Ministry for Primary Industries
Manatū Ahu Matua

Triggers and thresholds of land-use change in relation to climate change and other key trends: A Review and assessment of potential implications for New Zealand

MPI Technical Paper No: 2012/44

Prepared for the Ministry for Primary Industries
by Landcare Research (C09X0903)
September 2011

ISBN No: 978-0-478-40461-6 (online)
ISSN No: 2253-3923 (online)

November 2012

New Zealand Government

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Triggers and Thresholds of Land-use Change in Relation to Climate Change and Other Key Trends:

A Review and Assessment of Potential Implications for New Zealand

Contract: C09X0903

Landcare Research
Manaaki Whenua

Triggers and Thresholds of Land-Use Change in Relation to Climate Change and Other Key Trends: A Review and Assessment of Potential Implications for New Zealand

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Landcare Research Contract Report: LC 604

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SUMMARY

Project Code

- C09X0903

Business/Institution

- Landcare Research

Project Leader

- Daniel Rutledge

Project Title

- Triggers and Thresholds of Land-Use Change in Relation to Climate Change and Other Key Trends: A Review and Assessment of Potential Implications for New Zealand

Goal

- Undertake a systematic, integrated, multi-scale review to identify the implications of climate change and its interactions with other key trends for triggers and thresholds of land-use change to answer 3 questions:
  - To what degree could climate change influence triggers and thresholds of land-use change, either individually or combined with other key trends?
  - To what degree, if any, will those influences vary among the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) scenarios?
  - Conversely, to what degree does climate change not influence land-use trends, e.g., conservation lands are designated for perpetuity, major infrastructure has a very long life span?

Project Context

- New Zealand encompasses an area of 26.8 million hectares including the North, South, Stewart and inshore islands. Since humans arrived some 1000 years ago, we have modified the landscape to suit various purposes and fulfil various needs. The current patterns we observe reflect the influence of a range of driving forces including climate, soils, landform, biodiversity, ownership, culture, and economics.
- Currently nearly half of New Zealand supports primary production, a third is legally protected for various conservation purposes, and ~1.3% is urban. Remaining land (~18%) consists of unmanaged patches of native and exotic vegetation (weeds such as gorse and broom) and very low-density residential developments interspersed among productive and conservation lands.
- Climate change will alter land suitability for different uses both globally and in New Zealand. Shifting patterns, intensities, and frequencies of rainfall, temperature, winds, storms, and distributions of pests and weeds will trigger shifts in land use in complex ways. Some changes could be beneficial, such as increased length of growing season, while some will be detrimental, such as increased frequency of drought leading to increased risk of farm failure.

- Other key economic, environmental, social and cultural trends also drive land-use change. Collectively they operate across a range of spatial and temporal scales and reflect the collective outcome from decisions made by individuals, households, businesses, and government and private institutions both within New Zealand and globally. Over the next century the magnitudes and rates of change will likely be larger and more rapid than ever experienced before in human history. They will also interact in complex and unpredictable ways, thereby challenging our ability to respond and adapt in a timely and appropriate manner.
- The challenge ahead involves trying to understand the role and possible influence of climate change on land-use change, both individually and in combination with other key trends, so that we can anticipate potential impacts and adapt accordingly. This requires a holistic and integrated approach to identify possible triggers or thresholds of land-use change across a range of spatiotemporal, societal and organisational scales.

Approach

- We assessed the implications of 11 key trends operating at broad scales and resolutions and interpreted them at progressively finer scales from global to local using a systematic qualitative downscaling framework organised along two dimensions: four scenarios developed and analysed as part of the IPCC's 4th Assessment Report versus four major land-use categories (conservation, production, urban, unmanaged) and six sub-categories of production (arable, biofuels, carbon storage, dairy, forestry, horticulture, and sheep & beef).

Methodology

- Reviewed and synthesised the literature on 11 key trends: agricultural production, biodiversity, climate change, ecosystem services, economic development, energy, globalization, mineral resources, population and human migration, societal preferences for food & fibre, and water resources.
- Evaluated each of the 11 key trends overall and in the context of each of the four IPCC scenarios.
- Interpreted the implications of the 11 key trends for triggers, thresholds and reversibility of land-use change for New Zealand overall and at progressively finer scales (national, regional, local) using a qualitative downscaling framework developed specifically for the project. The framework included a conceptual integrated systems model to aid identification and evaluation of links and feedbacks of the 11 key trends with each other and with land-use and land-cover change.

Summary

The literature for each of the 11 key trends is substantial, such that we could only undertake a limited review of each trend to identify potential issues or aspects to consider. Despite these challenges and limitations, the review yielded important insights into possible implications of different cultural, economic, environmental and social trends on triggers, thresholds and irreversibility of land-use change. Below we summarise results at two scales: global and New Zealand.

Global

- A basic model of land-use change considers transfers among conservation, production, urban, and unmanaged land uses. It reinforces the finite nature of land supply both globally and within New Zealand and highlights the need to monitor and anticipate irreversible changes that might limit future land-use options.
- Conservation and urban land uses have increased, and continue to do so. Production land uses have been more variable and reflect country-specific, sub-national, and local conditions. They are declining or stable in many developed countries and increasing in many developing countries, usually via conversion of natural ecosystems. Unmanaged lands are increasing in some countries via processes such as land abandonment and desertification.
- Climate change will influence land-use change differently in different regions and countries via heterogeneous shifts in temperature, precipitation, winds, frequency and severity of extreme events, and changes in distributions of non-native species (i.e. pests and weeds). Countries at higher latitudes may benefit from overall warmer temperatures, while sub-tropical and tropical areas may suffer. Shifting precipitation patterns are expected to increase water stress, especially along equatorial regions. More intense and frequent storms will cause issues everywhere, but especially in coastal areas.
- Assumptions about population trends, economic development, etc., in the IPCC scenarios had significant implications for land-use change, including the allocation of productive land uses. For example projected changes for grasslands ranged from a low of -1537 million hectares to a high of +307 million hectares, or a difference of nearly 2 billion hectares across the four scenarios. Other land uses showed similarly large low-to-high ranges: forestry – 1,352 million hectares, cropland – 719 million hectares, and other land (includes urban) – 614 million hectares. Such high variability makes long-term assessments of triggers, thresholds, and reversibility of land-use change extremely challenging.
- Societal preferences and worldviews will also significantly impact on land use via demand for various goods and services, as evidenced by the large variation in IPCC SRES scenario projections for croplands, grasslands, and forest. This will also be reflected in attitudes toward the natural environment, such as measuring and valuing ecosystem services.
- Trends in water resources could be some of the earliest manifestatios of climate change. Regional variations could trigger moderate to substantial rearrangement of primary production patterns and/or affect productivity of existing productive areas.
- Recent analyses have resulted in revisions to projections for energy resources and suggested that an earlier and more rapid transition to renewable energy is needed than was forecast for the IPCC SRES scenarios. The need to secure non-renewable energy resources will trigger development for bioenergy production both globally and within New Zealand, which will have corresponding consequences for land-use change.
- Other key trends could evolve independently in a manner that challenges global and national governments and societies to respond, mitigate, and adapt. The likelihood is also increasing that two or more key trends will co-evolve in unpredictable ways that could trigger substantial changes in land use and land-use patterns.

New Zealand

- Urban and conservation land uses have increased over time, usually as the result of expansion into productive land uses. Conservation lands have also increased over time via public and private processes, e.g.,. covenanting of private land by landowners. Unmanaged lands are decreasing, primarily as a result of transfer to conservation (e.g., private covenanting as above) or transfer to production, although trends are difficult to quantify accurately, given the limited availability and quality of land-use information.
- Climate change impacts are expected to be moderate relative to other countries. Assuming moderate changes, growing season would lengthen and productivity increase given warmer temperatures and increased CO_2 concentrations. Projected changes in regional precipitation patterns are more complex but suggest overall wetter conditions in the west and south, and drier conditions in the north and east. Increased frequency and severity of storms and other extreme weather events could increase risk and therefore costs (i.e. insurance) across most land-uses.
- Urban land uses will continue to expand to accommodate population rises and associated increased economic development out to 2050-2060. Beyond 2060 population projections diverge, ranging from 4.0 (UN Low) to 9.5 million (UN High). Assuming historical trends continue, an additional 80,000-100,000 hectares of land would be needed for urban development before population begins to decline around 2040, followed by urban contraction/land abandonment under the UN low scenario. Conversely a doubling of population (UN High) would require ~ 350,000 hectares of new urban land. Efforts to densify existing and future development could reduce the demand for additional urban land but will depend on societal views and preferences.
- Conservation land will also increase, as least for the next 20-50 years, via additional covenants or via substantial additions to the conservation estate in exceptional circumstances. Climate change could trigger more dynamic approaches to conservation based on protection goals (i.e. desired outcomes) rather than legal protection (i.e. protect each land parcel in perpetuity) as was historically the case. Climate change will also challenge management in existing conservation areas as some species may need assistance to adapt to climate change (e.g., assisted migration) or cope with increased pest and weed pressures.
- Future projections for production land uses in New Zealand out to 2100 are highly uncertain and, as evidenced by the IPCC scenarios, strongly dependent on key underlying assumptions. Nonetheless several emerging trends will influence changes within and among production land-uses:
  - New Zealand will need to meet an increasing share of its energy demand domestically as a result of decreasing global energy supply due to increasing population (initially), declining supply of fossil fuels, and rising affluence. Demand for increased energy supply will trigger land-use change, especially conversion of unmanaged lands, some existing forestry land, and marginal, hill country pasture lands to bioenergy production.
  - Continued increases in global population and changing societal preferences will likely drive further expansion and intensification of dairy land in the short-term. Longer term developments become increasingly uncertain and sensitive to assumptions about population trends, economic and technological development, societal preferences, and lifestyle choices.

  - Crop and vegetable production should remain stable or, more likely, increase to meet increasing domestic demand resulting from projected increases in the New Zealand population. Increased need or desire for more localised food production could trigger displacement of pastoral production by crops on remaining suitable soils near urban areas that remain available for production.
  - Overseas demand for horticultural products should grow in the short term, triggering growth in horticultural land use. The most likely increase will occur via transfers from pastoral uses in areas with existing infrastructure to support expansion. As for dairy, longer term trends are sensitive to assumptions about future trends.
  - Sheep & beef production and forestry will likely experience a 'squeeze' from bioenergy, horticulture, and dairy production. Declines in both seem likely over the long term but ultimately depend on the relative demands globally for food versus material goods, such as timber. However, forestry has the potential to expand into unmanaged lands currently occupied by exotic weeds, e.g., gorse and broom, partly to offset any future losses to bioenergy expansion.
- Establishment of acceptable thresholds (minimums or maximums) for ecosystem services will influence land use by triggering changes from land uses that cannot comply with established standards. A recent example was the change in land use resulting from the implementation of rules to limit total nutrient inputs into Lake Taupo to achieve future water quality targets.
- The fate of unmanaged land presents an interesting consideration, as some land supports weed species and would be a good candidate for conversion. Other unmanaged land retains significant value for native biodiversity (e.g., native cover), such that conversion to non-native covers to satisfy non-conservation uses would result in additional biodiversity decline.
- Overall
  - Short term (10–20 years): New Zealand will continue to experience population growth, leading to irreversible losses of productive land to urbanisation. Conservation lands will continue to expand, primarily via continued application of private covenanting schemes, although the area affected will be small, on the order of several thousand hectares per year. Overseas demand for agricultural products will continue to expand with expanding global population and increasing affluence. Initially the balance will continue to shift towards dairy and horticulture, triggering further conversions to those land uses. Emerging carbon and biofuel markets will create demand triggering conversion of some marginal lands from pastoral to forest production.
  - Medium term (20–50 years): New Zealand, along with the rest of the globe, will experience increasing uncertainty and variability, creating what Shell International (2011) called a "zone of extraordinary opportunity or extraordinary misery". The zone represents a critical transition period during which decisions made or not made and actions taken or not taken will have long-lasting and significant repercussions. Climate change impacts will begin to alter patterns of global and domestic production, with flow-on effects for New Zealand in terms of export markets. All population projections point to increasing global population at least out to mid-century, so additional agricultural production will be needed. Bioenergy production will need to increase to offset declines in the availability of affordable energy supply due to declines in fossil

fuel, especially conventional oil, and increasing competition from rising affluence in many countries.

– Long term (50–100 years): the IPCC SRES scenarios remain as one of the best, most comprehensive and most accessible guides for exploring future global development. They are also among the few scenarios that comprehensively attempted to outline possible future trends to 2100. Most other scenarios have much shorter (e.g., 20–50 year or less) timeframes. The IPCC SRES scenarios depict four highly divergent trajectories of development out to 2100 with significantly different outcomes for land-use change. Including more recent information on trends in energy, ecosystem services, minerals, and societal preferences adds further complexity to the analysis and reinforces the need for further research. Collectively the IPCC SRES scenarios and more recent studies reinforce the need to build resilience into and across our cultural, economic, environmental, and social systems such that we can adapt and prosper, regardless of what the future may hold. New Zealand would be well-positioned if it began to adapt its policy, planning, and resource management to maximise land-use options.

Suggested Citation

Rutledge DT, Sinclair RJ, Tait A, Poot J, Dresser M, Cameron M, Greenhalgh S 2011. Triggers and thresholds of land-use change in relation to climate change and other key trends: a review and assessment of potential implications for New Zealand. Landcare Research report prepared for the New Zealand Ministry for Agriculture and Forestry. 114 p.

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1 The Challenge

New Zealand encompasses an area of ~26.8 million hectares including the North, South, Stewart and inshore islands. Since humans arrived some 1000 years ago, we have modified the landscape to suit various purposes and fulfil various needs (Figure 1). The current patterns we observe reflect the influence of a range of driving forces including climate, soils, landform, ownership, culture, and societal, and economics preferences. Given the lack of systematic and coordinated collection and analysis of land-use information in New Zealand, accurate data on land use and land-use change are difficult to obtain. Table 1 summarises the best current available information based on a combination of data sources, including the Land Cover Database, Land Use and Carbon Analysis System (LUCAS), Agribase®, Protected Areas Network (PAN-NZ) database, and Land Use New Zealand dataset.

Table 1 Estimated percentage of major land uses within New Zealand as of 2010

PRODUCTION	%	NON-PRODUCTION	%
Arable	1.3	Conservation[1]	33.4
Exotic Forestry	7.1	Unmanaged[2] – Land	15.0
Horticulture incl. viticulture	0.3	Unmanaged[2] – Water & Wetlands	2.5
Pastoral	39.0	Urban[3]	1.3

[1]Total of conservation estate, regional parks, and private covenants

[2]Areas where land use is not currently ascertainable based on available data

[3]Includes rural residential = lifestyle blocks from Agribase®

Over the next century, climate change will alter the suitability of land for different uses both globally and within New Zealand. Shifting patterns, intensities, and frequencies of temperature, precipitation, winds, etc., will trigger shifts in land use in complex ways as land owners respond to changing conditions locally, regionally, nationally, and internationally. Some changes could be beneficial, such as increased length of the growing season or new product opportunities generated by the combination of local growing conditions and changing markets overseas. Other changes could be detrimental, such as increased frequency of drought leading to a higher risk of farm failure.

Other key economic, environmental, and socio-cultural trends will also drive land-use change. Collectively those trends operate across a range of spatial and temporal scales and reflect the collective outcome from decisions made by individuals, households, businesses, and government and private institutions both within New Zealand and globally. Over the next century the magnitudes and rates of change will likely be larger and more rapid than ever experienced before in human history, thereby challenging our ability to respond and adapt in a timely and appropriate manner. For example, Statistics NZ projections of New Zealand's population in 2061 range from 4.9 to 6.7 million or 15–60% higher than the June 2009 population. Such high uncertainty has profound implications for future land-use planning.

The challenge ahead involves trying to understand the role and possible influence of climate change on land-use change, both individually and in combination with other key trends, so that we can anticipate potential impacts and adapt accordingly. This will require taking a holistic and integrated approach to identify possible triggers or thresholds of land-use change across a range of spatiotemporal, societal and organisational scales.

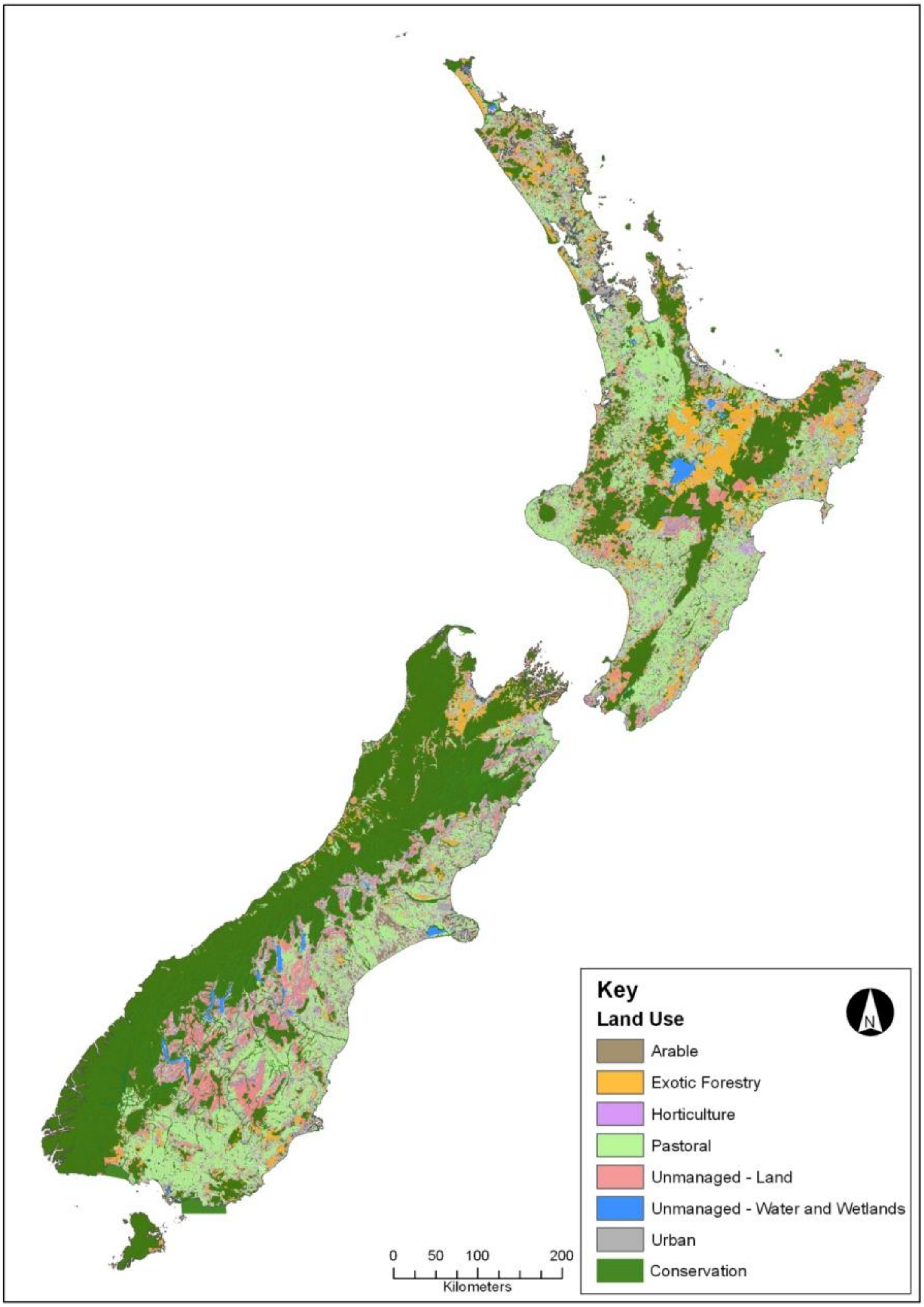


Figure 1 Distribution of major land uses in New Zealand as of 2009 based on an amalgamation of various data sources (see text for further details).

2 Land Use and Land-use Change: Background

Land use is defined as the function or purpose that we derive from the land (see Rutledge et al. 2009 for an overview). It results from interactions among resources (i.e. soil, water, plants & animals) and the series of activities and operations that we undertake to manipulate those resources to produce desired goods and services. Similarly, land-use change is a complex process resulting from the interplay of decisions and frameworks operating across a range of organisational, societal, and spatiotemporal scales (Figure 2).

