Climate Changes, Impacts and Implications for New Zealand to 2100

Synthesis Report: RA5

Exploring Options for New Zealand under Different Global Climates

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CONTENTS

Summary of climate/socio-economic scenarios for New Zealand (see Table 2 for more detail).

	SSP1	SSP2	SSP3	SSP4	SSP5
RCP8.5			**Unspecific Pacific** no mitigation, fragmented world, reactive NZ (8.5-3-A)		
RCP6.0					**Homo economicus** global growth with little mitigation, NZ does minimum but adapts smartly (6.0-5-D)
RCP4.5			**Kicking, screaming** fragmented world that mitigates through power blocks, NZ dragged along (4.5-3-A)		**Clean leader** global growth, significant mitigation, NZ leads, strategically exploits competitive advantage (4.5-5-F)
RCP2.6	**100% smart** global cohesive sustainability focused world with ambitious mitigation, with NZ riding front wave (2.6-1-F)				**Techno-garden** global ambitious mitigation in a cohesive rich world focused on economic gain, NZ keeps economic focus (2.6-5-B)

HIGHLIGHTS

We provide:

- A socio-economic scenario architecture to 2100 that links global, national and local modelling of climate change and its impacts and implications with a range of key quantitative and qualitative indicators
- This combines various feasible global responses to climate change with national climate policy and non-climate policy dimensions

We observe that development of meaningful scenarios must:

- Enable understanding about the extent to which global, national and local-scale societal developments can influence the nature and severity of climate change risks
- Involve researchers across many disciplines; stakeholders with an interest in long-term impacts and implications; and policy-makers who take the long-view
- Be credible, salient and legitimate but not necessarily downscaled from global models

THE PROCESS

Shared Socioeconomic Pathways (SSPs) describe future global socioeconomic conditions including emissions of greenhouse gases (GHGs). They outline plausible alternative states of human and natural societies at a macro scale including both narrative and quantitative elements of socio-ecological systems such as demographic, political, social, cultural, institutional, lifestyle, economic and technological variables and trends. They also include the human impacts on ecosystems and ecosystem services such as air and water quality and biodiversity. The global SSPs are defined for global scales and lack the detail critical for understanding climate change risks at national and local scales. In RA5 we describe development of national-scale socio-economic scenarios for New Zealand, nested within SSPs, to inform national and local-scale studies of climate change impacts and implications.

Shared climate Policy Assumptions (SPAs) describe potential climate change mitigation and/or adaptation policies specific to New Zealand, which enable New Zealand-specific futures to diverge from (accelerate, slow down or even counteract) the trends that are assumed in global-scale SSPs. The SPAs capture key climate policy dimensions not specified in the SSPs and provide a means to employ common assumptions across studies. Shared-climate Policy Assumptions for New Zealand (SPANZ) were developed to illustrate how approaches to both mitigation and to adaptation will impact the future (Table 1).

We discuss the challenges that result from these choices in the development of national-scale socioeconomic scenarios for impacts; adaptation and vulnerability research, and demonstrate their utility and limitations in a local-scale case study (Table 2).

A set of quantitative and qualitative indicators have been identified for each scenario with sources from the project and more widely (Table 3).

INTRODUCTION

Risk related to climate change is the product of three interacting drivers: climatic hazards, exposure to those hazards, and vulnerability to those hazards (IPCC 2014). All three change over time. Much research has focused on better understanding and quantifying future changes in climate-related hazards, and understanding and modelling the sensitivity of natural and human systems to those changes, often based on current conditions. Much less effort has been invested in understanding how socio-economic trends could alter both exposure and vulnerability to hazards over time, which could have a critical influence on actual risks from climate change and the feasibility and effectiveness of adaptation options. The Shared Socioeconomic Pathways (SSPs) were developed to provide a typology of alternative futures, and to enable a systematic exploration of the challenges to adaptation and mitigation arising from alternative socioeconomic futures. However, the architecture for this and actual use of SSPs in impacts, adaptation and vulnerability studies has mostly been at the global or broad regional scale (e.g. Arnell and Lloyd-Hughes 2014; Hasegawa *et al*. 2015; O'Neill et al. 2015). While risks from climate change always reflect an interplay of forces across different scales, local conditions can critically influence the severity of climate-related risks and adaptation options. However, to date there are only few examples of studies that build on the SSP architecture but apply them at the regional, national or sub-national scale (Carey 2014; Absar and Preston 2015; Alfieri *et al*. 2015; König *et al*. 2015; Nilsson et al. 2016; Steininger *et al*. 2016).

We describe a framework for establishing globally-linked national-scale socio-economic scenarios for New Zealand (NZ). These were developed to enable a better understanding of potential societal changes and how those changes may interact with changing climatic conditions, to inform climate change vulnerability and adaptation research and decisions. These scenarios were intended to be *"plausible and often simplified descriptions of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces and relationships"* (Rounsevell and Metzger 2010). In particular we seek to understand how to map out socio-economic trajectories for a small, geographically remote but heavily trade-reliant country that will be consistent with global scenarios but reflect a country's unique aspects and development choices that arise within any given global socio-economic development trajectory.

We first examine how to nest climate change scenarios for New Zealand within the global models (Section 2) and then make decisions about which suite of scenarios are most meaningful (Section 3) and how this varies for different interested parties (Section 4) before populating these with quantitative data derived from numerical models and supplemented with qualitative proxies as necessary (Section 5). In turn these national scenarios are downscaled across five local landscapes (Section 6) before we reflect on the processes to date and how that might inform future research (Section 7).

