be necessary to overcome institutional and technological barriers to **broad-scale, long-term data gathering in the marine environment** if our science system is to adequately support decision-makers faced with climate volatility.
2. Information is also likely to become increasingly contested, raising the value of **timely and independent science advice.** There is typically no mature market for the types of climate information the science system must provide – until it is urgently needed. Bridging the gap between the point at which data must be gathered and the time when it is needed will likely require **additional, non-contestable core funding**.
3. Finding routes to **tailor data outputs to the needs and decision contexts of operational users** will be key to optimising investments in scientific research.

Introduction

2. Introduction

2.1 Purpose of this report

Although a global coronavirus pandemic was always a possibility, few probabilistic models would have predicted that this event would occur in early-2020. The magnitude, timing, and velocity of climate-related impacts are similarly uncertain.

This report presents climate-related risk scenarios developed by KPMG with The Aotearoa Circle and its government, iwi, corporate, and civil society partners.

The report aims to:

— Support strategic decision making about the sustainable utilisation of New Zealand's ocean resources despite inherent uncertainties in the magnitude, timing, and velocity of climate-related impact.

— Reduce costs and other barriers to effective climate-related risk management by stakeholders across New Zealand's marine fisheries and aquaculture sector.

The scenarios in this report are intended to challenge conventional assumptions about New Zealand's future and provide stakeholders with a means of stress-testing policy and investment decisions, as well as potential trade-offs associated with their decisions. During this process, decision-makers are expected to contest and/or embellish our scenarios in light of their unique perspectives on market behaviour, societal dynamics, and political response. This is both a foreseeable and welcome outcome.

In this *Introduction*, we explore the role of scenario analysis in helping organisations contend with climate change, highlight the strengths and weakness of scenario analysis, summarise our approach to scenario development, and present key features of our 'Māko' and 'Kahawai' scenarios. In *Context*, we provide important background information, including a typology of climate-related risks and important characteristics of New Zealand's marine ecosystem. *Integrated Scenarios* presents our 'Māko' and 'Kahawai' scenarios in full, while *Next Steps* explores how they might be used by stakeholders in New Zealand's fisheries and aquaculture sector. A glossary of terms, methodological details, scenario inputs, climate projection data, and sources are provided in the *Appendices*.

2.2 Role of scenario analysis

2.2.1 A stress-test for strategy

Scenarios are a validated tool for exploring the limits of "What *could* happen?" in order to be better prepared for whatever *does* happen. The purpose and power of scenarios is not to predict the future, but in identifying and interrogating the assumptions that underpin critical decisions today. Peter Schwartz (1990), a pioneer in applied scenario analysis, describes scenarios as:

> *Stories that can help us recognise and adapt to changing aspects of our present environment. They form a method for articulating the different pathways that might exist for you tomorrow, and finding your appropriate movements down each of those possible paths.*

Most analysis is a retrospective exercise, involving the exploration of past events and data to understand causal relationships and draw conclusions. In contrast, scenario-based analysis focuses on how uncertain, forward-looking variables might logically interact to create a plausible future state.

Many organisations and sector-based associations already use scenarios to stress-test business strategies under different future states. For example, the BusinessNZ Energy Council developed 2050 and 2060 scenarios for the domestic energy sector because they can be more useful than long-term forecasts at dealing with uncertainty (BEC 2015, p25):

> *Traditional forecasting approaches set out to make predictions about the future – future oil prices, discoveries, exchange rates, investments and policies. However, simple forecasting techniques often fail to inform us of the uncertainty that exists, particularly as we consider time periods decades into the future.*

Scenario analysis has also been applied to the fisheries sector. In 2018, for example, the International Council for the Exploration of the Sea (ICES) convened an expert workshop on socio-political scenarios to guide strategy (ICES 2019).

2.2.2 Strengths and limitations

Scenario analysis is particularly valuable within the context of managing climate-related risk. Due to uncertainties in the magnitude, timing, and velocity of climatic change, the Task Force on Climate-related Financial Disclosures (TCFD 2017a) recommends using scenarios, including at least one <2°C transition scenario, to explore the strategic implications of climate-related financial risks.

A key feature of scenarios is that they should challenge conventional wisdom about the future. However, this should not be interpreted as license for the imagination to run wild. Indeed, 'good' scenarios (TCFD 2017c) are:

— *plausible* (i.e. the narratives describe conceivable futures)

— *coherent* (i.e. constituent components are internally consistent)

— *challenging* (i.e. the narratives should confront business-as-usual assumptions)

— *relevant to decision-makers* (by enabling strategists to test their intentions against the scenarios).

Scenarios are *not* probabilistic predictions, nor are they the inevitable outcome of a given trajectory. As such they cannot be used as a lens to determine the 'most likely' future conditions an organisation will encounter. However, they *can* illustrate a plausible spectrum of risks that organisations can use to challenge assumptions, consider resilience and stress-test potential responses.

According to ICES (2019), socio-political scenarios are valuable in a marine context because they can help:

— Evaluate potential risks and opportunities for fisheries, get people talking, and energise those who will be most impacted.

— Highlight the importance of exploring how markets, social dynamics, and regulatory frameworks might develop in future, in addition to considering the impact of physical variables on marine ecosystems.

— Unify disparate disciplines and provide a common language about how the future could unravel.

— Identify the potential scope for adaptation and characterise the behavioural response of fishers under different future conditions.

— Long-term modelling by cutting-through complexity and channelling thousands of potential permutations into predefined pathways, by encouraging the exchange the quantitative outputs, and by defining key assumptions that enable future fish availability, fuel prices, and consumer demand to be modelled.

Wind-tunnel analogy

Scenario analysis is analogous to evaluating the performance of an aircraft in a wind-tunnel. The value of the exercise is not due to the wind-tunnel reproducing only the most likely future weather conditions the aircraft will encounter, but because it helps manufacturers to explore the outer limits of the aircraft's resilience to stressors in a safe, controlled and cost-effective way.

The same is true with respect to businesses and climate-related risk. Scenario analysis can help organisations to explore their operational resilience and strategic limitations under challenging, yet plausible, climate futures.

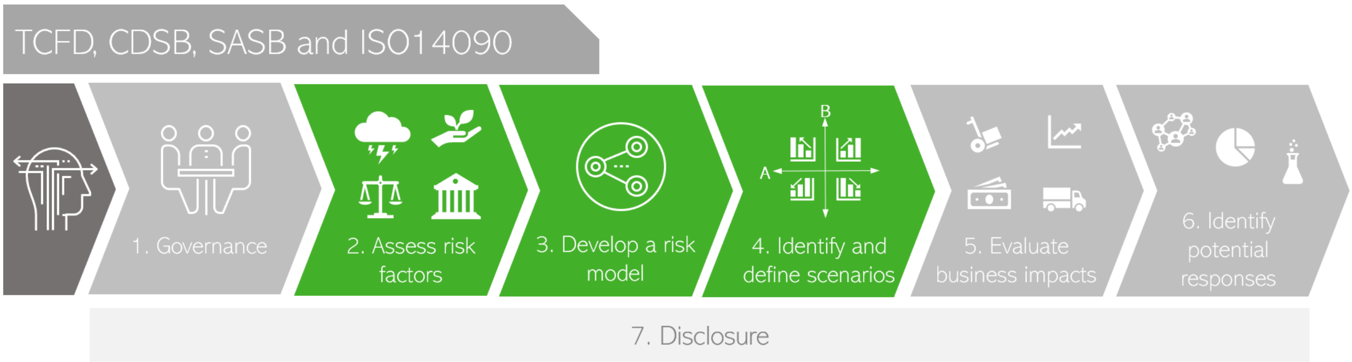


Figure 1: The KPMG methodology, drawing on insights from TCFD, CDSB, SASB and ISO14090 to stress-test business strategy in the face of climate-related risk. The three phases highlighted in green are the focus of this project.

2.3 Our scenario development approach

KPMG has designed a climate-related financial risk assessment and disclosure methodology which combines the insights of the TCFD, the Climate Disclosure Standards Board (CDSB), the Sustainability Accounting Standards Board (SASB) and the principals and practices of ISO14090. Scenario analysis forms a key component of KPMG's methodology, as illustrated in Figure 1 above.

The nature and scope of this engagement saw the work focus on three specific phases of KPMG's methodology:

1. **Assessment of risk factors**: Significant and uncertain risk factors were elicited from experts at a stakeholder workshop.
2. **Development of a risk model**: Critical risk factors were identified for our scenario axis, and a climate-related risk model for fisheries (Maury et al 2017) was used to structure the interactions between key drivers. The model was tailored to New Zealand conditions by referring to New Zealand-specific scenarios and material provided by sectoral experts at the facilitated workshop.
3. **Identification and definition of scenario narratives**: Scenarios were developed based on an array of global and national scenario models, and other secondary research. The narratives were refined with stakeholders to ensure their robustness, plausibility and coherence.

A detailed description of the methods employed in undertaking these three phases are provided in *Appendix B: Methodology*.

Figure 2: Photos from the Auckland expert stakeholder workshop

2.4 2050 scenarios for New Zealand's fisheries and aquaculture

Two scenarios, 'Māko' and 'Kahawai', were developed for this report to explore the nature of climate-related risks at either end of a spectrum (Figure 3).

At one end lie the most **extreme physical risks of climate change**, where, if global action fails to achieve significant reductions in greenhouse gas (GHG) emissions, we will find ourselves facing:

— accelerating temperature increases in the atmosphere and ocean

— increasing ocean acidity

— accelerating sea level rise

— potentially profound changes in the abundance and distribution of commercial fish species.

At the other end of the risk spectrum, in a world where strong efforts to curb GHG emissions and enhance carbon sinks have alleviated the worst of the physical impacts of climate change, we face **profound transition-related challenges** that will complicate business planning and raise costs. These stem from changes in:

— the energy relied on for transport and industrial processes

— changes in the expectations of consumers in relation to sustainability and transparency

— changes in the regulatory environment that will demand more of the business sector in achieving societal goals beyond fuelling economic growth.

The scenarios were developed to illustrate the nature of risk which might plausibly emerge as a result of climate-related physical and transition risk to 2050.

Each scenario is summarised in a one-page overview illustrating the key parameters, risks and opportunities.

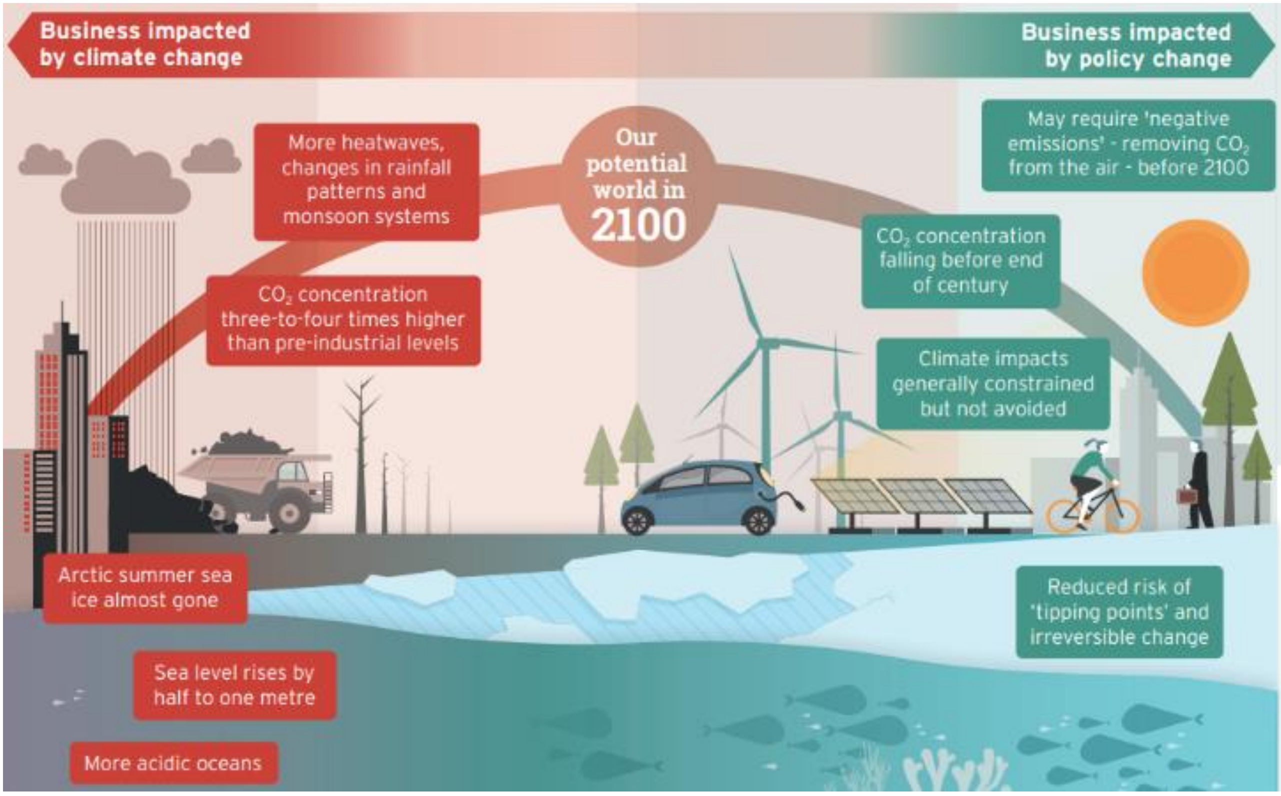


Figure 3: The spectrum of climate risk, adapted from IPCC 2013.

Māko 2050

Māko are **fast, aggressive, and unpredictable** shortfin sharks. The 'Māko' scenario describes a 2050 world where **change is moving through the marine environment quickly**. Failure to curb emissions mean the world is navigating the physical and socioeconomic consequences of significant climate disruption. Under this scenario storyline, warming is on-course to exceed 4°C by 2100.

1°C
Average air temperature increase around NZ
(1986-2005 baseline)

Global Indicators:

Global Population: 11b

Global GDP: $USD180trillion (0–500)

Carbon Price: $USD55 (0–200)

Aquaculture
160Mt
Global Production
70% cost increase
Fishmeal & fish oil

Fisheries
80Mt
Global Production
25% cost decrease
Operating & capital costs

0.28m
Average sea level rise around the coast of NZ

1.5°C
Maximum sea surface temperature increase around NZ

2%
Decline in dissolved oxygen in the ocean around NZ

7.94 pH
Acidification in the ocean around NZ

87.6
$MtCO_{2e}$
NZ's maximum projected yearly emissions in 2050

Risks

- Commercially valuable QMS species migrate south, out of northern QMAs
- Sea level rise and increasing storm activity damages shore infrastructure
- Global market access is constrained by tariff and non-tariff trade barriers
- Aquaculture is forced offshore to find cooler, cleaner waters
- Synthetic and cultured proteins begin to pose a significant challenge to fish products at the volume end of the market
- Policy and regulation lags behind the pace of climate change, hampering adaptation
- Uncertainty lowers the value of quota and undermines financial stability in the fishing industry

Opportunities

- Warm water species from the sub-tropics migrate south and are brought into the QMS
- Snapper, blue cod and kingfish appear in southern QMAs in much greater numbers
- Operational and capital costs decline in the fishing industry as government support for food self-sufficiency becomes paramount and regulatory burdens are reduced
- Global demand for marine protein rises significantly as the global population seeks secure food sources
- New Zealand's relatively benign climate impact regime and stable catch levels provide a comparative advantage

Kahawai 2050

Kahawai are a relatively abundant finfish that **transition through several distinct stages** of life development, **collaborate to avoid danger**, and are known for punching well above their weight when caught. The 'Kahawai' scenario describes a 2050 world that has succeeded in implementing the Paris Agreement and is **likely to keep total warming below 2°C over the course of the century**

0.7°C
Average air temperature increase around NZ
(1986-2005 baseline)

Global Indicators:

Global Population: 8.5b

0.23m
Average sea level rise around the coast of NZ

0.8°C
Maximum sea surface temperature increase around NZ

0 – 500
Global GDP: $USD300trillion

0 – 200
Carbon Price: $USD180

1%
Decline in dissolved oxygen in the ocean around NZ

pH 8.0
Acidification in the ocean around NZ

Aquaculture
124Mt
Global Production
58% cost increase
Fishmeal & fish oil

Fisheries
70.8Mt
Global Production
50% cost increase
Operating & capital costs

13.1 $MtCO_{2e}$
NZ's maximum projected yearly emissions in 2050

Risks

- Costs rise substantially as ambitious policy goals give rise to changing **sustainability regulations and reporting burdens**
- Transition to **new fishing methods and energy sources** carry additional ongoing costs
- **Barriers to market entry** are imposed by sustainability-conscious consumers who demand transparently ethical, low carbon products
- Global **demand for animal proteins declines** by 30%
- The inertia in the climate-ocean system mean sea **level rise, acidification and ocean warming will continue to impact marine and terrestrial operations**, despite the success of mitigation efforts
- **Synthetic and cultured proteins** begin to pose a significant challenge on ethical/animal welfare grounds

Opportunities

- **Catch potential increases** as warm water species move south and existing populations thrive
- High levels of economic growth, open global trade settings and the development of a prestige market niche in low-carbon, sustainable fish sees **NZ's fishing and aquaculture sectors generate strong revenue**
- Innovation in methods sees both inshore and offshore aquacultural production expand considerably
- New Zealand's **marine governance system becomes more flexible and collaborative**, enhancing the resilience of fisheries and aquaculture operators
- Due to the transparency, sustainability and social equity of our marine governance and food production systems, **New Zealand enjoys a strong comparative advantage in the global marketplace**

Context

3. Context

3.1 Climate change

Climate change is happening. The IPCC's Special Report on Global Warming of 1.5°C (2018) concludes that human activities have already altered our climate system and will continue to do so. Over the past century, land and sea surface temperatures have increased. The impacts of this warming are having a profound impact on biological systems. To understand the fundamentals of climate change, we only need to grasp a handful of numbers:

3m

Atmospheric levels of GHGs are currently the highest they have been for 3 million years. The last time there was this much CO_2 in the Earth's atmosphere, humans didn't exist, mega-toothed sharks prowled the oceans, the global average temperature was 2–3°C higher than the late-1800s, and the world's seas were up to 25 meters higher than today (Willeit et al. 2019).

1.1°C

Since the late-1800s, the planet's average surface temperature has risen by about 1.1°C (WMO 2020). Most of this warming has occurred in the past 35 years, with the last five years being the hottest years in history. Scientists are highly confident that this warming is a direct result of GHG emissions from human activities, especially the burning of fossil fuels and land use change (IPCC 2014).

90%

Our oceans are currently taking the brunt of climate change-induced warming. Since 1970, over 90% of the excess heat trapped in the climate system has been absorbed by the oceans (IPCC 2019). This additional energy has contributed to marine heatwaves, sea level rise, and ocean stratification. Over the same period, about a quarter of all CO_2 emitted by human activities has been directly absorbed by our seas, altering their chemical composition and causing ocean acidification.

1.5°C

In 2010, international negotiators agreed on a goal of limiting total warming this century to 2°C. However, the impacts of climate change to-date have been worse and more widespread than anticipated. The Paris Agreement, signed in 2016, includes a more ambitious goal of pursuing efforts to limit warming to 1.5°C. The risks and consequences of exceeding 1.5°C (IPCC 2018) include significant disruption to marine, land, and human systems, and the possibility of triggering global 'tipping points' that cause abrupt and potentially irreversible change. Coral reefs, for example, are anticipated to decline by 70%-90% in a 1.5°C world, and 99% in a 2°C world.