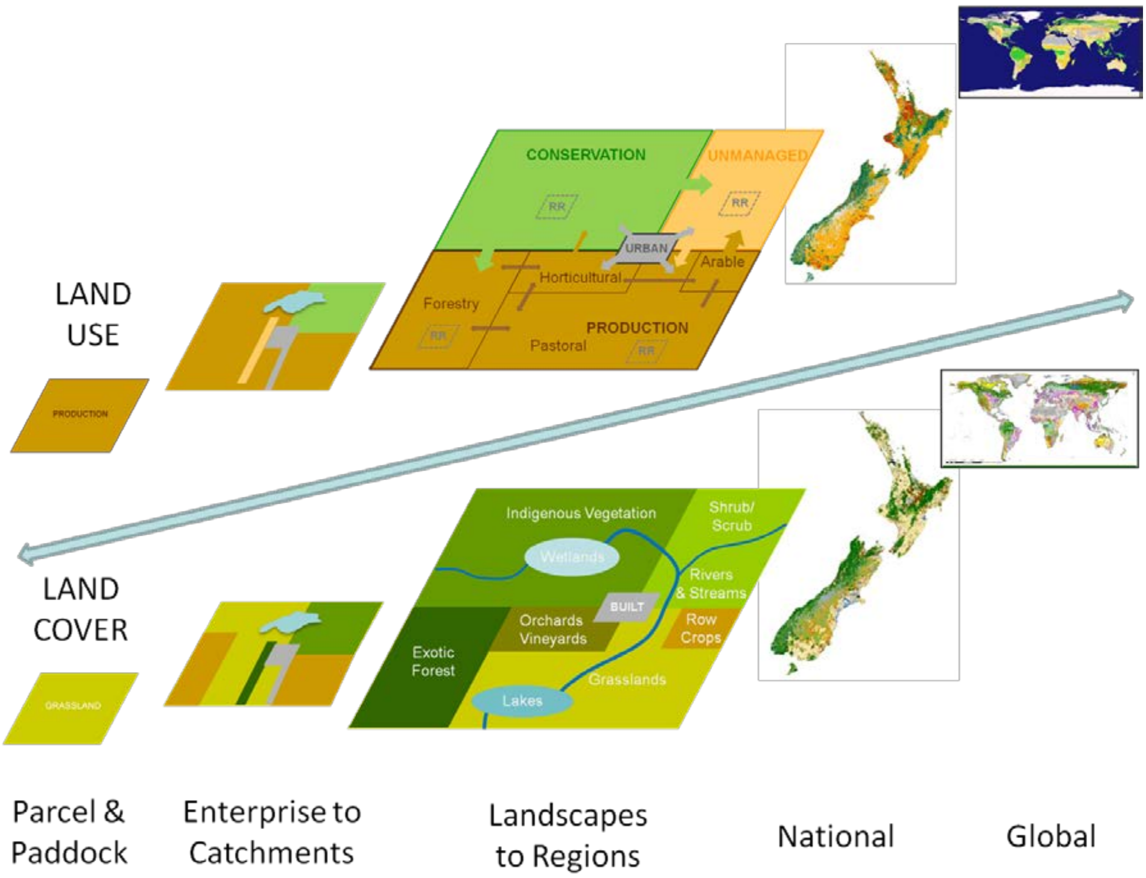


Figure 2 Conceptual representation of land use and land cover across scales.

Both land use and land-use change can be characterised, measured and interpreted quite broadly. Land use and land-use change are often inferred based on observed changes to land cover or the biophysical environment, such as conversion from forestry to dairying or development of agricultural areas into residential subdivisions. However, land-use change can also result from changes in activities or operations that are more difficult to detect. Examples include agricultural intensification, implementation of new management practices or adoption of new technologies, although some might not consider those as “land-use change” if the primary use does not change (e.g., dairy farming). Regardless, all those types of land-use change will have economic, environmental, social and cultural consequences.

Across scales, trends such as climate, demographics, lifestyles, natural resources, energy, etc., influence and drive land-use change. Trends operate both individually and collectively, which partly explains why land-use change is complex and why understanding and modelling it is so challenging. For example, climate change affects land-use change in complex ways depending on the degree and distribution of expected changes to weather patterns (e.g., temperature, precipitation) and how they interact with other key trends both globally and within New Zealand. The interactions and feedbacks among different trends can lead to unexpected or surprising outcomes.

At each scale different processes are operating to influence land-use decisions (Figure 2). Paddocks and parcels represent a fundamental unit at which people typically make decisions about land, e.g., grazing rotation, cropping choices, plantings, what type of business to undertake, what type of residence to build and occupy. Paddocks and parcels are embedded in broader enterprises and catchments. Collections of paddocks or parcels are often managed collectively, such as with farm enterprises. Enterprises and catchments occur across landscapes and regions, which represent the scale at which formal land-use planning occurs in New Zealand. This includes land-use policy development and planning and related activities undertaken by regional, city, and district councils under the Resource Management Act and Local Government Act. For example, most district councils in New Zealand divide their districts into zones and designate what activities can/cannot occur in each zone. Regions are further embedded in nations that control and influence land-use change through various laws, policies, regulations and strategies. In New Zealand, for example, the Reserves Act provides for the designation of conservation land uses. The recent Emission Trading Scheme is also starting to influence land-use decisions through the creation of a carbon trading market. At the global scale economic and socio-cultural forces also combine to drive land-use change, for example, shifting food preferences can trigger increasing demands for agricultural commodities. Multi-national agreements, such as the European Union, also influence governance arrangements, which in turn affect the flow of people and goods among countries and continents.

The different colours shown for *land use* at the landscape and regional scale in Figure 2 represent different areas (stocks) of various land uses, e.g., hectares of land for conservation (green), production (brown), urban (grey), and unmanaged (orange). Similarly, the different colours shown for *land cover* at the landscape and regional scale represent areas (stocks) of different land covers (e.g., dark green for exotic forest). Land use and land cover are not the same, as land use is the purpose that we derive from the land, while land cover represents the biophysical condition of the land itself. However, land use and land cover are related such that particular land uses usually – but not always – correspond with particular land covers.

Most importantly, the figure emphasises that the land supply is finite, such that increasing the area of one land use decreases the area of another land use. Similarly, the total supply of different types of land, represented by land cover, is also fixed. The four main categories of land uses are shown adjacent to each other. The corresponding coloured arrows signify changes (flows) between land uses and convey graphically the process of one land use expanding in space and over time to replace another. Land-use change could also have consequences for land cover, but, to keep the diagram simpler, the depiction of land cover does not include similar arrows. The situation is even more complex, given that a parcel of land could support multiple land uses or functions, either simultaneously (e.g., farm stays on a sheep & beef farm) or over time (e.g., alternation of cropping and grazing).

As stated earlier, land-use change within New Zealand is difficult to estimate given the lack of systematic information collection. However, we determined some very broad trends based on an informal analysis of available datasets. Urban areas increased from approximately 143 000 ha in 1985 to 215 600 ha in 2001/2002, which implies an urbanisation rate of ~4500 ha per year during that period. That rate does not include changes to rural residential land uses, which are currently difficult to quantify, although census data document an overall increase in dwelling densities outside urban areas over the period 1996–2006.

Conservation land area has gradually been expanding. Recent additions resulting from the High Country Tenure Review process added to the Conservation Estate, but those increases were partially offset by transfer of Crown pastoral lease land to freehold. Bay of Plenty and Horizons have recently established regional parks to add to those already well established in Auckland and Wellington. Covenant schemes continue to increase the total conservation area. Under the QE II National Trust, 108 932 ha of private land had been covenanted as of June 2010. The Trust has been operating since 1977, which results in an average covenanting rate of ~3300 ha per year. Similarly the Nature Heritage Fund has protected 340,000 hectares since 1990, for an average rate of ~16 400 hectares per year. As of 2007, 146 800 hectares of Maori land were protected under the Nga Whenau Rahui scheme, implying an annual rate of ~9 200 hectares per year. Therefore conservation land increases by ~29 000 ha per year on average when those three schemes are combined.

Inferring changes in land use by comparing Land Cover Databases version 1 and 2, conversions among production land uses were on the order of 140 000 hectares annually from 1996/97 to 2001/02. More recent analyses based on satellite imagery acquired for Kyoto protocol accounting showed a net increase of 554 000 hectares of planted forest between 1990 and 2007, balanced by decreases in grasslands (–508 000 hectares) and "other land" (–5000 hectares). Conversely, perennial croplands increased by 5500 hectares and annual croplands by 1000 hectares. The analysis also showed a decrease of 51 000 hectares in natural forest (a land cover); the corresponding land use was not specified.

Because the Request for Proposal requested that we "scope and identify current and potential future environmental, economic, social, and cultural triggers and thresholds for current land-use change with a changing climate," it is important to explore the concepts of "triggers" and "thresholds" in relation to land-use change. It is also important to introduce a third concept, "reversibility," for purposes explained below.

- A *trigger* is "anything (act or event) that serves as a stimulus and initiates or precipitates a reaction or series of reactions." (Source: www.dictionary.com)
- A *threshold* is "the point that must be exceeded to begin producing a given effect." (Source: www.dictionary.com)
- *Reversibility* refers to the ability to change between or among different states or, in this context, among different land uses.

The freezing/thawing and boiling/condensation of water provide a simple example to illustrate these concepts. Temperatures of 0^0 C and 100^0 C represent thresholds above/below which water changes between solid/liquid and liquid/gaseous states. Increasing or decreasing the temperature above/below those thresholds triggers changes in the arrangement of the individual water molecules (microscopic changes) and produces the observed change in (macroscopic or observed) state, i.e. water freezes, melts, boils, or condenses. The state of water is reversible such it melts/boils or condenses/freezes repeatedly as temperatures rise or fall. Lack of reversibility for water would have disastrous consequences, as explored by Kurt Vonnegut in his book *Cat's Cradle*. Furthermore the thresholds can be altered, such as adding salt to water decreases the temperature threshold for freezing/thawing.

Land use is clearly more complex than water. Triggers and thresholds of land-use change depend on various economic, environmental or socio-cultural factors, both to varying degrees and in varying combinations. For example, increased growing season length as a result of climate change could cross a threshold that triggers the planting of new crops in areas where they previously could not be grown profitably. An influx of ex-pat New Zealand citizens living overseas would trigger the need for new urban development. New carbon markets could trigger the planting of additional forests if prices pass a suitable threshold that makes carbon sequestration more profitable than other potential land uses.

Regarding reversibility, the time horizon adopted is a key consideration. Most land-use change is reversible given enough resources and/or time, e.g., some ancient cities now exist only as archaeological remains. In the context of climate change, a key consideration is how land use will change in the near- to medium-term future, i.e. 50–100 years. For that time horizon the following general trends apply:

- Urbanisation is most difficult to reverse due to the establishment of high thresholds that prevent it from being removed once established. Such thresholds depend on, among other things: land values, substantial economic cost and physical effort to remove existing infrastructure, restoration of soils to suitable conditions, or resistance to displacement by affected residents.
- Conservation can be reversible or irreversible, depending upon the manner of conservation. Legally designated parks and reserves are typically protected in perpetuity (e.g., irreversible). Informal conservation efforts, such as pest control by local community groups, may come and go based on interest and resources (e.g., reversible). Also legal protection does not guarantee functional protection, e.g., poaching of wildlife in protected areas is a substantial problem in some countries.
- Changes among production land uses are reversible to the extent that the underpinning ecosystems and associated services remain intact. Reversibility in this case is also a function of time. Forests cleared for pastoral production, such as those recently converted in the central North Island, can be replanted but require several decades to re-grow. In contrast, shifting among different types of livestock production can occur more rapidly, and shifting among different crops can occur even more rapidly, e.g., seasonally. Changes to the underpinning natural capital can reduce future land-use options either permanently (e.g., desertification) or require substantial investment to return the ecosystem to a suitable state capable of providing the desired service (e.g., remediation of soil contaminants).

Again, those are broad trends that do not hold all the time. For example, many groups throughout New Zealand are undertaking efforts to restore different areas to more natural conditions. Also, while New Zealand is becoming more urbanised overall, trends are not evenly distributed such that some towns and villages are losing population.

3 Our Approach

3.1 Overview

We undertook a broad systematic, integrated, multi-scale study to scope potential implications of climate change and its interactions with other key trends for triggers and thresholds of land-use change. Specifically, we addressed 3 questions:

- To what degree could climate change influence triggers and thresholds of land-use change, either individually or combined with other key trends?
- To what degree, if any, will those influences vary among the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) scenarios?
- Conversely, to what degree does climate change not influence land-use trends, e.g., much of the conservation estate is fixed, long lifespan of major infrastructure?

Our approach followed a systematic downscaling procedure organised along two dimensions (Figure 3): future scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) as part of its 4th Assessment Report (AR4 Scenarios) versus major land-use categories (conservation, production, and urban) across multiple scales from global to local.

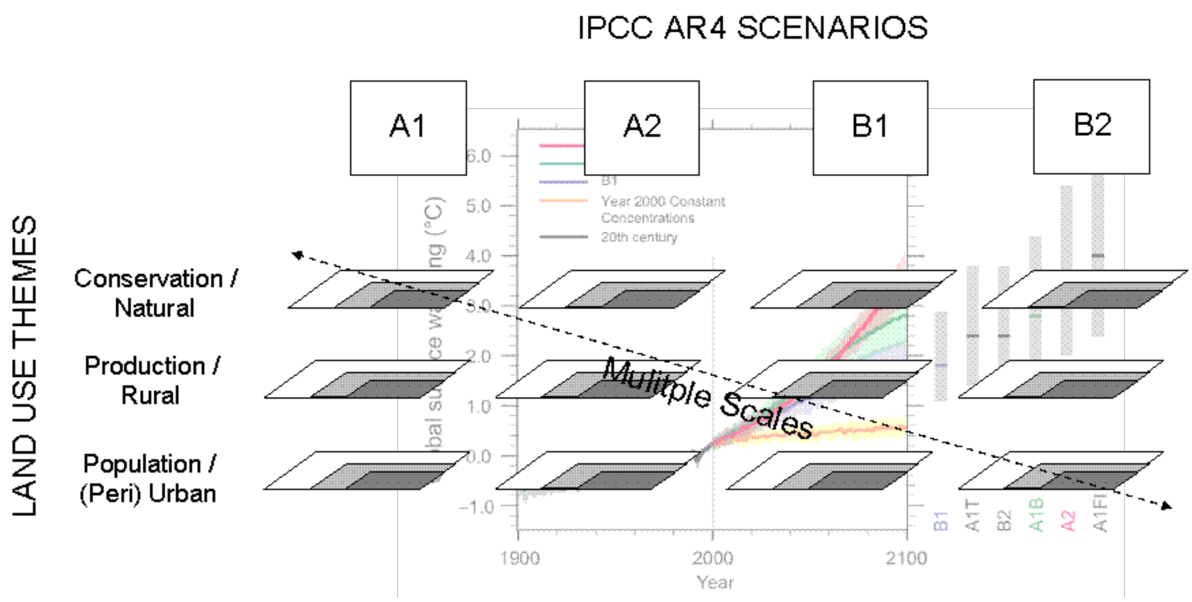


Figure 3 Conceptual diagram of the downscaling framework used in this report.

Downscaling involves depicting the processes or modelled outputs at a coarse scale and resolution and depicting them at finer scales and resolutions. In climate studies values of climate variables such as temperature, precipitation, etc., generated by global circulation models typically operate at grid cell resolutions of 0.5–2°, which translate to sizes of 50–200 km. To understand the consequences of climate change at regional or local scales, climate variables can be downscaled to finer scale grids with resolutions of 5 km or even smaller. The values from the coarse-scale models bound or anchor the values of the fine-scale cells, which are then modified based on comparisons to data generated from regional or local modelling and/or observations. Various techniques exist to downscale climate data, and no single techniques works best everywhere.

We took a similar approach qualitatively to understand how different cultural, economic, environmental, and social trends could affect triggers and thresholds of land-use change individually or in conjunction with climate change or each other.

3.2 Qualitative Downscaling Procedure

The qualitative downscaling procedure involved a systematic assessment of the key trends globally and their implications for triggers and thresholds of land-use change at national, regional, and local scales within New Zealand. The Intergovernmental Panel on Climate Change 4th Assessment Report Special Report on Emissions Scenarios ("IPCC SRES scenarios" hereafter) provided the broad context for assessing potential effects on conservation, production, and urban land uses across scales from global to local. "Unmanaged" land use, i.e. land not subject to discernable activities or management, emerged during the review as an important consideration. Therfore we added the category "unmanaged land" to our analysis. The overall procedure proceeded as follows (Figure 4):

- **Step 1 – Review, Compare and Contrast Key Trends**
  Globally and within New Zealand various key trends, including climate change, will influence future land-use change. For this report we reviewed 11 key trends with high relevance to agriculture and forestry. For each trend we summarised the global situation and then discussed the broad implications for New Zealand.

Table 2 Key trends included in the review

• Agricultural Production	• Globalisation
• Biodiversity	• Mineral Resources
• Climate Change	• Population and Migration
• Economic Development	• Societal Preferences for Food and Fibre
• Ecosystem Services	• Water
• Energy	

- **Step 2 – Systematic Evaluation of Key Trends on Land-Use Change**
  We evaluated the influence of key trends individually and in combination with each other on triggers and thresholds of land-use change at the global scale. We developed a conceptual systems model that links the 11 key trends with land use and land cover to aid our evaluation for each IPCC SRES scenario (Figure 4, Step 2). The systems model helped delineate potential pathways that could influence land-use change and identify potential non-linearities or unexpected outcomes that can occur in complex systems.

The overall structure of our systems model was broadly similar to the structure of the integrated assessment models used to analyse the IPCC SRES scenarios. Population, economic development, and social trends are key drivers of land-use change. Together they influence decisions about land use and drive land-use chaneg across scales that in turn affect land cover. Changes to land-cover result in changes to several biophysical systems including climate, hydrological cycles (water), biodiversity, minerals, energy – both renewable and non-renewable – biodiversity and ecosystem services. Changes to the biophysical systems feedback to the economic and socio-cultural systems to influence subsequent decisions about land use. One of the key trends reviewed, agricultural production, was depicted as part of the land-use component in the systems model, rather than as a separate box, as the other key trends.

- **Step 3 – Downscaling Global Key Trends to New Zealand**
  Using the systems model as a guide, we qualitatively downscaled the key global trends to New Zealand. The downscaling procedure resulted in a broad summary of the potential implications for New Zealand if a particular IPCC scenario eventuated.
- **Step 4 – Multi-scale Assessment of Triggers and Thresholds of Land-Use Change for New Zealand**
  In the final step we assessed potential consequences of the 11 key trends for each of the four major land-use categories across three scales: national, regional, and local. We presented the results of the assessments as tables with major land-use categories as rows and scale (national, regional, local) as columns. For production uses we also assessed the potential implications for land-use dynamics among major sub-categories including arable land, biofuels, carbon storage, dairying, forestry, horticulture, and sheep & beef. While not currently prominent in the landscape, we expect demand for biofuels and carbon storage to increase as a result of future efforts to mitigate climate change and compensate for decreasing global supply of affordable fossil fuels.

3.3 Organisation of the review

We organised the review as follows. First, we presented the results of the review of the 10 key trends other than climate change that affect triggers and thresholds of land-use change (Step 1 from above). Second, we provided an overview of climate change both globally and within New Zealand, followed by an overall summary of each IPCC SRES scenario as well as a table that facilitated comparisons across scenarios (Step 2). We also included the corresponding projected changes in global land use produced for each scenario to provide additional context. Third, for each scenario we analysed the possible implications of the key trends for New Zealand overall (Step 3) and then more specifically for triggers and thresholds of land-use change at national, regional, and local scales (Step 4). Fourth, we outlined potential gaps and limitations of our review. Fifth, we addressed the three questions posed originally in the context of the information reviewed.

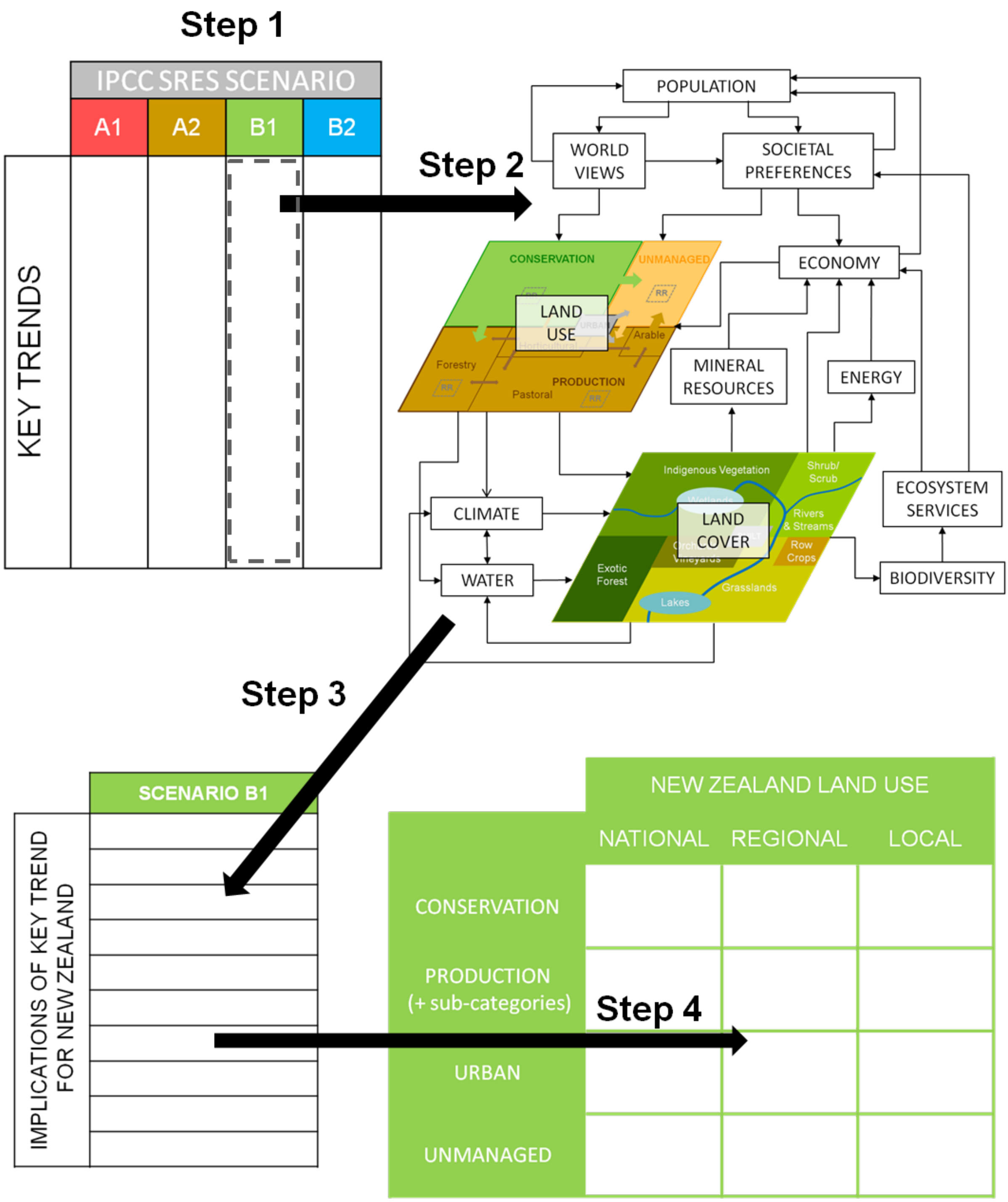


Figure 4 Schematic of the downscaling procedure. Step 1: Key trends are evaluated both overall and compared/contrasted across the IPCC AR4 SRES scenarios. Step 2: Information from Step 1 is used to populate the systems model of key drivers of land use/cover change to check for internal consistency and help refine the scenario information. Step 3: Implications for New Zealand for each of the 10 key trends are evaluated. Step 4: Implications for major land use themes and production sub-themes within New Zealand are evaluated across national, regional and local scales.