TESTING NEW ZEALAND IN GLOBAL SCALE SCENARIOS

The process we used to develop our scenario framework builds on the global climate scenario toolkit (Ebi et al. 2014) following the work of Schweizer and Kriegler (2012); Kriegler et al. (2014); O'Neill *et al*. (2014); van Vuuren et al. (2014). However these existing approaches mostly rely on a top-down downscaling of the extensive global models to provide information necessary for national-scale scenarios. Yet New Zealand is not a *'mini-world'*: our small size, and strong reliance on trade and migration for its economic development mean that its socio-economic development is strongly dependent on but unlikely to be captured appropriately by simply downscaling global scenarios (van Vuuren *et al*. 2010). Furthermore, for scenarios to have traction in their local jurisdiction they must have (Cash *et al*, 2003):

- Credibility that involves the scientific adequacy of the technical evidence and arguments;
- Salience which deals with the relevance of the assessment to the needs of decision-makers; and
- Legitimacy that reflects the perceptions that the production of information and technology has been respectful of stakeholders' divergent values and beliefs, unbiased in its conduct, and fair in its treatment of views and interest.

While global scenarios clearly matter, national-scale scenarios that have credibility, salience and legitimacy with stakeholders need to employ a nested approach of national and sub-national datasets that would combine upwards to link with assumptions in global models, while retaining an ability to reflect unique national development choices that may reinforce or actively go against a global trend (e.g. to exploit niche markets and that reflect regional power relationships). New Zealand's history strongly demonstrates such independence, which can result in relative leadership or laggardness compared to global trends. Scenarios that have legitimacy with stakeholders thus have to include non-climate and climate policy elements that reflect the perceived, or real, degree of national independence and ability to forge one's own path, while employing credible scientific techniques to ensure robust links between global and national scale developments are made where relevant. This will highlight issues such as land-use and water reform for their economic impact as well as on the production of greenhouse gases, and more generally the positioning of New Zealand climate change policies (with regard to both mitigation and adaptation) relative to those embedded at global scales for different SSPs and climate scenarios.

The architecture of the scenarios therefore adopts two elements from the Toolkit (Ebi et al, 2014) scaled down plus one bottom-up element. The scaled-down elements are:

Representative Concentration Pathways (RCPs) describe the global atmospheric radiative forcing associated with varying levels of greenhouse gas (GHG) concentrations. GHG concentration pathways depicted in the RCPs serve as inputs to global climate modelling which, in turn, provides boundary conditions for regional climate modelling, with finer spatial and temporal resolutions of more relevance to policy, planning and resource management. The emissions that give rise to the RCPs are consistent with some potential socio-economic development pathway, but they are not primarily development pathways.

Shared Socio-economic Pathways (SSPs) describe future global socioeconomic conditions including emissions of GHG. They outline plausible alternative states of human and natural societies at a macro scale including both narrative and quantitative elements of socio-ecological systems such as demographic, political, social, cultural, institutional, lifestyle, economic and technological variables and trends. They also include the human impacts on ecosystems and ecosystem services such as air and water quality and biodiversity. The global SSPs are designed to be extended to regional and sectoral scenarios but make no assumptions about global or national-level climate change policy.

In addition, *Shared climate Policy Assumptions (SPAs)* describe potential climate change mitigation and/or adaptation policies specific to New Zealand, which enable our futures to diverge from (accelerate, slow down or even counteract) the trends that are assumed in global-scale SSPs. These are described through a set of societal categories which are elaborated as indicators in more detail. A mix of qualitative and quantitative factors was used to describe indicator elements and scenario narratives. The SPAs capture key climate policy dimensions not specified in the SSPs and provide a means to employ common assumptions across studies. But crucially, they allow national-level development choices that may reinforce global trends or actively go against them. As such they provide a third axis to the scenario matrix.

While Kriegler *et al*. (2014) recommend that global SPAs should only contain information about climate policies, we propose that national SPAs need to contain a mix of climate specific policies and non-climate specific policies to ensure scenarios are salient for the climate change risks that individual countries face, and are credible with stakeholders where non-climate policy choices materially affect implications of climate change and national or local-scale response options. For example, the approach to water allocation will have a strong interaction with the implications of changing drought risk for New Zealand's livestock industry; but it would limit the plausibility of a New Zealand SPA to assume a first-come first-served approach to allocation of water rights while at the same time assuming a strategic climate change adaptation policy approach that assumes an optimal re-allocation of natural resources across all sectors of the economy. Similarly, it is important to ensure internal consistency within a scenario regarding general provisions for and attitudes to international trade (a non-climate policy dimension), and the assumptions made e.g. in models and climate change case studies about the extent to which international trade can buffer the New Zealand economy against drought related shocks.

This three-tiered approach enables us to create legitimate New Zealand specific scenarios of greater salience to case studies with credibility for stakeholders, whose focus tends to lie more on non-climate than climate aspects of scenarios (see Section 6). SPAs can contain qualitative and quantitative information that describe attributes of climate policies aimed at climate mitigation or adaptation such as:

- The amount of climate change experienced based on global scenarios and the direct primary impacts at national scale, but also consequences of global-scale impacts on commodity prices;
- Climate policy goals such as emissions reductions targets and national-scale choices about the degree of New Zealand's participation in global-scale responses;
- Policy regimes and measures such as mitigation measures that might include carbon taxes / emission trading schemes; the impact of global carbon prices on national sectors; attitudes to and principles employed in adaptation responses such as national and local-scale decision-making; and the implications of this for the feasibility of adaptation responses that rely on strong vertical integration; and
- Implementation limits and obstacles to the extent to which they are considered and not part of an SSP such as regions outside global agreements. For New Zealand, this includes considerations such as access to regional trade markets, niche market demand for New Zealand-specific products, region-specific migration, stability or development aid issues that affect demographic trajectories and labour force.

