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## Climate change impacts and implications: an integrated assessment in a lowland environment of New Zealand

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**Abstract:** New Zealand's mixed economy includes a range of sectors (e.g. primary production, energy, tourism) that depend heavily on the state of natural resource capital. This makes the economy heavily dependent on future global climate change and the global economic situation. In this paper, we present a framework to evaluate socio-economic and environmental impacts of future climate and land-use change, and give results for one scenario in a typical lowland environment in New Zealand. The future scenario was designed as a combination of global climate and socio-economic assumptions, along with New Zealand-specific policy assumptions. We evaluated the impacts and implications of this scenario through an integrated assessment using both a quantitative and narrative approach. The quantitative results were obtained using biophysical models operating at a sector (primary production) and landscape level (e.g. water supply, pest risk, wetland vulnerability). These results were then interpreted and projected in a narrative form for different elements of the scenario (e.g. population, economic development, environmental factors, and technological development). This framework is very flexible and can be applied to the evaluation of a wide range of other scenarios and assumptions.

**Keywords:** climate scenario; shared socioeconomic pathways; land-use change; spatial modelling.

## 1 INTRODUCTION

New Zealand's mixed economy includes a range of sectors (e.g. primary production, energy, tourism) that depend heavily on the state of natural resource capital. The relatively small size and geographic isolation of New Zealand makes its economy particularly vulnerable to the world's economic situation. Both climate and socio-economic conditions are difficult to predict, yet tools are needed to anticipate potential adverse outcomes and to foster better foresight for decision makers. Changes and interactions between sectors are particularly complex in lowland environments, where climate change could impact on productivity and where trends in the global economy may have an even greater influence on the land and its use. An integrated assessment is valuable to help better understand the complex interactions of the social-ecological system, and brings together natural, social and economic information for a given future scenario. Previous work in New Zealand included studies on impacts of climate change on production (Warrick et al., 2001) and risk assessment (Ministry for the Environment, 2008), but didn't incorporate socio-economic considerations. The Fifth Assessment Report (IPCC, 2014) has released new scenarios that are now incorporating both climate and socio-economic assumptions. Our research programme "Climate Change Impacts and Implications" (CCII) was designed to integrate these new components

and help stakeholders answer questions on potential impacts and implications of climate variability and trends on the biophysical environment, and the economy and society of New Zealand.

In this paper, we present a framework to evaluate socio-economic and environmental impacts of climate and land-use change in a lowland environment based on one plausible alternative future. The future scenario is a mixture of climate, socio-economic and policy assumptions. We present results of the integrated assessment in a case study and discuss utility of our approach.

## **2 METHODS**

### **2.1 Input scenario**

The architecture of the New Zealand scenario adopts two global elements from a global scenario toolkit (Ebi et al., 2013) plus one national-scale element. These are global Representative Concentration Pathways (RCP), global Shared Socio-economic Pathways (SSP) and New Zealand-specific Shared climate Policy Assumptions (SPA), all of which are described in more detail below.

#### **IPCC Representative Concentration Pathways (RCP)**

The Inter-governmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) adopted four greenhouse gas concentration trajectories referred to as Representative Concentration Pathways (RCP). Climate outcomes based on RCPs are modelled via the Coupled Model Inter-comparison Project (CMIP5) through numerous Earth System Models or General Circulation Models (GCM). We used six GCMs (BCC-CSM1.1, CESM1-CAM5, GFDL-CM3, GISS-E2-R, HadGEM2-ES, and NorESM1-M) to update and improve regional-scale projections of New Zealand climate trends and variability to 2100. The output variables were precipitation, maximum and minimum air temperature, relative humidity, solar radiation, and wind speed. Each variable was calculated on a regular grid (0.05°) using the Virtual Climate Stations (VCS) from NIWA (Tait and Turner, 2005) at a daily, monthly and annual temporal resolution for the 1971–2100 period. In our example, we focused on radiative forcing value of 8.5 W/m<sup>2</sup> denoted as RCP8.5. It corresponds to the highest greenhouse gas concentration trajectory adopted by IPCC AR5.

#### **Shared socio-economic pathways (SSP)**

Unlike earlier assessments, AR5 scenarios for climate change decoupled the climate model outputs, expressed through RCPs, from their socio-economic drivers, expressed through the concept of SSPs. Shared socio-economic pathways describe plausible trends in the evolution of society and global economy. van Vuuren and Carter (2013) introduced a framework to illustrate combinations of RCPs and SSPs. These new scenarios can be compared to the old IPCC AR4 scenarios. In our example, we chose to investigate SSP3, corresponding to high socio-economic challenges for both mitigation and adaptation.