4 Review of Key Trends

This section summarises the key trends other than climate change, which is overviewed in the following section. The key trends reviewed include those examined closely in the IPCC SRES scenarios: demographic change, social and economic development, globalisation, energy, and technological change. Our review also included consideration of trends in biodiversity, ecosystem services, mineral resources, societal preferences for food and fibre, and water. Each of those additional trends has been the subject of further analyses following the IPCC SRES scenarios by the IPCC or others; however, integrated analyses of all trends operating together remain uncommon given the complexities involved.

Unlike the IPCC SRES scenarios, we did not evaluate technology individually. The IPCC SRES scenarios considered technology primarily via its influence on energy, e.g., rates of change in energy use efficiency, prices, etc., and the resulting consequences for future emissions from the energy sector. In our review we attempted to evaluate potential technological developments for each key trend where feasible. In that sense our assessment of technology was broader but much less detailed than the IPCC SRES scenarios. One exception was our examination of future trends in mineral resources, as future technological development will depend on the availability of affordable raw materials such as rare earth minerals.

For each trend we undertook a broad literature review to assess possible future developments both globally and within New Zealand and to assess how those trends could affect triggers and thresholds of land use and land-use change across scales from global to local (within New Zealand). Given the scope of the study, we concentrated on the key aspects of each trend and how they might drive future land-use change. In particular, we tried to identify how each trend might affect different thresholds and thereby trigger changes in land use, both individually and in combination, and what the trends might imply for future land-use options, given the reversibility or irreversibility of land-use decisions.

The findings presented are by no means exhaustive. Each trend is itself a complex subject with a substantial body of accompanying literature and is worthy of more in-depth study and analysis. Each trend has implications globally and for New Zealand. Our hope is that the analysis will aid thinking and discussion about the possible consequences for land-use change in New Zealand over the next 100 years and stimulate healthy debate about how best to satisfy land-use demands in an on-going and sustainable manner.

4.1 Agricultural Production

Agricultural production is a function of the complex interplay between environmental suitability, economic viability, and social capacity. Globally, climate change will directly and differentially affect the environmental suitability for different types of agriculture in different regions. Such changes will indirectly influence other regions through compensating responses to changes in patterns of supply, either positive or negative.

The factors influencing agricultural production are intrinsically linked. The complexity of the soil system, the biotic and abiotic components, nutrient cycling systems, gaseous exchange and the ability of the system to adapt, all make this a very challenging system to analyse. The likely effects of climate change range widely in magnitude, uncertainty, and spatial heterogeneity. Despite the expected variability, however, some broad trends are emerging (Table 3). Effects will vary according to changes in temperature (average or extreme), CO_2 concentrations, rainfall, frequency and the intensity of extreme events such as storms and nutrient cycling as well as changes to the ecology of related organisms such as weeds or insect pests.

Table 3 Summary of key climate factors, their resulting trends as a result of climate change, and expected effects on agricultural production

Factor	Trend	Effect
Temperature	Increasing temperatures (min, mean, max)	Variable; positive for plant growth to a particular threshold, negative thereafter; increases/ decreases in growing season & range for different production types
CO_2	Increasing atmospheric concentration	Positive for plant growth and possible compensation for adverse temperature effects
Precipitation	Regionally variable	Negative effects in tropical zones and possibly some temperate zones
Extreme Events	Increases in probability of occurrence, magnitude, and unpredictability	Negative effect via increased costs and risks affecting long-term profitability
Weeds & Pests	Increased incident rates of both known weeds & pests and new species	Negative effect through increased risk of invasion and increased costs associated with control and eradication

Plant production correlates positively with temperature up to certain thresholds that vary among crops (e.g., C3 or C4 crops). Beyond those thresholds, including warmer night-time temperatures, crop yields begin to decline, sometimes more sharply than they increased. Experimental studies demonstrated that increased production also correlates with increased CO_2 concentration, which could partially compensate for adverse temperature effects.

Climate change is expected to increase the variability, intensity, and unpredictability of rainfall and storm events. This will directly affect crop production through, for example, increased chance of drought or perhaps damage to crops, particularly at sensitive periods of development, e.g., fruit set. Higher levels of uncertainty will challenge planning and management, which will disadvantage developing nations with lower capacities for adaptation or levels of resilience.

Globally, studies indicate the possibility for medium-term increases in production under moderate (1–3°C) temperature increase. In the longer term an overall decline in agricultural production is expected due to a number of factors. Developing nations and semi-arid/tropical zones are expected to fare worse than developed nations and temperate zones, although studies from nations in temperate zones such as the United States, China, and Russia show a strong possibility for decline in production.

Temperature increases will likely lead to an increase in soil microbial activity. Various conflicting reports demonstrate that this activity, detectable via soil respiration, is likely to decline after a few years due to exhaustion of food supply, while other studies suggest the soil biota will adapt and continue at a heightened respiration rate. This will influence the rate of organic matter breakdown, and thus the C:N ratio in soils. It has also been suggested that the C:N ratio affects the propensity of soil to compact and the ease of restructuring of soil after a compaction event (i.e. heavy machinery, animal hooves, etc.). The nutrient cycling in the soil system is also vastly important for crop growth – be that arable crops, pasture, horticulture, silviculture, etc.

In New Zealand climate change, coupled with shifts in international production and markets, will trigger land-use changes. Climate change within New Zealand is expected to be more benign than it will be globally. Modelling suggests temperatures will increase less than the global average due to New Zealand's oceanic climate. A general trend of increased rainfall in the west and drier conditions in the east is expected. Agricultural regions in eastern New Zealand that do not have Alps-fed rivers are likely to face greater shortages of water. Under moderate (1–3°C) temperature and CO_2 increases, pastoral systems may fare better than arable systems. Increased frequency and severity of drought or susceptibility to disease or pests could increase variability in production levels and trigger changes in farm ownership patterns.

If certain parts of New Zealand begin to experience wetter winters and drier summers, then some specific areas may become more reliant on single types of production or become uneconomic altogether. This could trigger population shifts from less- or unproductive areas as land managers, growers and field staff vie to retain jobs and income. If, on the other hand, annual rainfall changes very little, then population movement will be minimal. Dairy could be significantly impacted by climate change. For example, a 10% reduction in milk production as a result of drought, similar to levels experienced in 1998/1999, could reduce private consumption and GDP by 0.3–0.5%.

Variability – and therefore uncertainty – will be most pronounced at farm and paddock scales. Farmers will be faced with more complex decisions in response to changing climate experienced in the context of local weather patterns, changing markets and the interactions among environmental and social drivers. They will have to adapt farm practices in often unpredictable ways and likely be more open to experimentation and adaptation. However, both agricultural technology and our understanding of agricultural systems and how to manage them effectively are continually improving, and could help future adaptation.

4.2 Biodiversity

Biodiversity represents the totality of life on the planet, ranging from broad biomes such as tropical forests or dry savannahs to the genetic diversity found within a species. Current patterns of biodiversity within New Zealand resulted from evolutionary processes operating over millions of years combined with more recent changes over tens to hundreds of years resulting from human activities, particularly land conversion.

The Convention on Biological Diversity's 2010 Targets (http://www.cbd.int/2010-target/) identified climate change as a key threat to global biodiversity (Goal 7). The effects of climate change will be diverse owing to the complex nature of ecosystems and ecological communities. Species will respond differently depending on their physiology, distributions, life cycles (e.g., phenology or the timing of flowering), relationships with other species, and the impacts of other driving forces of biodiversity change including disturbance (e.g., extent and intensity of habitat loss and fragmentation), increased likelihood for the introduction and spread of invasive species, or reduced viability of species and ecosystems resulting from pollution or other debilitating factors.

Although predicting the exact nature, location, and timing of climate change effects on biodiversity will be difficult, a number of broad effects on biodiversity are expected:

- Increased loss of biodiversity due to species extinctions
- Suitable habitats for many species will shift to higher latitudes or higher elevations as average temperatures increase overall
- Disturbance intensity and frequency (e.g., storms) will increase, favouring some species that colonise disturbed areas while disadvantaging others
- Coastal wetlands could decrease globally by 20%
- Extinction risk will increase for many species, either globally, regionally, or locally.

Overall, climate change is expected to exacerbate observed trends in biodiversity decline, including deforestation, decrease in average species abundance, increased risk of extinction, increased fragmentation, alteration of nutrient cycles, or intensification of harvest of commercial species.

New Zealand can expect similar broad biodiversity trends. As climate changes, we can expect changes to ecological integrity (*sensu* Lee et al. 2005) as shifting species and communities alter patterns of indigenous dominance, species occupancy, and environmental representativeness. The nature of those changes will vary in complex ways, but overall we can expect local trends to be similar to global ones, i.e. shifting ranges of species to higher latitudes (north to south) and elevations, as temperature is a key driver affecting species distributions.

Globally, the 2010 Biodiversity Target is 10% protection for all ecosystems. New Zealand is fortunate in having roughly a third of its area protected for biodiversity conservation, including national conservation estate, regional parks, local reserves, and private covenant schemes such as the Queen Elizabeth II National Trust and Nga Whenua Rahui. Nationally, the target for protection of biodiversity is 20% of each of the 500 Level IV land environments nationally. Despite the relatively high level of overall protection, the protected areas network does not well represent all ecosystems and habitats. It is biased towards colder, wetter, and economically less productive land environments, such that two-thirds of the 500 Level IV land environments are threatened or under-protected. Lowland and coastal ecosystems have experienced higher rates of loss in terms of percentage remaining in indigenous vegetation, and overall have lower levels of formal legal protection. As climate changes, less mobile or poorly dispersing species could be particularly challenged, especially those remaining in isolated forest fragments throughout depleted lowland and coastal environments.

From a national perspective, responding to climate change will trigger a re-evaluation and re-prioritisation of conservation lands across New Zealand, with the degree of change depending on the magnitude of climate change. Factors to consider will include the total size of the protected area network, the distribution of areas subject to formal and informal protection, and the schedule of management actions needed to maintain or enhance ecological integrity.

Protected area network size could increase to include remaining unprotected areas of native cover, or an additional 17.6% of New Zealand's total area (Table 4). However, further research would be needed to determine the benefits of expanding the network. Any substantial increase in network size would also be highly contentious, as it would reduce the land available for other uses such as production or urbanisation.

Table 4 Percent of area in native and non-native cover that is protected/not protected

	Protected	Not Protected
Native Cover	32.0%	17.6%
Non-Native Cover	1.5%	48.8%

If the protected areas network did not increase substantially in total area, the key considerations become their location and maintenance. A more flexible approach to protected areas could be adopted nationally and regionally. For example, iconic areas such as national parks would be preserved as they provide much more than just biodiversity benefits. Other areas such as scientific reserves could be re-evaluated and traded for remaining areas of non-protected native cover if analyses showed that alternative areas provided greater biodiversity benefits to counter climate change, perhaps via market-like mechanisms similar to those for carbon. In addition, consideration might be given to take a more active role in assisted migration of species, especially in highly fragmented landscapes.

Locally, climate change could also lead to increased pressure from pests and weeds and thereby hamper efforts to maintain native biodiversity. For example, climate partly limits the distribution of the Australian brushtail possums, a key pest species. A warmer climate would increase their potential range and abundance, thus triggering the need to expand the area or increase the intensity and frequency of control. A similar response could be expected from most of NZ's warm-blooded mammalian pest species. Finally, warmer temperatures would increase the viable range of many weedy plant species and also necessitate the need for more strenuous control and containment measures across a range of scales, leading to increased costs for pest control overall.

4.3 Ecosystem Services

Ecosystem services are those functions provided by ecosystems that are beneficial and useful to humans. They have gained increasing attention since the publication of Costanza et al.'s (1997) seminal paper that attempted to calculate the economic value provided by ecosystem services. They estimated the total value of global ecosystem services as $33 billion US dollars, or twice global GDP at the time of the analysis.

The Millennium Ecosystem Assessment (MEA hereafter) represented the first attempt to classify and describe comprehensively the state and trend of ecosystem services globally. It identified 24 services divided into four categories: supporting, provisioning, regulating, and cultural (Figure5). Based on the best information available at the time of publication in 2005, the MEA found that 15 of the 24 services are either degraded or not used sustainably.

The MEA modelled scenarios projecting increases in demand for services globally such as cereal consumption (1.5–1.7 times higher), fish consumption (1.3–1.4), water withdrawals (1.3–2.0), and biofuel production (5.1–11.3). However, increases in supply were more uncertain and potentially varied substantially across regions, e.g., increased soil erosion in Sub-Saharan Africa or regional water stress as demand begins to outstrip supply.

PROVISIONING SERVICES			REGULATING SERVICES		
Food	Crops	▲	Air Quality Regulation		▼
	Livestock	▲	Climate Regulation		▼
	Capture Fisheries	▼		Global	▲
	Aquaculture	▲		Regional and Local	▼
	Wild Foods	▼	Water Regulation		+ / –
Fiber	Timber	+ / –	Erosion Regulation		▼
	Cotton, Hemp, Silk	+ / –	Water Purification and Waste Treatment		▼
	Wood Fuel	▼	Disease regulation		+ / –
Genetic Resources		▼	Pest Regulation		▼
Biochemicals, Pharmaceuticals, Natural Medicines		▼	Pollination		▼
Freshwater		▼			

CULTURAL SERVICES			
Spiritual and Religious Values	▼	Recreation and Ecotourism	+ / –
Aesthetic Values	▼		

Figure 5 Global trends in ecosystem services. Figure adapted from the Millennium Ecosystem Assessment (2005).

While the scenarios did not point to global thresholds being crossed that could drastically alter provision of services, the models used in the analysis lacked the inclusion of critical non-linear dynamics needed to identify possible tipping points or thresholds.

Subsequent studies to the MEA also highlighted uncertainty and variability in future ecosystem services, especially in light of climate change. Globally, risks of forest loss, wildlife declines, and changes in runoff among different regions are high. Preliminary studies have also shown no consistent relationship between the potential provision of ecosystem services and global biodiversity conservation. Conversely, a study of the Willamette Valley in Oregon, USA did observe positive relationships between possible future provision of ecosystem services and biodiversity.

Several European studies also reported variability, both in type and location, in future ecosystem service supply and vulnerability. In one study, forested and bioenergy production area increased, while the number of populations subjected to water stress increased, as did expected rates of local extinction and total soil organic carbon. A second study projected negative impacts on food and fibre production, which in turn impacted on farmer livelihood, and positive impacts on energy production and outdoor recreation. However, both studies identified southern Europe as being more vulnerable to future climate changes.

A detailed review of all trends in ecosystem services is beyond the scope of this report. Instead we provide additional detail for four ecosystem services that are important in a New Zealand context to illustrate the issues highlighted globally by the MEA:

- eutrophication/nitrogen enrichment of water ways (provisioning service)
- pollination (regulating service)
- air quality (regulating service)
- soil erosion (supporting service).

Eutrophication, the increase in nutrients such as nitrogen into fresh and coastal waters, is a growing problem across the world. Eutrophication can increase unwanted algal vegetation in lakes, negatively affecting fish populations and making the affected water body unsuitable for drinking or recreational uses. The MEA considered eutrophication one of the most important direct drivers of ecosystem services change. Although many sources of increased nutrients exist, such as industrial/storm water runoff or septic tank leakage, the most significant source is non-point source run-off containing synthetic fertilisers. All drivers of eutrophication have increased globally over the previous few decades, and an increase in eutrophication has been documented in New Zealand following an increase in intensive agriculture.

Pollination services have been found to be in decline worldwide. A reduction in pollination services would affect both planted crops and native plants by reducing reproductive success. Declines in pollination have been linked directly to increased urbanisation and a lack of foraging area and has been hypothesised as also being affected by invasive bee species, pesticide use and emerging diseases.

Air quality is influenced by the presence of gases and particulates, and dependent on the ability of the atmosphere to cleanse itself. The concentrations of several gases in the atmosphere have increased in the last decades. This has included not only the Kyoto or greenhouse gases (CO_2, CH_4, N_2O), but also other forms of air pollution such as particulates in the air. Air-borne particulates and increased smoke pollution can negatively affect vegetative productivity and cause decreases in rainfall, both of which in turn affect multiple ecosystem services. Ecosystems can contribute to the regulation of air quality for instance by "soaking" up gases; the feedback loops that prevent this service are therefore dangerous.

Soil erosion has increased due to the increase in intensive land use and some soil management practices combined with the decrease in appropriate soil conservation practices. In New Zealand this has followed an increase in land converted from native or plantation forests to agriculture. Soil erosion has been identified as a problem in several New Zealand regions or catchments including the Styx river catchment, south Canterbury Downlands, Mackenzie Basin, and Manawatu River. However, more recent research suggests that New Zealand overall is a carbon sink, which could have important implications for national carbon emission budgets.

4.4 Energy

Energy is the lifeblood of the economy. Access to inexpensive and plentiful energy has underpinned the industrial revolution by reducing geographic trade barriers and fostering global supply chains. In wealthier countries such as New Zealand it has dramatically affected land-use planning via the development of extensive transport networks, dispersed urban and peri-urban development, and dramatic transformations in lifestyle.

Globally, long-term prognoses for energy security vary significantly. While there is agreement that energy supplies will not run out in the next 100 years, opinions vary dramatically regarding future supply-demand balance. A permanent shortfall of supply relative to demand would trigger cost increases across all goods and services and lead to a substantial reconfiguration of the global economy and, by extension, land use across all scales. Conversely, sharp price spikes, perhaps coupled with efforts to "de-carbonise" the global economy to reduce CO_2emissions into the atmosphere, could spur more rapid transition to renewable energy sources such as bioenergy and wind power.

On the demand side, the US Energy Information Agency (US EIA) projects a 49.2% increase in global energy consumption from 2007 to 2035 across all energy categories (Table 5). The International Energy Agency projections are similar: 40% growth from 2007 to 2030. Energy demand growth is expected to come primarily from the developing world as a result of both population and economic growth. Non-OECD consumption is expected to rise by 83.6%, which represents 86% of all new demand. Demand in China and India alone will account for approximately half the expected increase, followed by strong increases from Associsation of Southeast Asian Nations (ASEAN) countries (Table 7) and 10% from the Middle East.

For example, rising standards of living in China and India are expected to increase demand for private passenger vehicles. According to the World Bank, New Zealand had 615 passenger cars per 1000 persons as of 2007, whereas China had 22. The World Bank provided no statistic for India, although Wikipedia provided a figure of 12 per 1000 as of 2008. Expected population increases and rising affluence among major oil producing nations, especially OPEC, could also trigger "peak net exports," as more production shifts to satisfy domestic demand.

On the supply side, considerable variation exists in expected future trends, particularly related to liquid fuels. The variation stems from 1) lack of robust and independently verifiable data for proven reserves and rates of production, 2) disagreement over the magnitude of "unproven" or undiscovered reserves, 3) long-term implications of investment trends, and 4) uncertainty regarding how quickly and to what degree non-conventional, non-renewable (e.g., tar sands, shale oils) or renewable (e.g., solar, wind, biofuels) energy sources could be substituted for conventional energy sources such as oil, natural gas, and coal.

For liquid energy supplies, estimates vary from dire, e.g., global oil production has peaked or will soon peak, to highly optimistic, e.g., peak oil is a myth, although recently (May 2011) the chief economist of the International Energy Agency indicated that crude oil production peaked in 2006. Given the diversity of opinion on future supply trends, data on observed historical trends help shed some light on the situation. Rates of discovery (volume of new source per year) peaked in the 1960s and has declined steadily since then. In its Statistical Review of World Energy 2010, BP reported long-term (1965–2009) trends for 49 individual nations: as of 2009, seven countries reported maximum production representing 7.6% of global production; another 7 countries reported production within 90% of maximum levels, accounting for 15.2% of 2009 production; the remaining 35 countries had 2009 production levels <90% of maximum production, which occurred in 2005 or earlier in all cases except one (United Arab Emirates in 2006).