50%

In order to prevent more than 1.5°C of warming, GHG emissions must fall around 50% by 2030 (from 2010 levels) and reach near zero by 2050 (IPCC 2018). Responsible governments, cities, and businesses are setting commitments in-line with these targets. However, notwithstanding the emission reductions associated with COVID-19 lockdowns, global emissions have maintained an upward trajectory since the Paris Agreement was signed and are forecast to continue increasing into the 2020s. According to the UN Environment Programme's 'Emission Gap' analysis (2019), the world is currently on track for over 3°C of warming, even if all countries meet their stated commitments under the Paris Agreement.

3.2 Climate-related risks

Responding to climate change requires systematically identifying and analysing a range of risks, their interaction, and how they may be affected by existing or emerging issues under alternate future scenarios. To manage this task, KPMG relies upon an analytical framework of "Risk Pathways" in combination with integrated scenarios. Our approach builds upon emerging best practices recommended by the TCFD (2017a), the IPCC (2014), and the International Standards Organisation (ISO 2019). This approach to framing risk has been employed across agri-food, energy, and transport sectors in numerous jurisdictions (TCFD 2017b).

Risk Pathways

The risks that climate change poses to New Zealand's fisheries and aquaculture sectors span the following:

- *Physical risks*, which include long-term 'chronic' changes (e.g. sea level rise and stratification) and 'acute' climate-related events (e.g. storms and marine heatwaves). Physical risks threaten biomass and marine ecosystem health, as well as fisheries operations, supply chains, and employee safety.
- *Transition risks*, which reflect the challenge of shifting to a lower-carbon economy or adapting to the impacts of climate change. Sector-relevant examples of transition risk include:
  - regulations that increase the price of carbon or preserve resources which are threatened by climate change
  - the development and uptake of green technologies (e.g. electric fishing vessels) that affect organisational competitiveness
  - shifting supply or demand for products and services (e.g. a reduction in overseas demand for long-haul imports)
  - changing consumer/community perceptions of an organisation's contribution to climate change.
- *Legal risks*, which arise from non-compliance with regulations, from civil lawsuits, from Boards and Executives failing to fulfil their fiduciary duties, or from insufficient disclosure of financial risks. A legal opinion commissioned by the Aotearoa Circle (2019) concluded that climate change already presents a foreseeable risk of financial harm to many businesses and, under current law, directors must assess and manage climate-related risk as they would any other financial risk.
- *Capital risks*, which accrue as a result of unresolved physical, transition and liability risks. Capital risks include the loss of share value and diminished access to equity and capital debt markets.

Figure 4: Summary of climate-related financial risk pathways: physical, transition, legal and capital.

3.2.1 New Zealand's marine environment

The impacts of climate change on New Zealand's marine environment are widespread and varied. The latest research suggests that:

— On average, New Zealand's coastal waters are warming by 0.2°C per decade and marine heatwaves are becoming more frequent (MfE & Stats NZ 2019). The rate of open ocean warming varies across New Zealand's Exclusive Economic Zone (EEZ), but higher rates of warming have been observed off the South Island's west coast and east of the Wairarapa coast.

— The ocean around New Zealand is becoming more acidic. The Sub-Antarctic waters off the Otago coast have become 7.1% more acidic in the last 20 years (MfE & Stats NZ 2019). We could be headed for as much as a 150% increase in acidity under a high-end climate scenario (Law et al. 2017b).

— Changes in primary productivity (phytoplankton abundance) has varied across different waters over the past 20 years, typically decreasing in northern waters and increasing in southern waters (MfE & Stats NZ 2019). Primary productivity can correlate with wider marine ecosystem productivity.

— Looking ahead, these ocean properties are deemed highly sensitive to future GHG emissions. The largest projected changes to New Zealand's marine environment correspond with high emission scenarios (Law et al. 2016).

— The impact of climate change on New Zealand's oceans will vary by region. The areas projected to be the most sensitive to climate change include Sub-Antarctic waters south of 50°S, the eastern Chatham Rise, and subtropical waters north-east of New Zealand (Law et al. 2016).

Appendix D presents physical climate impact projections for New Zealand's marine environment in more detail.

3.2.2 Fisheries and aquaculture

The fisheries and aquaculture sectors contribute to climate change via fossil fuel-powered fishing vessels, fish farming systems, industrial processes, refrigeration, distribution, and waste, amongst other sources of GHG emissions (FAO 2015). Meanwhile, climate change affects fish abundance, fishing conditions, and global trade opportunities through a number of complex and often cascading pathways.

Overall, the many-layered impacts and implications of climate change will likely be profound for New Zealand's fisheries and aquaculture sectors and include:

— how much wild fish can be sustainably caught, as well as when and where stocks are available

— which aquatic species can be most profitably farmed in New Zealand waters

— damage to shore infrastructure, threats to the health and safety of fishing crews, and disruptions for supply chains and wider economic systems as a result of increasingly unpredictable and severe weather events.

As markets and governing institutions seek to mitigate and adapt to climate change, fisheries and aquaculture operators will face shifting regulatory requirements and market expectations. But to what degree, for example, will consumers weigh environmental impact in their food purchasing decisions? Will unease about climate-related risk mean that insurance becomes unaffordable, or capital unavailable? And will concerns about food security or economic recession compel governments to introduce protectionist trade barriers or subsidies?

Changes in the energy mix are also likely to affect up and downstream supply costs, service parameters and operational performance standards. For instance, wider reliance on hydrogen and electrification is plausible under all future scenarios for reasons of self-sufficiency or emissions reduction, leading to changes in cost, transport infrastructure and vehicle performance envelopes.

Scenario analysis can help organisations to explore and assess these complex climate-related risks, including the overlap between drivers and the interplay between risk factors.

Integrated Scenarios

4 Integrated Scenarios

Overview

The climate-related risk scenarios developed with and for government, iwi, corporate and civil society partners of The Aotearoa Circle's Marine Domain are:

— *Integrated.* To ensure plausibility and internal coherence, our scenarios reflect an integrated array of global, regional, climate, energy, and socio-economic models, such as the IPCC's Representative Concentration Pathways (RCPs) and the IEA's World Energy Model scenarios.

— *Exploratory.* Our scenarios are exploratory, narrative-based, and qualitative rather than quantitative. Because the scenarios are not probabilistic forecasts, a single scenario would have limited value. Scenarios are typically developed in pairs to allow decision-makers to interrogate the boundaries of how we might plausibly expect the future to unfold.

— *Set in the 2050s.* Although many businesses are already grappling with climate change impacts, the most significant effects of climate change will likely emerge over the medium to long-term. The climate-related risk scenarios developed for this report are set in the 2050s in order to explore medium to long-term uncertainties, while avoiding a time period too far in the future, which would lack relevance for near-term business decisions.

We have entitled the scenarios 'Māko' and 'Kahawai'.

Māko

Māko are fast, aggressive, warm-blooded shortfin sharks. The 'Māko' scenario describes a world in 2050 that has failed to curb emissions and is struggling to navigate the physical and socioeconomic consequences of significant climate disruption. Under this scenario storyline, warming is on-course to exceed 4°C by 2100.

Key characteristics of the Māko scenario:

- Climate-related risks are predominantly physical with cascading economic and market impacts.
- The Māko scenario constrains adaptive resilience in the face of deteriorating marine ecosystems due to weak global cooperation.

Kahawai

Kahawai are a schooling finfish that have several distinct stages of life development and punch above their weight when caught. The 'Kahawai' scenario describes a world in 2050 that has succeeded in implementing the Paris Agreement and is likely to keep total warming below 2°C over the course of the century.

Key characteristics of the Kahawai scenario:

- Climate-related risks are predominantly transitional with cascading impacts on governance and market structures.
- The Kahawai scenario favours sustainable economic growth, but there is pressure to demonstrate agility and flexibility to meet evolving consumer preferences.

4.1 Māko: A rapid warming scenario

'Māko' describes a world that has failed to curb emissions and is struggling to navigate the physical and socioeconomic consequences of significant climate disruption. Under this scenario storyline, warming is on-course to exceed 4°C by 2100.

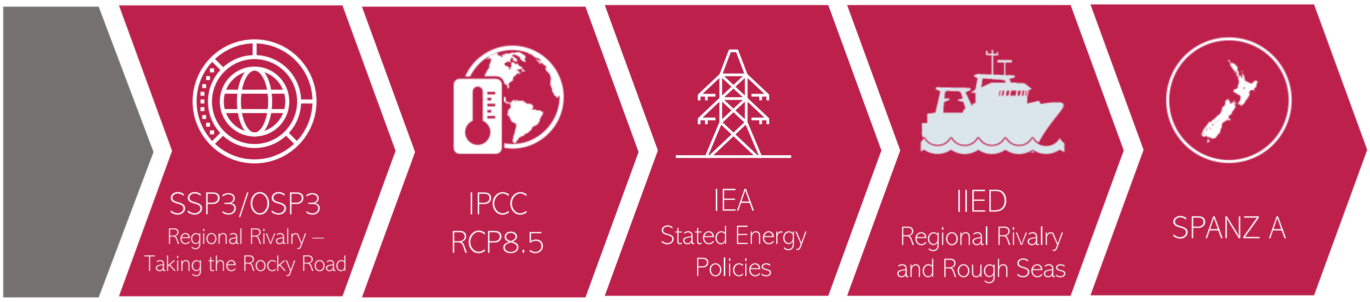
Patterns of unsustainable energy use and resource consumption continue largely unchanged. Economic development and wellbeing indices are declining across the Pacific. Climate change-induced displacement contributes significantly to political instability.

New Zealand has been less hard-hit by the physical impacts of climate change than its neighbours, but inflexible policy settings mean it is ill-prepared for what lies ahead.

With neo-liberal economics and short-term thinking continuing to dominate, the future is heavily discounted in nearly all climate and environmental policy decision-making. Despite claims to the contrary, both public and private sector adaptation is predominantly reactive and predicated on short-term cost-benefit calculations.

Marine primary productivity declines in some areas and increases in others due to climate-induced biogeochemical changes. Wellbeing indices across New Zealand, including income inequality, poverty, and deprivation indicate a negative trajectory – especially in rural communities whose fates are interwoven with primary industries.

Scenario data: Māko 2050 at a glance



Socioeconomics
- Population: ~11b
- GDP: $180t (2005 USD)
- GDP/capita: $17,000
- GINI Index: 0.51
- Trade settings; closed, tariffs
- Consumers: protein consumption governed by cost
- Land use: deforestation and increase in pasture/cropland sees water quality decline
- Wild fish demand: volume over value

Climate change
- SST: 0.7-1.5°C rise, variable with location
- Dissolved O2: ~2% reduction
- Acidification: pH falls to 7.93
- Storms: greater volatility, unknown impact on Tropical Cyclone freq./intensity
- Significant wave height >5m: moderate increase south of NZ
- Habitat loss: reduction in cold-water corals

Global energy
- Carbon price: ~US$55/t [Advanced economies: US$140/t by 2040; US$33-43/t by 2030]
- Fuel cost: Crude oil US$103/ barrel [2040], market volatility
- Fossil fuel dependence persists
- Maritime emissions: broadly stable(relative to 2008 levels)

Global fisheries
- Net Primary Productivity: 5% reduction
- Mean sp. Abundance: 11-24% reduction
- Sp. Distribution: uncertainty in stock location, many follow changing temp. gradients
- Costs: reduce 25%
- UNCLOS: De-powered due to global instability
- IUU: drivers to flout rules increase

Shared Policy Assumptions NZ
- Emissions: 50.8-87.6 $MtCO_{2e}$
- QMS: Reactive responses to changing circumstances.
- Tiriti o Waitangi: Contest and legal conflict emerges.
- Initial public distrust and reduced social licence to operate gives way to support for primary sector in securing food self-sufficiency.

Figure 5: 'Māko' scenario data at glance.

1. Climate change and marine ecosystems

Global failure to alter the trajectory of greenhouse gas (GHG) emissions sees climate change impacts increasingly alter the natural world of the 2030s and 2040s (Trisos et al. 2020). Temperatures rise 1°C on average around New Zealand, helping to fuel the intense extra-tropical storms which strike the oceans and coasts, risking the lives and livelihoods of inshore and pelagic fishers (MfE 2018). With 0.28m of sea level rise raising the stakes, shore infrastructure such as jetties, wharves and processing facilities are also affected. This **increases the cost of maintenance and, for those who can obtain it, insurance**.

Sea surface temperature around New Zealand warms on average 1.5°C, altering the surface mixing layer depth and increasing the risk of stratification in the water column in some areas (Law et al. 2017a). The risk of productivity loss in Sub-Tropic warmer waters is offset by potential **productivity gains in cooler Sub-Antarctic waters**. The frontal zone of the Chatham Rise remains a fisheries hotspot but extreme fluctuations in catch hamper long-term financial planning.

Where nutrient flows between the surface and deeper ocean are interrupted by thermal stratification, the abundance of key commercial species such as hoki and ling becomes more volatile year-to-year. **Vessels must spend longer at sea, travel further, trawl at greater depth, and incur higher fuel and crew costs** in order to target them. Despite these additional costs, the reduction of environmental regulation and introduction of subsidies see operating and capital costs fall by 25%

However, there are upsides. **Warm-water species from the tropics begin intermittently migrating south** with marine heat wave events, altering the composition of marine food webs. Traditionally prized New Zealand species such as **snapper and kingfish migrate in greater numbers to the coastal waters of the South Island**. Some North Island QMA fishers suffer financial losses due to a collapse in quota value of these species but are awarded quota for warm water species as compensation.

Ongoing acidification of the surface ocean around New Zealand sees pH fall from 8.1 in 2020 to 7.935 by the 2050s (Law et al. 2017b), effectively a **150% increase in acidity in 30 years** (Woods Hole Oceanographic Institute, 2010). The implications for farmed shellfish are dire, with growth rates and productivity greatly

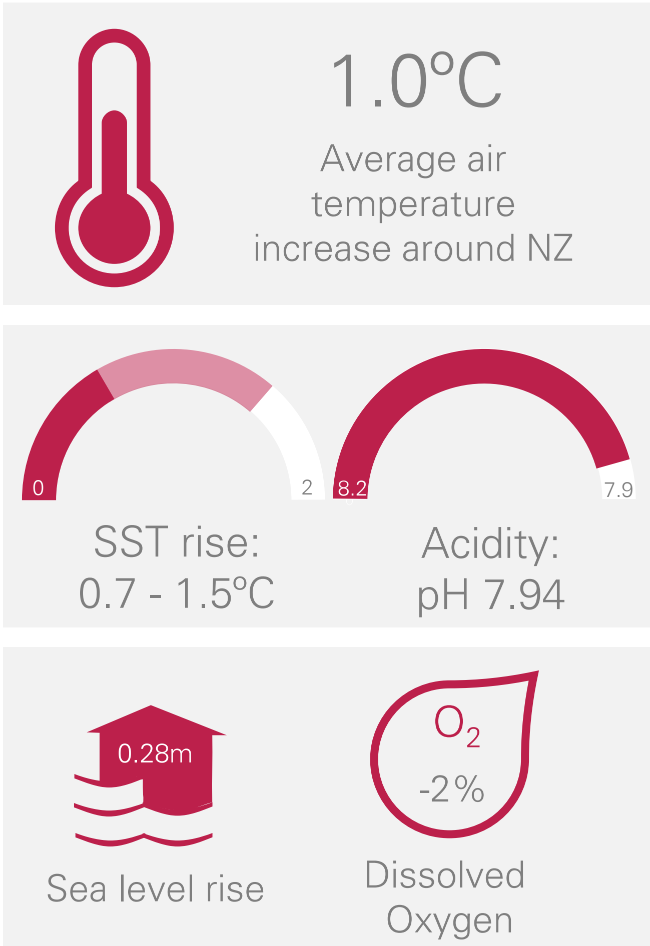


Figure 6: RCP8.5 projections for New Zealand - figures include average annual temperature rise across New Zealand; projected SST change for different regions of the seas around New Zealand; average sea level rise around the coast of New Zealand; reduction in dissolved oxygen in New Zealand's EEZ.

diminished (Boulais et al. 2017). Dissolved oxygen content reduces ~2% (Hoegh-Guldberg et al. 2014), further worsening conditions for inshore fisheries affected by land-based activities such as sedimentation and nutrification.

By the 2050s, global climate impacts motivate some nations to independently geoengineer a way out of the worsening crisis. Merchant ships moving through international waters, and the EEZs of other states, have been observed trailing plumes of powdered iron to fertilise phytoplankton blooms, which, when they die, draw carbon into the deeper ocean. Other **marine geoengineering efforts are underway**, such as using sea-water particles to reflect a greater proportion of solar energy back into space, installing upwelling devices to end-of-life oil rigs to cycle nutrients to the surface and carbon into the water column, and piping carbon captured in energy generation processes to the bottom of the ocean where it remains relatively stable in liquid form (GESAMP 2019). The impact of these activities on marine ecosystems is, at best, poorly understood.

New Zealand remains reliant on foreign oil, and rising fuel prices increase the costs of production (Maury et al. 2017). Although by the 2030s recreational fishers use electrical vessels, alternative fuels and batteries are not yet sufficiently mature for industrial purposes. Rising costs nevertheless drive industry innovation, including fuel-efficient hull designs and remote-sensing to assist in targeted fishing.

Insurers develop new offerings to manage fisheries' physical climate risks (Sainsbury et al. 2019), but the increasing premiums are prohibitive for many. As the recognition of the potential of future risk cascades through commodity and financial markets, and worldwide climate disruptions escalate from the 2030s, **businesses without a robust resilience strategy find themselves unable to access affordable capital.**

2. Economy and governance

Combative nationalism and de-globalisation policies cause economic upheaval, resulting in **minimal economic growth** and GDP per capita flatlining at $17,000 (2005 US dollar equivalent) (O'Neill et al. 2017). **High energy costs**, with crude oil reaching $US103 per barrel in 2040 (IEA 2019), contribute to the economic headwinds experienced globally. Overseas producers monopolise regional markets and New Zealand's primary sector exporters struggle to remain competitive in the face of tariff and non-tariff trade barriers. The Pacific becomes an economic backwater, with rural areas particularly hard-hit (Frame et al. 2018a).

With international markets beholden to protectionist governments (O'Neill et al. 2017), some global value chains collapse entirely. As a result, many commercial fish species can no longer be obtained outside their region of extraction (Maury et al. 2017). These constraints result in a limited range of products – typically of lower quality – on the open market. Consumers are driven primarily by cost and, with a relatively low carbon price of around $US55/ton across the OECD, there is little premium for low-carbon, sustainably sourced food (Frame et al. 2018a). This is accentuating the drive to value volume over quality. Disparities in the distribution of wealth create small pockets of elite consumers seeking high-quality luxury products, though their global disaggregation and limited number make servicing this end of the market a small-scale endeavour.