#### **Shared Policy Assumptions for New Zealand (SPA)**

The Shared climate Policy Assumptions (SPAs) are specific to New Zealand. SPAs describe potential climate change mitigation and/or adaptation policies not specified in the SSPs. They provide a third axis to the scenario matrix and allow national-level development choices that may reinforce global trends or actively go against them. In our example scenario, we hypothesise that New Zealand is lagging relative to global efforts to mitigate, with incremental and reactive adaptation on a piecemeal basis, which we internally refer to as SPA-A.

To help assess plausible scenarios, O'Neill et al. (2013) suggested outlining several elements that are relevant for defining both challenges to mitigation and

adaptation (Table 1). They were evaluated quantitatively via modelling where possible, and complemented with narratives from the CCII research team.

**Table 1.** Elements of scenario analysis (adapted from O'Neill et al., 2013)

Categories	Elements
Demographics	Total population and age structure, urban vs. rural populations, and urban forms
Economic Development	Global and regional GDP, trends in productivity, sectoral structure of national economies (share of agricultural land)
Environmental factors	Air, water, soil quality, ecosystem functioning
Resources	Fossil fuel resources and renewable energy potentials fresh water, land.
Welfare	Human development, educational attainment, health.
Institutions and governance	Existence, type and effectiveness of national/regional/global institutions
Technological Development	Type (e.g. slow, rapid, transformational) and direction (e.g. environmental, efficiency, productivity) of progress
Broader societal factors	Attitudes to the environment/sustainability/equity and world views, life styles, societal tension and conflict levels
Policies	Non-climate policies

## 2.2 Generic framework

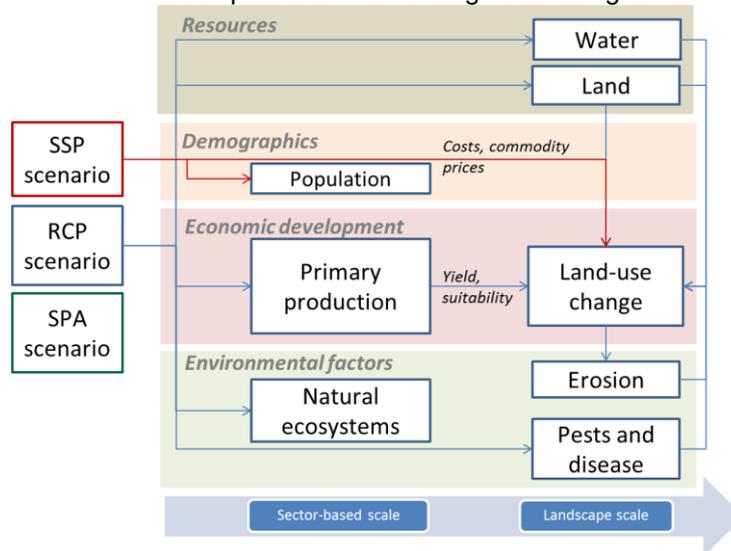
Each element from Table 1 was assessed on the basis of an example scenario that was chosen, in this case RCP8.5/SSP3/SPA-A. A series of models was available to quantify some elements of resources (water and land), demographics, economic development (primary production and land-use change) and environmental factors (natural ecosystems, erosion, pests and disease) (Table 2).

**Table 2.** Models used for the quantitative assessment

Domain	Model	Indicator
Population	Population model output (Cameron, 2013)	Demographic
Water	TOPNET (Clark et al., 2008)	Water discharge
Land	Sea level rise calculator (Stephens and Bell, 2015)	Area at risk of sea level rise and storm surge
Economic development	Climat-DGE (Fernandez and Daigneault, 2015)	Commodity prices downscaled to New Zealand
Primary production	cenW (forestry) (Kirschbaum et al., 2012)	Yield change
	APSIM (maize) (Holzworth et al., 2014)	Yield change
	BiomeBGC (pasture) (Keller et al., 2014)	Yield change
	suitability index (kiwifruit)	Suitability index
Land-use change	NZFARM (Daigneault et al., 2014)	Change in land use area and spatial allocation
	LURNZ (Olssen and Kerr, 2013)	
Natural ecosystem	Vulnerability model (wetlands) (Bodmin et al., 2014)	Change in water supply per wetland type
Erosion	NZEEM (Dymond et al., 2010) with climate impacts	Sediment loss due to added risk of storminess
Pests and disease	CLIMEX (Sutherst et al., 1999)	Suitability index for pests/diseases

These models operate at two different scales (sector-based scale and landscape scale) (figure 1) and have as inputs either the RCP scenario only (primary production, wetlands) or a combination of RCP and SSP assumptions (for example the land-use change models). The models from Table 2 were run with the climate scenarios for RCP8.5 up to 2100 and assumptions fitting with SSP3 and SPA-A.