Table 5 Projected growth in global energy consumption and production to 2035 in the Reference Case (Source: US EIA International Energy Outlook 2010)

Energy	2007	2035	Growth (%)	Units
Consumption				
Total World	495.2	738.7	49.2	10^{15} Btu
OECD	245.7	280.7	14.4	
Non-OECD	249.5	458.0	83.6	
Production				
Liquid Fuels				10^{6} barrels per day
Total	84.8	110.6	30.4	
Conventional	81.4	97.7	20.0	
Unconventional	3.5	13.0	271.4	
Extra-heavy Oil	0.6	1.5	150.0	
Bitumen	1.4	5.2	271.4	
Coal-to-Liquids	0.2	1.4	600.0	
Gas-to-Liquids	0.1	0.4	300.0	
Shale Oil	0.0	0.4	-	
Biofuels	1.2	4.1	391.7	
Natural Gas	3.0	4.4	46.7	10^{12} m^3 per year
OECD	1.1	1.3	18.2	
Non-OECD	1.9	3.1	63.2	
Coal	132.7	206.9	55.9	10^{15} Btu per year
OECD	41.6	49.3	18.5	
Non-OECD	91.1	157.5	72.9	
Electricity	18.8	35.2	87.2	10^{15} watts per year
OECD	10.1	13.6	34.7	
Non-OECD	8.6	21.6	151.2	

The US EIA projects an additional 26.2 million barrels per day of world liquid fuels production by 2035: 16.3 million and 9.5 million barrels per day from conventional and non-conventional sources, respectively (Table 5). Unconventional sources have several drawbacks including: 1) lower net energy ratios compared to conventional sources, 2) continuity of supply for some renewables (e.g., solar, wind), and 3) substantial lead-times to construct associated infrastructure. Biofuels in particular currently receive quite a lot of attention, particularly given their potential to help mitigate greenhouse gas emissions. Large shifts to biofuel production would have substantial impacts on land use. A recent report led by Scion indicated that New Zealand could potentially meet its transport energy needs from biofuels through woody biomass production on approximately two million hectares of marginal lands.

A global modelling study similarly concluded that there is ample land area to produce biomass capable of meeting future energy needs without affecting either food production or nature conservation. Interestingly, the US EIA projects only a modest growth in biofuel contribution to global energy supply by 2035, from 1.2 to 4.1 million barrels per day, or from 1.4% to 3.7% of total liquid fuel supply. Furthermore, the 2010 projection was lower than the 2009 projection: 3.5 versus 5.9 million barrels per day in 2030.

Natural gas production increases were expected almost entirely from non-OECD countries, with 20% each coming from the Middle East and the non-OECD Europe/Eurasia and Asia, and Africa accounting for 15%. However, that trend may change given increasing investment in natural gas production via hydraulic fracture techniques (“fracking”), especially in the United States. Coal shows similar trends, with 90% increases for non-OECD countries, with China’s coal-fired electricity generation capacity tripling by 2030. However, increasing use of either natural gas or coal would exacerbate CO_2 production unless steps are taken to curb emissions. For example, the IEA projects 17% less use of natural gas in its 450 Scenario compared to the Reference scenario.

Coal and electricity production are also projected to rise markedly, particularly among non-OECD nations (Table 5). However, even with such large increases, per capita production of coal and electricity will remain much lower in non-OECD than OECD countries by 2035.

Overall, efforts to improve energy security over the next 50–100 years will have significant implications for land-use patterns. From a supply perspective, shifts to more renewable energy sources such as biofuels or wind power will directly drive land-use changes as the value of those uses increases. The IPCC SRES scenarios all forecast increased land area for biofuel production, although the range varies substantially among the scenario families.

From a demand perspective, reductions in energy use without corresponding gains in energy efficiency, especially with regard to transport, would necessitate new paradigms in land-use planning. Such trends have already begun to emerge to some degree, as evidenced by “smart growth” and “new urbanism” movements that advocate more compact, multi-use, multi-modal development. However, substantial changes to existing urban developments, which can encompass 80–90% of the existing infrastructure, would require substantial investment and likely take decades to achieve.

For New Zealand the consequences of a permanent supply/demand imbalance (e.g., Peak Oil) would be profound, given its remote location. Likely consequences would be lower overall economic activity as a result of reduced exports and tourism, increased cost of imported goods due to increased competition and costs, and, domestically, the need to reconfigure landscapes to adapt to lower energy availability. Conversely, rapid and successful adaptation to renewable energy sources, both globally and domestically, could help adapt current land-use patterns and living standards to future conditions.

4.5 Economic Development

Continued economic development is necessary both to maintain current living standards in developed countries and to lift living standards in developing countries. Fostering economic development is a key policy objective of all levels of government and business and is a prime motivator behind many international agreements and treaties, such as free trade agreements and economic alliances, e.g., the EU.

Almost all scenarios or projections of economic development forecast future growth over the next 50–100 years, regardless of the timeframe involved. Economic development is typically represented via trends in gross domestic product (GDP). The IPCC SRES scenarios forecasted global GDP to increase from $21 trillion in 1990 to a range of $243–500 trillion 550 trillion (measured in constant 1990 US dollars). The nearly two-fold difference in global GDP in 2100 resulted from a modest difference in expected annual rate of global growth: 2.25% (low estimate) versus 3.01% (high estimate).

More recent research showed similar trends, albeit over shorter timeframes. Projections vary depending upon methods used and underlying assumptions made. Although most projections report values in US dollars, there is considerable variability in the exact form used. Different studies index to different years, some use absolute values, others use purchasing power parity (PPP), yet others use market exchange rates. This makes direct comparisons among projections challenging.

Despite those issues there is broad agreement that the next 50 years will bring a shift in the world economic order. The main themes in that regard are the emergence of Asia and some South American and African economies in both absolute and relative terms. Table 6 provides examples of those expected shifts while also highlighting the difficulty of cross-study comparisons. The table lists the largest economies by rank for 2010 based on International Monetary Fund data and for two projections to 2050 based on two recent reports by Price Waterhouse Cooper and HBRC, which each use different US dollar metrics. The IMF estimated 2010 global GDP at $62,888 billion US dollars. New Zealand GDP at $140,434 billion US dollars ranked 51st globally. Of the top 30 countries in terms of 2010 GDP, thirteen were developing countries. This listing has remained relatively stable since 1996. Between 2003 and 2006, China, India and Argentina experienced GDP growth rates above 8% per year. In contrast, the high income countries such as the United States, New Zealand, Australia and most of Europe, experienced an average 2.5% growth over the same period.

Going forward the two projections show a substantial re-ordering of national economies. China overtakes the USA in the 2030–2040 timeframe. India is also expected to eclipse the USA, although disagreement exists whether that shift will happen before 2050, hence India's rank differs between the two projections. Several European economies, such as Belgium, Sweden and Norway, and Austria, drop out of the top 20 or 30. Others, such as Germany, France, Spain, and Italy, retain relatively high rankings but lose ground relative to emerging economies such as Brazil and Mexico. Development in other countries such as Russia and Indonesia shows more variability. Finally, a number of developing countries have the potential to break into the top 20 or 30 by 2050.

Table 6 Global rank, estimated GDP, and percent (%) global GDP by country as of 2010 and projected 2050 GDP and global rank. USD = United States Dollars. PPP = Purchasing Power Parity. * indicates a developing country. (Data Sources: International Monetary Fund, World Economic Outlook Database, April 2011, Hawksworth & Tiwari 2011; Ward 2011)

	Top 30 2010 (IMF)			Top 20 2050 (Hawksworth&Tiwari 2011)		Top 30 2050 (Ward 2011)	
Country	GDP (10^9 USD)	% Global GDP	Rank	GDP at PPP (10^9 2009 USD)	Rank	GDP (10^9 2000 USD)	Rank
United States	14,658	23.31	1	37,876	3	22,270	2
China*	5,878	9.35	2	59,475	1	24,617	1
Japan	5,459	8.68	3	7,664	5	6,429	4
Germany	3,316	5.27	4	5,707	9	3,714	5
France	2,583	4.11	5	5,344	11	2,750	9
United Kingdom	2,247	3.57	6	5,628	10	3,576	6
Brazil*	2,090	3.32	7	9,762	4	2,960	7
Italy	2,055	3.27	8	3,798	15	2,194	11
Canada	1,574	2.50	9	3,322	16	2,287	10
India*	1,538	2.45	10	43,180	2	8,165	3
Russia*	1,465	2.33	11	7,559	6	1,878	15
Spain	1,410	2.24	12	3,195	18	1,954	14
Australia	1,236		13	-	-	1,480	17
Mexico*	1,039	1.65	14	6,682	7	2,810	8
South Korea*	1,007	1.60	15	3,258	17	2,056	13
Netherlands	783	1.25	16	-	-	798	23
Turkey*	742	1.18	17	5,298	12	2,149	12
Indonesia*	707	1.12	18	6,205	8	1,502	16
Switzerland	524	0.83	19	-	-	711	27
Poland	469	0.75	20	-	-	786	24
Belgium	466	0.74	21	-	-	-	-
Sweden	456	0.72	22	-	-	-	-
Saudi Arabia*	444	0.71	23	3,039	19	1,128	21
Taiwan	431	0.68	24	-	-	-	-
Norway	414	0.66	25	-	-	-	-
Austria	377	0.60	26	-	-	-	-
Argentina*	370	0.59	27	2,549	20	1.477	18
South Africa*	357	0.57	28	-	-	529	30
Iran*	357	0.57	29	-	-	732	25
Thailand*	319	0.51	30	-	-	856	22
Colombia	-	-	-	-	-	725	26
Egypt	-	-	-	-	-	1,165	19
Hong Kong	-	-	-	-	-	657	28
Malaysia	-	-	-	-	-	1,160	20
Nigeria	-	-	-	4,530	13	-	-
Venezuela	-	-	-	-	-	558	29
Vietnam	-	-	-	3,939	14	-	-

A number of interrelated factors will contribute to this overall expected trend. Population is a key factor. Most Asian, African, and some South American countries are expected to experience substantial population increases, resulting in increasing numbers of younger citizens and a growing middle class. In contrast, developed economies such as the EU, USA, and Japan will experience slowing population growth or even stabilisation/decline, resulting in an aging population and leading to reduced work force participation and higher levels of government and private investment to care for the larger share of older citizens. Such trends are also expected in New Zealand. Structurally, Asian countries appear to be in a more favourable position, given their substantial manufacturing base, lower labour rates, and higher rates of saving and investment. Balance of trade has also been strongly in the favour of many Asian economies recently and that trend is expected to continue, at least into the foreseeable future.

The coming economic shift thus will create many opportunities and challenges for New Zealand, with corresponding repercussions for land-use change. On the demand side, the expanding Asian and other Southern Hemisphere economies will grow or open up new market opportunities for New Zealand products, assuming that demand growth cannot completely be met domestically. Conversely, existing market destinations such as the EU seem likely to stabilise or even decline. On the supply side, economic growth in the same developing countries will spur investment in research, technology and infrastructure, which could increase competition with similar New Zealand products.

On balance, overall global economic development in developing countries should generate a net increase in demand for New Zealand products, especially agricultural products. Prospects for expansion of agricultural production are as follows:

- ~300 000 ha (~1%) of New Zealand supports exotic vegetation (gorse and broom, mixed exotic shrub, deciduous hardwoods) occurring on a range of land use capability classes
- ~ 4.7 million hectares of land supports unprotected native cover. This land would be available for agricultural expansion but will have consequences for native biodiversity and ecosystem services.

Conversely, increased demand for manufactured products or services will trigger demand for additional urban land. While not extensive in total area, urbanisation trends have been shown to encroach differentially on areas with higher land use capability ratings.

Assuming the total production area remains the same or increases only slightly, economic trends will trigger shifts among production land uses as prices cross above or below different thresholds. The direction and magnitude of those shifts is the subject of this report and dealt with in detail in later sections.

4.6 Globalisation

Assumptions about globalisation constituted one of the two main axes that delineated the IPCC SRES scenarios. In two scenarios the world continue on a path towards globalisation, resulting in an integrated world where wealth, resources, and technology are shared more equitably. In the other two scenarios the world departs from more recent trends and becomes more disconnected and regionalised, leading to more heterogeneous outcomes and higher degrees of disparity between “winners” and “losers.”

Since the late 1800s the world has moved noticeably closer towards globalisation. The past 20-30 years have witnessed the establishment of a number of regional free trade areas or common markets (Table 7). In many cases, the number of countries within the agreement has grown or subsequent agreements have been made between various trade areas, e.g., ASEAN countries and the three larger Asian countries in terms of GDP and ASEAN countries and ANZCERTA (Australia and New Zealand).

While these trends generally point towards increasing globalisation, more recent events cast some doubt over whether such trends can be sustained in the long term. The global financial crisis of 2008 has strained the European Union as a result of financial bailouts for several member states. As a result, parties with nationalist agendas have gained representation and there are calls to modify or perhaps abandon the Schengen Agreement and reinstate border control among participating EU member states. In addition, there has been continued failure to implement a global free trade agreement, post-Kyoto climate change negotiations have not been successful to date, progress towards the Millennium Development Goals has been uneven, and targets for reducing rates of biodiversity loss by 2010 have been missed. Conversely the number of bi-lateral or multi-lateral agreements are increasing, including successful and on-going efforts by New Zealand to secure free trade agreements several trading partners.

Trends in world views will have consequences for land use in New Zealand in a number of ways. Economic treaties and trade agreements shape market conditions, which in turn affects land-use decisions. Strong swings in market conditions can have long-lasting effects, such as through provision of infrastructure that constrains future land-use options or leads to conversions such as forestry-to-dairy that would require decades to reverse. Other agreements such as those related to climate change, biodiversity, global security, or humanitarian endeavours can also affect land-use change by either limiting uses at some locations, e.g., protection of significant wetlands under the international RAMSAR agreement, or driving land-use changes to meet internationally agreed targets, e.g., carbon reduction under the Kyoto Protocol.

Table 7 Trade agreements and their member countries

Agreement	Start Year	Aim	Country Members
Association of Southeast Asian Nations(ASEAN)+3	1999	Accelerate economic growth, social progress, and cultural development	Brunei, Cambodia, China, Indonesia, Japan, Korea, Lao People's Democratic Republic, Malaysia, Myanmar, The Philippines, Singapore, Thailand, Vietnam
Australia New Zealand Closer Economic Relations Trade Agreement (ANZCERTA)	1983	Free Trade Agreement	Australia and New Zealand
AANZFTA (ASEAN-Australia-New Zealand Free Trade Area)	2009	Free Trade Agreement	ASEAN countries + Australia and New Zealand
AANZFTA — ASEAN+3	Not yet ratified		
ASEAN Free Trade Area (AFTA)	Signed 1992	Trade bloc agreement supporting local manufacturing in all ASEAN countries	Brunei, Indonesia, Malaysia, Philippines, Singapore and Thailand. Vietnam joined in 1995, Laos and Myanmar in 1997 and Cambodia in 1999.
African Free Trade Zone (AFTZ)	Signed but yet to be ratified by all countries	Free Trade Agreement	Angola, Botswana, Burundi, Comoros, Djibouti, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Lesotho, Libya, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Rwanda, Seychelles, Swaziland, South Africa, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe.
Asia-Pacific Trade Agreement (APTA)	1976	Promote economic development and cooperation through the adoption of mutually beneficial trade liberalization measures	Bangladesh, China, India, Republic of Korea, Lao People's Democratic Republic, Sri Lanka
Central European Free Trade Agreement (CEFTA)	1992	Participating countries hoped to mobilize efforts to integrate Western European institutions and through this, to join European political, economic, security, and legal systems, thereby consolidating democracy and free-market economics	Current members: Albania, Bosnia and Herzegovina, Croatia, Macedonia, Moldova, Montenegro, Serbia and United Nations Interim Administration Mission in Kosovo (UNMIK)
Commonwealth of Independent States Free Trade Agreement (CISFTA)	1994	Free Trade Agreement	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Kyrgyzstan
Dominican Republic – Central America Free Trade Agreement (DR-CAFTA)	2009	Free Trade Agreement	United States, Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua, Dominican Republic

Agreement	Start Year	Aim	Country Members
Economic and Monetary Community of Central Africa (CEMAC)	1999	Promote economic integration among countries that share a common currency	by Cameroon, Central African Republic, Chad, Congo, Equatorial Guinea and Gabon
European Economic Area (EEA)	1994		Countries from European Free Trade Association (EFTA), the European Community (EC), and all member states of the European Union (EU)
CARICOM http://www.caricom.org/jsp/community/community_index.jsp?menu=community	First formed in 1972; several revisions – last revision 2000; agreement with EC in 2008	Purpose is to promote economic integration and cooperation among its members, to ensure that the benefits of integration are equitably shared, and to coordinate foreign policy	Member states: Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Lucia, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago Associate members: Anguilla, Bermuda, British Virgin Islands, Cayman Islands, Turks and Caicos Islands
Economic Community of West African States (ECOWAS)	1975	Promote economic integration	Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, Gambia, Ghana, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo
Greater Arab Free Trade Area (GAFTA) http://www.mit.gov.jo/Default.aspx?tabid=732	1998	Establish an Arab common market	Saudi Arabia, Egypt, United Arab Emirates, Kuwait, Morocco, Iraq, Syria, Sudan, Tunisia, Qatar, Libya, Oman, Yemen, Lebanon, Jordan, Bahrain, Palestine
Latin American Integration Association (ALADI)	1980	Create a free trade zone in Latin America	Argentina, Brazil, Chile, Mexico, Paraguay, Peru, Uruguay, Bolivia, Colombia, Ecuador, and Venezuela
North American Free Trade Agreement (NAFTA)	1998	Create a trilaterial trade block	United States, Canada and Mexico
South Asia Free Trade Agreement (SAFTA)	2006	Creates free trade area	India, Pakistan, Nepal, Sri Lanka, Bangladesh, Bhutan and Maldives
South Pacific Regional Trade and Economic Cooperation Agreement (SPARTECA)	1981	Nonreciprocal trade agreement – Australia and New Zealand offer duty-free and unrestricted access for specified products originating from the developing island member countries of the Pacific Islands Forum	Australia, New Zealand and developing islands in the Pacific Islands Forum
Trans-Pacific Strategic Economic Partnership (P4)	2005	Multilateral free trade agreement	Brunei, Chile, New Zealand and Singapore.

4.7 Mineral Resources

Mineral resources play an important role in land use directly and indirectly. Mining operations, especially surface mining, prevent other land uses, either while extraction takes place or to maintain future access to the desired resource. Mining can also limit adjacent land uses due to, for example, health, safety or aesthetic concerns.

Globally, extraction and processing of all minerals are showing long-term increasing trends, although fluctuations do occur over shorter timeframes reflecting current economic conditions. Extracted minerals strongly indirectly influence land use via 1) altering land suitability for agriculture, 2) providing raw materials for construction of infrastructure, or 3) serving specialised uses in highly technical applications.

Application of mineral-derived products (e.g., superphosphate) alters patterns of agricultural production by enhancing suitability and productivity. In New Zealand five major elements derived from minerals substantially improve land productivity: phosphorus, potash (potassium), calcium, sulphur, and iron. Trace elements including boron, cobalt, copper, iodine, magnesium, molybdenum, selenium and zinc also help overcome natural limitations in certain locations. Without these inputs agricultural uses in some locations would not be economically viable and in other areas would be impossible.

For construction, key primary materials traded globally include aluminium (from bauxite), cement, and iron ore for steel manufacturing. Continued availability at affordable prices will strongly influence the capacity for future infrastructure development. Other common construction materials such as sand and gravel, clay, or aggregate tend to come from much closer sources, i.e. within New Zealand.

Specialised uses range widely including non-agricultural or construction uses of common minerals (e.g., iron as a dietary supplement) or highly technical applications such as electronic components, manufacturing equipment, or medical devices. For example, rare earth minerals are essential components for many high-tech applications related to telecommunications or hybrid vehicle technologies that could influence future land-use patterns. Many uncommon minerals with highly specialised functions only occur in economically viable concentrations in a limited number of countries, raising concerns about long-term security of supply and affordability.

While climate change will not likely directly have an impact on mineral production in most cases, climate change coupled with decreasing access and affordability of mineral resources would have significant repercussions for land-use change. For example, reduced availability of inexpensive mineral phosphorus could trigger fertiliser price increases. This could affect farm profitability and lead to shifts among production land uses or, in the worst case, land abandonment. Similar issues with other minerals could have similar effects. Decreasing access to other minerals could also limit the rate of production and adoption of new technologies.

Table 8 lists many of the major mineral resources traded globally. It shows estimates of remaining global supply as compiled by the US Geological Survey as of 2008. The table shows estimated global extraction rates, estimated levels of economic reserves (i.e. reserves that can be extracted at current prices) and the global reserve base, which estimates the total amount of recoverable reserves currently known to exist. The right hand three columns estimate the years of supply remaining, assuming 1) three different rates of growth in extraction rates (0, 1, 3%), 2) no increase in the reserve base, and 3) no recycling. While admittedly a simple analysis, it does highlight that without conservation and recycling the remaining known lifespan of many minerals is decades to perhaps hundreds of years at best. Also, the total reserve base does not indicate the quality (e.g., grams per tonne) of remaining reserves, which influences extraction and production costs. Many minerals already show declining trends in terms of resource quality.

Table 8 Global status of selected mineral resources (Source: U.S. Geological Survey 2009). n/a = not available

				Supply Remaining (Years)[1]		
Mineral	Extraction (Tonnes)	Reserve (Tonnes)	Reserve Base (Tonnes)	0% Growth	1% Growth	3% Growth
AGRICULTURAL						
Phosphorus	156,000,000	15,000,000,000	47,000,000,000	301	140	78
Potash	36,000,000	8,300,000,000	18,000,000,000	500	180	94
Calcium	151,000,000	n/a	n/a			
Sulphur	69,000,000	n/a	n/a			
Boron	4,100,000	170,000,000	410,000,000	100	70	47
Cobalt	71,800	7,100,000	13,000,000	181	104	63
Copper	15,700,000	550,000,000	1,000,000,000	64	50	36
Iodine	27,000	15,000,000	27,000,000	1000	241	116
Magnesium	4,460,000	2,200,000,000	3,600,000,000	807	222	109
Manganese	14,000,000	500,000,000	5,200,000,000	371	156	84
Molybdenum	212,000	8,600,000	19,000,000	90	64	44
Selenium	1,590	86,000	172,000	108	74	49
Zinc	11,300,000	180,000,000	480,000,000	42	36	28
BUILDING AND INFRASTRUCTURE						
Bauxite	205,000,000	27,000,000,000	38,000,000,000	185	105	64
Iron	2,200,000,000	73,000,000,000	160,000,000,000	73	55	39
SPECIALISED						
Beryllium	180	n/a	80,000	444	170	90
Bismuth	5,800	320,000	680,000	117	78	51
Chromium	21,500,000	n/a	n/a			
Germanium	105,000	n/a	n/a			
Rare Earths	124,000	88,000,000	150,000,000	1210	259	122
Titanium	6,250,000	730,000,000	1,500,000,000	240	123	71
Vanadium	60,000	13,000,000	38,000,000	633	200	101

[1]Assuming no recycling.