As the global population passes 11.5b in 2050, **demand for fish as a source of nutrition grows significantly**,

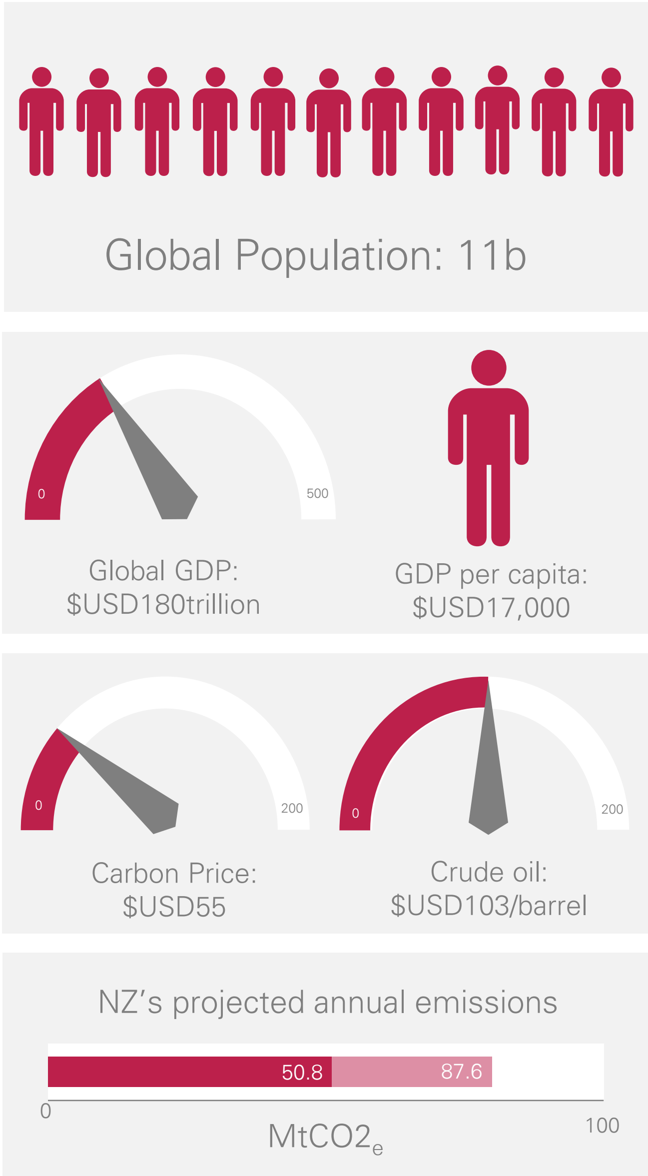


Figure 7: SSP3/IEA Stated Policies projections for global socioeconomic change - figures include a global population of 11b; total global GDP of $180t, at a GDP per capita of $17,000; Carbon price in the region of $55/metric ton; crude oil at $103 per barrel; Climate Action Tracker projects New Zealand's 2050 emissions to be between 50.8 – 87.6 $MtCO_2$ equivalent (on a 4°C 2100 pathway).

particularly in developing economies where increasing patterns of protein consumption per capita (Maury et al. 2017) have coincided with a collapse of many commercial fish stocks in warming tropical waters.

Despite thousands of climate-induced migrants from the Pacific Islands, Asia, Africa, and other regions seeking refuge in Australasia (Richards & Bradshaw 2017), New Zealand's population declines from the 2050s (Rutledge et al. 2017). New arrivals and locals alike predominantly opt for an urban life, and coastal infrastructure begins to decay as **fishing communities shrink in number** (Frame et al. 2018b).

As climate impacts escalate and socioeconomic hardships deepen, the diversity of iwi perspectives on what fisheries management should prioritise becomes a focus of partisan political commentary. **Populist parties are emboldened to lobby for policies that diminish the partnership role of Māori in decision making** or recognition of iwi rangatiratanga and property rights in the fishing sector.

Subsequent back-room political manoeuvring to renege on Treaty-based quota obligations damage Crown-Māori relations. With diminishing support from iwi, **the fisheries management system becomes increasingly contested**. This dispute serves as a catalyst for wider challenges against the status quo of New Zealand's already strained resource management system, which is beset by legal claims and regulatory uncertainty.

Dissatisfaction with environmental degradation in New Zealand peaks in the late-2020s, triggering episodes of civil unrest (Christian, 2019). Increasingly militant climate and conservation groups take direct action against primary sector organisations. However, as climate impacts and global economic upheaval gather pace in the 2030s, the **pressing need to maintain food self-sufficiency** sees public support rally behind farmers and fishers. The value of the primary sector to the social and economic wellbeing of New Zealand is reinvigorated and protests subside.

The erosion of international collaboration **delays the diffusion of innovation**, with many scientific breakthroughs withheld by security-conscious governments (O'Neill et al. 2017). New Zealand's fishing industry is unable to access the AI or nanorobotics developed by Chinese and US agencies.

3. Aquaculture

Sustained year-on-year expansion (Kobayashi et al 2015; Merino et al. 2012) sees **aquaculture becoming the fastest growing food sector in the world in the early 2020s** (Poppick 2019). Due to the increasing difficulty of keeping farmed fish healthy in warm, acidic, and heavily sediment and pathogen-laden coastal waters, expansion is both on-land in Recirculating Aquaculture Systems (RAS) (Poppick 2019) and offshore in cooler, deeper waters.

The move toward on land RAS uptake is fuelled by its lower cost compared to offshore aquaculture, particularly in light of operators' access to subsidised fossil energy. Offshore ventures carry much greater setup and maintenance costs and leave valuable stock and infrastructure at the mercy of increasingly unpredictable storm and wave impacts. However, uncertainties regarding RAS biosecurity and waste removal, coupled with the immediate demand for fish in volume, compels many operators to **explore offshore expansion as well as onshore options**.

Growth in the range of New Zealand's aquaculture products sees its relative share in the marine protein sector increase as the century progresses. While ocean acidification devastates the viability of shellfish operations (Boulais et al. 2017), finfish prove more resilient to pH change. **Competition from synthetic and cultured proteins begins to erode profit margins by the 2040s**, but the efficiency with which both animal and plant-based proteins can be farmed in an aquaculture environment ensures the sector's profitability.

By the 2050s, a hungry and insecure global population demands food in unprecedented quantities. Aquaculture plays a crucial role in serving this need despite ongoing challenges in navigating physical and economic barriers to overseas markets.

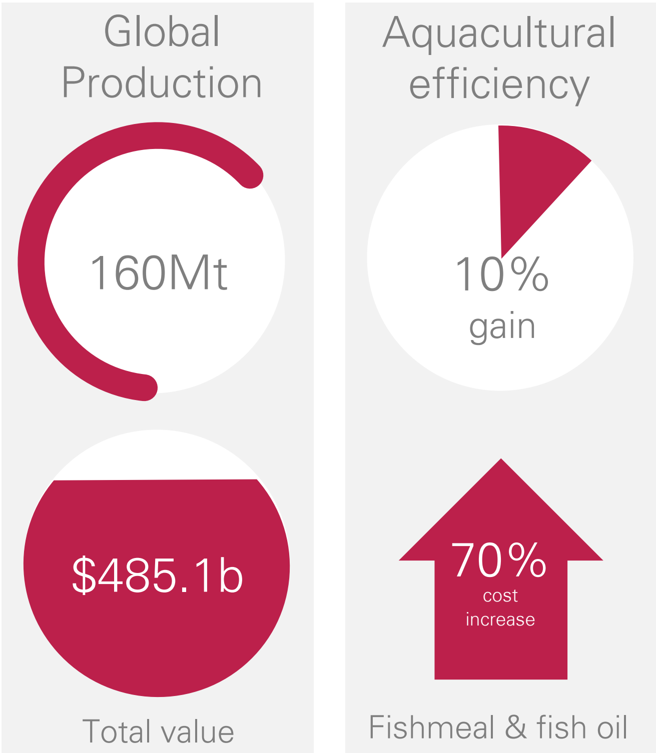


Figure 8: FAO and WRI projections of change in global aquacultural output, adjusted to meet the needs of a 15% greater global population than the WRI baseline assumption of 9.6b. This figure represents a doubling of current production and will involve considerable intensification, raising global demand for aquacultural inputs, particularly fishmeal and fish oil (Linehan et al. 2013). Under Māko, breakthroughs in novel feeds are closely guarded and not readily promulgated across the industry. The WRI also assume a baseline improvement of 10% in aquacultural production efficiency. The environmental impact of expansion of this magnitude is likely to be problematic under this scenario, given the wider governance settings and socioeconomic conditions.

4. Wild capture fisheries

The fishing industry is dominated around the world by regionally powerful private and semi-state entities that use political connections to foster protectionist policies (Maury et al. 2017).

Geopolitical fragmentation sees non-compliance with international agreements becoming more common (Maury et al. 2017), and Regional Fisheries Management Organisations breaking down. Incursions into EEZs by **Illegal, Unreported and Unregulated (IUU) fishers increase as food security becomes a paramount concern** (Rice & Garcia 2011; Maury et al. 2017).

Growing domestic and international pressures alter the priorities of policymakers, in turn seeing **regulators prioritise maintaining food security and creating jobs** in the face of frequent international disputes over marine resources (Maury et al. 2017). The inherent strengths of the QMS mean New Zealand is better prepared than most to cope with these challenges, but the fractured global marketplace nevertheless places industry and regulators under increasing strain. Policy changes are primarily reactive and ecosystem impacts have been de-prioritised in the face of pressing economic concerns (Frame et al. 2018a). Low wages and weak economic prospects (Frame et al. 2018a) mean that deepwater fishing vessels are crewed exclusively by foreign labour (Maury et al. 2017).

In global terms, fish species dependent upon specific habitat features for their reproduction and survival periodically suffer as climatic conditions change, contributing to an overall decline in mean species abundance of 11-24% by mid-century (Cheung et al. 2019). **New Zealand avoids the worst of the global biomass decline**, however, because it sits in a 'goldilocks zone' where cold and warm waters meet. Escalating uncertainty nevertheless makes business planning and marketing increasingly complex.

In response to warming waters, **species which can migrate south begin to enter New Zealand waters from the sub-tropical north** and offer new catch potential (Cheung et al. 2019; EC 2017). Their introduction into the QMS typically outpaces scientific understanding of their biomass characteristics, making the setting of Total Allowable Catch (TAC) limits challenging. This increase in supply offsets the price premium created by global and domestic demand (Cheung et al. 2019), keeping the industry in the black but making profit margins tight.

While New Zealand's geographic isolation mean it is party to fewer transboundary conflicts than other states, **rigid policy frameworks constrain the fishing sector's adaptive capacity in the face of changing circumstances**. Many fishing communities, for example, lack alternative livelihood options beyond their strained inshore fisheries (Ojea et al. 2017), where the appropriate level of Annual Catch Entitlement necessary to continue fishing is becoming increasingly difficult to predict in advance.

TAC settings are subject to significant year-on-year change as regulators grapple with volatility in the abundance and distribution of fish stocks. In conjunction with trade restrictions and increasing operational costs, **quota values marginally decline from the 2030s**. Regulatory compliance suffers due to the combination of inappropriate policy settings, weakening economic performance, outdated monitoring technology, and natural capital being undervalued (Kazmierow et al. 2010; Maury et al. 2017). These forces see the relative capital and operating costs of fishing decline as the century progresses (Cheung et al. 2019).

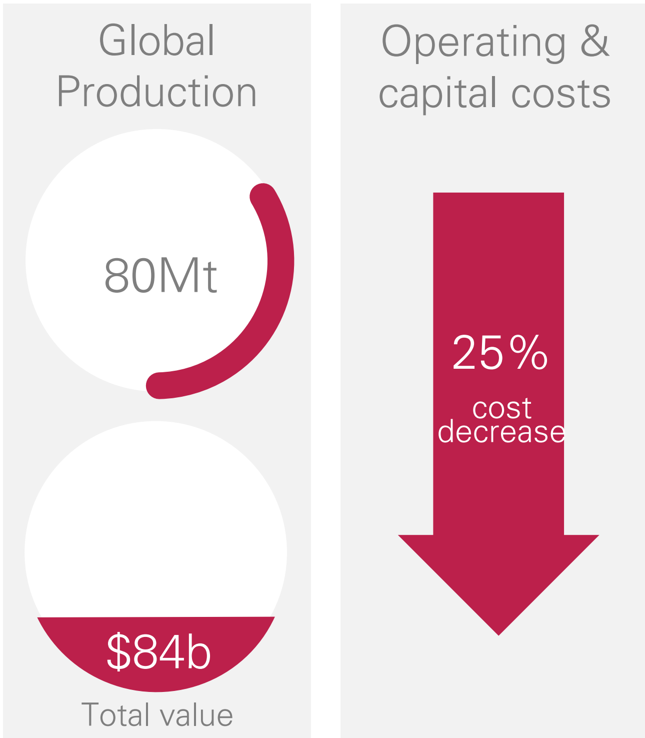


Figure 9: FAO and WRI projections of change in global wild capture fisheries, adjusted to meet the needs of a 15% greater global population than the WRI baseline assumption of 9.6b. The figure of 80Mt total production is counterintuitively high – representing only a 10% decline on present day production, despite the myriad of physical challenges this scenario introduces. Meeting this figure would require enormous fishing effort, likely incorporating substantial catch of lower trophic level species. Needless to say, it would represent an unsustainable level of harvest. The IIED Regional Rivalry scenario projects costs to decline, primarily through technological innovation targeting cost reduction (rather than environmental or quality concerns), the removal of much of the regulatory burden, and via the introduction of subsidies to shore up production.

By the 2040s, wild capture fishing operators must move quicker than ever to exploit marine resources. Though no one seeks an environmental 'race to the bottom,' operators feel it forced upon them by unpredictable migratory patterns, fluctuating levels of biomass, uncertain long-term commercial viability, and the breakdown of institutional mechanisms for collaboration and good practice.

These pressures cause **greater degradation of New Zealand's marine environment** and **challenge the capacity of the regulatory and enforcement systems to govern the EEZ sustainably** (CERES 2016).

The experimental introduction of mesopelagic species further down the food chain than traditionally targeted species helps to offset catch lost to species migration and localised population collapse (EC 2017). However, scientific understanding of the impacts of fishing at this trophic level is very limited and considerable uncertainty surrounds its commercial viability. More generally**, the rate and extent of change in fish stocks and marine ecosystems far outstrips the capacity of New Zealand's science system to generate new knowledge**. The uncertainties begin to overwhelm fisheries governance, leaving the long-term sustainability of wild capture fisheries an open question.

4.2 Kahawai: A strong mitigation scenario

‘Kahawai’ describes a world that has succeeded in implementing the Paris Agreement and is on track to keep total warming below 2°C over the course of the 21st century.

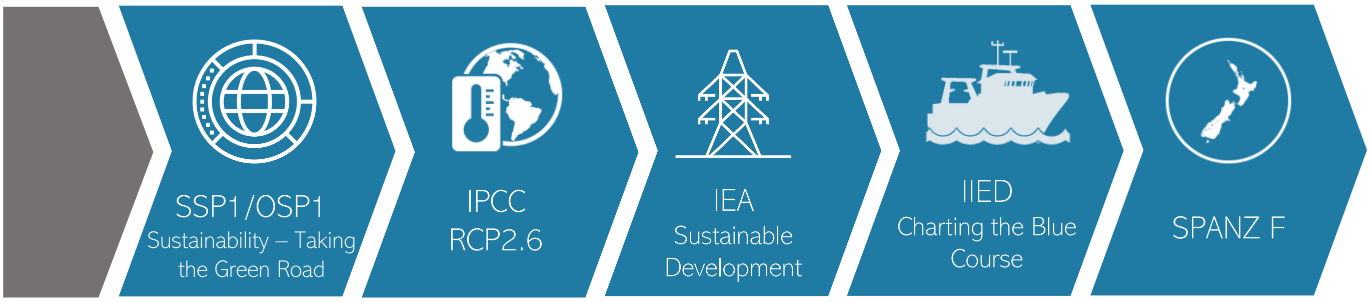
The South Pacific has carved out a global role for itself as an innovator in trade and service provision. Indigenous populations are thriving throughout the region, and reinvigorated cultural identities have helped foster an intergenerational commitment to sustainability – particularly with regards to fisheries.

New Zealand’s Climate Change Response (Zero Carbon) Amendment Act 2019 provided a critical platform for change. Delivering on this promise became a guiding principle of post-COVID-19 economic recovery, as the Government employed the greatest fiscal stimulus package in the nation’s history to kick-start a zero-carbon transition. Indeed, the ‘Green New Deal’ Budget of 2021 signalled a paradigm shift for the lives and livelihoods of most New Zealanders.

Though challenging for many sectors, the transformation resulted in one of the world’s most stable economies with high levels of energy efficiency across industries, robust trade in innovative environmental goods and services, and primary products sought by customers around the world as a direct result of New Zealand’s ‘clean & green’ reputation.

In line with all other sectors, aquaculture and fisheries have achieved carbon neutrality by mid-century. Technological change has swept through the marine sector, rendering the sector virtually unrecognisable to a 20th century observer – ushering in new modes of operation and income streams. Even so, many businesses are challenged by New Zealand’s political economy of ‘conspicuous conservation,’ particularly if unskilled in the art of instant knowledge co-creation via social media.

Scenario data: Kahawai 2050 at a glance



Ocean System Pathway
- Population: 8.5b
- GDP: $300t (2005USD)
- GDP/capita: $36,000
- GINI Index: 0.33
- Trade settings; open, little support for tariffs
- Consumers: 30% less animal protein
- Land use: afforestation improves water quality
- Wild fish demand: high in some (niche) high value markets

Climate change
- SST: 0.12-0.79°C rise, variable with location
- Dissolved O2: ~1% reduction
- Acidification: pH falls to 8.1 – 8.0
- Storms: impact on extra-Tropical Cyclone freq./intensity unknown
- Significant wave height >5m: minor increase south of NZ
- Habitat loss: minor reduction in cold-water coral habitat

Global energy
- Carbon price: ~US$180/t [Advanced economies: US$140/t by 2040; US$100/t by 2030]
- Fuel cost: Crude oil US$59/barrel [2040], market volatility
- Increased wind, solar, hydrogen, biofuel, and CCUS
- Maritime emissions: <50% GHG emissions (relative to 2008 levels)

Global fisheries
- Net Primary Productivity: 2% reduction
- Mean sp. Abundance: 10% reduction
- Sp. Distribution: ongoing fluctuations, uncertainties
- Costs: at least 50% increase
- UNCLOS: Restrictive High Seas fishing rules
- IUU: declines as technology and market values make adherence to regulation easier and more

Shared Policy Assumptions NZ
- Emissions: NZ net-zero in 2050
- QMS: Regulation becomes more flexible. Decisions with high near-term costs are undertaken to improve long-term sustainability and adaptive resilience.
- Tiriti o Waitangi: Indigenous wellbeing and property rights prioritised.

Figure 10: ‘Kahawai’ scenario data at a glance.

Kahawai 2050

1. Climate change and marine ecosystems

The successful curbing of global GHG emissions sees some climate impacts begin to plateau by mid-century (Kirtman et al. 2013). However, the inertia of the atmosphere-ocean-climate system means the main benefits of strong mitigation are not fully felt until later in the 21st century. Marine ecosystems, particularly those in shallower coastal waters, **suffer ongoing impacts of warming, acidification, and sea level rise-induced coastal squeeze**.

Sea surface temperature continues to rise, varying by region around New Zealand, but on average ~0.8°C warmer than a 2017 baseline (Kirtman et al. 2013; Law et al. 2017a; Cheung et al. 2019). Dissolved oxygen content declines ~1% (Hoegh-Guldberg et al. 2014), and acidity marginally increases, with pH falling to 8.0 (Law et al. 2017b), an **ocean acidity increase around 30%**.

The magnitude and direction of change in storm activity is impossible to identify amid the 'noise' of climatic volatility, but conditions promoting significant wave heights (>5m) marginally increase to the south of New Zealand (Mullan et al. 2011).

Global species abundance declines by around 10% (Cheung et al. 2019), but **New Zealand fares much better than most**, with net primary production in the oceans around New Zealand remaining broadly unchanged (Law et al. 2017a), and commercial catches holding up well.

By the 2050s, **catch potential increases by around 25%** on a 2019 baseline (Cheung et al. 2019), due to scientific advances in our understanding of population and habitat dynamics allowing for better decision making, and increased flexibility under New Zealand's Quota Management System allowing commercially fished populations to thrive.