Table 1 presents our national-scale SPAs for New Zealand (SPANZ) that capture national attitudes and approaches to climate change adaptation and mitigation, relative to global-scale approaches to adaptation and mitigation implicit in SSP narratives when combined with specific RCPs. The broad classifications can also be used to capture key non-climate policy settings that would be expected to interact strongly with climate change outcomes, such as approaches to water allocation and balancing economic and non-economic benefits and costs of different policy approaches.

Table 1: Shared-climate Policy Assumptions for New Zealand

Shared-climate Policy Assumptions for New Zealand (SPANZs)		Domestic approach to adaptation (relative to SSP/RCP)	
		Incremental and focussed on short term gains	**Strategic and transformational**
Domestic approach to mitigation (relative to SSP/RCP)	**Lags behind global efforts**	**A** NZ is lagging relative to global efforts to mitigate. Adaptation tends to be incremental and reactive on a piecemeal basis, influenced by short-term economic gains and vested interests. This policy stance is dominated by a strong focus to minimise near-term costs and avoid transformational approaches both mitigation and adaptation with minimal adherence to international expectations.	**C** NZ is lagging relative to global efforts to mitigate. Adaptation is done with a strategic perspective that includes transformational changes where this is necessary to achieve long-term goals. This policy stance is driven by a perception that NZ has no meaningful role to play in limiting climate change through mitigation but has to focus on securing its own long-term resilience and viability by adapting to inevitable changes.
	Consistent with global efforts	**B** NZ neither leads nor lags behind global efforts to mitigate. Adaptation tends to be incremental and reactive on a piecemeal basis, influenced by short-term economic gains and vested interests. This policy stance is dominated by a strong focus to minimise near-term costs and fundamental transformations in adaptation, and to comply with international expectations on mitigation.	**E** NZ neither leads nor lags behind global efforts to mitigate. Adaptation is done with a strategic perspective that includes transformational changes where this is necessary to achieve long-term goals. This policy stance is dominated by a sense that compliance with international expectations on mitigation is necessary but the real key to long-term prosperity and resilience lies in effective adaptation.
	Leads global efforts	**C** NZ leads global mitigation efforts in terms of ambition and innovation. Adaptation tends to be incremental and reactive on a piecemeal basis, influenced by short-term economic gains and vested interests. This policy stance is dominated by an assumption that adaptation is a 'second-best' response to climate change and the only solution is via strong mitigation that protects NZ's international reputation and market access.	**F** NZ leads global mitigation efforts in terms of ambition and innovation. Adaptation is done with a strategic perspective that includes transformational changes where this is necessary to achieve long-term goals. This policy stance reflects an assumption that adapting to change, including through transformation, is key to NZ's well-being, which includes adaptation as well as mitigation that secures NZ's international reputation and market access as well as moral obligations.

SCENARIOS: SELECTION AND SPECIFICATION

A key challenge of this approach is that the number and types of possible futures increases manifold if the national-scale is not simply a downscaled version of a global-scale SSP. Even if the world follows a particular GHG concentration pathway and a particular socio-economic characterisation (as expressed in the RCPs and SSPs), New Zealand could still choose a different pathway. It could either be at the leading or lagging edge of any trend; or try to remain outside entirely for some period; or make non-climate policy choices that materially influence the impacts and implications of climate change. But even a wide set of SPANZs will clearly not cover all, or even a comprehensive range of alternative choices.

For example, if four RCPs are combined with four SSPs (omitting the 'central' SSP2), but each of those global scenarios is then analysed with regard to four alternative domestic policy SPANZ within those global settings (e.g. New Zealand taking a proactive or laggard approach to climate change mitigation, and a strategic or reactive approach to natural resource management from an adaptation perspective), this would generate 64 individual scenarios. While such an approach might be useful for probabilistic approaches (notwithstanding the challenges of assigning probabilities to individual scenarios); it would clearly be unconstructive and unworkable if the goal is to explore the implications of climate change under alternative scenarios in any detail.

Our study selected a manageable number of contrasting policy assumptions to construct a set of plausible national-scale scenarios within the global RCP/SSP architecture. Existing studies have tended to use qualitative bottom-up approaches to develop sub-national scale scenarios, as these ensure salience and credibility with stakeholders (e.g. Birkmann et al. 2015) but can be difficult to quantify and to locate within the global SSP framework. The SPANZ sought to provide individually legitimate yet contrasting examples of socio-economic developments, using a combination of quantitative elements from integrated assessment and population models, and qualitative elements that reflect socio-economic developments identified as credible by researchers and salient to climate change risks and implications by stakeholders.

Six scenarios were developed consisting of combinations of RCPs, SSPs and SPAs that aim to provide a wide range of physical and socio-economic futures that enable researchers and stakeholders to explore and understand the extent to which alternative socioeconomic futures will interact with, and possibly dominate, different physical manifestations of climate change. Within those six scenarios, decisions had to be made whether to explore the full range of climate outcomes (i.e. the range covered by RCP) but a narrower range of socio-economic futures, or to focus on contrasting socio-economic global futures (reflected by different SSPs), or different national choices within such global futures (reflected by different SPAs) within a more limited range of climate outcomes.