4.8 Population and Migration

Climate change modelling relies on estimates of emissions, which in turn relies on estimates of socioeconomic conditions including projections of human populations. Population projections for New Zealand and the world take account of expected trends in fertility, mortality, and migration among countries.

Projected global population for the IPCC SRES scenarios came from two organisations: the United Nations and the International Institute of Applied Systems Analysis. Collectively the projected global population in 2100 ranged from 6.507 to 15.090 billion (Table 9). More recent projections by the United Nations showed slightly higher values by 2050 but a slightly lower value to 2100. For comparison the US Census Bureau's 2009 projection to 2050 agreed with the 2010 UN medium variant projection.

Table 9 Population projections used in the IPCC 4th Assessment Report scenarios compared to more recent projections. IIASA = International Institute for Applied Systems Analysis, UNPD = United Nations Population Division, USCB = United States Census Bureau

		SCENARIO		POPULATION (10^6 People)		
SOURCE	DATE	NAME	IPCC SRES	2010	2050	2100
IIASA	1996	Rapid Transition	A1	6850	8488	6507
		Slow Transition	A2	7168	11300	15090
		Rapid Transition	B1	6850	8488	6507
	2007	Probabilistic Projections		6820	8750	8.390
				(6740–6880)†	(7780–9900)†	(6160–11050)†
UNPD	1996	Long-Range Medium	B2	6981	9367	10414
	2008	Low		6909	7959	n/a
		Medium		6909	9150	n/a
		High		6909	10461	n/a
		Constant Fertility		6909	11030	n/a
	2010	Low		6895	8112	6177
		Medium		6895	9306	10125
		High		6895	10614	15805
		Constant Fertility		6895	10942	26844
USCB	2009	World Projection		6845	93170	n/a

†Range from 10th to 90th percentile n/a Not available

The estimated resident population of New Zealand in June 2010 was 4.37 million. Population growth for the year prior was estimated at 52 000 or 1.2%, with 35 500 attributed to natural increase and 16 500 attributed to net permanent migration. Statistics New Zealand recently produced nine population projection series for the period 2010–2061, using the 2009 population as the base value. Each series combined assumptions (low, medium, high) about fertility, mortality, and net migration. For its 2010 population prospects, the UN Population

Division provided estimates for New Zealand population out to 2100 for each of the four variants examined. Table 10 compares projections for New Zealand from Statistics NZ, the UN, and the US Census Bureau.

Table 10 Population projections for New Zealand for selected years from 2010 to 2100. StatsNZ = Statistics New Zealand. UNDP = United Nations Population Division. USCB = US Census Bureau. n/a = not available

SOURCE	BASE	SCENARIO NAME	POPULATION (10^3 People) 2010	2050	2061	2100
Statistics NZ	2009[1]	Series 1	4366	4928	4864	n/a
		Series 2	4372	5317	5359	n/a
		Series 3	4373	5484	5608	n/a
		Series 4	4369	5310	5386	n/a
		Series 5	4374	5597	5755	n/a
		Series 6	4379	5885	6124	n/a
		Series 7	4375	5707	5900	n/a
		Series 8	4376	5888	6174	n/a
		Series 9	4382	6298	6708	n/a
UNPD	2010	Low	4368	5025	4881	4019
		Medium	4368	5678	5841	6323
		High	4368	6376	6926	9473
		Constant Fertility	4368	5705	5884	6479
USCB	2008		4252	5199	n/a	n/a

[1]2009 base value = 4.316 million

Fertility effects: The impact of climate change on fertility is likely to be indirect. Global fertility is still above the rate at which the global population simply replaces itself, but is expected to fall below replacement by about 2020. Due to population momentum (still large numbers of young people at that time) the world population will not stop growing until the end of the 21st century. The main driver of fertility decline is development: higher living standards in developing countries lead to a sharp drop in fertility. Global climate change is predominantly affecting the poor in developing countries.

Mortality Effects: Without effective control measures in place, climate change could affect global mortality as diseases like malaria and dengue fever become more widespread. More frequent and intense heat waves may also increase mortality among the elderly. On the other hand, at higher latitudes, cold-related diseases may decrease. The Global Humanitarian Forum (GHF) estimates that climate change already kills 315 000 per year through hunger, sickness and weather disasters. That figure is expected to rise to half a million by 2030.

Migration Effects: Most of the demographic impact will be via any redistribution of the global population that may be triggered by climate change. Out-migration is expected from countries and regions that are adversely affected by coastal vulnerability, wind (cyclones, typhoons, hurricanes) or water-related stress (water availability, droughts and floods). GHF estimates that at present some 325 million people are seriously affected and that this number will increase to 10% of the world population by 2030. The Stern Report and the International Organisation for Migration (IOM) expect that by the middle of the century more than 200 million people may become permanently displaced. On the other hand, many more will simply adapt to climate change in situ.

Where climate change does trigger migration, much of the redistribution will be within country borders. Only about 3% of the world population (200 million people) currently live outside their country of birth. This may increase to at most 4.5% by 2050. Given continued global population growth, even such a relatively small percentage increase implies a doubling of the number of people moving predominantly to and between middle and high income countries. Within the developing world, climate change may also accelerate urbanisation. Already more than 50% of the world population is urban.

Although climate change may lead to re-location within country borders in most of the world, in New Zealand the main impact will be through international migration. This is because the New Zealand population is highly urbanised, with 78% of the population living in main or secondary urban areas. The rural population, whose livelihood may be directly affected by climate change, is relatively small. On the other hand, research has shown that people increasingly take lifestyle factors into account in their migration decisions. The ageing of the population will increase the number of retirement migrants, who may be attracted to relatively warm and sunny – often coastal – areas. However, research on labour migration has shown that even for people for whom the primary migration motive is work or family, a pleasant climate is increasingly becoming a secondary motive for migration, as weather-dependent leisure activities are demanded more when real incomes increase.

It is difficult to speculate to what extent international migration to and from New Zealand will be affected. The impact will be certainly bigger on immigration than on emigration, because New Zealand emigrants predominantly move to cities in other highly developed countries, in which the impact of climate change is reduced through new infrastructure that protects against storms or flooding. With respect to immigration, various factors may play a role. First, trans-Tasman migration is unrestricted. If Australia is strongly affected through persistent droughts and constrained water availability, this may lead to increased return migration of New Zealanders. Currently about half a million New Zealand citizens live in Australia. Second, there may be some migration to New Zealand from low lying atolls in the Pacific. This issue of the impact of climate change on Pacific Island populations is probably exaggerated. Recent research contends that most of the local populations in the Pacific will prefer adaptation, not migration, with the numbers who are likely to migrate to New Zealand being relatively small.

The potentially biggest impact on New Zealand may be due to migration from global climate change "hot-spots": areas that combine large and high density rural or coastal populations facing relatively large anticipated climate change. The largest number of affected people may be found in India and Bangladesh, coastal China, and the Mekong delta in Vietnam. All four countries have already significant migration linkages with New Zealand. Most of the increase in migration is likely to be through existing channels and policies of the skilled/business stream, the family stream and the humanitarian stream. In 2007/08, 46 000 people were approved for permanent residency. The international obligations/humanitarian stream, through which refugees are admitted to New Zealand, accounts for only 9% of all residence approvals. It is still uncertain that a new official category of environmental refugees, or eco-migrants, will emerge. A global organisation for multi-lateral legally binding institutional arrangements regarding migration, equivalent to the WTO for trade, has not yet been established.

4.9 Societal Preferences for Food and Fibre

Preferences for food and fibre affect land use and land-use change both directly and in combination with other key drivers. An increasing global population will require more food, as would shifts in dietary preferences as outlined above. Increasing and/or changing needs can be met from expansion of production land, increased productivity on existing productive land, or both.

Food preferences and the way both developed and developing countries are choosing their foods have changed. This section will examine trends at the broad scale of developed and developing countries, as well as for New Zealand and nine developing countries which are represented in the list of top 30 nations by GDP (Brazil, China, India, Indonesia, Mexico, Republic of Korea, Russian Federation and Turkey) (Table 6).

An examination of data for food production indicators from the 1960s to the present has provided an insight into some of these trends. Both developing and developed countries have increased their food production since the 1960s, with developing countries increasing production by a larger margin than developed countries. Developing countries have experienced a four-fold increase in cereal production since the 1960s. The eight countries of interest have not experienced the same projections of cereal production growth. China and India, however, have both experienced exponential growth in cereal production. For China at least, this is more likely to be caused by demand fuelled by an increase in population than an increase in cereal within an individual's diet. Indeed, consistent with trends across developing nations, Chinese meat consumption on an individual level increased dramatically since the 1960s, while cereal consumption has levelled off.

One emerging trend is that developing countries are eating more calories per person per day, and consuming more meat compared with the 1960s. Kilocalorie intake per person per day increased across all developing countries from 1923 kilocalories per person per day in the 1960s to 2665 kilocalories per person per day in 2001. It also rose steadily on an individual country basis in all nine countries of interest. Meat consumption per capita rose steadily from 9.2 kg per person in 1961 to 28.1 kg per person in 2001. While much higher than historic values, these per capita values remain much lower than in developed countries (3281 kilocalories per day, 78 kg meat per year as at 2001), many of which also have worsening problems with obesity, including New Zealand.

4.10 Water

Climate change affects hydrological cycles across scales, which in turn changes patterns of the distribution and access to water resources. Coupled with growing populations, especially in developing countries, and associated economic, social, and technological trends, water stress is expected to increase markedly in certain areas of the world over the next century. Furthermore, impacts on water resources are expected to be one of the earliest mechanisms through which climate change will manifest itself.

The IPCC undertook a technical analysis of the potential impacts on water resources as part of the SRES scenarios. The report highlighted the linkages between observed climate change and water-related impacts over the past several decades. Potential changes to hydrological cycles included:

- Precipitation increases at high latitudes and parts of the tropics and decreases in some sub-tropical and lower mid-latitude regions
- Higher uncertainty elsewhere due to variability in projections among different climate change models
- Increased intensity and variability leading to increased flood and drought risk
- Decrease in glaciers and snow cover, leading to changes in seasonal water flows
- Changes in water quality due to higher water temperatures and increased intensity and variability.

Regarding water resources and security, the report drew the following conclusions:

- Water availability increasing with precipitation at high latitudes and some tropical areas
- Decrease in water availability in mid-latitude and tropical dry areas (i.e. dry areas become drier)
- Changes to water management regimes and infrastructure are necessary
- Increased unpredictability challenges current knowledge
- Decreased food security and increased vulnerability, especially in the arid and semi-arid tropics and Asian and African megadeltas.

A recent UN review reported similar findings. Global precipitation trends showed substantial spatial and temporal variability, with some areas showing decreasing precipitation trends over the past century (1901–2005) but increasing trends more recently (1979–2005). Conversely, water stress has increased over many portions of the globe based on recent IPCC assessments, especially in the Sahel and west Africa, southern Africa, eastern Australia, Mediterranean, Central America, south and southeast Asia, northeast China, south-eastern Brazil, and northern North America. Water storage in glaciers and other snow is declining in many areas that depend on seasonal availability for agricultural production, whereas trends in ground water and surface water storage are more variable.

Recent global water modelling projected trends in water stress using three different indicators for two IPCC scenarios (A2 and B2). Water stress increased and decreased across 62.0–75.8% and 19.7–29.0% of global river basin area, respectively, depending on the scenario. Decreasing water stress occurred primarily due to increased precipitation. Increasing water stress occurred primarily due to larger water takes caused by higher incomes. The different indicators moderately agreed in that they overlapped up to 73% in terms of areas identified as under "severe stress." However they disagreed in other areas, suggesting that more work is needed to characterise and measure water stress consistently. Earlier modelling projected that between 1.1 and 2.8 billion people could experience increased water stress by the 2050s as a result of climate change, depending on the underlying assumptions.

The increased variability and uncertainty in the hydrological cycle and downstream effects on water availability, infrastructure, and planning could have major implications for land-use change. Changes in hydrologic regimes would affect conservation efforts by altering environmental suitability for areas for different species. As discussed in an earlier section as well as here, agricultural production could be substantially affected, especially from increasing frequency of extreme events causing floods or droughts. Global variability among regions and countries could shift relative commodity prices and thus trigger corresponding changes in production choices within New Zealand or increase pressure to intensify current practices to maintain supplies and overcome global shortfalls. Within New Zealand, regional changes in water supply could also intensify competition among different users, especially between agricultural (e.g., irrigation) and urban (e.g., domestic use).

5 Overview of IPCC AR4 SRES Scenarios

This section briefly summarises the IPCC SRES scenarios and global climate modelling simulations and downscaling. These summaries provide critical context for understanding the downscaling procedure undertaken in this report. It also provides a brief overview of climate model downscaling work undertaken by NIWA to generate climate projections at more useful scales for application in New Zealand. In that regard, it serves as a primer to help understand the downscaling more generally, although NIWA's research is more robust, given that it is both quantitative and more limited in scope.

5.1 IPCC AR4 SRES Scenarios

In its Fourth Assessment Report (AR4), the IPCC presented projections that covered a wide range of possible future emissions scenarios depending on assumptions of economic, political and social developments during the 21st century. These scenarios are known as the "SRES Scenarios" after the name of the report, the *IPCC Special Report on Emissions Scenarios* (see Nakicenovic et al. 2000).

The SRES scenarios were divided into four families, or storylines, that described distinctly different future developments of economic growth, global population, social development and technological change, with resulting implications for global greenhouse gas emissions and climate change. These four families were known as A1, A2, B1, and B2 (Figure 6). The A1 family was further subdivided into three subgroups (A1FI, A1T and A1B) that represented substantially different assumptions about emissions, so there were a total of six major scenario groups within the four families. In all, 40 individual scenarios were developed that specified the time evolution of greenhouse gas and aerosol emissions. The IPCC did not promote any one SRES scenario as being more likely than any other. Within each scenario family, the IPCC selected one scenario as a "marker" scenario that best exemplified the overall family. Most results discussed in this report relate to those marker scenarios.

Broadly the scenarios were divided along two major axes representing world views and relative societal emphasis on economic versus environmental outcomes (Figure 6). The scenario families do not represent either/or situations but rather illustrate relatively distinctive and disparate possible future conditions. The horizontal axis represented a divergence between a world that becomes more integrated and homogeneous (Global) versus one that became more segregated and heterogeneous (Regional). The vertical axis represented a divergence between continued emphasis on economic growth versus a shift towards environmental goals. Each family then included more specific assumptions as follows:

- Population: Higher (A1, B1) versus Lower (A2, B2)
- Economic Growth: Very High (A1), High (B1), Medium (A2, B2)
- Emissions: Higher (A1, A2) versus Lower (B1, B2)
- Energy Use: Higher (A1, A2) versus Lower (B1, B2)
- Technological Development: Higher (A1, A2) versus Lower (B1, B2)

Section 7 provides more detail about the differences among the four marker scenarios.

All scenarios described futures that are generally more affluent than today; and in many of the scenarios a narrowing of income differences between world regions was assumed. In most scenarios, global forest cover will continue to decrease for some decades. This trend is eventually reversed, with the greatest increase in forest area by 2100 occurring in the B1 and B2 scenario families. Sulphate aerosol emissions are generally lower than in an earlier IPCC emission scenario (IS92) because of concern about impacts of local and regional air pollution, a likely shift toward increased fuel efficiency and improvements in clean-burning technologies.

The important thing to remember is that assumptions about trends in demographics, energy use and technology underpin the scenarios. The scenarios do not describe how the particular emissions track might be achieved and, indeed, New Zealand is too small a geographic region to be considered explicitly. However, it seems unlikely that New Zealand could follow an A1 track, for example, while the world as a whole went down a B1 pathway.

The SRES scenarios do not specify any volcanic eruptions through the century, although obviously we would expect some to occur, and they also keep solar radiation fixed at the level of the current annual cycle. As required in their Terms of Reference, the scenarios do *not* allow specifically for political initiatives that would lead to implementation of the United Nations Framework Convention on Climate Change or to meeting the emissions targets of the Kyoto Protocol.

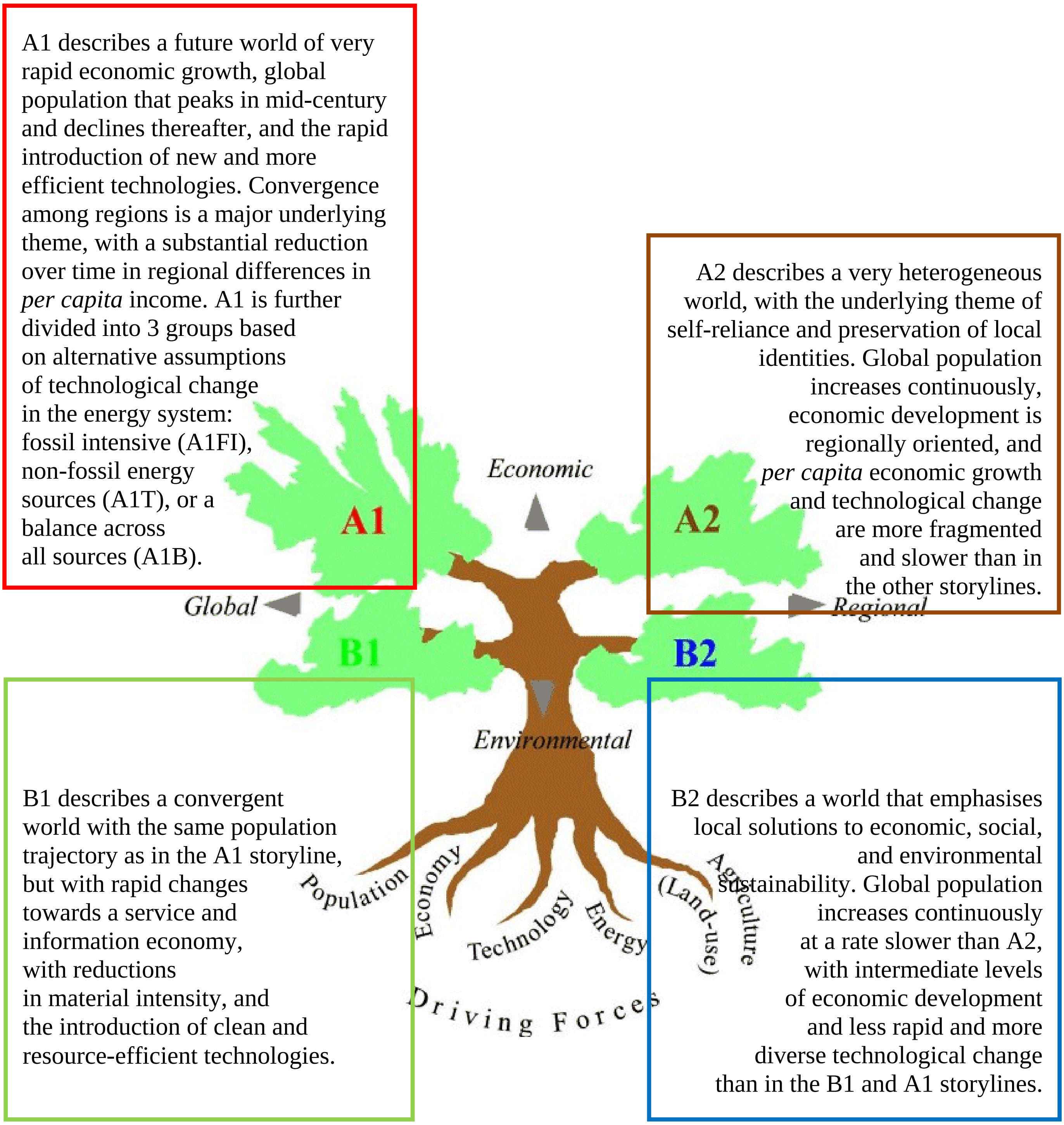


Figure 6 Schematic illustration and accompanying brief summaries of the storylines of the four SRES scenarios as branches of a two-dimensional tree. The two dimensions indicate the relative orientation of the different scenario storylines toward economic or environmental concerns (vertical axis) and global and regional scenario development patterns (horizontal axis). The A1 storyline branches out into different groups of scenarios to illustrate that alternative development paths are possible within one scenario family.

Figure 7 shows the track of carbon dioxide emissions through the 21st century from the four SRES families. The emissions are converted into atmospheric concentrations through carbon cycle models. The concentrations of all greenhouse gases, plus sulphate aerosols, are then provided to the global climate models, which calculate the consequences for the planetary energy budget, and hence simulate changes to temperature, precipitation, circulation, sea level, and so on.