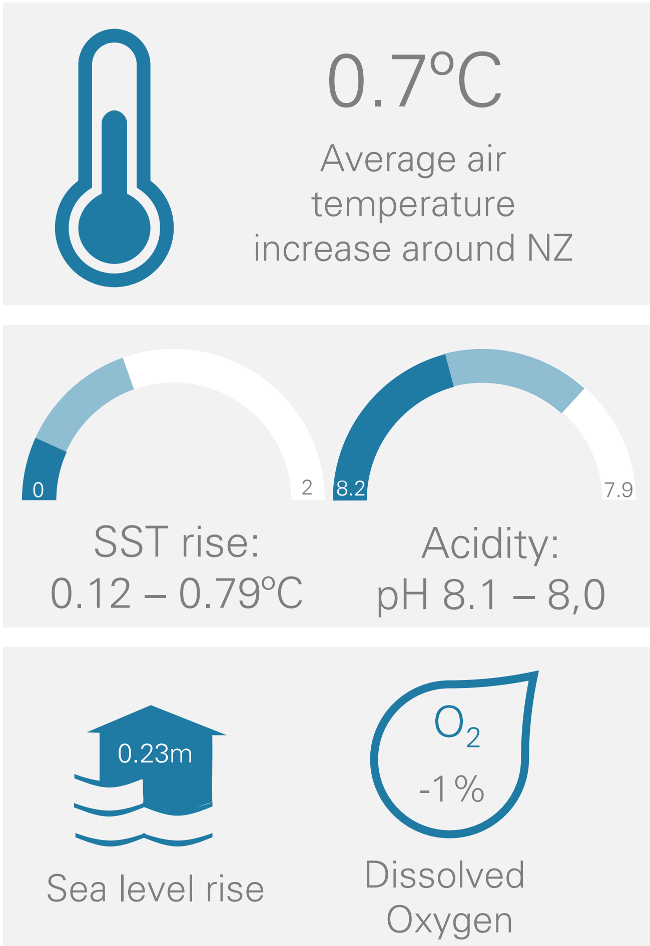


Figure 6: RCP8.5 projections for New Zealand - figures include average annual temperature rise across New Zealand; projected SST change for different regions of the seas around New Zealand; average sea level rise around the coast of New Zealand; reduction in dissolved oxygen in New Zealand's EEZ.

Figure 11: RCP2.6 projections for New Zealand - figures include average annual temperature rise across New Zealand; projected SST change for different regions of the seas around New Zealand; average sea level rise around the coast of New Zealand; reduction in dissolved oxygen in New Zealand's EEZ.

2. Economy and governance

International institutions incrementally strengthen in the wake of the 2020-21 pandemic, and successfully overcoming this global challenge provides a collaborative model for tackling other existential threats, such as climate change and biodiversity loss. Sustainability gradually becomes the new global paradigm, re-figuring conceptions of wealth and prosperity, and triggering a global expansion of investment in health and education (O'Neill et al. 2017).

Well-managed fisheries are increasingly regarded as a sustainable source of nutrition to meet global food security challenges (Bénéet al. 2015). In contrast with the institutional developments seen elsewhere, the defining characteristic of New Zealand's fisheries management is the evolution of its rights-based Crown-Māori governance model, which helps to position New Zealand as an early leader in the global marketplace for sustainably and equitably sourced marine proteins.

As the global community does its best to reconnect international relationships post-COVID-19, **New Zealand's integrated trade settings create an economy strongly geared toward capitalising on export opportunities** (Frame et al. 2018a). Government support for low-carbon protein exports leads to significant investment in the aquaculture and fisheries sectors from the mid-2020s.

New Zealand's population grows to 5.5m, with around 1.5m aged over 65 (Stats NZ 2016). Immigration from Australia and the Pacific Islands increases as drought conditions worsen and sea levels rise (Tennant 2015; Cameron 2013), but immigration from other regions is subject to strict vetting based on economic suitability. GDP growth in NZ supports the retention of strong social safety nets, particularly for pensioners, and a focus on human capital sees significant investment in education and training (Frame et al. 2018a).

Indigenous populations flourish in the Pacific, with respect to health, well-being and sustainable development (Frame et al. 2018a). In New Zealand, **the Crown's obligations in relation to Te Tiriti o Waitangi increasingly underpin governance decisions**. Parliament expresses a willingness to undertake constitutional reforms that uphold the tino rangatiratanga of iwi and hapū (Matike Mai 2016), and regulators recognise Māori as equal partners in governing marine resources.

Crown and iwi negotiators build clauses into international trade and natural resource management agreements which preserve the right of Māori to exercise tino rangatiratanga (Smith 2018). The application of **kaupapa Māori, tikanga Māori, and Māori governance principles drives holistic management in many fisheries** (Toki 2010; Reid et al 2019), but the decentralisation of power in the fisheries sector causes initial teething difficulties as stakeholders look to different institutions for direction. By the 2030s these issues are largely resolved, and fisheries and aquaculture stakeholders work together to realise ecological, social and commercial objectives.

Throughout the 2020s, regulators, mandated iwi organisations, and other stakeholders collaboratively address aspects of the QMS which are perceived to require greater agility in the face of changing physical circumstances, particularly the distribution of target species. While not a rapid process, these changes include greater flexibility in the location, trading and exchange of quota, and enabling the necessary regulatory agility to navigate periods of abundance and dearth as species distribution varies under climatic extremes (Cheung et al. 2019; EC 2017). These developments see the value of quota rise significantly, improving the balance sheets of quota holding entities.

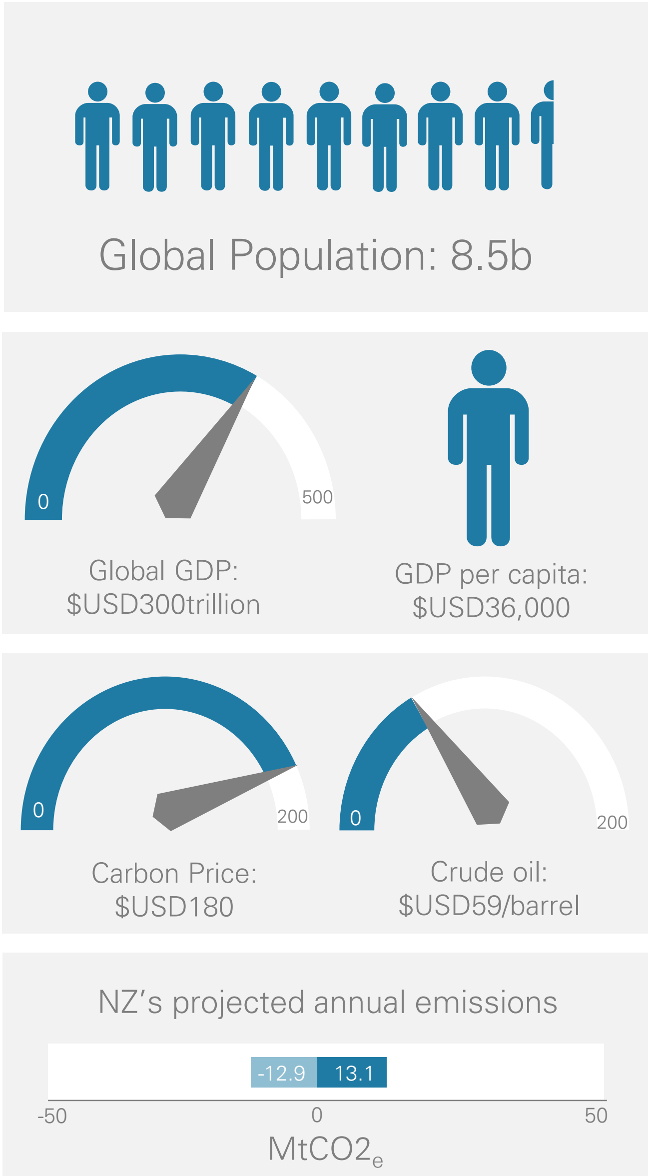


Figure 12: SSP1/IEA Sustainable Development projections for global socioeconomic change - figures include a global population of 8.5b; total global GDP of $300t, at a GDP per capita of $36,000; Carbon price in the region of $180/metric ton; crude oil at $59per barrel; Climate Action Tracker projects New Zealand's 2050 emissions to be between -12.9 – 13.1 $MtCO_2$ equivalent (on a 2°C 2100 pathway).

There is **slower progress regarding the regulation of recreational fishing, RMA reform, and the disputed role of MPAs in sustainable marine management.** Delays and frustrations add to the cost of participating in collaborative governance initiatives, but trust and mutual understanding build incrementally through long-standing engagement (OAG 2016), making breakthroughs possible for inshore fisheries management by the late 2020s. The role of iwi leaders and organisations towards realising positive outcomes is increasingly recognised as the decade progresses, ensuring a balance is struck between the needs of quota owners, communities, and Tangaroa.

Fisheries and aquaculture are nevertheless increasingly beset by **allegations regarding unsustainable management and animal welfare transgressions**. Civil society pressure is constant, and operators struggle to prove their ethical and ecologically sustainable credentials to consumers in a post-truth world (Lubchenco 2017; Iyengar & Massey 2018), despite the vast increase in the quality and quantity of information via image-based data processing software, artificial intelligence, and machine learning (Bradley et al. 2019). To maintain trust in this complex environment, many businesses abandon traditional branding and certification strategies in favour of **direct relationships with communities and consumers** (Baines & Edwards 2018), often through digital channels.

3. Aquaculture

Global production of farmed fish surpasses the volume of wild capture fisheries for human consumption in the mid-2020s and is around 30% greater by the 2030s (FAO 2018). Although salmon have little trouble coping with acidifying waters, the difficulty of keeping finfish free of pests and pathogens as inshore waters warm triggers **most farms to move offshore in the mid-2020s, providing substantial scope for expansion but greatly increasing costs** (Gentry et al. 2017). Government support for R&D drives a shift to microbial biomass aquafeeds from 2025 (Hua et al. 2019), reducing the footprint of farmed fish and alleviating some of the cost burden on the sector.

Mussel farms move to hatchery strains of spat in the 2020s rather than relying on natural wild-caught spat (MPI 2019). These have been selectively bred not only for their rapid development potential but also for their resistance to increasingly acidic coastal waters.

Inshore aquaculture begins to revive in the 2030s and 40s as the successful implementation of Mountains to Sea catchment management policies sees coastal waters become less prone to disturbance by terrestrial sediments, nutrients and pathogens. **The adoption of Integrated Multi-Trophic Aquaculture (IMTA) also reduces the resistance of local populations to sharing their coastal waters** with fish farms (Carr 2019). IMTA systems combine fed finfish species with seaweeds, aquatic plants, shellfish and invertebrate communities to greatly reduce the environmental impacts of farmed fish (Chopin 2018).

IMTA is also employed to help restore the biodiversity of disturbed coastal habitats which had been subject to dredging or domination by a single species in prior decades. Carefully designed and implemented **IMTA operations also generate revenue under the Emissions Trading Scheme as 'Blue Carbon' sinks**, with their biomass of seaweeds, seagrasses, and mangroves actively managed for carbon sequestration purposes.

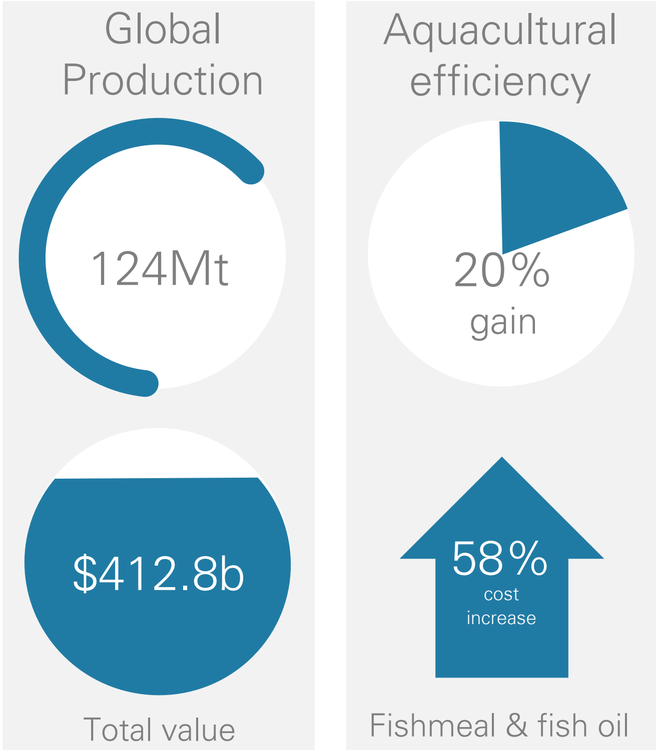


Figure 13: FAO and WRI projections of change in global aquacultural output, adjusted to meet the needs of a 12% smaller global population than the WRI baseline assumption of 9.6b. This figure represents a 50% increase on 2016 global production (80Mt, generating $231.6b revenue), in turn raising global demand for aquacultural inputs (Linehan et al. 2013) though the greater reliance of non-fish feed sources mitigates the increase. The WRI also assume an improvement of 20% in aquacultural production efficiency under their 'Highly Ambitious' scenario. The value of aquacultural production is comparable to that under the Māko scenario ($485b), but at a much lower environmental footprint and at reduced cost.

They also generate 'Resilience Credits' (The Global Innovation Lab for Climate Finance 2020), creating a revenue stream for aquaculturalists which recognises the contribution of IMTA in providing services such as coastal protection through wave energy attenuation, and biodiversity gains brought on by the creation of artificial reefs that are quickly colonised.

Demand for products which are organic, traceable, and perceived by consumers to be ethically sourced and transported, outstrips supply in the global market-place (O'Neill, et al., 2017; Maury et al. 2017). As a result, aquaculture operators who can prove the environmental and ethical credentials of the products using blockchain authentication thrive (FAO 2018), building a loyal consumer following and securing their position in the global marketplace in the face of rising plant-based and synthetic protein sources.

4. Wild capture fisheries

The impacts of climate change on commercially fished marine species is partially offset by changes to global rules regarding fisheries management on the high seas (Cheung et al. 2019). An international agreement to impose more rigorous limits and enforcement protocols on high seas fisheries sees **greater numbers of migratory fish populations arriving in New Zealand's EEZ**.

Profits from wild capture fisheries in the global marketplace reach record levels (Gaines et al. 2018; Maury et al. 2017), but the sustainability-related barriers to market entry are high and continue to rise. To meet these expectations, many fishing companies become early adopters of technologies that offer the promise of sustainability solutions. Insufficiently agile businesses struggle to remain competitive.

A rapidly rising carbon price (IEA 2019), combined with tightening emission regulations and fuel security concerns amidst an unstable oil market, **sees an expansion of energy-efficient 'green trawlers'** (FAO 2015) in the New Zealand fleet. As well as achieving greater fuel efficiency, these employ remote sensing to identify where target species are to be found in numbers, reducing fuel costs and assisting fishers to avoid areas of non-target by-catch. Within the decade, much of the industry's deepwater fleet, shore-based transport, and port infrastructure is converted to run on renewable energy sources, including domestically produced hydrogen.

To stay ahead of global competition in the sustainably-sourced protein marketplace, verifiable bio-tracing techniques, such as DNA barcoding, are **adopted to promote transparency and inform consumers** (Bartley et al. 2019). By the 2030s the sustainability arms race has moved on to include robotically equipped trawl gear which autonomously sorts fish using neural net learning algorithms (Siddiqui et al. 2018). These select out non-target species or age classes before reaching the cod end of the net. Though expensive and difficult to maintain, these systems are the price of doing business in a marketplace where discards and non-target species mortality are unacceptable.

By 2050, consumer pressures force even greater industry transformation. Trawling is banned and replaced by AI-driven autonomous undersea robotics that select fish for harvest deep in the water column. Here they are sorted again for harvest suitability before being hauled to the surface. As a result of these and other changes, industry-wide operational costs increase 50% relative to a 2020 baseline (Cheung et al. 2019), and wild capture fisheries move closer to the boutique end of the market.

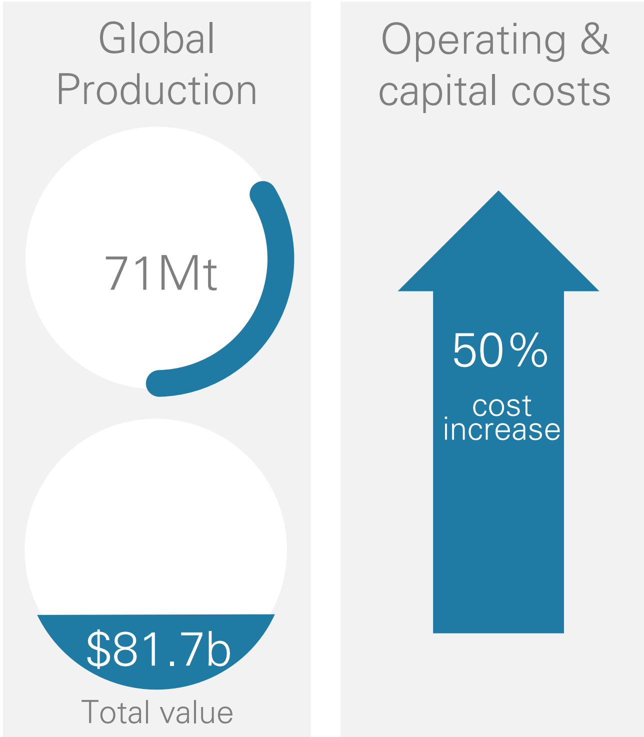


Figure 14: FAO and WRI projections of change in global wild capture fisheries, adjusted to meet the needs of a 12% smaller global population than the WRI baseline assumption of 9.6b. The figure of 71Mt total production is lower than that under Māko, despite conditions favouring greater productivity under this scenario. The discrepancy is due to greatly reduced demand side drivers, with consumers reducing animal protein consumption and insisting on impeccable sustainability credentials in wild capture fishery management, maintaining stock levels well above MSY. The IIED Charting the Blue Course scenario projects fishing effort costs to increase, primarily due to technological innovation targeting environmental or quality concerns, an increased regulatory overhead, and the removal of subsidies globally.

The **global demand for cultured and synthetic proteins reaches a critical mass by the 2050s**, pushing most fishing operators towards the curation of genetic intellectual property rather than the supply of harvested wild fish.

Along with other key innovators in the sector, iwi enterprises are key players in creating **new international market niches for changing marine protein products**, be they plant-based, cultured or semi-synthetic. Customary fishing and domestic commercial demand for wild fish nevertheless remain buoyant in New Zealand throughout the 2020-2050 period, and the underlying Te Ao Māori connection with Tangaroa continues to guide iwi-managed fisheries, irrespective of global management trends.

Next Steps

5. Next Steps

5.1 Apply best practice

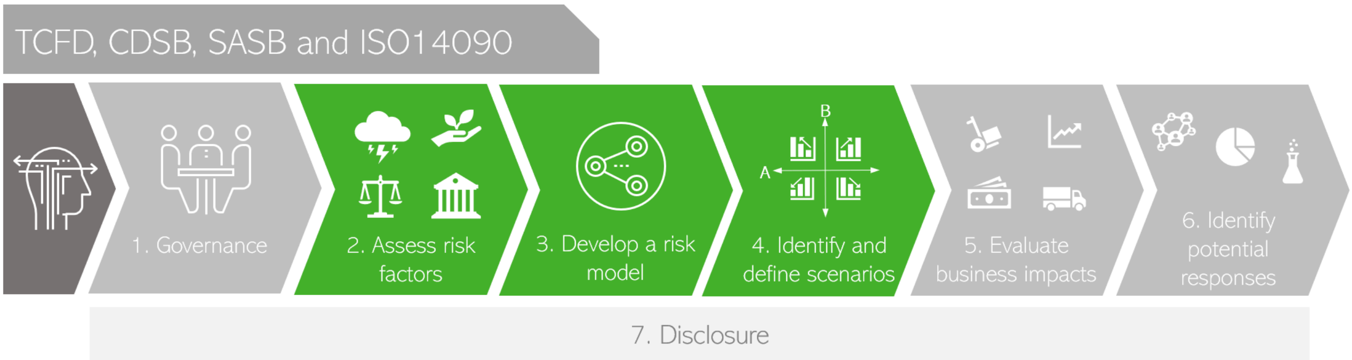


Figure 15: Best practice approach to climate-related risk assessment. The three phases highlighted green are the focus of this project

Current best practice approach to identifying and assessing climate-related financial risks and opportunities at an organisational-level involves a seven-stage process (TCFD 2017c; CDSB 2020; CDSB & SASB 2019a; ISO 2019). The scenarios developed for this report focus on **stages 2 – 4**. When used appropriately, climate-related scenarios can help to inform all seven stages of this approach.