Since the main use of our scenarios is to test the sensitivity of climate change implications to alternative socio-economic futures, SSP2 was dropped as it represents a 'middle of the road' scenario. For some RCP/SSP combinations, we decided not to explore combinations that may be legitimate though less credible, such as RCP8.5 and SSP1, or RCP2.6 and SSP3. For two climate scenarios (RCP4.5 and RCP2.6), we decided to explore two contrasting socio-economic contexts each for how those climate outcomes might be realised (based on alternative SSPs and SPAs), while upper end climate outcomes are represented by only one socio-economic scenario each. While this removes richness from the scenario landscape, it was seen as preferable to focus on scenarios that have more intuitive resonance with stakeholders, and to use this core set to build national capacity in using scenarios. Nonetheless, it is important to recognise that these choices for a greatly reduced set of scenarios are necessarily subjective, even if they were based on existing research strengths and entry points for stakeholder engagement on climate change. Table 2 summarises the six scenarios and their key elements.

The SPANZ identifiers are as in Table 1, and Table 2 sets out a regional context interpretation of the RCP/SSP combination. Such broad regional narratives for RCP/SSP combinations into which national-scale SPAs can then be nested don't appear in the literature. Indeed, there could be many possible regional-scale SPAs since multiple regional interpretations of RCP/SSPs are possible. Specifying the regional context enables the NZ-specific SPANZ to focus solely on New Zealand. In turn, the last two columns summarise key elements of national-scale climate and non-climate policies that were identified as playing a critical role in understanding climate change implications for New Zealand. These descriptions are non-exhaustive and present only the 'flavour' of those scenarios.

Table 2: Summary of climate/socio-economic scenarios for New Zealand

Scenario	RCP	SSP	Regional context	SPA-NZ	NZ climate policy dimensions	NZ non-climate policy dimensions
Unspecific Pacific	8.5	3	The Pacific region is becoming a backwater that is sliding downwards economically, with a break-down of global trade and security, mounting refugees from Pacific Islands and regional conflicts.	A	Continued exploitation of accessible fossil fuel reserves and livestock food production with limited consideration of other environmental side-effects. Adaptation strongly driven by short-term economic interests and by both local and national special interest groups with little attention to the most vulnerable groups or non-monetary values. Transformational changes are avoided unless these are forced by circumstance, can be justified by short-term economic returns or serve dominant interest groups; where transformation occurs there is limited attention on managing the transition.	Strong prioritization of tangible economic values over environmental or intangible social values. Water access rights served through a first-come, first-served policy with minimum flow regimes and water quality requirements given limited consideration unless a tangible economic value can be demonstrated. Trade relationships dominated by power blocks with shifting and non-transparent rules. A severely resource-constrained world neither cares nor can afford the luxury of environmental goals, hence no market premiums for "clean green" brand other than for very small niches. Immigration regulated mainly by economic priorities, with a mix of high-value and cheap labour immigrants; limited strategic foresight to address demographic issues.
Homo Economicus	6.0	5	The region is dominated by changing powers dependent on economic ascendancy within a globalized trade regime. Strong regional migration based on maximizing labour supply, which results in strong regional competition to attract business.	D	NZ views mitigation as not its primary concern: it prioritises mitigation by co-benefits and links to weak global CO2 emissions markets and uses selective accounting for land-use change contingent on economic benefits. Agriculture does not face a carbon charge anywhere and is focused on maximizing production. Impacts and risks from climate change are taken mainly if they have economic implications including biosecurity for primary production. Assets are mostly protected by additional infrastructure, but strategic land-use decisions are made with a medium-term economic focus through market mechanisms. In recognition of significant climate change, NZ focuses on strategic adaptation to ensure continued economic viability and retaining competitive advantages. The need for and objectives of transformations are primarily defined by their economic returns over extended time horizons.	Strong prioritization of tangible economic values over environmental or intangible social values. Water access rights served through auctioning to highest bidders with limited protections for minimum flow regimes and water quality requirements. Trade is dominated by global market requirements and domestic policies adjusted to maximize trade access. Few market premiums for "clean green" brand, with an overriding focus on total production rather than niche products and branding. Immigration regulated mainly by economic priorities and to manage demographic bottlenecks, with displacement of under-skilled local labour by more highly educated economic migrants. High discount rates are a major driver for government expenditure and environmental conservation is a low government priority.
Clean Leader	4.5	5	The region is an important global player owing to its economic dominance within global markets. Technology, trade and economic migration are resulting in increasing homogenization of the region.	F	NZ is at the forefront of increasing global mitigation efforts through technological innovation and policy design, including forestry incentives, reaching net CO2 neutrality well before 2100 and ahead of most other OECD countries. NZ fully prices emissions from agriculture as part of a comprehensive and internationally linked emissions trading scheme even though this is done only by some, but not all, of NZ's competitors, as this is seen to reduce inefficient land use and supports use of new mitigation technologies. Strategic land-use decisions are made with a view to maximizing economic growth in a warming and carbon-constrained world. Adaptation takes a strategic approach to minimize primarily economic risks in the near and long term. Transformations are facilitated actively where an economic case can be made including by accounting for ecological services.	Environmental or intangible social values are considered in decision-making by monetizing their value. Water access rights served through auctioning to highest bidders with protections for minimum flow regimes and water quality requirements based on their monetized value. Trade is dominated by global market requirements and domestic policies adjusted to maximize trade access, including competitive advantages that can be derived from a "clean green" brand and technological innovation, efficiency and increasing focus on global services. Immigration regulated mainly by economic priorities and to manage demographic bottlenecks, with efforts to ensure local labour can compete with more highly educated economic migrants. Variable discount rates are explored in NZ as a means of creating change which is attracting global profile for NZ goods and services with environmental conservation a strong government-business partnership.
Kicking, Screaming	4.5	3	The region is one of several competing trade blocks, and countries within the region seek shifting alliances that serve their near term interests. Some countries within the region remain in severe poverty while others, and urban elites within countries, rapidly gain wealth.	A	Climate action is dominated by concerns about competitiveness within shifting and restricted markets. NZ lags behind increasing global mitigation efforts by adopting weak targets, uses selective accounting for land-use change and continues to exempt agriculture from carbon charges on the basis that this is not done by all of its competitors. Adaptation is piecemeal and reactive, motivated primarily by short-term economic gains and powerful special interests. Transformation occurs, mainly by accident, force and with little protection of vulnerable groups or environmental trade-offs.	Strong prioritization of tangible economic values over environmental or intangible social values. Water access rights served through a first-come, first-served policy with minimum flow regimes and water quality requirements to maximize land-based production. Trade relationships dominated by power blocks with shifting and non-transparent rules; market premiums for "clean green" brand are possible but are not explored as this would require shifting the underlying production paradigm. Immigration regulated mainly by economic priorities; limited strategic foresight to address demographic issues as NZ is usually feeling that it has to catch up with other countries first before it can afford to consider structural changes. High discount rates are a major driver for government expenditure and environmental conservation is a low government priority.