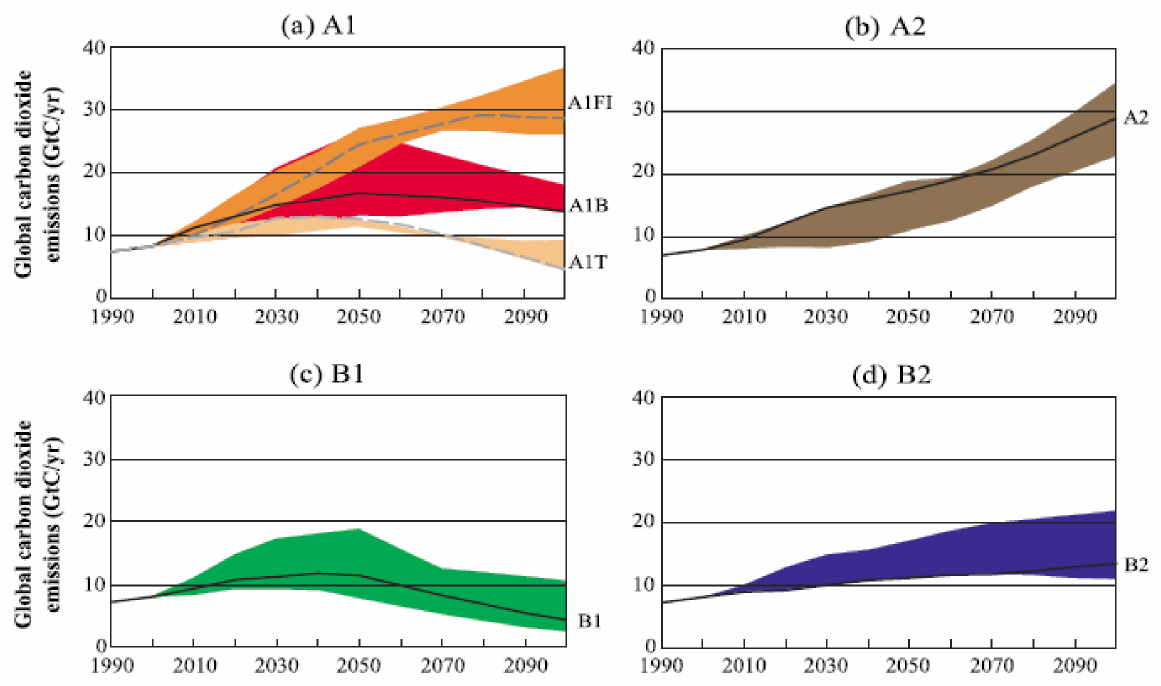


Figure 7 Total global annual CO_2 emissions from all sources (energy, industry, and land-use change) from 1990 to 2100 (in gigatonnes of carbon per year) for the four scenario families A1, A2, B1, and B2.
Note: The solid lines indicate the four illustrative marker scenarios of these four families, with the coloured bands showing the range of emissions scenarios within each group. For the A1 scenario (panel (a)), the two illustrative scenarios A1FI and A1T are also shown (dashed lines) (Reproduction of Figure 3 in Summary for Policymakers, Nakicenovic Swart (2000)).

5.2 Global climate model simulations and downscaling

5.2.1 What are climate models?

Climate models use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. They are used for a variety of purposes from study of the dynamics of the weather and climate system to projections of future climate. All climate models are designed to balance, or very nearly balance, incoming energy as short wave electromagnetic radiation (visible and ultraviolet) to the earth with outgoing energy as long wave (infrared) electromagnetic radiation from the earth, via the many mechanisms of energy exchange (Figure 8). To preserve the global energy balance, changes in greenhouse gas concentrations in the atmosphere must be offset by a change in the average temperature of the earth.

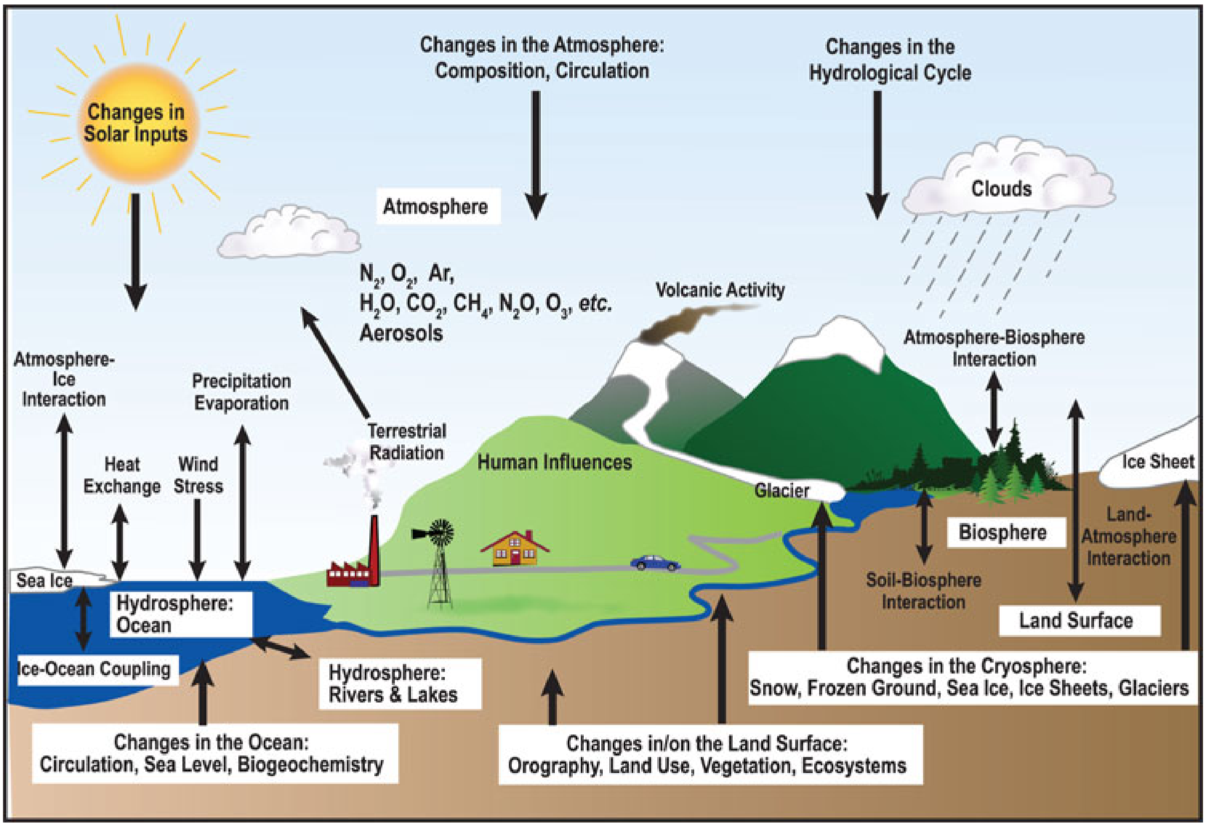


Figure 8 Schematic of the Climate System as represented in Atmosphere-Ocean Global Circulation Models (Source: IPCC 2007).

Coupled atmosphere-ocean general circulation models (AOGCMs) combine the two general circulation models, atmospheric and ocean. They thus have the advantage of removing the need to specify fluxes across the interface of the ocean surface. These models are the basis for sophisticated model projections of future climate, such as are discussed by the IPCC. AOGCMs represent the present-day pinnacle of complexity in climate models and internalize as many processes as possible. They are the only tools that could provide detailed regional projections of future climate change.

For the IPCC AR4 process, a set of standard experiments was run by institutions that operated AOGCMs. A control simulation was made of what was called the 20th century climate, although runs actually started as early as 1860 for some models. The 20th century run used observed changes in solar radiation and volcanic aerosols, in addition to the observed greenhouse gas increases from both natural and anthropogenic sources. From the year 2000 onwards, the models were forced by the SRES scenarios. Owing to computing and data storage constraints, only 3 of the SRES scenarios were studied in detail: all models (a total of 24) examined the A1B mid-range scenario, and most models also completed B1 (low emissions) and A2 (high emissions) simulations.

Figure 9 indicates the range of global temperature increases likely out to 2100. This range encompasses not only the range of plausible emissions scenarios, but also the uncertainty in the climate response as represented by a number of global climate models. The global-average temperature increase at 2100, relative to the average over 1980–1999, varies from

+1.1°C (least sensitive model – i.e. has the lowest temperature change for a given change in greenhouse gas concentrations – combined with the lowest emission scenario B1) to +6.4°C (most sensitive model with the highest emission scenario A1FI). The multi-model average (or IPCC 'best estimate') of the temperature increase for the A1B scenario is +2.8°C.

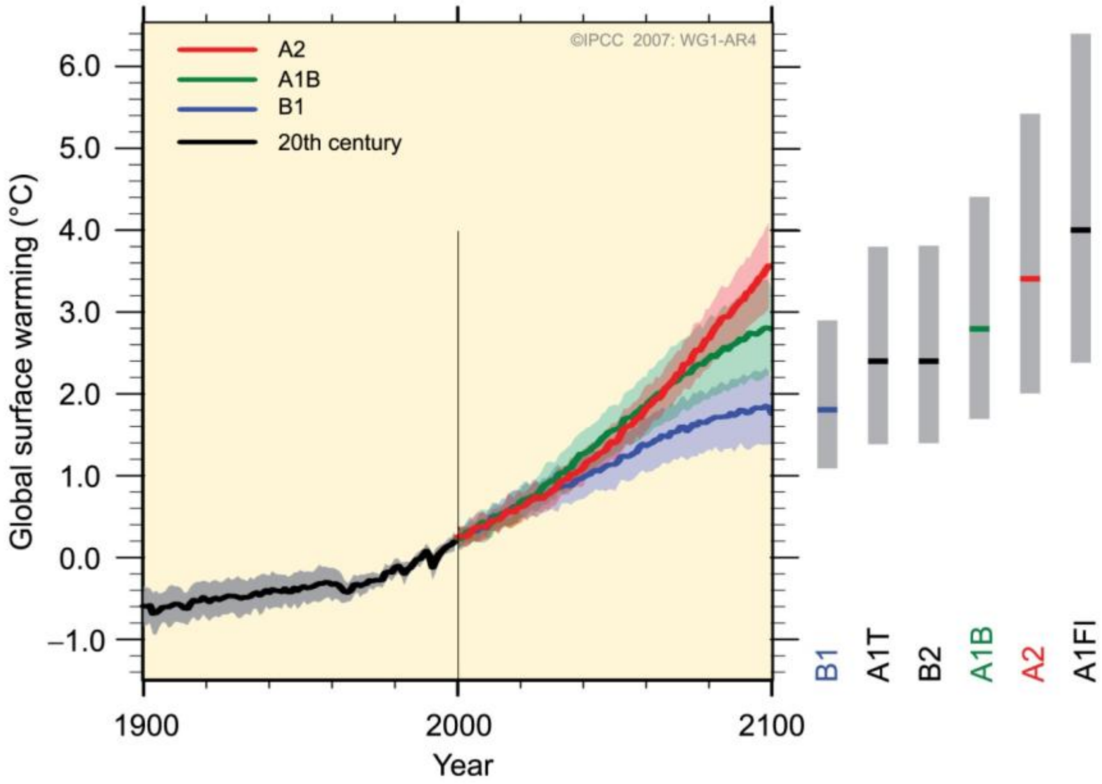


Figure 9 IPCC projections of global temperature increase. Solid coloured lines are multi-model global averages of surface warming (relative to 1980–1999) for emission scenarios B1, A1B and A2, shown as continuations of the 20th century simulations (black line). The coloured shading denotes the ±1 standard deviation range of individual model annual averages. The grey bars at right indicate the best estimate (solid horizontal line within each grey bar) and the 'likely range' across 6 scenarios that span the full range of all IPCC emission scenarios (Source: IPCC 2007).

Global-scale patterns for the three scenarios B1 (low), A1B (mid) and A2 (high) and three future time periods are given in Figure 10. In each case, greater warming over most land areas is evident. Over the ocean, warming is relatively large in the Arctic and along the equator in the eastern Pacific, with less warming over the North Atlantic and the Southern Ocean.

The patterns of change for temperature (Figure 10) are relatively consistent among AOGCMs. This aids the efficient presentation of the broad scale multi-model results, as patterns depicted for the standard A1B 2080–2099 case are usually typical of other cases. Where there is similarity of normalised changes, values for other cases can be estimated by scaling using the appropriate ratio of global mean warming (Figure 11). Note that for some quantities like variability and extremes, such scaling is unlikely to work.

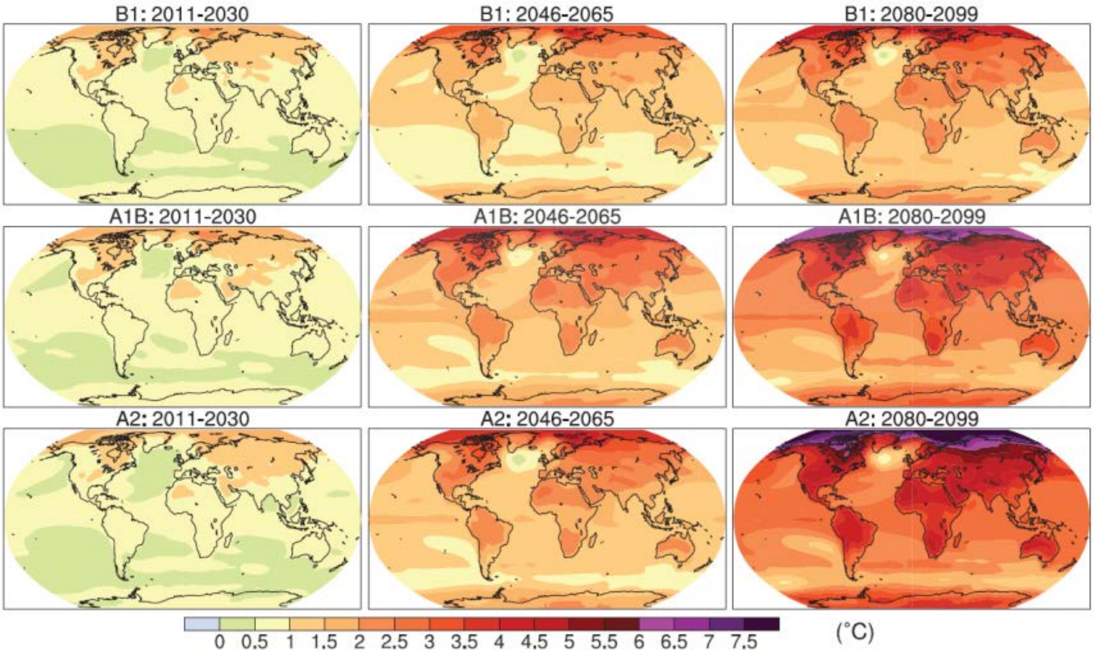


Figure 10 Multi-model mean of annual mean surface warming (surface air temperature change, °C). For the scenarios B1 (top), A1B (middle) and A2 (bottom), and three time periods, 2011–2030 (left), 2046–2065 (middle) and 2080–2099 (right). Anomalies are relative to the average of the period 1980–1999 (Source: Meehl et al. 2007).

	Global mean warming (°C)			
	2011–2030	2046–2065	2080–2099	2180–2199
A2	0.64	1.65	3.13	
A1B	0.69	1.75	2.65	3.36
B1	0.66	1.29	1.79	2.10

Figure 11 Global mean warming (annual mean surface air temperature change) from the multi-model ensemble mean for four time periods relative to 1980–1999 for each of the available scenarios. The mean for the base period is 13.6 °C (Source: Meehl et al. 2007).

The projected surface warming fields and changes in precipitation and sea level pressure for the extra-tropical winter and summer seasons, December to February (DJF) and June to August (JJA), are shown for scenario A1B in Figure 12. The projected high-latitude warming is rather seasonal, being larger in winter as a result of decreasing sea ice and snow cover. Precipitation is generally projected to decrease in the sub-tropics to extra-tropical regions and increase in equatorial regions. Surface pressure, particularly in the Southern Hemisphere latitudes between approximately 30 and 50°S, is projected to increase, while polar areas are likely to experience lower surface pressures (having a general effect of increasing the strength of the circumpolar westerly wind belt). It should be noted that the amount of inter-model consistency (as represented by the stippling on the maps of Figure 12, but not shown on the Figure 10 maps) is reduced at the seasonal scale compared with the annual scale.

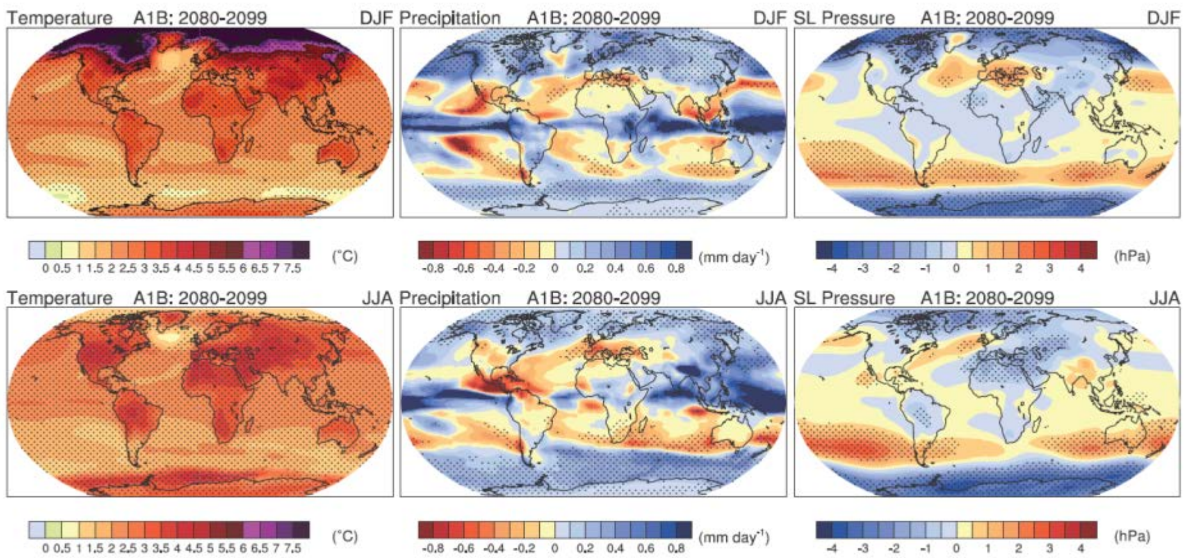


Figure 12 Multi-model mean changes in surface air temperature (°C, left), precipitation (mm/ day, middle) and sea level pressure (hPa, right) for December–January–February (DJF, top) and June–July–August (JJA, bottom). Changes are given for the SRES A1B scenario, for the period 2080–2099 relative to 1980–1999. Stippling denotes areas where the magnitude of the multi-model ensemble mean exceeds the inter-model standard deviation.

5.3 Downscaled climate projections for New Zealand

NIWA validated the performance of the available AOGCMs in simulating 20th century climate in the New Zealand-South Pacific region by comparing AOGCM mean sea level pressure output for 1970–1999 against NCEP reanalysis data, and selected 12 of the models for ‘downscaling’ over New Zealand. Downscaling is a technique for building in local scale detail that is consistent with the global model output at a much larger spatial scale but that also takes account of more localised influences, such as realistic terrain. For example, AOGCMs typically have grid-points spaced 1–3^{o} latitude apart, which in New Zealand latitudes is approximately 100–300 km, making them less useful for understanding potential impacts, assessing vulnerabilities, and devising appropriate adaptation strategies.

The downscaling procedure uses historical monthly anomalies to develop regression equations for precipitation and mean temperature, and is applied to a NIWA gridded data set that covers all of New Zealand with 0.05° latitude–longitude (approximately 5 km) boxes, known as the Virtual Climate Station (VCS) network (Tait et al. 2006). There are approximately 11 500 grid-points over the New Zealand land mass. For each climate element, the grid-point anomaly is related to three predictors: the large-scale zonally-averaged anomaly over 160–190°E at the same latitude as the gridpoint, and the anomalous components of two wind indices known as the Trenberth Z1 and M1 indices (Trenberth 1976). In simple terms, the circulation anomaly imposes spatial structure on the broad-scale change. Thus, if there is very low explained variance in the regression at some location, the climate change at that point will effectively be the same as the latitude-average evaluated at the model grid scale. Further discussion of the statistical downscaling methodology is given in MfE (2008), and the scientific details in Mullan et al. (2001).

In MfE (2008), downscaled projections of temperature and precipitation were derived only for the 12 A1B simulations. Since that report, the same downscaling has been applied to GCM output from the B1 (low emissions) and A2 (high emissions) scenarios. Figure 13 and Figure 14 are from MfE (2008), and show the projected annual temperature and precipitation change between 1980–1999 and 2030–2049 (midpoint reference year 2040) and 2080–2099 (midpoint reference year 2090). Figure 15 shows the projected seasonal precipitation changes between 1980–1999 and 2080–2099. Note, these maps show projections based on the average of 12 AOGCMs (each downscaled to New Zealand), and for the mid-range (A1B) emission scenario.

As mentioned above, there is potential for scaling projections for different models and emission scenarios, particularly for interpreting changes in the long-term mean values (scaling is less well suited to quantities like variability and extremes). Scaling factors used for New Zealand studies to translate 12-model average temperature projections from the A1B (mid-range) emission scenario to the other SRES marker emission scenarios, based on the average global temperature projections for each scenario, are 0.65 (A1B to B1), 0.85 (A1B to B2 & A1B to A1T), 1.21 (A1B to A2) and 1.44 (A1B to A1FI). These scaling factors can be directly applied to the temperature change maps shown in Figures 12–14, and can also be applied to the precipitation maps after these data have been converted from percentages to actual changes (in mm).