It is important to recognise, however, that Māko and Kahawai were developed at a sectoral scale, whereas this seven-stage process must be undertaken through an organisational lens. This means considering how systemic climate-related risks and opportunities relate to your specific circumstances and identifying potential responses that fit your unique situation.

5.1 Adapting to climate-related risk

In accordance with the seven-stage best practice approach, we recommend the following next steps:

1. **Governance**: First, ensure that climate-related risk management is being appropriately addressed at the Board and Executive level.

Secondly, use the Māko and Kahawai scenario narratives to help:

2. **Assess risk factors**: Identify and assess your organisation’s climate-related risks (and opportunities).

3. **Develop a risk model**: Inform your strategic thinking by structuring these risk factors based on their significance, uncertainty, underlying drivers, and dynamic interplay.

4. **Identify and define scenarios**: Use scenarios to capture and explore systemic climate-related risks that are relevant to your organisation, including, if necessary, drawing on Māko and Kahawai to help develop your own climate-related scenarios which reflect your unique context.

Finally, in light of your scenario-based risk assessment:

5. **Evaluate business impacts**: Evaluate the plausible climate-related impacts on your business and your key sensitivities.

6. **Identify potential responses**: Identify and evaluate the potential responses to these climate-related risks and opportunities.

7. **Disclosure**: Document and disclose the climate-related risks you have identified, and how you will respond to them.

More detailed guidance about how to use the scenarios in this report is set out below.

5.1.2 Develop an adaptation strategy

Having identified your climate-related risks and explored potential responses, the next logical step to take is to follow ISO 14090 best practice principles in developing a climate change adaptation strategy.

The strategy’s primary aim should be to enhance long-term resilience. Doing so will require the identification of flexible pathways to future growth in the face of uncertain change, each carrying prioritised adaption options, and trigger points to help identify when they should be actioned.

5.2 How to use the scenarios to help identify and assess climate-related financial risks & opportunities

Climate-related scenarios are developed at different scales. Some scenarios, such as the IPCC and IEA scenarios, are developed at a global scale, while others fit a national or sectoral scale. Each scale provides important context to help organisations apply a 'whole systems approach' to identifying and evaluating their climate-related risks and opportunities.

When using scenarios, organisations must ensure that they undertake scenario analysis through an organisational lens by (a) considering how systemic risks and opportunities relate to their specific circumstances, and (b) identifying the potential responses that fit their unique situation.

For some organisations, relying heavily on 'off-the-shelf' scenarios and models will be a more appropriate and cost-effective approach to scenario analysis. For others, the process of developing scenarios from scratch, drawing on a wide range of credible global, national and sectoral inputs, will be valuable in itself. This is because the scenario development process can help decision-makers to stimulate creativity, conceptualise change, address uncertainty, and interrogate risk in greater detail.

5.2.1 A scenario mindset

As explained in Part 2, it is crucial to engage with the mindset that scenarios are simply tools to help organisations challenge assumptions, inform strategy, and explore risks and opportunities under plausible future states. The Māko and Kahawai scenarios are not probabilistic predictions. Nor are they the inevitable outcome of a given direction of travel. The future is inherently uncertain. New Zealand will most likely navigate a path between the two scenarios, and the future of fisheries and aquaculture may feature characteristics from both – or neither – of the narratives.

It is also important to recognise that different decision-makers will draw different insights from Māko and Kahawai. This is a foreseeable and valuable outcome of scenario analysis. As explained in the introduction to the BusinessNZ Energy Council's scenarios for New Zealand's energy sector as follows (BEC 2015, p 39):

> *The scenarios are deliberately meant to challenge New Zealand's future… They are intended to give stakeholders from government and business a means of testing policy and investment decisions against each scenario, and understanding the trade-offs associated with their decisions…*
>
> *Users of these scenarios will bring to them their own views on such factors as risk, market behaviour, and political/societal pressure that will, in practice, see the clarity of the sometimes sharp distinctions between our stories and modelling results begin to blur. This does not diminish the usefulness of what we have done, rather it places it into context – decision-makers must inevitably apply their judgment to these matters and our goal is to help inform that judgment.*

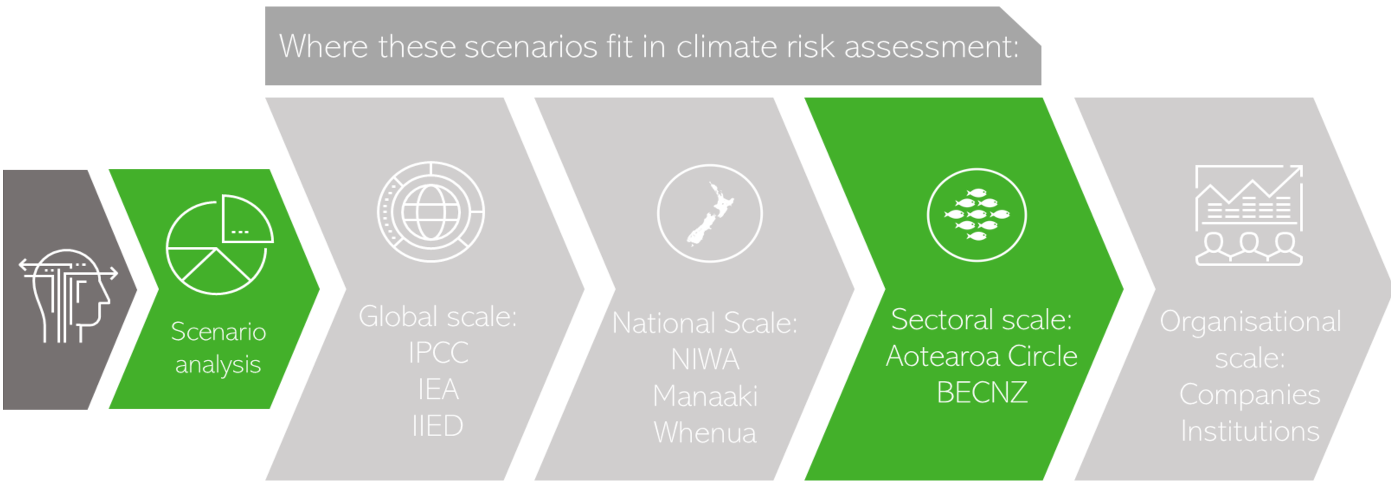


Figure 16: Overview of scenario models at global, national, sectoral and organisational scales

5.2.2 Interrogating the scenarios

Guiding questions

The following questions can be used to guide your analysis of the Māko and Kahawai scenarios (TCFD 2017c)

1	Based on your interpretation of the scenarios, what are the climate-related financial risks and opportunities facing your organisation? Consider your physical risks, transition risks, legal risks, and capital risks, in light of: — the geographic location of your value chain (upstream and downstream) — your assets and the nature of your operations — the dynamics of your supply and demand markets — your customers and other key stakeholders.
2	Taking a 'whole systems approach', what are the implications of these risks and opportunities for your strategy, capital allocation, and costs and revenues, both at an enterprise-wide level, and for specific regions and markets? What are the potential impacts for your inputs, operations, supply chain, and business continuity?
3	How resilient are your strategies and plans to the future conditions set out in the scenarios? What are your key sensitivities?
4	What are your options to improve your organisation's resilience to these climate-related risks and opportunities? Responses may include: — adjusting your strategic and/or financial plans — changing your operating model — reassessing your assets or portfolio mix — investing in new capabilities and technologies.
5	Based on your analysis of the scenarios, your assessment of climate-related financial risks and opportunities, and your evaluation of potential responses, which of these responses should be implemented, when, and how?

Workshopping the questions in a group setting, and documenting the outcomes for wider circulation and review, will provide a key component of recommended good practice in climate-related financial disclosure.

5.2.3 Case studies

Using scenario analysis to inform climate-related risk management can be a daunting proposition. A useful place to start is by learning from the experience of others.

Wesfarmers Group

Case study #1

The Australian-based Wesfarmers Group owns businesses that range from retail chains to chemical producers and heavy industry. Wesfarmers has adopted climate-related risk management processes at the Board and Executive level and developed 1.5°C, 2°C and 4°C scenarios to inform their strategic thinking. After analysing these scenarios over the short term, medium term, and long term, Wesfarmers was able to formulate and disclose strategic responses to each of their climate-related risks and opportunities (Wesfarmers 2019).

Unilever

Case study #2

Unilever produces and sells food and beauty products in more than 190 countries. Unilever's analysis of 2°C and 4°C scenarios allows them to explore and respond to key climate-related risks (TCFD 2018), such as their exposure to future carbon taxes, and potential climate disruption to soybean yields. In 2019, Unilever provided 'Top Tips' for other organisations undertaking scenario analysis (Accounting for Sustainability 2019):

- get senior buy in
- do the 'thinking' up front
- understand the limitations of models
- mobilize a cross functional team
- start with what you've got
- keep it simple.

Meridian Energy

Case study #3

Meridian Energy's FY19 climate-related risk disclosure statement (Meridian Energy 2019) explains how 2°C and 4°C scenarios are used to inform their strategic business planning and stress-test risk management responses. The critical uncertainties explored through Meridian Energy's scenario analysis include future inflows, wind, and renewable energy demand.

5.2.4 Additional guidance

- The TCFD introduction to scenario analysis (https://www.tcfdhub.org/scenario-analysis/), which summarises key highlights from the TCFD *Technical Supplement on The Use of Scenario Analysis* (2017c).
- CDSB & SASB's *TCFD Good Practice Handbook* (2019b), which identifies good practice examples of aligning with the TCFD recommended framework, and CDSB's *Webinar: TCFD scenario analysis – First steps* (2018).

The TCFD has also announced the formation of an advisory group to develop further practical guidance on climate-related scenario analysis (TCFD 2019). The forthcoming guidance will cover how scenarios can help identify business-relevant climate-related risks and opportunities, inform strategic planning, and underpin climate-related disclosures that demonstrate an organisation's strategic resilience across scenarios, including financial implications.

Appendices

Appendix A Glossary

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Climate change: Climate change refers to a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate-related opportunity: Climate-related opportunity refers to the potential positive impacts related to climate change on an organization. Efforts to mitigate and adapt to climate change can produce opportunities for organizations, such as through resource efficiency and cost savings, the adoption and utilization of low-emission energy sources, the development of new products and services, and building resilience along the supply chain. Climate-related opportunities will vary depending on the region, market, and industry in which an organization operates.

Climate-related risks: Climate-related risks refers to the potential negative impacts of climate change on an organization. Physical risks emanating from climate change can be event-driven ('acute') such as increased severity of extreme weather events (e.g. cyclones, droughts, floods, and fires). They can also relate to longer-term shifts ('chronic') in precipitation and temperature and increased variability in weather patterns (e.g. sea level rise). Climate-related risks can also be associated with the transition to a lower-carbon global economy, the most common of which relate to policy and legal actions, technology changes, market responses, reputational considerations, and access to capital.

Integrated scenario analysis: Integrated scenario analysis is a method for predicting the possible occurrence of an object or the consequences of a situation, assuming that a phenomenon or a trend will be continued in the future.

Mitigation: A human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs).

Resilience: The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

Whole system approach: A method to understand how the various elements (e.g. sea surface temperature, acidity, pathogens, marine biomass, and people) within systems (e.g. ecosystems, climate-systems, organisations and communities) are related, and how they influence one another within a "whole". A whole systems approach enables understanding of the relationships and interactions among elements (and risks) within systems, to locate feedback looks (which may exacerbate risks), and to identify leverage points places in the systems that can be leveraged or changed.

Taking a whole systems approach to respond to climate change entails:

— Identifying systems of responsibility to inform climate response (i.e. all of the systems upon which an organisation is embedded in and depends upon to operate).

— Understanding how climate-related risks will impact elements and key stakeholders within each system of responsibility, and how climate-change with interact with other risks within these systems, as well as existing and emerging issues.

— Looking for solutions that address multiple issues at once (i.e. not just climate-related risks).

— Thinking about the potential ripple effects to other systems of implementing climate-related opportunities or projects.

— Collaborating with multiple stakeholders to ensure that adaptation efforts are integrated, consistent and efficient.

Appendix B Methodology

The climate-related risk scenarios in this report were developed as follows:

1. **Identify risks**: Significant and uncertain risk factors were elicited from experts at a stakeholder workshop (see Appendix C for risk factor data).
2. **Construct a risk model**: Critical risk factors were identified for our scenario axis, and a climate-related risk model for fisheries (Maury et al 2017) was used to structure the interactions between key drivers.
3. **Develop scenario narratives**: Scenarios were developed based on expert insights from our stakeholder workshop, an array of global and national scenario models, and other secondary research.
4. **Test and validate**: The narratives were refined with stakeholders to ensure their robustness, plausibility and coherence.

Constructing a risk model

A marine-specific climate risk model was identified in the literature which served as a useful starting point from which to begin the development of narrative storylines out to the 2050s (figure 17).

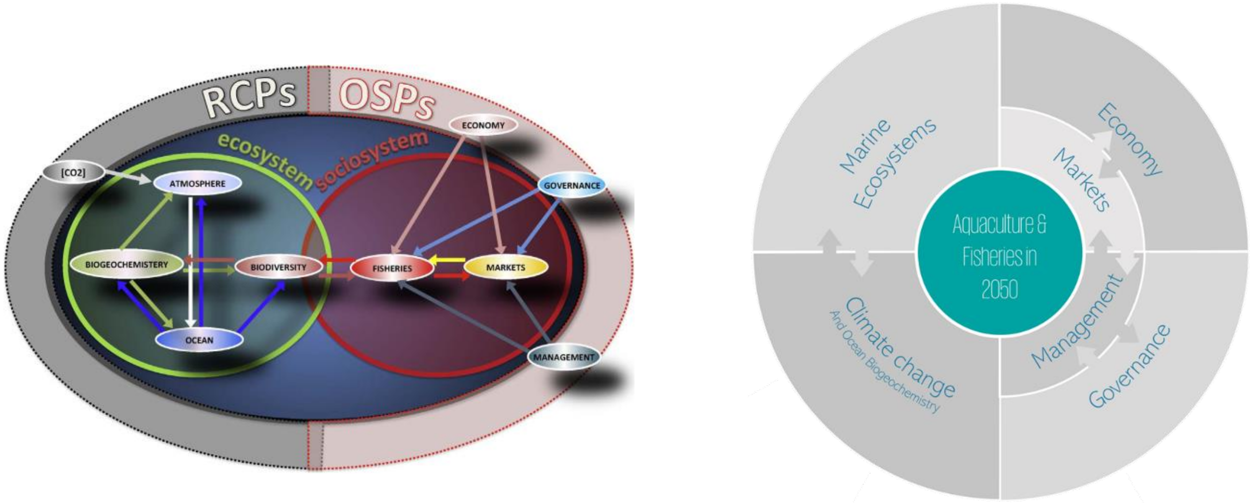


Figure 17: *Left*: Maury's simplified model linking IPCC Representative Concentration Pathway's (RCPs), 'Oceanic System Pathways' (OCPs) and the core structures and functions of marine ecosystems, fisheries and aquaculture (Maury et al. 2017). *Right*: The simplified, amended version of the Maury et al. model used to structure the climate-related risk data gathered during an expert stakeholder workshop.

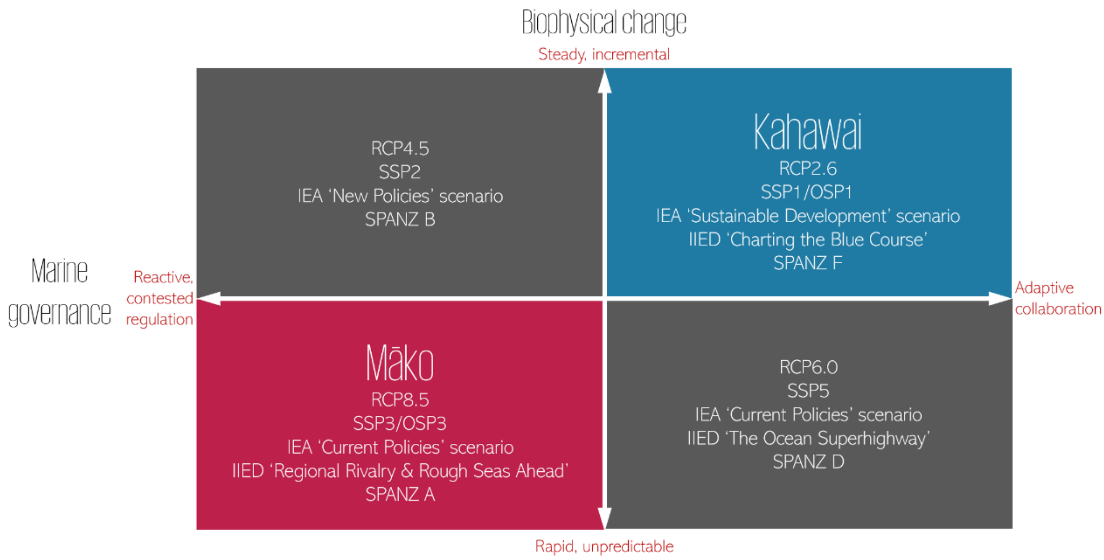


Figure 18: The scenario axes selected by the expert stakeholders attending a facilitated workshop. The categories of 'Biophysical change' and 'Marine governance' were considered to be the most significant and uncertain factors influencing climate-related risk. The Māko quadrant describe a world of rapid and unpredictable biophysical change coupled with reactive marine governance. The Kahawai quadrant describes a world of steady, incremental biophysical change coupled with adaptive marine governance.