Techno-Garden	2.6	5	The region is part of an effective global trade regime and seeks competitive advantages based on its cheap and abundant labour force to supply globally needed products and services. The region is becoming rapidly homogenized due to the near-universal spread of new technologies and economic migration.	B	NZ complies with stringent global mitigation efforts by minimizing costs and exploiting opportunities from new technologies, trade, and accounting. Land-use remains focused on livestock production with a goal of maximum productivity and efficiency within global markets. Adaptation is given little consideration on the basis that climate change will be limited and will not negatively affect NZ's competitiveness, and issues are addressed reactively with a focus on protection of existing assets and minimizing near-term costs. Transformations are made only where a business case consistent with near-term economic metrics can be made.	Protection of natural resources depends on their economic value, but such considerations take a strategic approach and use sophisticated models to understand feedbacks. Limited consideration to intangible values as technology results in rapid shifts to such values, with reduced focus on intrinsic value of natural spaces. Water rights are served through regular auctioning but with some safeguards for minimum flows and water quality. Effective global trade regime with a focus on economic efficiencies. NZ continues to innovate in livestock production and focuses on high-value products rather than a climate-friendly premium. Immigration is focused on the economic and structural benefit to recipient countries rather than protecting refugees, who are processed and distributed regionally. Variable discount rates are explored in NZ as a means of creating change. This attracts a global profile for NZ goods and services especially with environmental conservation driven by a strong government-business partnership.
100% Smart	2.6	1	The region is part of an effective global trade regime and seeks competitive advantage based on a growing service industry and niche products that support local labour markets and sustainable use of local resources. Migration is seeking to balance economic advantages with protecting local and indigenous populations, retaining distinct cultural differences.	F	NZ is leading even stringent global mitigation efforts, not only by working towards CO2 neutrality by 2050 but also by aggressive investments and incentives to reduce emissions from agriculture including through land-use change. Adaptation focused on strategic transitions in land-use and urban design consistent with sustainability, livability and resilience, at times with high near-term and transitional costs. Transformations are actively managed to protect the most vulnerable parts of society while allowing systems to re-adjust.	Strong emphasis on preservation of natural resources and non-monetary values that is consistent with international branding for a clean-green image and as a sustainability leader. Water rights are served through regular auctioning but with strong safeguards for minimum flows and water quality, which takes environmental values into account. Effective global trade regime with protection for local and indigenous markets and property rights. NZ able to exploit a market premium for climate-friendly grass-fed livestock products while also shifting towards non-livestock land-uses where possible. Immigration is part of a regional system taking into account refugees as well as voluntary migrants, with consideration to labour force development and addressing demographic bottlenecks. Introduction of low social discount rates for strategic investments changes government priorities in infrastructure development and environmental protection.

Examples of quantitative elements include population and GDP, but also carbon prices, with values determined mostly from downscaled global projections consistent with individual SSPs and SSP/RCP combinations. Note though that especially for a country like New Zealand, which has an unusual emissions profile (with almost 50% of emissions from livestock agriculture) and no shared borders with other countries, in principle there could be plausible scenarios where carbon prices in New Zealand differ from global prices, either in magnitude (because of domestic policy choices not to link fully with other emissions trading schemes) or in the sectors in which those prices apply (e.g. New Zealand could exempt agriculture from carbon pricing but expose all other sectors to the global carbon price, as is currently the case). For the scenarios developed in this study, however, we adopted the assumptions about agriculture and forestry pricing from O'Neill et al. (2015: supplementary information).

Examples of qualitative elements that were considered salient for understanding implications of climate change and adaptation options include attitudes to international trade, including the existence and ability to access global or regional markets, the willingness and ability to occupy niches within such markets (such as a 'clean and green' high-value brand image), attitudes to and management of migration that influences long-term trends in social values, and management of water resources (allocation mechanisms, such as first-come-first-served or based on highest economic value; and attitudes towards minimum environmental flows for non-economic purposes).