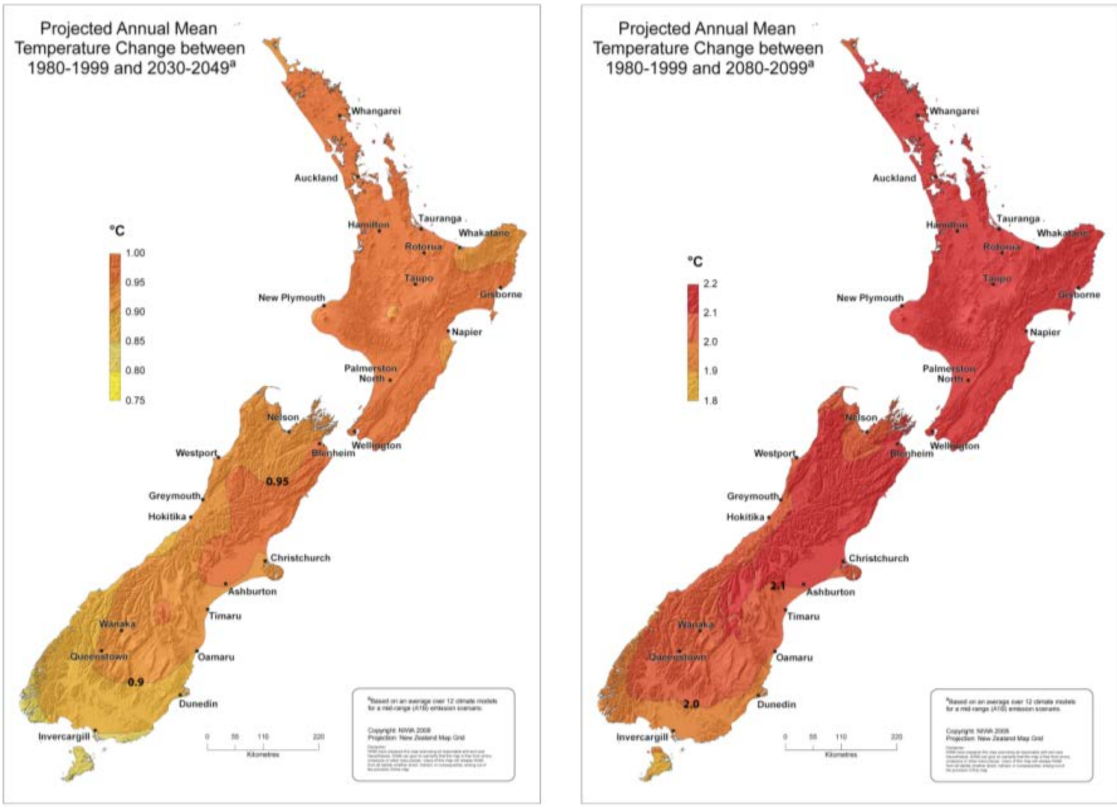


Figure 13 Projected mean annual temperature change (°C) between 1980–1999 and 2030–2049 (left) and 2080–2099 (right), A1B scenario, average from 12 downscaled AOGCMs.

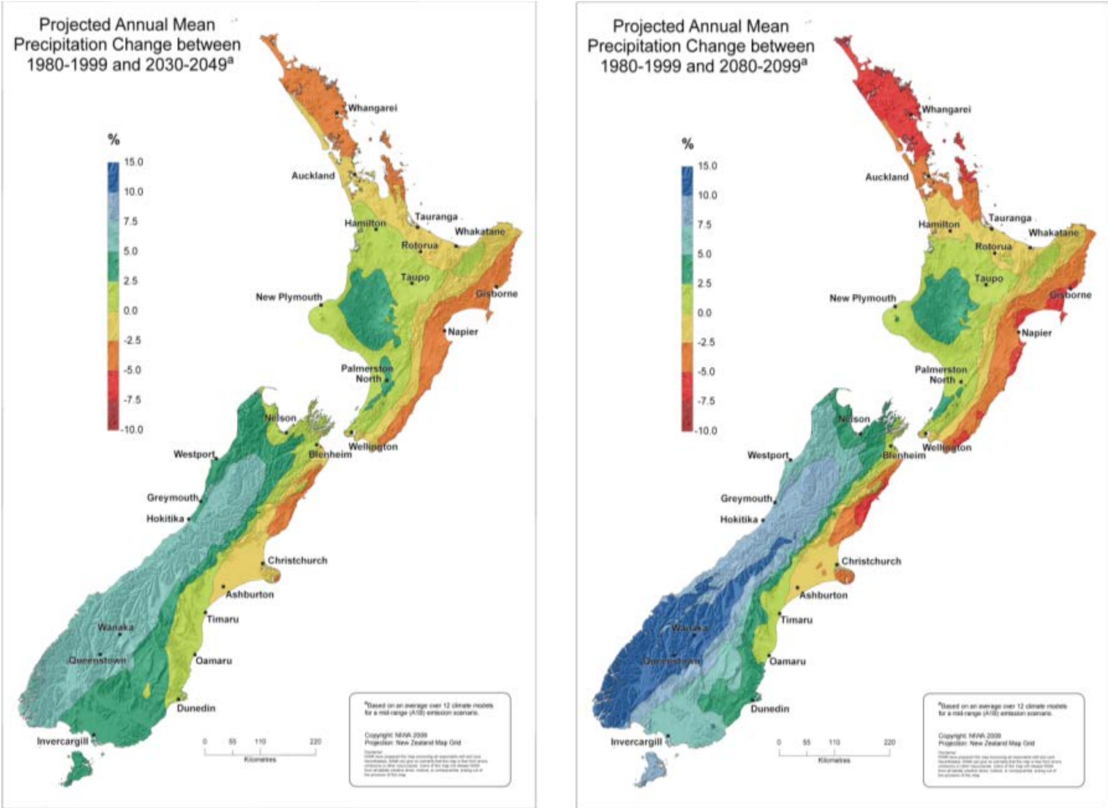


Figure 14 Projected mean annual precipitation change (percent) between 1980–1999 and 2030–2049 (left) and 2080–2099 (right), A1B scenario, average from 12 downscaled AOGCMs.

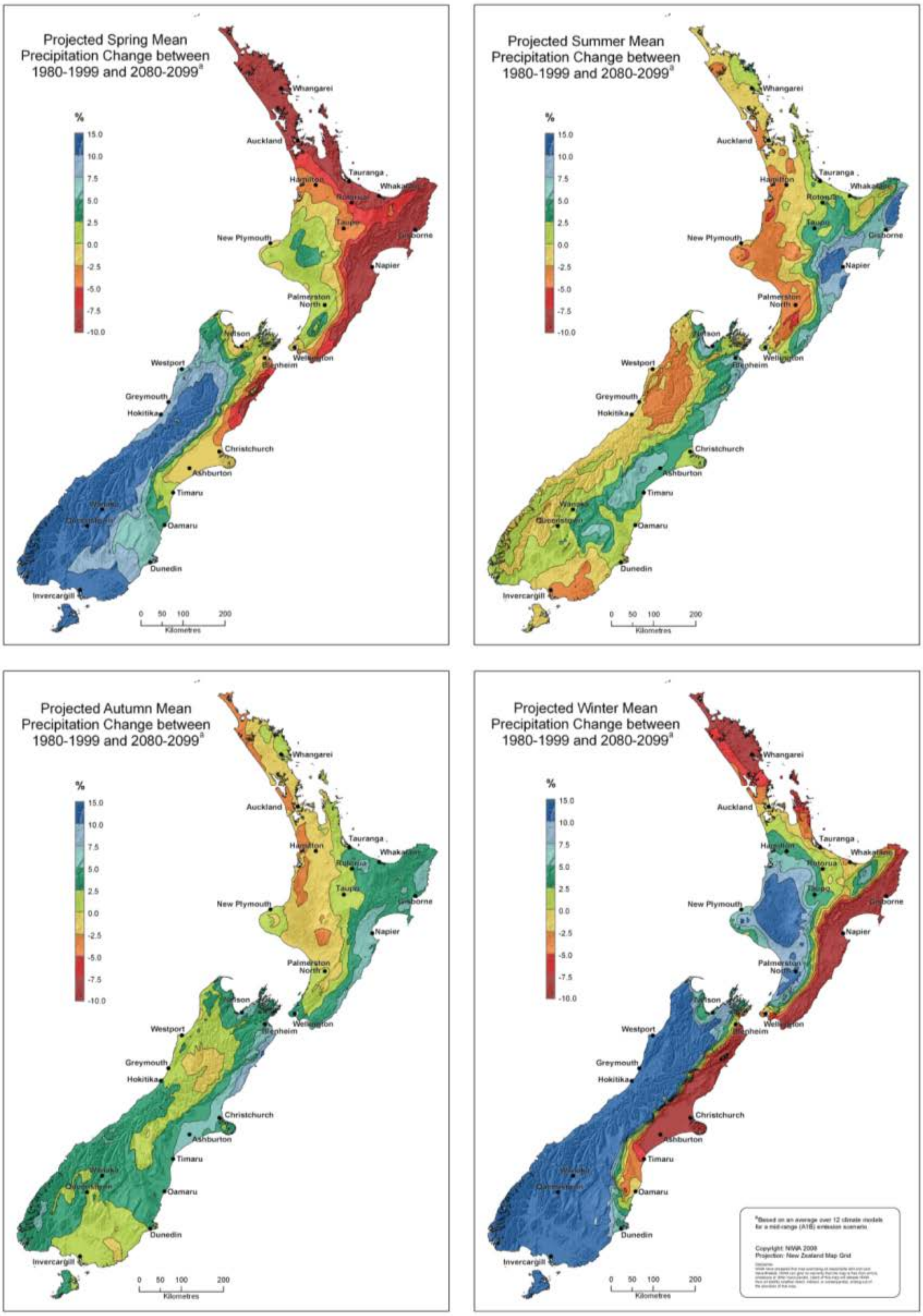


Figure 15 Projected mean seasonal precipitation change (percent) between 1980–1999 and 2080–2099, A1B scenario, average from 12 downscaled AOGCMs.

Table 11 is a reproduction of Table A2.1 from MfE (2008) and shows the global-average & NZ-average temperature changes for each of the 12 AOGCMs used to generate Figures 13-15. It can be seen that in all cases the projected NZ-average temperature change is less than the projected global-average. Further, Table 12 shows the regional breakdown of 2080–2099 projected annual temperature change by emissions scenario. The first value in each cell of the table is the 12-model average temperature change (from 1980 to 1999), while the two values within the square brackets are the lowest and highest projections corresponding to the AOGCMs with the least and most climate sensitivity to the changes in emissions. The temperature projections by 2080–2099 are the same for the A1T and B2 emission scenarios. The square-bracketed values in the A1B scenario column correspond to the end range asterisks depicted in Figure 19.

Table 11 Projected annual temperature changes (°C) relative to 1980–1999 for 12 GCMs forced by the SRES-A1B scenario. Changes are shown for different end periods, for both the global average and downscaled New Zealand average

Model (Country)	Global change	Change to 2030–49		Change to 2080–99	
	to 2090–2099	Global-avg	NZ-avg	Global-avg	NZ-avg
cccma_cgcm3 (Canada)	3.10	1.47	1.27	2.99	2.69
cnrm_cm3 (France)	2.75	1.30	0.87	2.60	1.83
csiro_mk30 (Australia)	1.98	0.65	0.54	1.84	1.13
gfdl_cm20 (USA)	2.90	1.29	0.82	2.83	1.96
gfdl_cm21 (USA)	2.53	1.31	1.22	2.44	2.16
miroc32_hires (Japan)	4.34	2.00	1.35	4.15	3.44
miub_echog (Germany/Korea)	2.86	1.19	1.12	2.76	2.23
mpi_echam5 (Germany)	3.31	1.09	0.33	3.15	1.75
mri_cgcm232 (Japan)	2.20	0.97	0.71	2.16	2.07
ncar_ccsm30 (USA)	2.71	1.57	1.19	2.63	2.11
ukmo_hadcm3 (UK)	2.90	1.24	0.66	2.79	1.56
ukmo_hadgem1 (UK)	3.36	1.35	1.14	3.22	2.21
12-model average	2.91	1.29	0.94	2.80	2.10

Table 12 2080–2099 projected annual temperature change (°C) for each Regional Council by emissions scenario (mean [low, high])

Regional Council Region	B1 Scenario	A1T/B2 Scenario	A1B Scenario	A2 Scenario	A1FI Scenario
Northland	1.3 [0.6, 2.7]	1.7 [0.7, 3.5]	2.1 [0.9, 4.1]	2.5 [1.1, 5.0]	3.0 [1.3, 5.9]
Auckland	1.4 [0.6, 2.6]	1.8 [0.7, 3.4]	2.1 [0.9, 4.0]	2.5 [1.1, 4.9]	3.0 [1.3, 5.8]
Bay of Plenty	1.4 [0.6, 2.5]	1.8 [0.7, 3.3]	2.1 [0.9, 3.8]	2.5 [1.0, 4.7]	3.0 [1.3, 5.5]
Waikato	1.4 [0.6, 2.5]	1.8 [0.8, 3.3]	2.1 [0.9, 3.8]	2.5 [1.1, 4.7]	3.0 [1.3, 5.6]
Taranaki	1.4 [0.6, 2.4]	1.8 [0.7, 3.2]	2.1 [0.9, 3.7]	2.5 [1.1, 4.5]	3.0 [1.3, 5.3]
Gisborne	1.3 [0.6, 2.5]	1.7 [0.7, 3.3]	2.1 [0.9, 3.8]	2.5 [1.0, 4.7]	3.0 [1.2, 5.5]
Hawke's Bay	1.3 [0.6, 2.4]	1.7 [0.7, 3.2]	2.1 [0.9, 3.7]	2.5 [1.0, 4.5]	3.0 [1.2, 5.4]
Manawatu	1.4 [0.6, 2.4]	1.8 [0.8, 3.2]	2.1 [0.9, 3.6]	2.5 [1.1, 4.5]	3.0 [1.3, 5.3]
Wellington	1.3 [0.6, 2.3]	1.7 [0.8, 3.1]	2.1 [0.9, 3.6]	2.5 [1.1, 4.4]	3.0 [1.3, 5.2]
Marlborough	1.3 [0.6, 2.3]	1.7 [0.8, 3.0]	2.0 [0.9, 3.5]	2.5 [1.1, 4.3]	2.9 [1.3, 5.1]
Tasman	1.3 [0.6, 2.3]	1.7 [0.8, 3.0]	2.0 [0.9, 3.5]	2.5 [1.1, 4.3]	2.9 [1.3, 5.0]
West Coast	1.3 [0.7, 2.2]	1.7 [0.8, 2.9]	2.0 [1.0, 3.4]	2.4 [1.2, 4.1]	2.9 [1.4, 4.9]
Canterbury	1.3 [0.7, 2.2]	1.7 [0.9, 2.9]	2.0 [1.1, 3.4]	2.5 [1.3, 4.2]	2.9 [1.6, 5.0]
Otago	1.3 [0.8, 2.1]	1.7 [1.0, 2.8]	2.0 [1.2, 3.2]	2.4 [1.4, 3.9]	2.8 [1.7, 4.6]
Southland	1.3 [0.8, 2.0]	1.6 [1.0, 2.7]	1.9 [1.2, 3.1]	2.3 [1.4, 3.8]	2.8 [1.7, 4.5]

Table 13 is also from MfE (2008) and shows the main features (direction of change, magnitude of change, and spatial and seasonal variation) of New Zealand's climate change projections, including the degree of confidence in the projections. The likely change to drought frequency (based an older analysis of two IPCC Third Assessment Report GCMs) is shown in Figure 16. From this analysis it can be seen that present-day 1-in-20 year droughts experienced in eastern areas of New Zealand are projected to be two to four times as frequent by 2070–2099. It should be noted that this drought study is currently being updated to be based on the AR4 models.

Table 13 Main features of New Zealand's climate change projections (Source: MfE 2008)

CLIMATE VARIABLE	DIRECTION OF CHANGE	MAGNITUDE OF CHANGE	SPATIAL AND SEASONAL VARIATION
Mean temperature	Increase (****)	All-scenario average 0.9°C by 2040, 2.1°C by 2090 (**)	Least warming in spring season (*)
Daily temperature extremes (frosts, hot days)	Fewer cold temperatures and frosts (****), more high-temperature episodes (****)	Whole frequency distribution moves right (see 2.2.3 of the source report)	See 2.2.3 of the source report
Mean rainfall	Varies around country, and with season. Increases in annual mean expected for Tasman, West Coast, Otago, Southland and Chatham Islands; decreases in annual mean in Northland, Auckland, Gisborne and Hawke's Bay (**)	Substantial variation around the country and with season (see 2.2.2 of the source report)	Tendency to increase in south and west in the winter and spring (**); tendency to decrease in the western North Island, and increase in Gisborne and Hawke's Bay, in summer and autumn (*)
Extreme rainfall	Heavier and/or more frequent extreme rainfalls (**), especially where mean rainfall increase predicted (***)	No change through to halving of heavy rainfall return period by 2040; no change through to fourfold reduction in return period by 2090 (**)	Increases in heavy rainfall most likely in areas where mean rainfall is projected to increase (***)
Snow	Shortened duration of seasonal snow lying (***), rise in snowline (**), decrease in snowfall events (*)		
Glaciers	Continuing long-term reduction in ice volume and glacier length (***)		Reductions delayed for glaciers exposed to increasing westerlies
Wind (average)	Increase in the annual mean westerly component of windflow across New Zealand (**)	About a 10% increase in annual mean westerly component of flow by 2040 and beyond (*)	By 2090, increased mean westerly in winter (>50%) and spring (20%), and decreased westerly in summer and autumn (20%) (*)
Strong winds	Increase in severe wind risk possible (**)	Up to a 10% increase in the strong winds (>10m/s, top 1 percentile) by 2090 (*)	
Storms	More storminess possible, but little information available for New Zealand (*)		
Sea level	Increase (****)	At least 18–59 cm rise (New Zealand average) between 1990 and 2100 (****)	Refer to Coastal Hazards and Climate Change guidance manual: www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual
Waves	Increased frequency of heavy swells in regions exposed to prevailing westerlies (**)	Refer to Coastal Hazards and Climate Change guidance manual: www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual	
Storm surge	Assume storm tide elevation will rise at the same rate as mean sea-level rise (**)	Refer to Coastal Hazards and Climate Change guidance manual: www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual	
Ocean currents	Various changes plausible, but little research or modelling yet done	See 2.2.9 of the source report	
Ocean temperature	Increase (****)	Similar to increases in mean air temperature	Patterns close to the coast will be affected by winds and upwelling and ocean current changes (**)

Note: The degree of confidence placed by the authors of the source report in the projections is indicated by the number of stars in brackets:

**** Very confident, at least 9 out of 10 chance of being correct. Very confident means that it is considered very unlikely that these estimates will be substantially revised as scientific knowledge progresses.

*** Confident.

** Moderate confidence, which means it is more likely than not to be correct in terms of indicated direction and approximate magnitude of the change.

* Low confidence, but the best estimate possible at present from the most recent information. Such estimates could be revised considerably in the future.

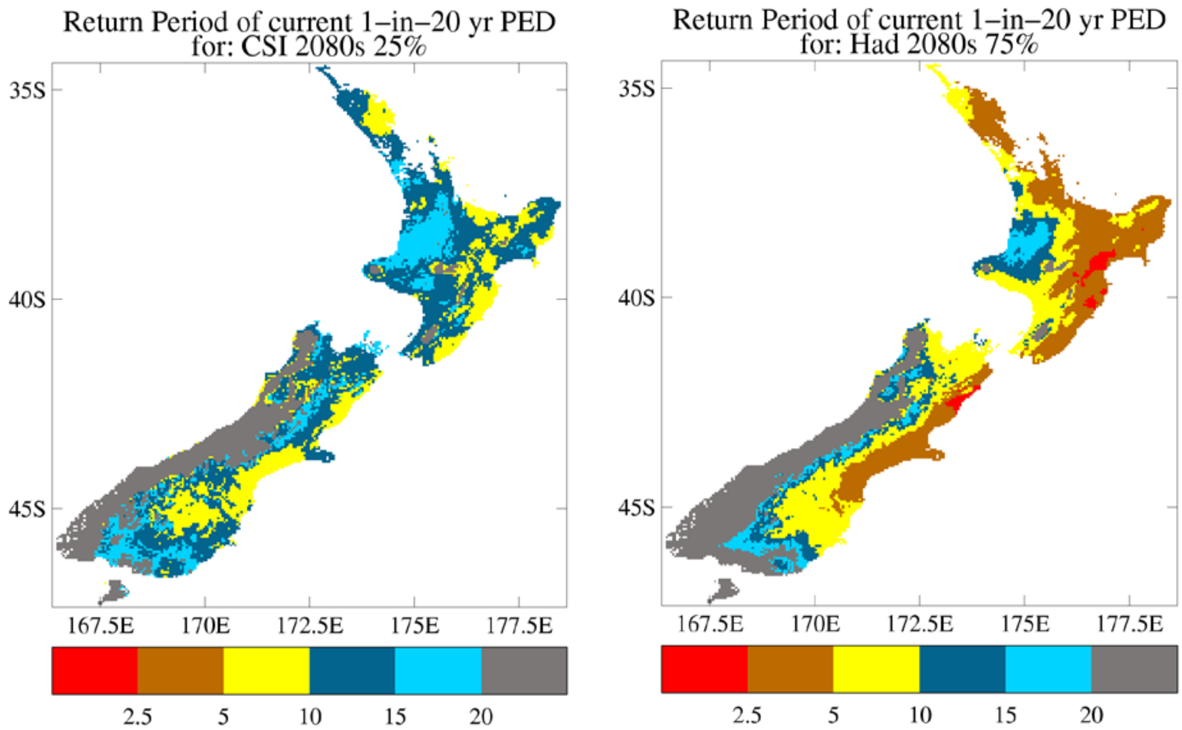


Figure 16 Projected change in the return period of present-day 1-in-20 year droughts (using the Potential Evapotranspiration Deficit (PED) as a drought index) for the future period 2070–2099. The left map is a "low-medium" scenario (based on the CSIRO model) and the right map is a "medium-high" scenario (based on the Hadley Centre model).