Māko

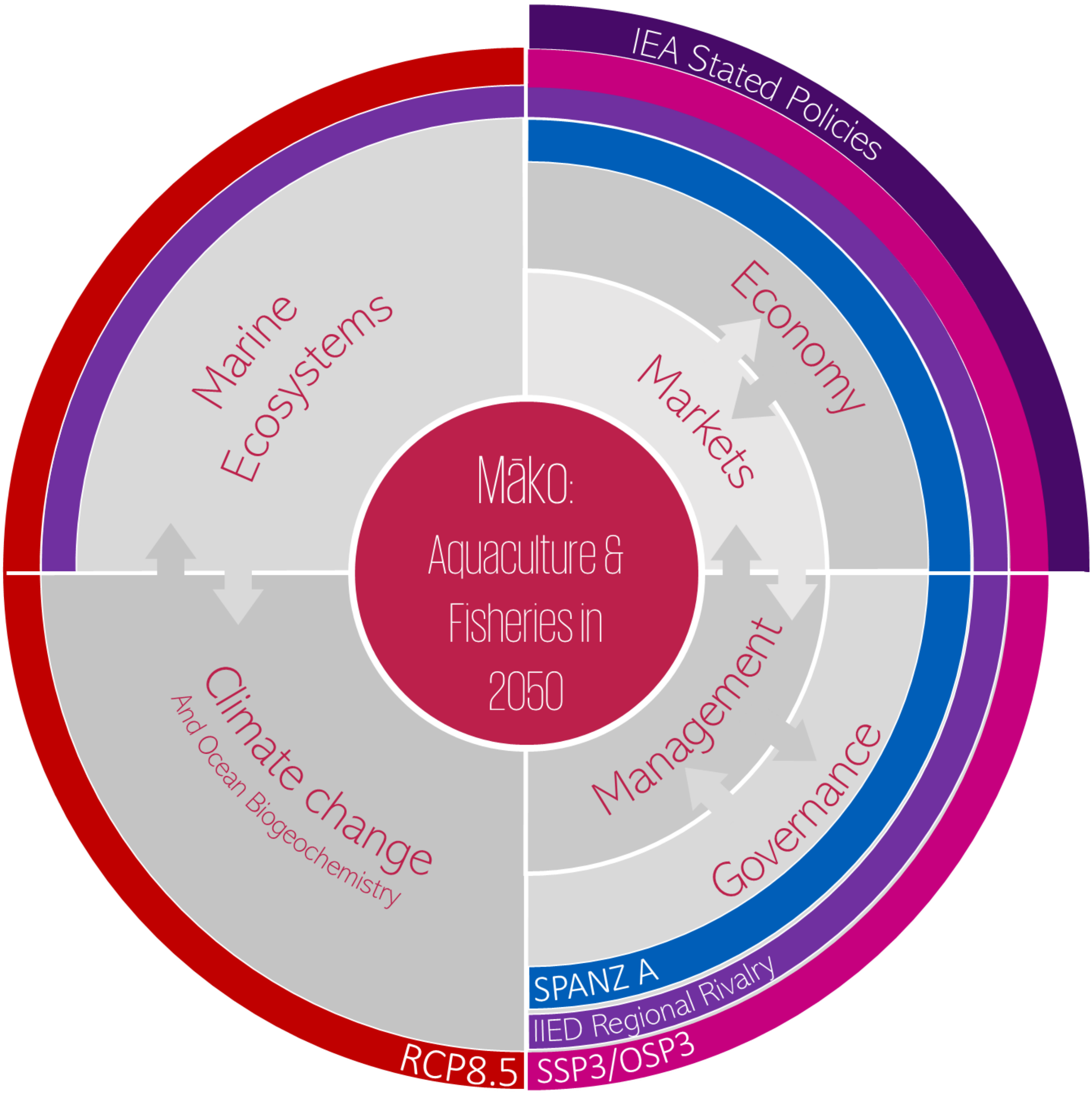


Figure 19: The scenario model for Māko, which visually demonstrates the global and sectoral scenarios applied as boundary conditions to the respective components of the model to explore climate-related risk in a fisheries context. Key inputs include:

- IPCC's Representative Concentration Pathway (RCP) 8.5 and Shared Socioeconomic Pathway (SSP) 3 'Rocky Road' scenario
- International Institute for Environment Development (IIED) High Seas Fisheries 'Regional Rivalry' scenario
- International Energy Agency (IEA) World Energy Model 'Stated Policies' scenario
- Manaaki Whenua's Shared Policy Assumptions for NZ (SPANZ) A 'Unspecific Pacific' scenario.

Kahawai

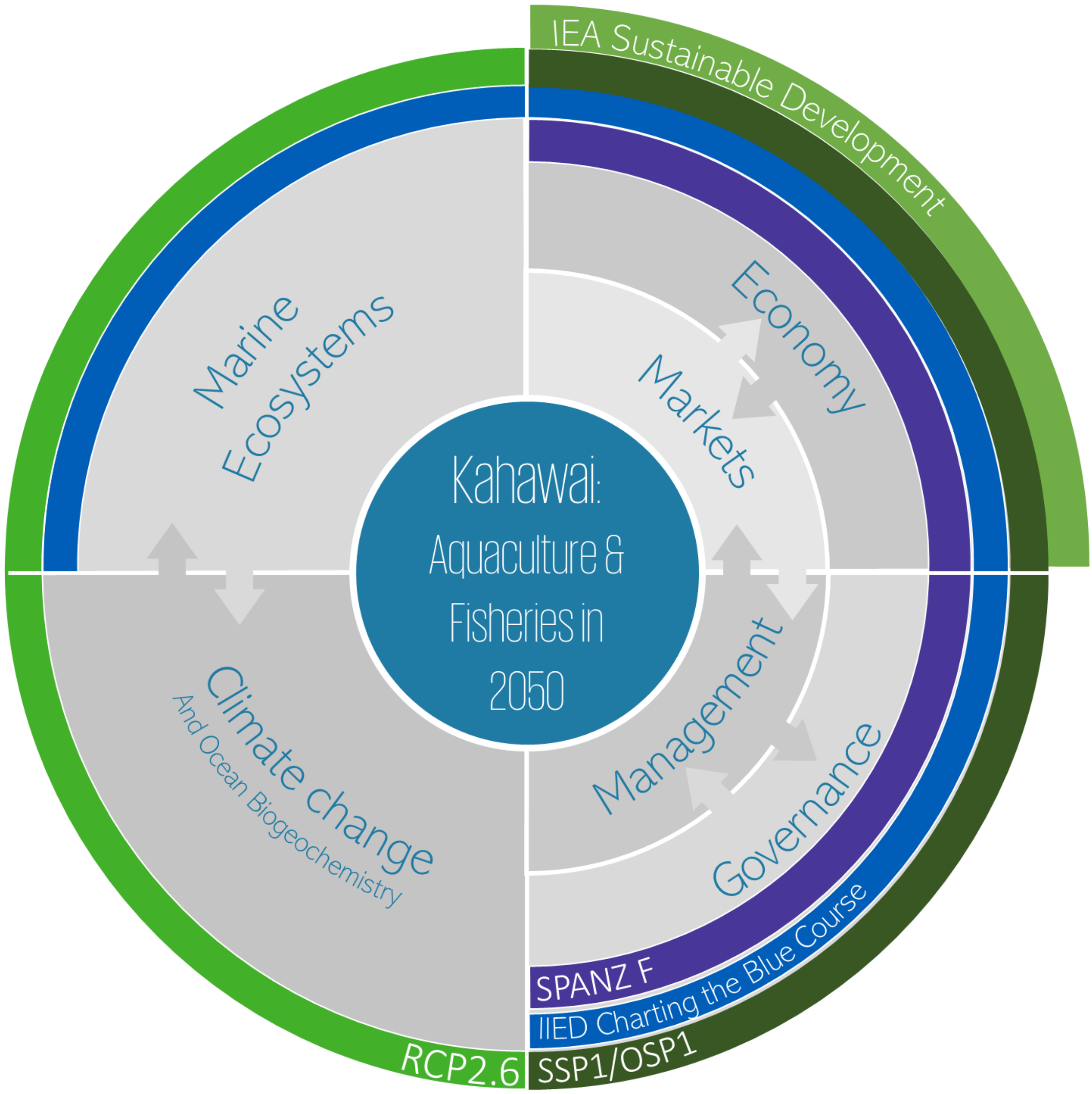


Figure 20: The scenario model for Kahawai, which visually demonstrates the global and sectoral scenarios applied as boundary conditions to the respective components of the model to explore climate-related risk in a fisheries context. Key inputs include:

- IPCC's Representative Concentration Pathway (RCP) 2.6 and Shared Socioeconomic Pathway (SSP) 1 'Green Road' scenario
- International Institute for Environment Development (IIED) High Seas Fisheries 'Charting the Blue Course' scenario
- International Energy Agency (IEA) World Energy Model 'Sustainable Development' scenario
- Manaaki Whenua's Shared Policy Assumptions for NZ (SPANZ) F '100% Smart' scenario.

Summary of stakeholder feedback

After developing earlier drafts of Māko and Kahawai, the scenario development process involved inviting experts and stakeholders to scrutinise their plausibility, coherence and relevance. Stakeholder feedback included the following.

Table 1: Summary of stakeholder feedback

General feedback	New Zealand context
— The scenarios are useful, but the key takeaway is: "What do we do next?" — A more user-friendly narrative structure suggested. — Correlation between the narratives and the workshop is not clear. — Critical pathways, risk factors, and underlying drivers require more emphasis. — The narrative approach requires a 'real-world lens' to avoid being perceived as academic commentary. — COVID-19 is a powerful example of the systemic disruption caused by a challenging, yet plausible, risk.	— The draft scenarios need more emphasis and exploration of New Zealand's rights-based Crown-Māori governance model, rooted in the Treaty of Waitangi, Deed of Settlement and QMS, in order to reflect New Zealand's unique context and ability to address climate-related risks and opportunities. — Te Ao Māori and Māori governance principles will endure, irrespective of global market/management trends. — The draft scenarios overtly rely on international literature at the expense of New Zealand-based perspectives.

Māko feedback	Kahawai feedback
— With ballooning populations in developing countries, low-cost nutrition will be in high demand. — Māko will drive self-sustaining behaviour to safeguard food security in New Zealand. — There are significant uncertainties for land-based aquaculture regarding energy inputs, biosecurity, and waste removal. Similarly, ocean-based aquaculture involves considerable risk and cost. The RMA implications are not clear for either option. — New Zealand is unlikely to experience IUU incursions to the same degree as other jurisdictions.	— It is important to explore 'locked-in' climate change impacts. — Agile marine management will be critical for both businesses and regulators. — The environmental benefits of ocean-based MPAs are highly contestable. — Collaborative governance may deliver outcomes, but it is a slow process. — In time, fisheries and aquaculture might describe their industry as the 'marine protein sector', which includes plant-based and synthetic marine proteins for a range of purposes (e.g. biofuel, 'blue carbon market'). — Aquaculture's feed conversion efficiency will underpin its competitiveness against lab-grown products. — Animal welfare is a key risk factor.

Appendix C Climate-related risk assessment data

The following table and figures graphically represent the findings of a stakeholder workshop which sought to elicit expert views regarding the most significant and uncertain risk factors affecting the aquaculture and fisheries sectors in New Zealand. These were elicited under four categories in the left column of the table below.

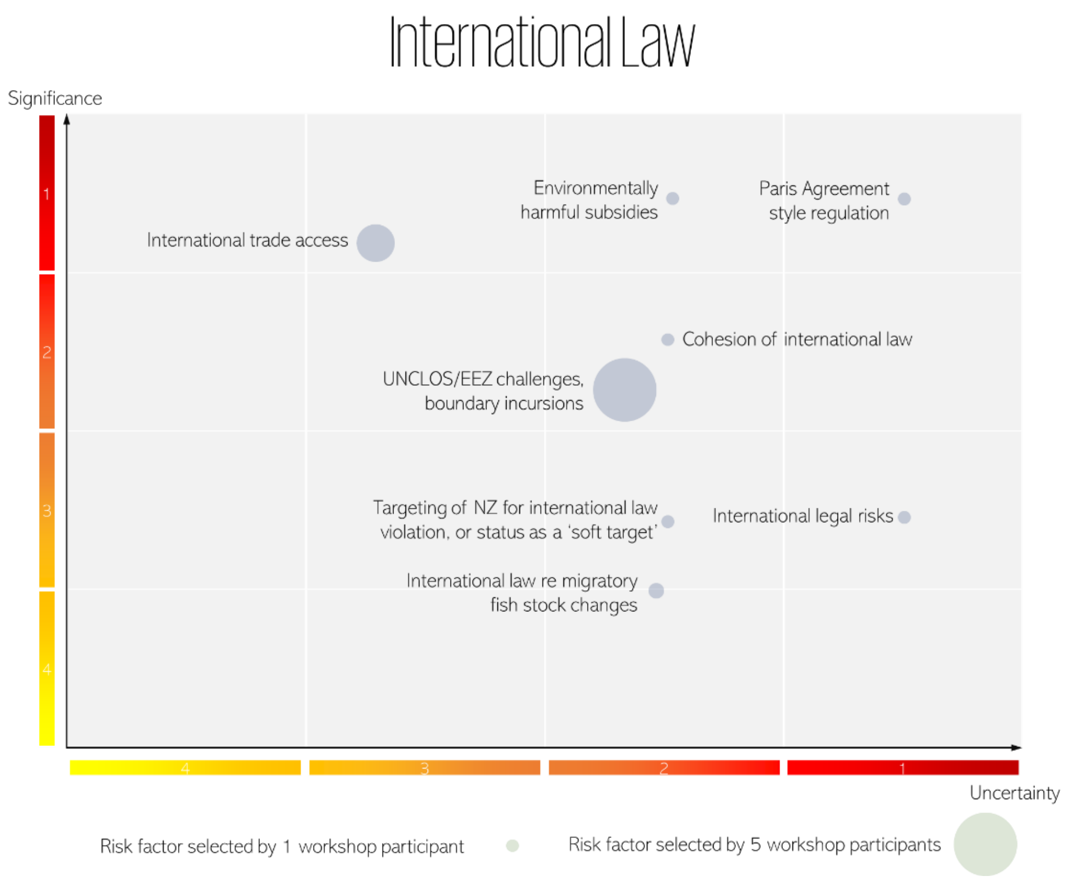
Table 2: Significant and uncertain risk factors elicited from our expert stakeholder workshop.

Risk category	Sub-category	Stakeholder data
Physical	Oceans	Sea surface temperature; Ocean acidification; Accelerated changes in climate and ocean chemistry (temperature, currents, pH); Ocean circulation
	Habitats and biodiversity	Habitat loss; Lower productivity; Biomass loss; Species migration; Ecosystem collapse; Stock recruitment; Stock distribution; Invasive species; Algal blooms; Abundance of species; Ecosystem changes; Impacts on aquaculture
	Land	Mountain to sea; Freshwater supply & quality; Ecosystem change (including land); Sediment run-off; Sea level rise and coastal squeeze
	Atmosphere	Storms; Atmospheric circulation; Accelerated and unpredictable change; Cumulative effects
Transition	Policy	Pace/agility of regulatory change ("climate moves faster than regulation"); Mountain to sea integration; Policy; Responsive management system
	Markets	Shifting/surprise government requirements re emissions; Aquaculture's ability to adapt through regulatory constraints; Access/protected areas; Need to reduce carbon emissions over next decade; Misinformation; Social license; Consumer preferences; Plant proteins / alternative proteins; New sectors; Shifting market expectations; Alternative proteins and consumer preferences; Market demand for low-carbon and transparency
	Industry	Fishing methods; Governance/shareholder buy-in; How we measure success; Focus on traditional performance measures; Resource user reactions
	Energy and tech	Energy supply; Carbon reduction / fuel cost; Technology and innovation
Capital	Assets and costs	Quota value; Operational costs; Higher operating costs and lower quota value; Less capacity to borrow against (or higher costs) against quota value because of uncertainty that the asset can generate and return; Share value; Export value; Financial headwinds
	Financial markets	Insurance; Global financial instability; Access to capital; Access to green capital at lower rates; Volatility of long-term capital based on short-term results
	Government	Government intervention in markets; Fiscal policy; Geostrategic risk to protecting EEZ from outside vessels; Agile, well-managed fisheries management provides competitive advantage globally
	Others	Recreation sector growth/pressures; Opportunity value of fish stocks increase due to global impact on fishing; Low-carbon protein; Low-carbon aquaculture provides market opportunities; Opportunity to differentiate NZ products based on relative global performance

Risk category	Sub-category	Stakeholder data
Legal	Tiriti o Waitangi	Te Tiriti o Waitangi; Waitangi Tribunal challenges over lack of action; Treaty settlement ramifications if quota value changes
	International law	UNCLOS/EEZ; International trade access; International law re migratory fish stock changes; International legal risks; Paris Agreement-style regulation; Environmentally harmful subsidies; NZ's international legal obligations and the possibility NZ is targeted by activists, or because we're seen as a 'soft target'; Cohesive international law
	Regulation	TACC/QMS/QMA; Animal welfare; Scientific uncertainty causing regulatory change; Directors' duties; More compliance with aquaculture consents; Regulatory change driven by general climate change policy change; Compliance with international law / domestic regulation (greater risk of non-compliance as stocks change); Regulatory management/monitoring
	Litigation	Civil society litigation; Class action against industry; Continuous disclosure and shareholder litigation

Each of the factors selected were scored by stakeholders for significance and uncertainty from 1 (lowest) to 4 (highest), giving a broad indication of the level of impact on the sector, and scale of change each factor might undergo in the future. These scores were averaged and represented graphically, with the size of the circle representing the number of stakeholders selecting the factor (see example below).

Figure 21: Example figure of significant and uncertain risk factors elicited from our expert stakeholder workshop.



Physical risk factors

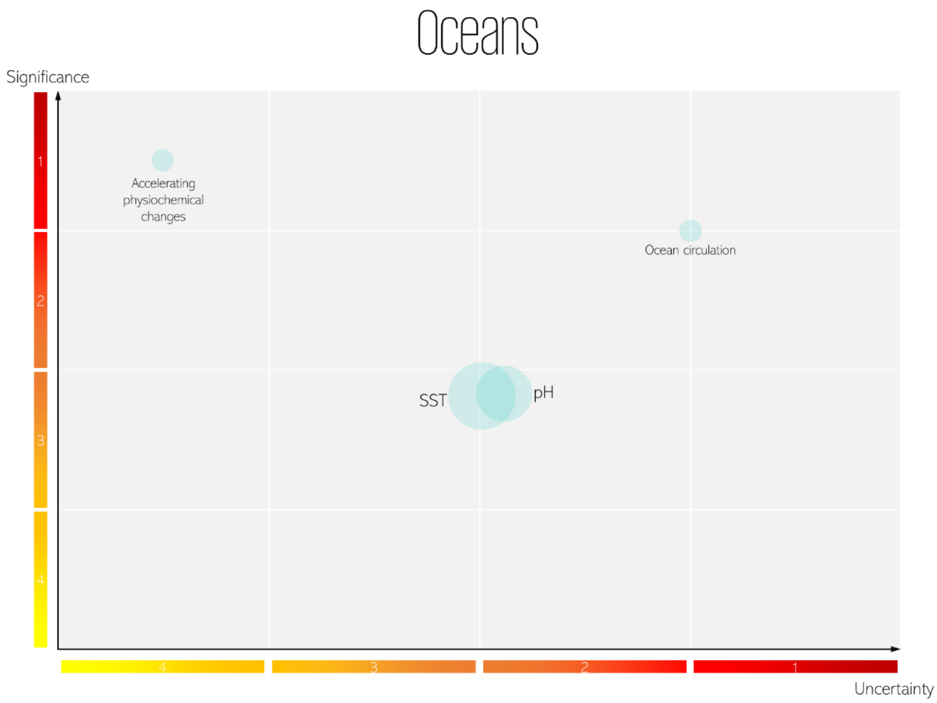


Figure 22: Ocean-related risk factors.

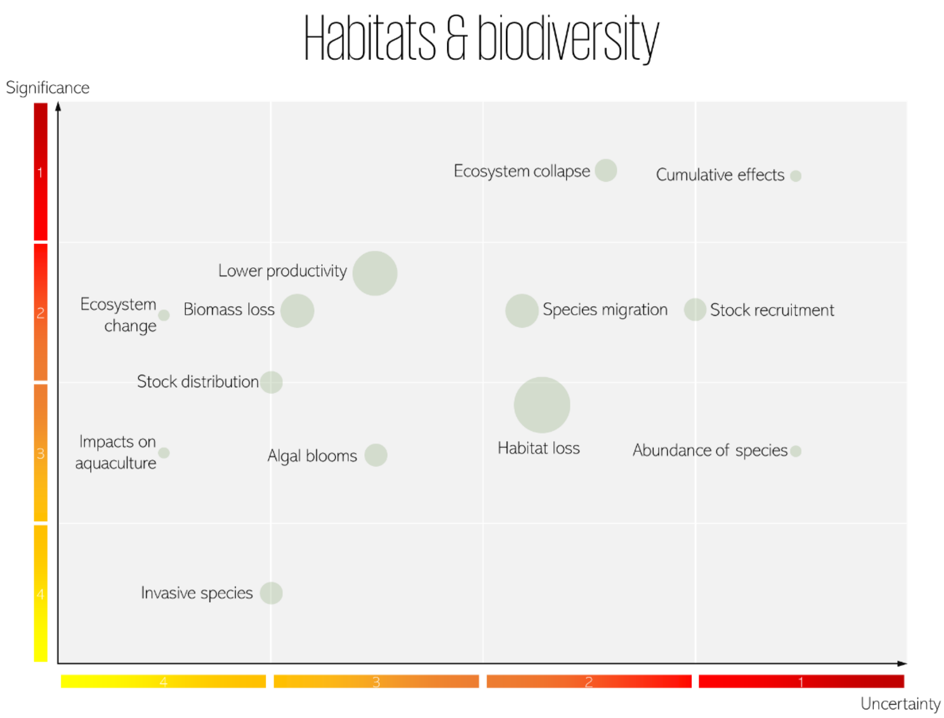


Figure 23: Habitats & biodiversity risk factors.