SCENARIOS: CHOICES AND CHALLENGES

Wicked problems require integrating across an increasingly large number of disciplines and this has an expanding literature exploring the many challenges (Brown et al, 2015). In turn, scenario development, both by multi-disciplinary research teams and by engaging stakeholders across different sectors and roles in decision-making in the public, private and not-for-profit sectors poses logistical and methodological challenges. There is the tension between researcher-driven data requirements which can be led by the international and domestic climate literature (global, SSP-led) or NZ-specific policy-driven needs which often don't take climate change and climate-related drivers into account, and where they do, don't necessarily match IPCC scenario architectures.

Maintaining internal and global credibility and salience among these multiple voices is critical but complex. Development of the scenario specifications drew on three quite distinct groups over four years. This was achieved through a mix of project-specific research workshops, various stakeholder groups as case studies and a national workshop. It involved:

(a) *Researchers:* drawing on prior studies, SSPs and international scenarios and comparable work done on regional-scale scenarios elsewhere, and with no consistent time frames between datasets; to develop scenario architecture. Comparing downscaled global scenarios for New Zealand (population, GDP) was complicated by the relative absence of long-term scenarios other than for population and the complete lack of recognition of climate change in various national scenario exercises;

(b) *Stakeholders:* providing feedback on case studies (see Section 6), helping focus on aspects of the future salient to how stakeholders envisage decision-making challenges and criteria, often interested in the short-medium term and heavily influenced by topical issues, such as commodity price fluctuations; and

(c) *National Influencers:* providing feedback on key quantitative and qualitative dimensions over long time frames. These too were a proliferation of sector-specific concerns with minimal congruence in terms of methodological approach though with a desire to understand relationships between, say, commodity prices, carbon prices and oil prices.

SCENARIOS: QUANTITATIVE AND QUALITATIVE DATA

A meaningful scenarios architecture is populated with a wide range of data, ideally all modelled with consistent assumptions to, in this case, 2100. This needs to come from various sources, some of which will not be to 2100 or be estimated by proxies. The data include:

- inferences from global data;
- extensions of current shorter term data; and
- inferred extensions based on declared suppositions.

In all cases the process for developing the data and underlying assumptions needs to be recorded and accessible with protocols available to challenge the data as new information becomes available. The combination of these should link to global RCPs and SSPs.

Clearly quantitative issues matter for climate change implications and these should, ideally, be amenable to consistent modelling or at least using mutually consistent assumptions. One option is to adopt scenarios coming out of downscaled SSPs in the International Institute for Applied Systems Analysis (IIASA) database. IIASA (www.iiasa.ac.at) conducts inter-disciplinary scientific studies on environmental, economic, technological and social issues in the context of human dimensions of global change. The database includes a variety of detailed sources which need to be explored prior to their use in applications in scenario case studies as their varying sensitivities will produce different results from different modelling groups. Alternatively it is possible to construct quantitative indicators from scratch that are internally consistent. There's a trade-off between degrees of freedom and arbitrariness.

Initially we considered the full set of categories and elements described in O'Neill et al (2014) but this was unattainable within our modest means even if much of the data did exist in a compatible form, which, in most cases, it did not. This required the first of many pragmatic compromises to build scenarios that combined to attain the high degree of salience, credibility and legitimacy that we identified as critical to success.

Our agreed indicator set, while drawing on the categories from O'Neill et al (2014) are a subset of the broader SSP categories based on available data and ability to provide consistent narratives with demonstrable implications for the types of climate change impacts considered important to New Zealand. In some cases, they are more detailed specifications. For example, the treatment of water resources is drawn out as particularly critical to New Zealand. In turn, case studies will use more specific models that translate climate and socio-economic drivers into downstream impacts such as river flow, which depends on rainfall as well as land-use.

Our national models used regional population and GDP figures from the downscaled SSP database with an explanatory, post-hoc, narrative, along with global emissions and carbon prices for SSP/RCP combinations, and the Climate Mitigation, Adaptation and Trade in Dynamic General Equilibrium (CLIMAT-DGE) model. This was developed by Landcare Research as a top-down dynamic, multi-sectoral and multiregional Computable General Equilibrium (CGE) model to describe the global economy and generation of greenhouse gas (GHG) emissions from energy and non-energy sectors. It represents a global dynamic economic model with a strong focus on New Zealand as a distinct region (Fernandez and Daigneault, 2015). It calculates parameters that either demonstrably matter for impacts studies, or could serve as input to models used to conduct impact studies (Fernandez and Daigneault, 2016). It was calibrated to reproduce the RCP emission trajectories along with key global SSP variables, which served as the basis for estimating NZ-level parameter estimates. Given New Zealand's dependence on international trade, these included commodity prices as these influence the extent to which climate policy and impacts might affect future productivity and land-use change. Labour force participation, and demand for goods and services could also have a material impact on the implications of climate change or the availability of cost of adaptation responses.

Accompanying qualitative descriptions were developed to explain and demonstrate connections between quantitative indicators, explain why certain choices were made in modelling (e.g. regarding the availability of international trade), and qualitative choices that were not modelled directly but could provide relevant benchmarks for subsequent case studies (e.g. allocation and pricing of freshwater consistent with the socio-economic settings that characterise the SSP/SPA-NZ combination for each scenario).

Table 3 provides an overview of key quantitative and qualitative indicators developed. The text applies

across all scenarios with each scenario taking a specific structure based on its underlying SSP / SPANZ assumptions. For example, with water the models are tailored to the allocation model (price-based / first-come-first-served; level of minimum environmental flows; etc.). The selection of indicators will be subject to the boundary conditions for case studies and the specific vulnerability of sectors or sub-national regions to climate change that they seek to highlight.