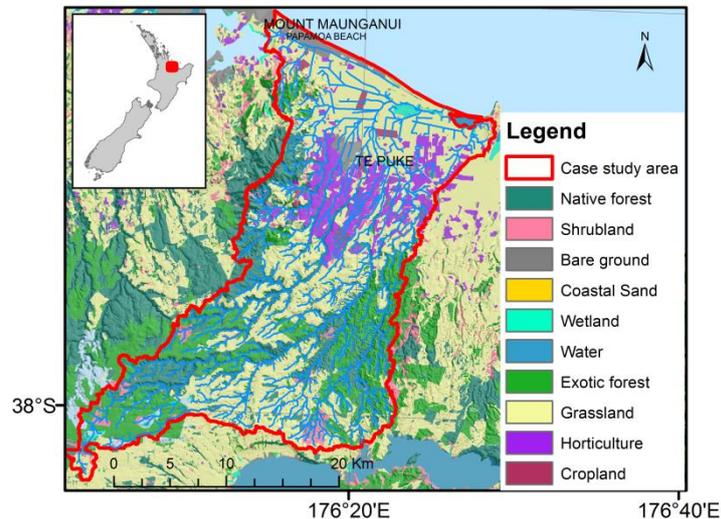
**Figure 1.** Framework for quantitative modelling of the integrated assessment



### 2.3 Stakeholder engagement and case study

Our stakeholder group was mainly composed of the local environmental authority, Bay of Plenty Regional Council (BOPRC). In partnership with them, it was decided to test our approach to the 63 000-ha Lower Kaituna river catchment with a coastal zone around Papamoa Beach, located in the North Island of New Zealand (Figure 2).

**Figure 2.** Case study area for the lowland environment



A workshop was organised with the local community, key businesses in the farming industry, and the BOPRC to highlight the main issues and concerns in this catchment. This area is subject to a community development strategy developed by the Regional Council that includes the development of a vision for the future. It represents a typical lowland environment in New Zealand, with a mixture of natural ecosystems (freshwater wetlands and native forests) and a wide range of primary production (maize cropping, kiwifruit horticulture, forestry, dairy, sheep and beef farming), with pressures from urban development and land-use intensification.

### 3 Results

Table 3 shows the direction of change up to 2100 from the quantitative models relative to a 'baseline' case with no climate change and historical socio-economic conditions. These quantitative results were interpreted to support narrative statements for each element of table 1, which we discuss in more detail below.

**Table 3.** Results from the quantitative assessment for scenario RCP8.5/SSP3/A (white triangle is a minor change, >5%; grey is a medium change, >10%; black is a major change, >20%; ▷ less than 5% change)

Categories	Elements	Change
Demographics	Total population	▽
Economic	Land-use change: Area in dairy	▲
Development	Area in sheep/beef	▼
	Area in forestry	▷
	Forestry productivity	▷
	Maize	△
	Pasture	△
	Kiwifruit suitability	▼
Environmental and ecological factors	Wetland vulnerability	▷
	Erosion (soil loss)	▲
	Pests and disease suitable areas	▲
Resources	Water (river) discharge	▽
	Land at risk of sea level rise	▲

#### 3.1 Demographics

The rural population could continue to decline. Rural areas typically have older populations, which leads to lower natural increase (or even natural decrease) of the population (Jackson and Cameron, 2015). Ageing is likely to lead to less mobile population that is less able to avoid hazardous situations like flood events. The New Zealand population is projected to peak at 5 million in 2040 (compared to a current population of just over 4 million). Development on coastal areas may slow down or stop. As a result of declining rural population there is likely to be further agglomeration of farm enterprises (Cameron et al., 2010).

#### 3.2 Economic development

In general, we could expect a decline in New Zealand's economic health. Food security, both internationally and within New Zealand, is expected to be a major driver, leading to a decline in overseas markets/trade (e.g. kiwifruit) and increase in diverse, local markets. The limiting factor for primary production is likely to be appropriate and consistent access to water and the impacts of any extreme weather events. For our scenario, we found that dairy farming is likely to increase to the detriment of sheep farming. A concern for the catchment might be the decline of kiwifruit biophysical suitability due to lack of winter chilling, adding extra costs to production by requiring the use of chemicals to improve flowering (Linsley-Noakes, 1989). This could be exacerbated by increased costs due to disease outbreaks and infrastructure costs. Regional climatic suitability for agricultural crops will change. For example, areas currently limited by low temperatures will be more suitable for cropping and rain-fed agriculture will become more vulnerable to drought, particularly for soils with low water holding capacity.