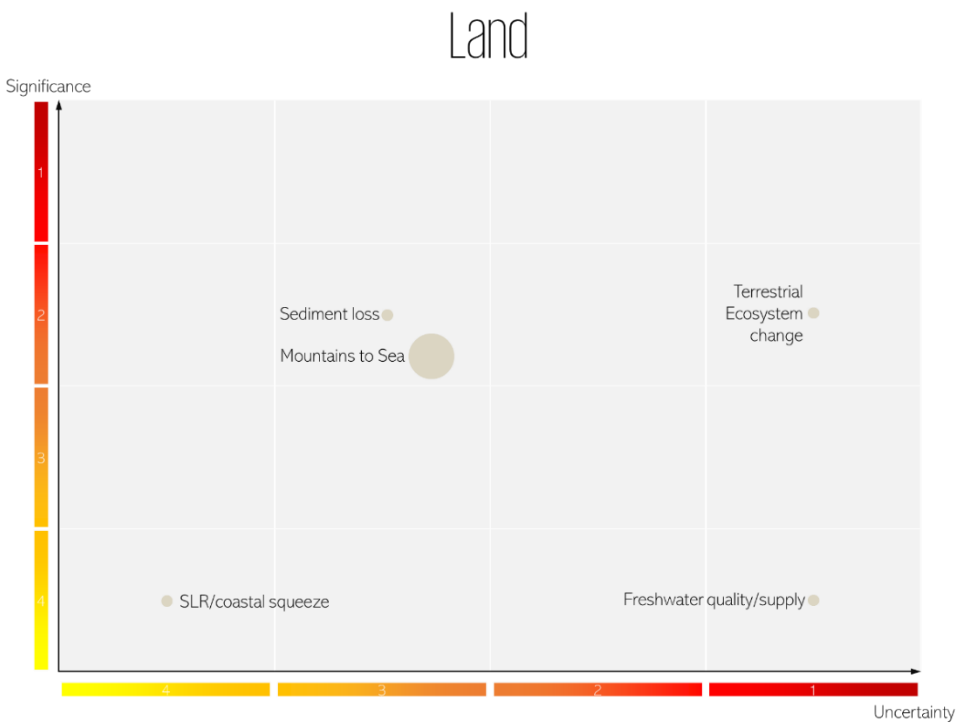


Figure 24: Land-related risk factors.

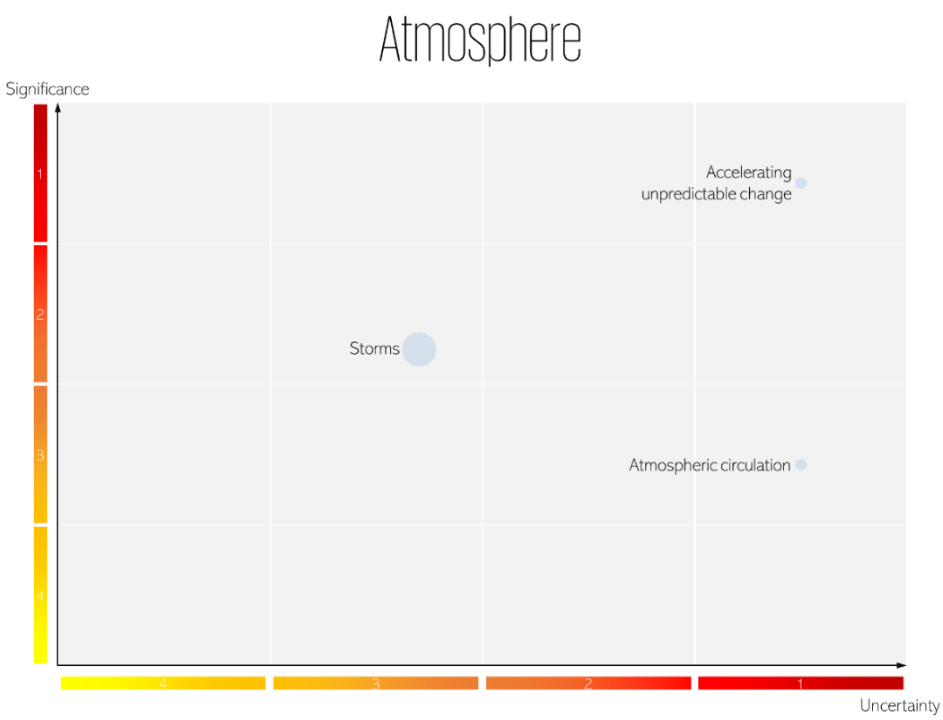


Figure 25: Atmosphere-related risk factors.

Transition risk factors

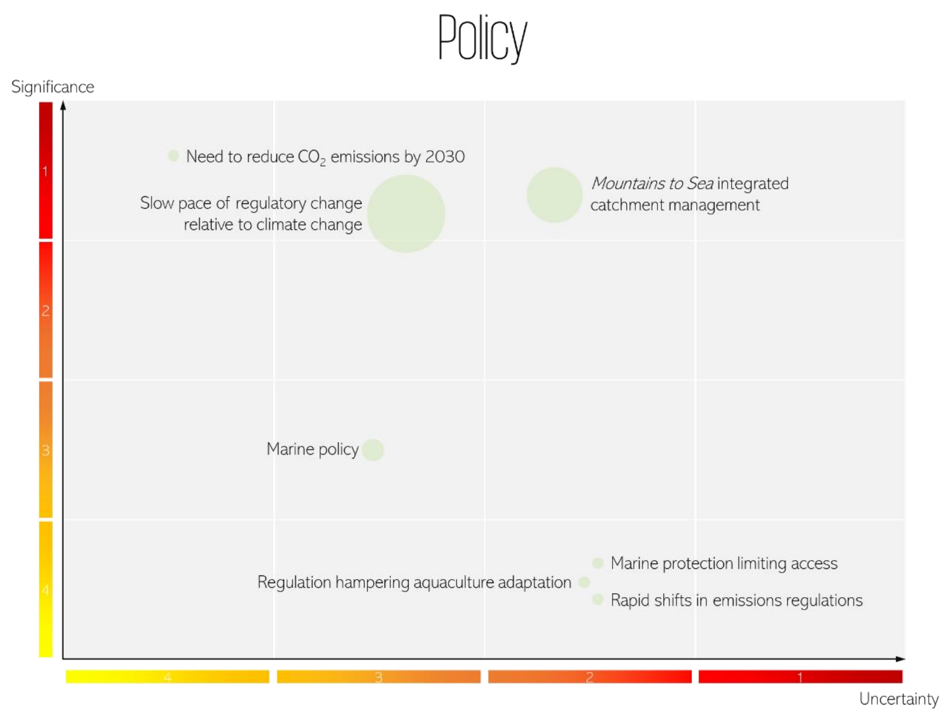


Figure 26: Policy risk factors.

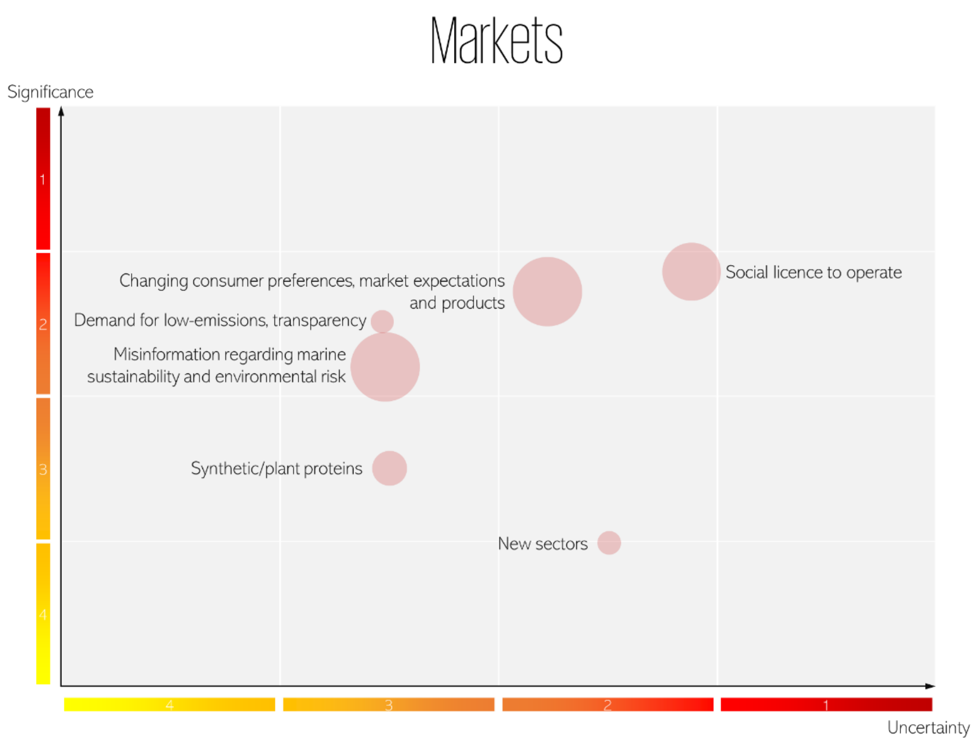


Figure 27: Market risk factors.

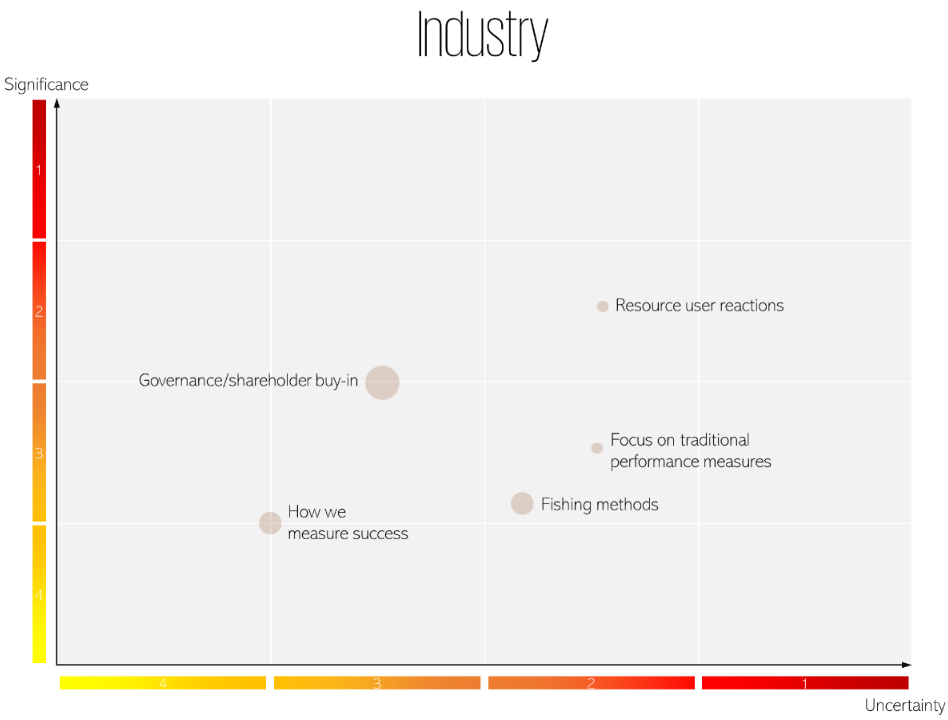


Figure 28: Industry risk factors.

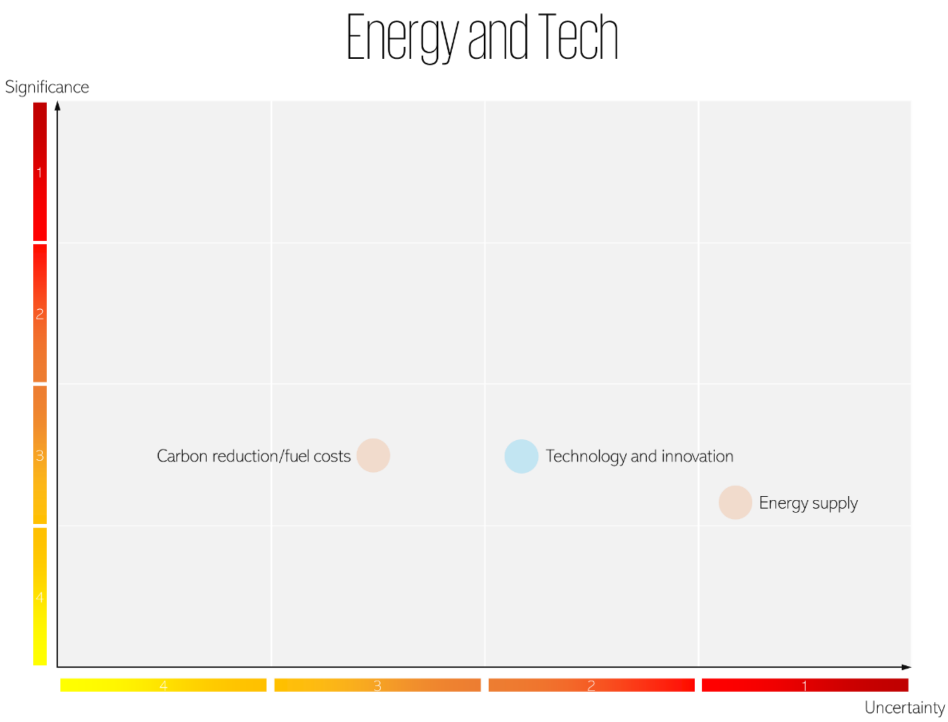


Figure 29: Energy & technology risk factors.

Capital risk factors

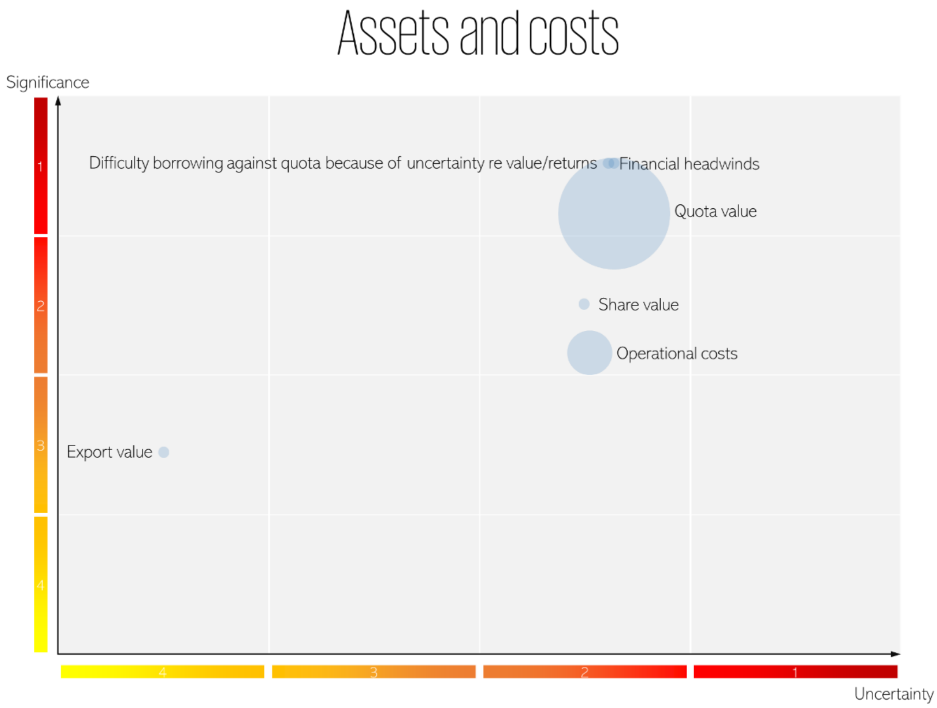


Figure 30: Asset and cost-related risk factors.

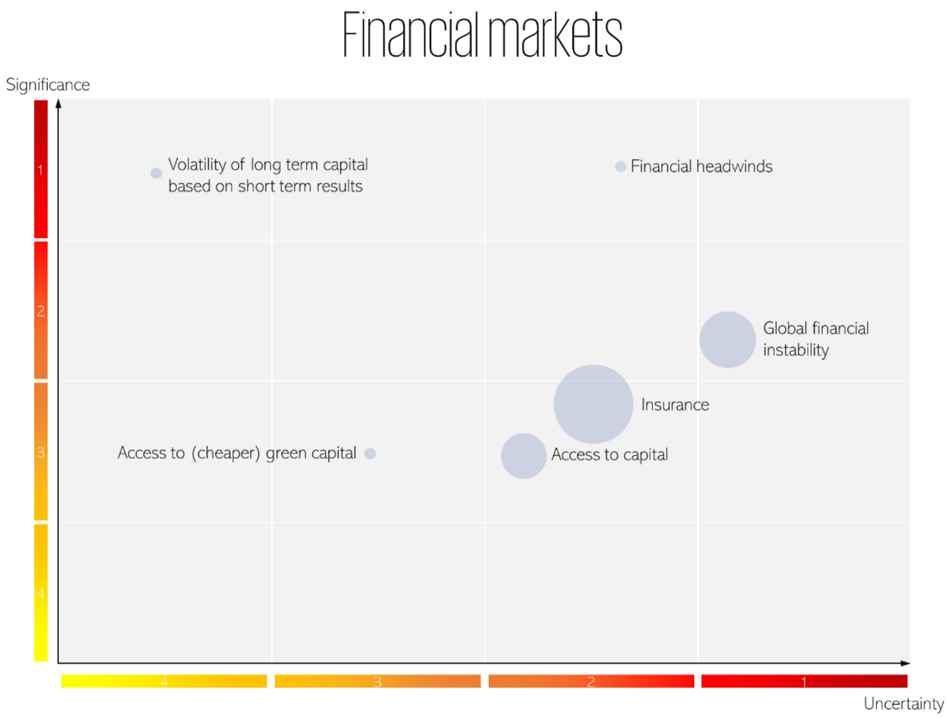


Figure 31: Financial market risk factors.