The indicators serve as inputs to vulnerability assessments, rather than what might be the outcome of such assessments under different scenarios. These did not include models for land-use productivity or ecosystem vulnerability (e.g. from erosion or pests and diseases) as these are outcomes from vulnerability studies, not scenario indicators that inform vulnerability studies.

Table 3. Key quantitative and qualitative indicators

Indicator	Qualitative/ Quantitative	Sources (Refs in Supplementary Material)	Treatment (see Table 2)	Comments
Population	Quant	SSP database at country-level; Sub-national: (Cameron MP 2013)	Use down-scaled population projections from global models. Range is broadly consistent with bottom-up projections from Statistics New Zealand (2015)	NZ could depart from the downscaled SSP population projections through the adoption of specific immigration policies consistent with different SPA-NZs. This could be explored in further refinements of this scenario framework.
Economic development	Quant	SSP database at country-level; CliMAT-DGE (Fernandez and Daigneault, 2016) for commodity prices and product output:	Use down-scaled GDP projections from global models. Commodity prices of relevance to specific sectors, especially land-use decisions, derived from NZ-focused global integrated assessment model	Specific global, regional and national shared policy assumptions could modify the generically downscaled GDP projections from global models. Subject to further calibration of CliMAT-DGE to global model results, GDP could be modelled entirely with CliMAT-DGE in a way that reflects specific policy assumptions and implications on commodity prices of importance to NZ's economy via domestic production and trade.
Climate	Quant	CMIP5 data (IPCC 2014), downscaled to sub-national scales using statistical and dynamic downscaling (RA1 report, Mullan et al. 2010); sea-level rise calculator (Stephens and Bell 2015)	Use downscaled climate projections at 5km virtual grid for given RCP. Consider upper end sea level rise projections as/where appropriate	Treatment of climate extremes dependent on case study context. Further development of appropriate statistics will be important but dependent on specific case study application and availability of other models (e.g. fire risk, pests, diseases, infrastructure stress) to make use of such projections.
Water	Quant / Qual	TopNET (Clark et al. 2008) for water discharge	Treatment of water allocation/pricing, and consideration of minimum flows and water quality constraints dependent on scenario	Current regional and farm-scale models have difficulty readily incorporating different approaches to water allocation and pricing; recommend sensitivity tests to different approaches where this is particularly important for specific case studies.
Land-use change	Quant / Qual	NZFARM (Daigneault et al. 2014) and LURNZ (Olssen A and Kerr S 2013)	Change in land use area and spatial allocation using models and emissions pricing assumptions	Additional qualitative considerations could arise where land-use change interacts with water quantity or quality issues, or infrastructure for forestry.
GHG emissions	Quant / Qual	SSP database for global carbon prices incl. different global-scale SPA; CliMAT-DGE, NZFARM, and LURNZ for sector-specific emissions	Differentiate treatment of emissions from agriculture, soils and land-use change	Implications of domestic pricing of agricultural emissions on NZ economy is strongly contingent on assumptions about global treatment of land-use emissions
Trade	Quant / Qual	CliMAT-DGE	Different assumptions whether a single global commodity price or regional prices apply to NZ	Modelling of regionally differentiated commodity prices, including trade barriers, is highly continent on assumptions and not well explored.
Technology	Quant / Qual	SSP database, CliMAT-DGE	Global rate of technology improvement; technologies of particular importance to NZ for climate change mitigation in agriculture	Imperfect understanding of how to model imperfect technology transfer in a heterogeneous world.
Governance	Qual	SSP narratives, NZ scenarios (this study)	Different role of special interests, and different actors and ability to instigate strategic and transformational changes	Governance could potentially play a very large role in determining vulnerability and viability of alternative adaptation strategies but remains imperfectly articulated and explored at national and sub-national scales within SSP framework.
Labour force	Qual	SSP narratives, NZ scenarios (this study)	Supply and skill level of labour force	At present the implications of different assumptions have not been explored quantitatively but could have a large influence on feasibility of adaptation strategies
Social values	Qual	SSP narratives, NZ scenarios (this study)	Balance of economic, social, environmental objectives; discount rates; time horizon of planning; societal heterogeneity; consideration of indigenous culture	At present the implications of different assumptions have not been explored quantitatively but could have a large influence on distribution of impacts and feasibility of adaptation strategies

APPLYING NATIONAL SCENARIOS TO SPECIFIC LOCAL LANDSCAPES

In the Climate Changes, Impacts and Implications (CCII) project, five case studies were developed across the range of NZ landscapes (Alpine, Upland, Lowland, Coastal and Marine) using SSP indicators specific to each. This is illustrated through one scenario (RCP8.5/SSP3/A) in the Lowland case study (Ausseil et al, 2016) with all case studies presented on the project website (http://ccii.org.nz).

Models were available to quantify land and water resources, demographics, economic development (primary production and land-use change) and environmental factors (natural ecosystems, erosion, pests and disease). These operate at both sector-based scale and landscape scale and use either the RCP scenario only (primary production, wetlands) or a combination of RCP and SSP assumptions (for example, land-use change models) as inputs.

The Lowland case study area, chosen in partnership with the local government authority (Bay of Plenty Regional Council), was the Lower Kaituna river catchment with the coastal zone around Papamoa beach. This typical New Zealand lowland environment has a mixture of natural ecosystems (freshwater wetlands) and a wide range of primary production (maize cropping, kiwifruit horticulture, forestry, dairy, sheep and beef), with pressures from a fast urban development due to population growth. The changes arising from the quantitative models coupled with quantitative statements for each element, corresponding to the RCP8.5/SSP3/A scenario, are summarised as:

Demographics: The rural population will continue to decline. Rural areas have typically older populations which lead to lower fertility as well. Ageing is likely to be felt most greatly in rural areas and would lead to less mobile population to avoid hazardous situations like flood events. New Zealand population would peak at 5 million in 2040 (compared to just over 4 million currently). Development on coastal areas may slow down or stop. As a result of declining rural population there is possible agglomeration of farm enterprises.