#### 3.3 Environmental and ecological factors

If land is abandoned due to unfavorable climatic or trade changes, the land could revert to natural wetlands. However, lack of funding for control measures could exacerbate the spread of exotic plants in wetland areas and create a risk for weed infestation of nearby cropping and pastoral farming. Native forests, wetlands and rivers could see a decline in biodiversity due to pest invasions, increased sedimentation, water diversion for economic uses, salinisation in the coastal zone

and lack of funding for conservation. With warmer temperatures, pests currently limited to warmer climates could expand their range into the case study area and become more prolific, causing a reduction in abundance or loss of native species. Water discharge could reduce due to a reduction in precipitation, creating water stress during summer.

### **3.4 Resources**

Fuel costs are expected to rise with an increased reliance on fossil fuel-based electricity, primarily coal. This, in turn, could increase primary production and household utility costs and use of public transport. The tourism sector could suffer from these additional costs through greater travel costs. The coastal zone could be impacted by sea level rise, affecting agricultural land (mainly dairy and maize cropping).

### **3.5 Human development/Welfare**

Sea level rise is expected to lead to a decline in coastal property values and eventual abandonment of the most vulnerable properties due to coastal encroachment. Human vulnerability to natural disasters could increase due to more frequent extreme events (e.g. floods). Life expectancy may decline, especially with potential reduced funding for healthcare services and the likely increases in the incidence of infectious diseases, with coastal areas becoming an increasingly important reservoir for disease vectors such as mosquitoes.

### **3.6 Institutions & Governance (excluding climate policies)**

Due to limited investment in sector/catchment-scale adaptation options to reduce risks, flood events could increase dramatically from added sedimentation in the rivers and lack of funding to raise stop banks. Road networks are likely to deteriorate, worsening the economic conditions in the region. Social inequities could deepen due to an inability to pay. Global agreements such as Kyoto Protocol could be regularly breached and contingent liability could be transferred to central government.

### **3.7 Technological development**

We assume that no new climate change mitigation options will be developed, but that local adaptation solutions will be created in a reactive way, lagging behind global initiatives. We expect that fewer research efforts will be funded by government and more by industry.

### **3.8 Broader social factors**

There could be a general disconnect from nature; recreation in and aesthetic appreciation of the outdoors ranks low on the list of people's priorities due to the high costs of living.

### **3.9 Policies (excluding climate policies)**

Loss of population and sea level rise could lead to *ad hoc* coastal protection. Insurance may be difficult to obtain or would not cover natural events. Development initiatives could be market-driven and lacking policies to include social, environmental or cultural elements.

## **4 DISCUSSION**

This paper provides an overview of potential future impacts of both climate change and socio-economic changes in a typical lowland environment of New Zealand. We demonstrated the use of quantitative and narrative statements for one particular scenario (RCP8.5/SSP3/A), in which there is almost no attempt to curtail climate change on a global scale and only very limited, reactive local efforts. In this scenario, costs of production would generally increase due to a need for increased environmental management for pest control and water shortages, with a higher risk for a decline in commodity prices due to increased global competition.

Our process was highly interdisciplinary, mixing biophysical and social science, and helped bridge the gap between research and policy. While we used categories of key elements from O'Neil et al. (2013), not all elements could be modelled quantitatively, either because our understanding of the behaviour of societies is not sufficient to model or predict anything, or because models were not calibrated for future projections. However, this provided a framework in which to form a coherent story and to incorporate narrative and quantitative statements about one possible future. This process highlighted the inter-dependencies between elements, and gave insight into the complex chain of events and feedbacks that could occur in the future. For example, the impact of climate change on some primary sectors can trigger land-use change creating trade-offs between food and timber provision (Dunford et al., 2015).

The quantitative models had a degree of integration via "soft-coupling" because biophysical outputs for production changes were linked to economic models to drive land-use decisions. There is potential for additional interdependencies that we would like to explore in the future, with dynamic feedbacks to be modelled by hard-coupling of models e.g. linking hydrological models with the land-use change model. However, the extra computational efforts need to be balanced with the value of added information. For example, if the land-use effect is revealed to be negligible then the hydrology model could assume a constant land-use pattern over time.

The combination of the three dimensions represented by RCP, SSP and SPA enables us to create a mix of New Zealand-specific scenarios of high relevance to stakeholders. However, this multiplies the number of possible scenarios given the number of RCPs, SSPs, and SPAs. The goal then is not to describe every possible policy landscape but to select a finite number of representative central policy assumptions to produce a set of climate policy scenarios that are plausible within the global RCP/SSP architecture. It would provide key messages to decision makers, giving trade-offs and synergies between positive and negative outcomes from climate and socio-economic pathways. We are therefore planning to develop several scenarios based on a combined RCP/SSP/SPA approach to provide some individually plausible yet contrasting exemplifications of socio-economic developments in New Zealand that could matter for the future impacts of climate change, societal vulnerability to climate change, and adaptation options. Testing other scenarios will allow comparisons and show the potential of societal adaptation options to make positive changes.

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