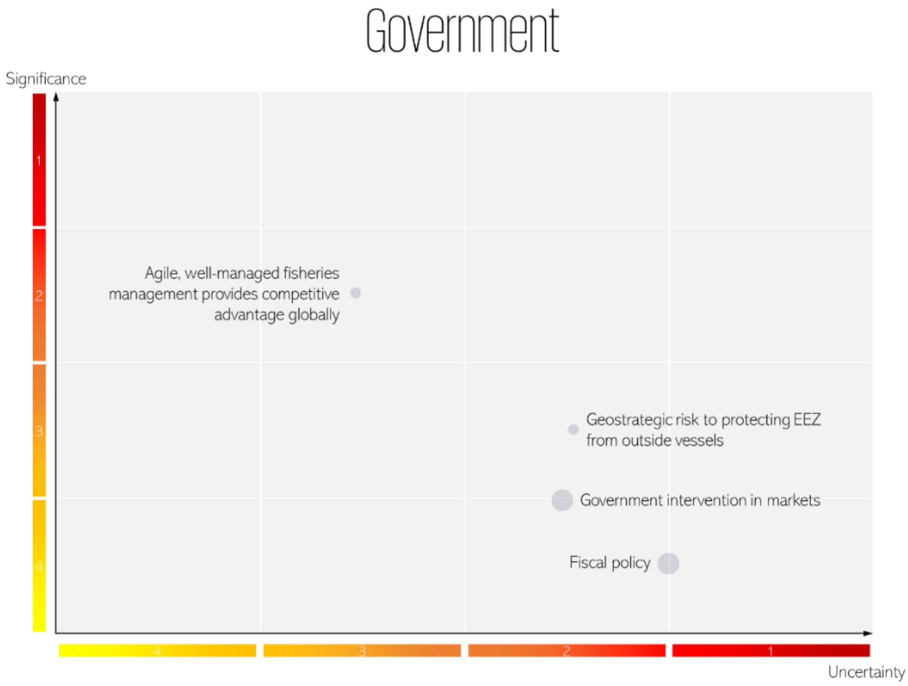


Figure 32: Government-related risk factors.

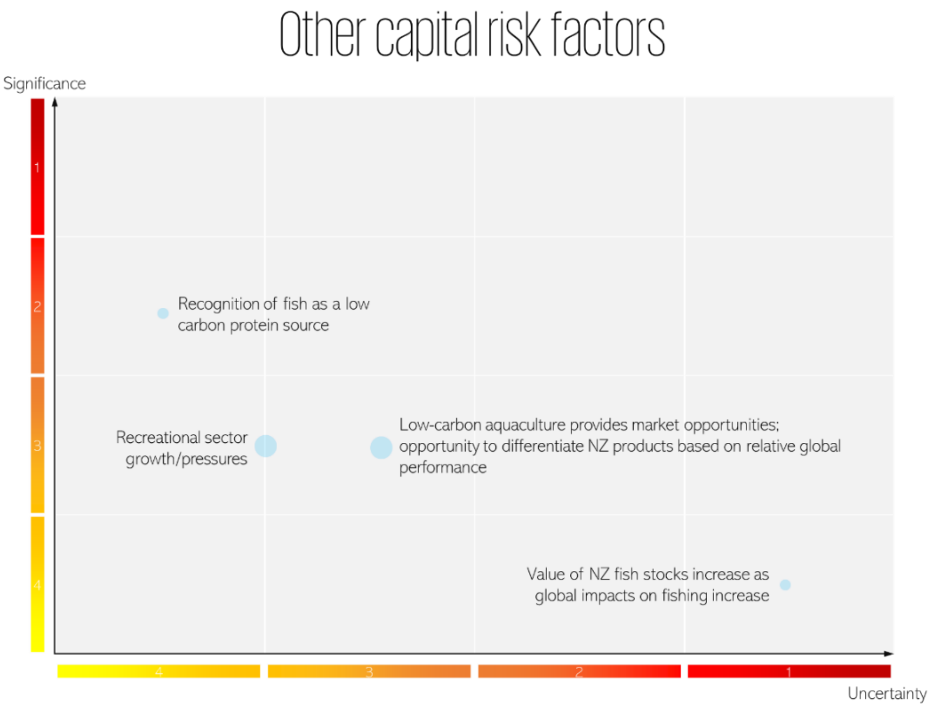


Figure 33: Other capital risk factors.

Legal risk factors

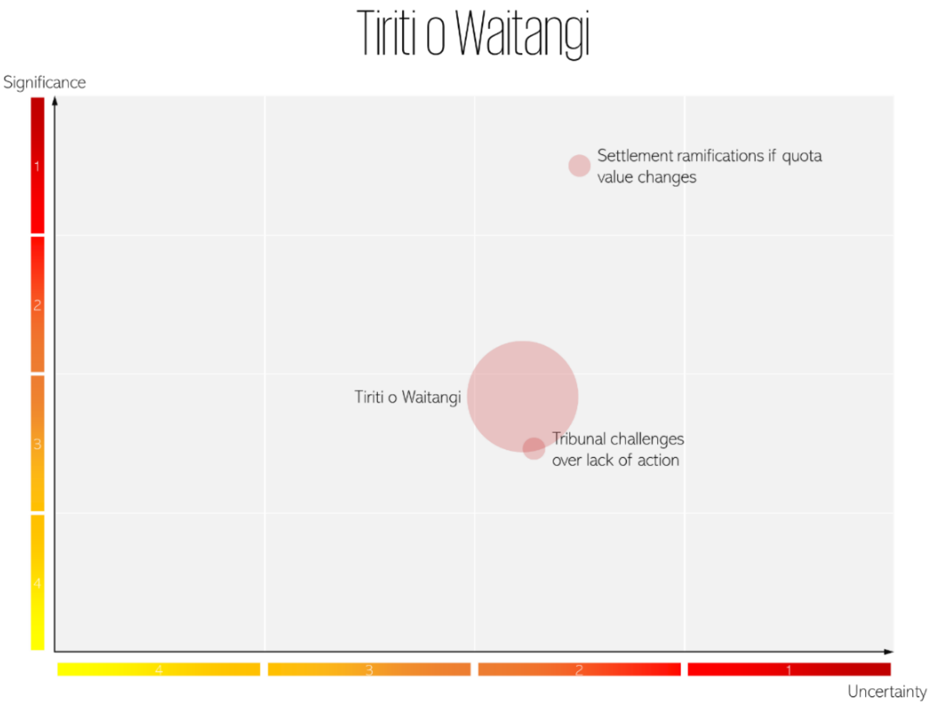


Figure 34: Tiriti o Waitangi-related risk factors.

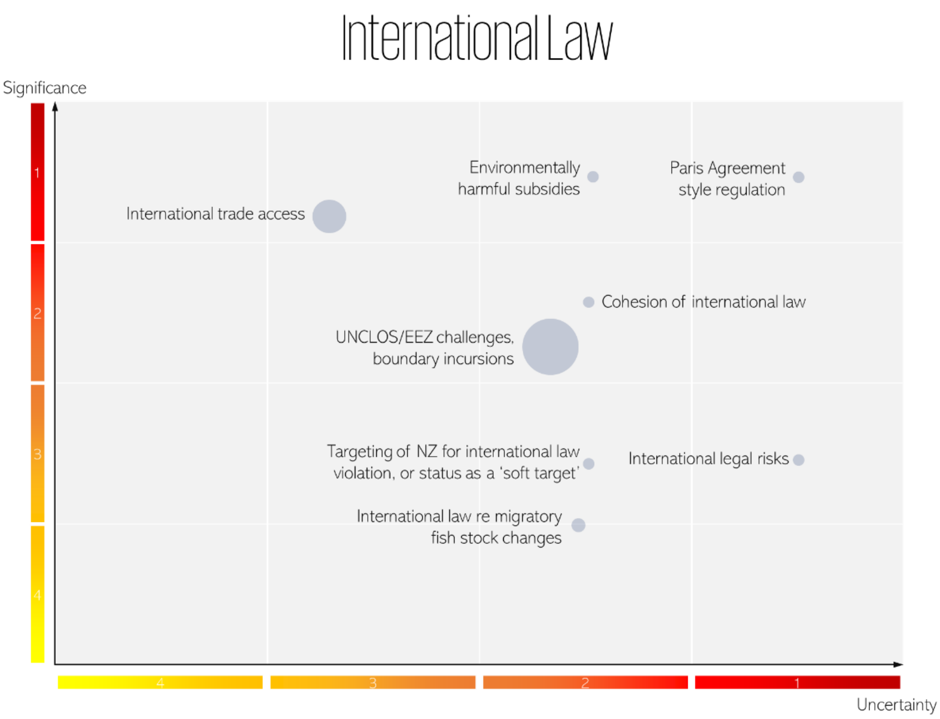


Figure 35: International law risk factors.

Figure 36: Regulation risk factors.

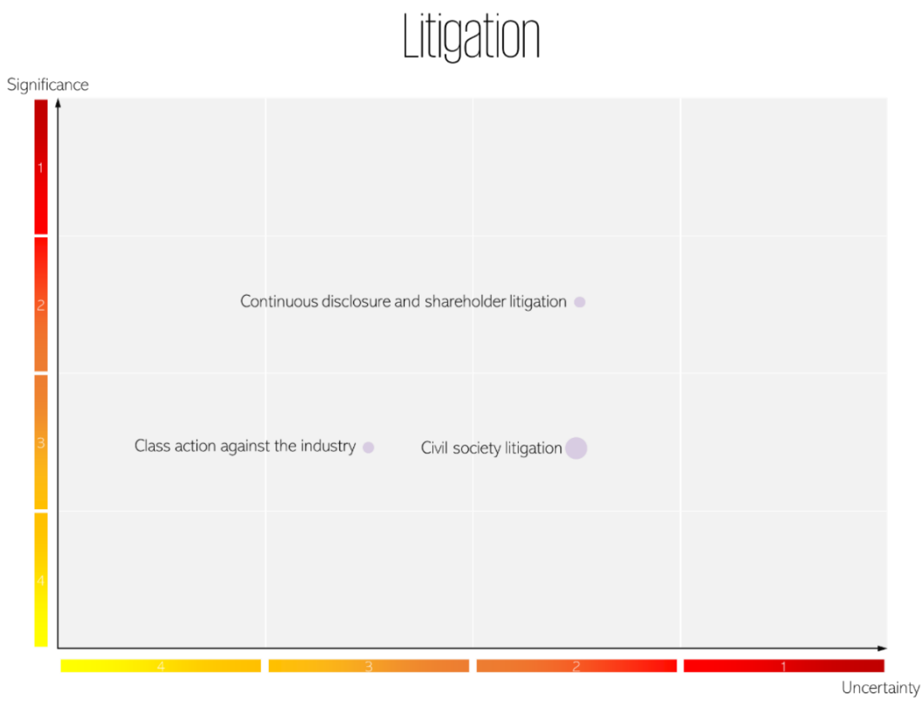


Figure 37: Litigation risk factors.

Appendix D Long-term climate and socioeconomic projections

Table 3: Projections of long-term climate and socioeconomic change used as boundary conditions for this analysis.

		Boundary condition factors	2050 Projections	
Māko	RCP8.5	Ocean circulation	Stratification increasing, circulation systems weakening	
		Air temperature	~1.0°C (on a 1986-2005 baseline)	
		Sea surface temperature	~0.7 - 1.5°C	Variable by location
		Sea level rise	~0.28m (1986 - 2005 baseline)	
		Ocean oxygen content	~2% reduction overall	
		Acidification	pH ~7.935	
		Storm frequency/intensity	Possible 30% reduction in Tasman Sea lows, Tropical cyclones unknown	
		Significant wave height conditions: >5m	Minor increase south of New Zealand	
		Marine habitats	Reduction in Coldwater coral habitat; changes in longitudinal temp. gradients	
	IIED 'Regional Rivalry and Rough Seas Ahead/WRI Creating a sustainable food future	Net primary productivity rate	~5% reduction	
		Mean species abundance (global)	~11-24% reduction	
		Distribution of fish stocks	Amplified poleward migration of temperate sp., sub-tropical sp. move south	
		Marine Protected Areas - High Seas	Reduced High Seas protection may impact access to Highly Migratory stocks within NZ's EEZ	
		Fishing methods	Slower pace of change, countries guard advances	
		UNCLOS settings	International competition weakens role of UNCLOS in ocean governance	
		Illegal, Unreported and Unregulated fishing	Drivers of IUU behaviour amplified as fishing fleets compete and oversight fails	
		Total global production: wild capture fisheries	80Mt	Catch cannot rise any higher to meet pop. growth demand
		Total global production: aquaculture	160Mt	Global pop.of 9.6b = 140Mt: Global pop. Of 11b = 160Mt (WRI 2014)
		Aquacultural production efficiency	10% increase	
		Total value: wild capture fisheries	$84b	2006 92Mt = $91.2b (UN) 2050 80Mt = $80b + 5% = $84b
		Total value: aquaculture	$485.1b (USD 2016)	$231.6 x 2 = $462b (@2016 value) + 5% = $485b
		Fishmeal and fish oil cost	~70% increase	
		Operating and capital costs of fishing effort	~25% decrease	
	SSP3/OSP3	Global GDP	Low growth ($17k/capita)	
		Global population	~11.5 billion	
		Global governance and institutions	Combative/ineffective	
		Market access and trade settings	Closed, tariffs/subsidies play significant role	
		New markets, products and synthetic proteins	Volume over value; Plant-based and synthetic protein dominate at the mass consumption end of the market	

Scenario	Source	Boundary condition factors	2050 Projections
Māko	SSP3/OSP3	Consumer preferences	Crop and pasture land use increases, suggesting greater focus on food provision than sustainability
		Corporate regulation and governance	Corporate reporting standards are tightly focussed on financial stability
		Technology and innovation	Slower initial development, many barriers to uptake
		Energy demand	Remains steady, efficiencies arise via innovation to avoid growing costs
	IEA 'Stated Energy Policies' scenario	Carbon price	~US$55/t [EU: US$43/t by 2040; US$33/t by 2030]
		Fuel cost/availability	Crude oil US$103/barrel [2040]; Oil security risks intensify
		Energy sources	Increased wind and solar, but slow uptake and investment
		International shipping	GHG emissions unchanged (relative to 2008 levels)
	SPANZ A	Fisheries Act: QMS/QMA/TACC settings	Fishing activity permitted with little consideration of ecosystem impacts
		Tiriti o Waitangi	Little focus on indigenous property rights or communities
		Aquaculture site consenting processes	Consents granted based almost exclusively on economic merit
		Mountains to Sea - freshwater management	Reactive regulation. Economic outcomes prioritised over environmental outcomes
		Conservation policy	Minimal protection of natural ecosystems.
		Domestic emissions policy	Laggard. Transformative change is avoided unless justified economically; 50.8 - 87.6 MtCO2e
		Social licence to operate	Loss of clean, green reputation but food security most pressing consumer concern
		Boundary condition factors	**2050 Projections**
Kahawai	RCP2.6	Ocean circulation	Stratification increasing, circulation systems weakening
		Air temperature	~0.7°C (on a 1986-2005 baseline)
		Sea surface temperature	~0.12 - 0.79°C; Variable by location
		Sea level rise	~0.23m (1986 - 2005 baseline)
		Ocean oxygen content	~1% reduction overall
		Acidification	pH ~8.1 - 8.0
		Storm frequency/intensity	Possible 30% reduction in Tasman Sea lows, Tropical cyclones unknown
		Significant wave height conditions: >5m	Minor increase south of New Zealand
		Marine habitats	Minor reduction in Coldwater coral habitat; changes in longitudinal temp. gradients
	IIED 'Charting the Blue Course/WRI Creating a sustainable food future	Net primary productivity rate	~2% reduction
		Mean species abundance (global)	~10% reduction
		Distribution of fish stocks	Poleward migration of temperate sp., sub-tropical sp. move south
		Marine Protected Areas - High Seas	High seas protection may enhance access to Highly Migratory stocks wihtin NZ's EEZ
		Fishing methods	Rapid changes required to stay ahead in sustainability arms race
		UNCLOS settings	International collaboration strengthens role of UNCLOS in ocean governance
		Illegal, Unreported and Unregulated fishing	Declines as fishing fleets reduce capacity and compliance becomes easier

Kahawai	IIED 'Charting the Blue Course/WRI Creating a sustainable food future	Total global production: wild capture fisheries	71Mt	9.6b pop. = 80Mt 8.5b pop. = 71Mt (fishing effort constrained by demand and environmental regulation)
Kahawai	IIED 'Charting the Blue Course/WRI Creating a sustainable food future	Total global production: aquaculture	124Mt	Global pop.of 9.6b = 140Mt: Global pop. Of 8.5b = 124Mt (WRI 2014)
Kahawai	IIED 'Charting the Blue Course/WRI Creating a sustainable food future	Aquacultural production efficiency	20% increase	
Kahawai	IIED 'Charting the Blue Course/WRI Creating a sustainable food future	Total value: wild capture fisheries	$81.7b	71Mt = $71b (Rough heuristic: 1Mt=$1b, 2006 values) (+15%) = $81b
Kahawai	IIED 'Charting the Blue Course/WRI Creating a sustainable food future	Total value: aquaculture	$412.8b	$231.6 x 1.55 = $359b (@2016 value) + 15% = $412.8b
Kahawai	IIED 'Charting the Blue Course/WRI Creating a sustainable food future	Fishmeal and fish oil cost	~58% increase	
Kahawai	IIED 'Charting the Blue Course/WRI Creating a sustainable food future	Operating and capital costs of fishing effort	~50% Increase	
Kahawai	SSP1/OSP 1	Global GDP	High growth ($US36k/capita)	
Kahawai	SSP1/OSP 1	Global population	~8.5 billion	
Kahawai	SSP1/OSP 1	Global governance and institutions	Strong, effective	
Kahawai	SSP1/OSP 1	Market access and trade settings	Open, tariffs/subsidies removed	
Kahawai	SSP1/OSP 1	New markets, products and synthetic proteins	"Conspicuous conservation"; Rise of plant-based and synthetic protein markets	
Kahawai	SSP1/OSP 1	Consumer preferences	~30% reduction in animal protein intake	
Kahawai	SSP1/OSP 1	Corporate regulation and governance	Reporting demands rise, TCFD and Better Business style reporting mandatory	
Kahawai	SSP1/OSP 1	Technology and innovation	Rapid development, high uptake	
Kahawai	SSP1/OSP 1	Energy demand	Low, efficiencies diminish demand-side	
Kahawai	IEA 'Sustainable Development' scenario	Carbon price	~US$180/t [Advanced economies: US$140/t by 2040; US$100/t by 2030]	
Kahawai	IEA 'Sustainable Development' scenario	Fuel cost/availability	Crude oil US$59/barrel [2040]	Significant market volatility
Kahawai	IEA 'Sustainable Development' scenario	Energy sources	Increased wind, solar, hydrogen, biofuel, and CCUS	
Kahawai	IEA 'Sustainable Development' scenario	International shipping	<50% GHG emissions (relative to 2008 levels)	
Kahawai	SPANZ F	Fisheries Act: QMS/QMA/TACC settings	Higher costs imposed for long-term sustainability and adaptive resilience	
Kahawai	SPANZ F	Tiriti o Waitangi	Indigenous wellbeing and property rights are protected	
Kahawai	SPANZ F	Aquaculture site consenting processes	Initially restrictive, becoming increasingly permissive as sector innovates to enhance marine ecosystem resilience	
Kahawai	SPANZ F	Mountains to Sea - freshwater management	Water governance is anticipatory, holistic, world-leading	
Kahawai	SPANZ F	Conservation policy	Increased pressure for marine protection (international and some domestic drivers); strident ecological lobby groups	
Kahawai	SPANZ F	Domestic emissions policy	NZ leads global mitigation efforts, achieving CO2 neutrality by 2050; -12.9 - 13.1 MtCO2e	
Kahawai	SPANZ F	Social licence to operate	Consumers willing to pay a premium for low-carbon, sustainable products	

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Appendix E Key participants

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Volker Kuntzsch	Sanford
Dan Bolger	Ministry for Primary Industries

Marine Domain participants

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Grant Rosewarne	New Zealand King Salmon
Jeremy Helson	Seafood New Zealand
John Morgan	NIWA
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KPMG IMPACT

A Global cross-sector initiative that integrates our knowledge and experience regarding global issues such as environmental, social, governance (ESG) performance and sustainability; economic and social development; climate change and decarbonisation; and sustainable finance. The initiative aims to improve outcomes for the most vulnerable in society with clear measurement and reporting. KPMG IMPACT will benefit our clients, accelerate our commercial growth and demonstrate the societal impact of our business.

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