Economic development: Food security would be a major driver, leading to a decline in overseas markets (e.g. kiwifruit) and increase in diverse, local markets. The limiting factor for primary production would be appropriate access to water and impacts of any extreme weather events. In this scenario, there would be an increase in dairy farming over sheep farming, which is consistent with recent trends. The Kaituna catchment might experience a shift of kiwifruit biophysical suitability to the south due to lack of winter chilling, adding extra cost to production with the need to use hydrogen cyanamide to improve flowering (Linsley-Noakes 1989). This would be exacerbated by increased costs due to disease outbreaks, infrastructure costs and increased overseas competition. The coastal zone would be impacted by sea level rise, affecting mainly dairy and maize cropping land-use.

Environmental factors: Abandoned land could revert to natural wetland areas. However, lack of funding exacerbates the spread of exotic weeds, creating seed sources that will impact cropping and pastoral farming. Native forests, wetlands and rivers would have declining biodiversity due to pest invasions, salinization, increased sedimentation, water diversion for economic uses and lack of funding for conservation. With warmer temperatures, pests currently limited to warm climates would expand their range to the case study area and become more prolific causing a reduction in abundance or loss of native species. New exotic pests from similar climates risk establishing. Water discharge would reduce due to a reduction in precipitation, creating water stress during summer.

Resources: Fuel costs would rise with an increased reliance on fossil fuels, primarily coal. This in turn would increase primary production costs and use of public transport and, in turn, impact the tourism sector.

Human development: Sea level rise would reduce coastal property values or lead to abandonment of property due to coastal encroachment. Vulnerability to natural disasters would be higher due to more frequent extreme events (e.g. floods). Life expectancy might decline, especially with reduced funding for healthcare services and likely increases in the incidence of infectious diseases.

Institutions & Governance: There would be minimal investment in catchment scale adaptation options to reduce risk. Flood events would have greater impact due to increased sedimentation in rivers and reduced funding for stop banks. Road networks could deteriorate, worsening the regional economy. Social

inequities would deepen. Global environmental agreements would be breached with contingent liability transferred to central government.

Technological development: Few mitigation options would be developed. Local adaptation solutions would be reactive responses lagging global initiatives. Research would be funded more by industry than government. Advances in technology would aim to eradicate invasive species, but collateral impacts would be poorly understood before their deployment.

Broader social factors: An increased disconnect from nature; recreation in and aesthetic appreciation of the physical environment ranks low due to high costs of living.

Policies: Reduced population and sea level rise leads to ad hoc coastal protection. Insurance becomes difficult to obtain with reduced cover for natural events. Development initiatives are market driven with few guiding policies for social, environmental or cultural elements included.

For the Lowland case study, quantitative models were not integrated apart from the land-use change models that took inputs from biophysical models of primary production. However the hydrological model could be dynamically linked, for example, with the land-use change model but the computational effort would be offset by the value of added information. For example, if the land-use effect is revealed to be negligible than the hydrology model could assume a constant land-use pattern over time.

Not all elements could be determined quantitatively as models were either unavailable or not calibrated for future projections. However, use of the qualitative and quantitative statements helped to understand the inter-dependencies between elements. Use of these statements in one scenario will inform extending the framework to other scenarios. In turn this will allow comparisons and highlight potential trade-offs between elements and show the level of societal adaptation needed if changes are required.

CONCLUDING COMMENTS

Here, we reflect on our experience of developing national, and local, scenarios consistent with global models of climate change. First we examine the content of the scenarios and the importance of examining them as a suite then suggest some topics for future study.

The richness, not just of the individual scenarios but their overall span as a suite of scenarios, is very important to understand. A consistent approach drawing on global models and informed by multiple national and local issues should provide a relatively value-neutral place from which to explore the scenario space. It would encourage researchers and stakeholders to populate missing elements to specific case studies. A generic scenario framework avoids new case studies having to start from scratch in an ad hoc manner. When examining other New Zealand examples of future energy and transport scenarios, such those by the Ministry of Transport Future Demand Scenarios (http://www.transport.govt.nz/futures) and the BusinessNZ Energy Council's BEC 2050 scenarios (https://www.bec.org.nz/projects/bec2050) we found an inconsistency between their underlying assumptions and those anticipated due to climate change. Further exploration identified a genuine need for a generic scenarios framework into which new information could be included. Such a scenarios framework could never be considered complete and would give sufficient descriptions of a future possibility space that did not exclude any option. This would be globally innovative and could arise from a grouping of scenarios across various jurisdictions demonstrating how this could develop.

More specifically, there is much to be gained by:

- comparing various scenarios within a single RCP;
- developing broad regional narratives for RCP/SSP combinations (possibly with global or regional-scale SPAs since multiple regional interpretations of RCP/SSPs are possible) in which national-scale SPAs can then be nested; and
- Accommodating cultural issues such as the bicultural framework in New Zealand.

Finally the scenarios should not be seen as stand-alone outputs but merely vehicles to help those conducting vulnerability studies to make informed decisions about relevant assumptions and boundary conditions, and to test sensitivity to alternative assumptions within the overall scenario characterisations.

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