5.3.1 Global model projections: a discussion of model range and variability

Figure 17 shows how the 12 global model projections translate to a specific location in New Zealand (Manukau City used as an example). Here, we have taken the global model grid-point changes, without any statistical downscaling – simply interpolated from the surrounding global grid-points to the location of Manukau City. The annual temperatures have been smoothed with a low-pass filter to remove most of the sub-decadal variability. There are still substantial inter-model differences as well as multi-decadal variability within each model. For example, the German Max Planck model (the solid red line in Figure 17, labelled as mpi) projects very little warming over northern New Zealand between 1990 and 2030, before 'taking off' and ending in the middle of the warming range by 2100. Note; the Japanese 'miroch' model (the dotted yellow line in Figure 17) is consistently the most sensitive (most warming) model for nearly all regions of the world.

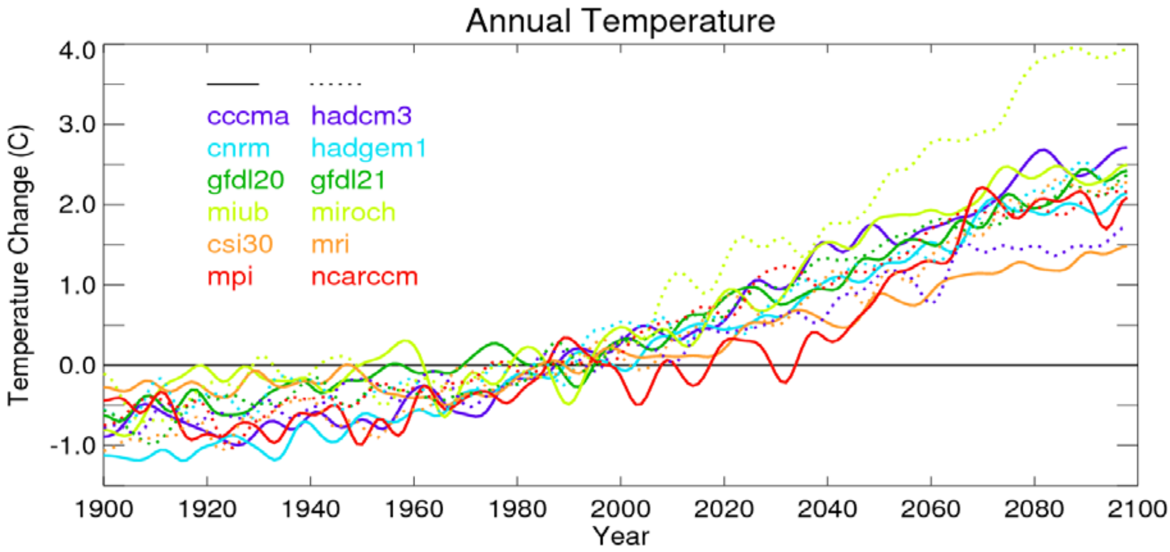


Figure 17 Projected changes in annual temperature (in °C, relative to the 1980–1999 average) over the period 1900–2099 from 12 global climate models, interpolated to the location of Manukau City. The changes have been smoothed to remove most of the year-to-year variability. Six of the models are shown as solid lines, and six as dotted lines, with the colours according to the inset legend.

Figure 18 demonstrates a further characteristic of global climate model projections that is important to appreciate. Climate models are simply weather prediction models that are run for a very long time, but where a lot more care is taken to better represent the 'slow' climate processes, such as the global energy budget, oceanic heating, and seasonal sea-ice formation, none of which are too critical for short-term weather forecasts. As is well-known, observed weather quickly (in a couple of weeks at most) departs from weather forecasts, due to the growth of small errors in the initial conditions and in solving the dynamical equations of atmospheric motion (i.e. the weather is too chaotic to predict after a couple of weeks). Climate modellers recognise this, of course, and thus the initial conditions (e.g., position and intensity of weather patterns on day 1 of a 150-year simulation) are unimportant in the climate context. However, this 'weather noise' affects not only the day-to-day weather patterns in the AOGCMs, but also the year-to-year variations such as El Niños which are therefore unpredictable at long-range.

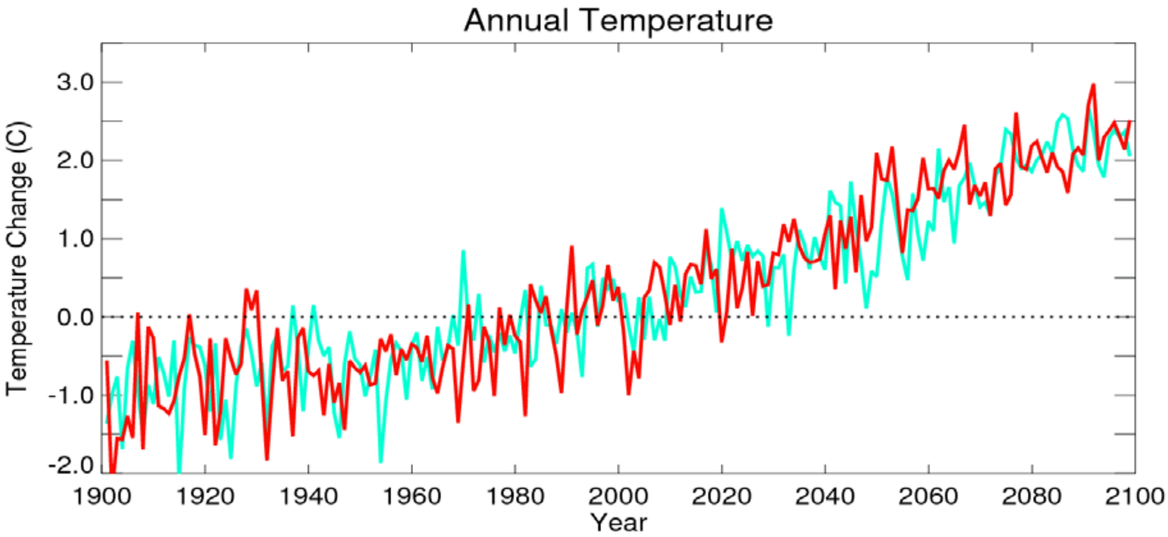


Figure 18 Projected changes in annual temperature (in °C, relative to the 1980–1999 average) over the period 1900–2099 from one global climate model, interpolated to the location of Manukau City. Two curves are shown, taken from two different simulations over 1900–2099, differing only in the starting weather analysis in January 1900 (green is run 1, corresponding to the smoother dotted orange line in Figure 17, and red is run 2).

To understand the impact of this natural variability on the climate projections, the AOGCMs can be run as 'ensembles'. In this experimental set-up, multiple model runs are made with exactly the same time evolution of greenhouse gases, and differ only in the starting analysis at the very beginning of the simulation. Several of the larger climate modelling institutions had the computing power to run ensemble simulations of the Fourth Assessment emission scenarios. Different ensemble members will have a different evolution of climate variations, and Figure 18 shows an example for the mri model from the Meteorological Research Institute in Japan. Here, the unsmoothed annual temperature variations at Manukau City are plotted for ensemble runs 1 and 2 (the dotted orange line in Figure 17 shows the smoothed annual variation of ensemble member 1). Annual temperatures at Manukau City can be as much as 1°C or more different between ensembles (in any one year), but the long-term trend is virtually identical. This is the critical aspect that needs to be appreciated. Climate sceptics have claimed that the inability to predict daily weather and seasonal climate fluctuations makes the climate model projections meaningless, but this is not so: the long-term trends are well constrained by the global model. All subsequent discussion of downscaled model projections uses a single ensemble member (run 1) from each modelling institution.

Last, it is also important to recognise that the 12-model average projections (i.e. as depicted in Figures 17–18) represent a central value within a range of model projections for the same emission scenario. A range of projections exists because while every AOGCM is based on the same fundamental principles and representations of physical laws, there are inter-model differences due mostly to resolution and parameterisations of sub-grid scale phenomena.

Figure 19 and Figure 20 show the range across 12 models in projections of mean annual temperature and precipitation for each region. In each box and whisker plot, the median change is indicated by the heavy black line, with the surrounding "box" extending from the estimated 25th percentile to 75th percentile of the data known as the inter-quartile range (IQR). The "whiskers" are indicated by the short horizontal lines, and are positioned at the last data points that lie within 1.5 times the inter-quartile range of the 25th and 75th percentiles (see Tukey 1977). The only data points plotted explicitly are those that lie outside the whiskers (considered as outliers): triangles mark any model between 1.5 and 3 times the IQR outside the 25th and 75th percentiles, and asterisks mark any model more than 3 times the IQR from the box.

Note that the projections for the South Island regional council areas tend to be more variable across the 12 models, so the IQR is larger and so the more extreme models sit at the ends of the whiskers and do not appear as outliers. From a climate change perspective, all 12 models are considered equally likely, so that the outliers should not be discounted.

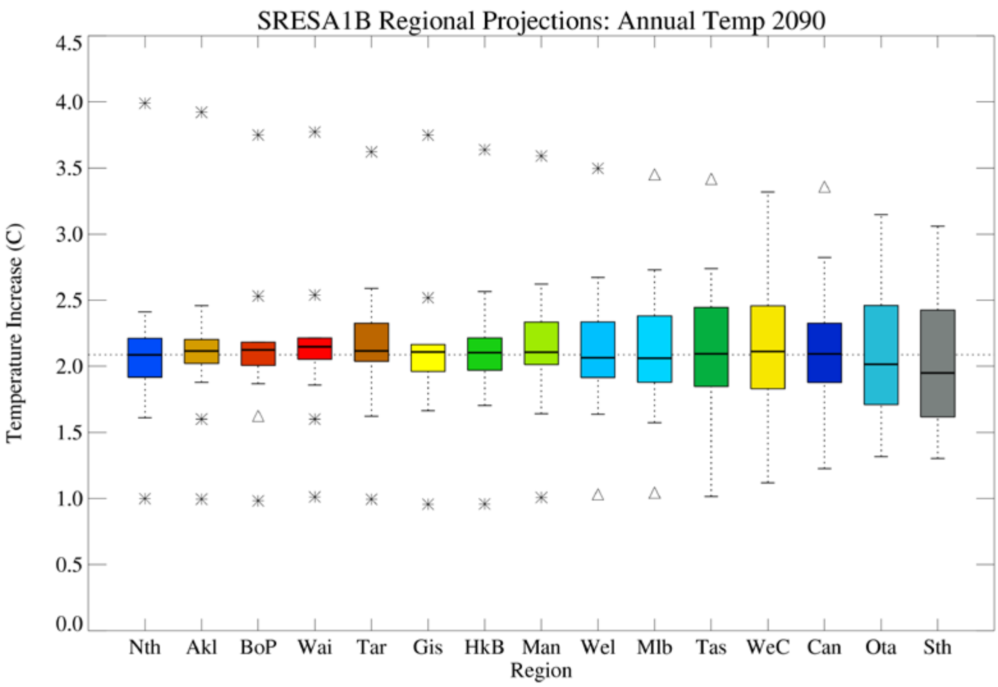


Figure 19 Box and whisker plots of projected mean annual temperature change (°C) between 1980–1999 and 2080–2099 for the A1B emission scenario for each regional council region in New Zealand. Asterisks and triangles represent 'outliers' in the standard box and whisker plot terminology (see text). The horizontal dotted line across all regions marks the national-average **median** temperature increase.

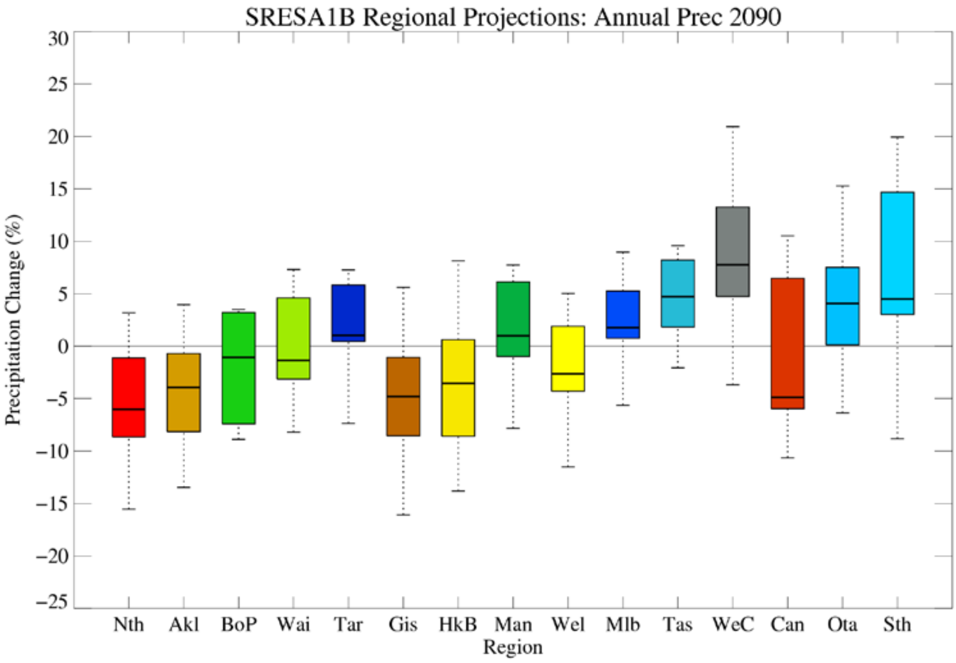


Figure 20 Box and whisker plot of projected mean annual precipitation change (percent) between 1980–1999 and 2080–2099 for the A1B emission scenario for a selected station (the first location in Table 2.4 of MfE, 2008) within each regional council region in New Zealand. Unlike temperature, the interquartile range in the precipitation projections is large enough that none of the 12 models qualify as an 'outlier' in the standard box and whisker plot terminology.

6 Results

In the section we present the results of the downscaling procedure as outlined in Section 3 (Figure 3). Step 1 (Comparison and Contrast of Key Trends) encompasses all four IPCC SRES scenarios. Steps 2, 3 and 4 are organised by individual IPCC SRES scenario family (A1, A2, B1, B2) and include:

- A brief narrative summary of the scenario.
- A systems diagram based on Step 2 of Figure 3. Each box in the systems diagram has been replaced with a very short summary of the main aspects and/or directions of each corresponding key trend. Where possible quantitative information was included (e.g., population, economics/GDP, climate).
- A table based on Step 3 of Figure 3. The table contains statements about how the key trends would likely evolve in New Zealand given the broader global trends.
- A second table based on Step 4 of Figure 3. The second table outlines the potential implications for triggers and thresholds of land-use change within New Zealand across national, regional, and local scales for each of the four major land-use categories plus production sub-categories based on the assumed global and New Zealand trends.

For the A1 scenario family we did not produce separate tables for each variant (A1T, A1B, A1F1) but instead highlighted differences among them where appropriate or discernable.

6.1 Review, Comparison, and Contrast of Key Trends

Table 14 summarises the review comparing and contrasting the key trends at the global scale across the four IPCC AR4 SRES scenarios. For each key trend we summarised the more detailed overview provided earlier in Section 3, including quantitative information where available (e.g., GDP, population estimates) from the literature, and qualitative information intended to highlight the differences among the scenarios. In many cases differences were not discrete but more continuous, such that relative rather than absolute comparisons were more appropriate, e.g., “less likely” or “stronger”.

Table 15 summarises the projected changes in global land use from the modelling conducted to evaluate the IPCC SRES scenarios.

Table 14 Summary of key trends in the context of IPCC AR4 SRES Scenarios. Scenario colours match those used in the IPCC reports (e.g., IPCC 2002; Nakicenovic et al. 2000). n/a = not available

Key Trend	Summary	IPCC SRES SCENARIO					
		A1F1	A1B	A1T	A2	B1	B2
Climate	• Average Temperature Change 1990-2099 (°C)	+4.0	+2.8	+2.4	+3.4	+1.8	+2.4
	• Cumulative CO_2 Emissions 1990-2100						
	Total (10^9 Tonnes)	2189	1499	1068	1862	983	1164
	Fossil Fuels (10^9 Tonnes)	128	1437	1038	1773	989	1160
	Land Use (10^9 Tonnes)	61	62	31	89	-6	4
Agricultural Production	• Warmer temperatures trigger an expansion of crop choice southwards and increase growing season for existing crops in many areas • Enhanced growth from increased CO2 concentrations but balanced by risk of lower growth if temperatures above particular thresholds • Heterogeneous changes to regional rainfall patterns • Risks increase due to larger extremes (e.g., drought, flood) and increased uncertainty • Risk of exposure from and damage by pests & weeds increases	Expected substantial increase in meat and dairy production to satisfy rising demand in developing countries, triggered expansion of grasslands and croplands			Substantial expansion of primary production to provide for large global population and compensate for lower productivity gains given lower global wealth and income	Loss of cropland and grassland due to reduced demand given shifts in dietary preferences and expected productivity gains from remaining areas; forests reclaim large tracts of abandoned agricultural land as a result	Larger global population triggers demand for more production lands, leading to increase in croplands, grasslands, and forests

Key Trend	Summary	IPCC SRES SCENARIO					
		A1F1	A1B	A1T	A2	B1	B2
Biodiversity	• Species & ecosystems ranges shift to higher latitudes & elevations • Increased disturbance intensity and frequency • Increased extinction risk • Greater pressure from invasive pest and weeds • Need to shift protected areas in compensation and/or assist with species migrations across fragmented landscapes	Impacts vary based on expected climate changes; some benefits possible from co-benefits of energy biomass or more eco-friendly technologies			Higher impacts based on expected climate changes; extreme urbanisation pressures from high population; land use impacts not explicitly analysed in the studies reviewed	Lowest likely impacts based on expected climate changes; strong benefits from large increases in forest and possibly also energy biomass	Moderate impacts based on expected climate changes; some benefits from increased forest and possibly also energy biomass
Economic Development	• 2100 Global GDP (1990 = 21) Total (10^{12} 1990 $USD) Per Capita ($10^{3}$ 1990 $USD)	 525 73.9	 529 74.5	 550 77.5	 243 16.2	 328 46.2	 235 22.6
	• Recent trends show rapid GDP growth in several developing countries including China, India, and Argentina • Sub-Saharan African countries have highest poverty rates • Agriculture is a key export commodity among low-income countries, some middle-income countries and one high-income country (New Zealand)	Significant increase in global GDP & GDP per capita, likely partly due to emphasis on technology; move towards more equitable wealth sharing			Lowest economic growth; likely decline in overall global standard of living, with some nations experiencing increased poverty; highly heterogeneous	Moderate economic growth; eventually shift to more equitable wealth sharing	Low to moderate growth; regional differences in wealth distribution;

Key Trend	Summary	IPCC SRES SCENARIO					
		A1F1	A1B	A1T	A2	B1	B2
EcosystemServices	• Supporting Services: highly variable, both negative and positive effects reported; relationship between biodiversity and ecosystem service provision requires more study • Provisioning Services: increased demand as a result of increased population and affluence • Regulating Services: decreasing as a result of human influence such as eutrophication, erosion, air quality • Cultural Services: requires additional study	Stabilised population suggests stabilised demand for Provisioning Services; effects to Supporting & Regulating Services depends on variant selected, e.g., A1T implies better ES conditions through application of technology			Likely the worst scenario given magnitude of climate change, poorer economic conditions leading to increased degradation, and high population	Large increases in forest bodes well for Supporting & Regulating Services; stabilised population suggests stabilised demand for Provisioning Services	Supporting & Regulating Services benefit from land-use change; Provisioning Services demand increases to meet increasing population, which will also put pressure on Supporting and Regulating Services
Energy	• Primary Energy Use in 2100 (1990 = 351) Global Total (10^{18} Joules/year) Global Per Capita (10^{12} Joules/year)	2073 292	2226 313	2021 284	1717 114	514 72	1357 130
	• Fossil fuel use continues to rise to 2030, >40% according to both EIA & IEA • To 2100 IPCC scenarios vary regarding replacement with renewable sources • Supply forecasts vary widely; uncertainty stems from lack of verifiable data on reserves and production • Renewable energy is a wildcard; differing opinions whether it can meet increasing demands versus a permanent decline to a lower global energy state	High demand but substantial variation by source; % of zero carbon energy in 2100 is 31% (A1F1), 65% (A1B), 85% (A1T) Strong demand for biofuels triggers land-use change			Second highest; high reliance on fossil fuel supply esp. coal (53%)	Significantly lower than other scenarios; balance between fossil and renewable sources	Intermediate; balance between fossil and renewable sources

Key Trend	Summary	IPCC SRES SCENARIO			
		A1F1 A1B A1T	A2	B1	B2
Globalisation	• Global (A1/B1) versus Regional (A2/B2) emphasis • Trend in regional free trade agreements and/or common markets likely to continue • Uncertainty around post-Kyoto protocol commitments	Global Reliance on global economic policies and solutions; regional differences blurred	Regional Regional alliances/trading zones more likely; regional differences sharpened	Global Reliance on global economic policies and solutions; regional differences blurred	Regional Regional alliances/trading zones more likely; regional differences more pronounced but not as much as in A2
Mineral Resources	• Remaining supply of key minerals varies from several decades to hundreds of years • Increased demand expected overall but especially with increased reliance on technology (e.g., A1 & B1) • Ore grades decreasing in many cases implying increasing price to maintain supply but possibly offset by technology improvements • Peaking in global phosphorus production would have profound implications	Higher reliance on minerals to support rapid technology; implied increases in efficiency/recycling, lower costs	Lower reliance on minerals due to slower technology, more localised solutions could result in more regionalised markets for some minerals	Higher reliance on minerals to support rapid technology but possibly very expensive and uneven benefits	Lower reliance on minerals due to lower technology adoption

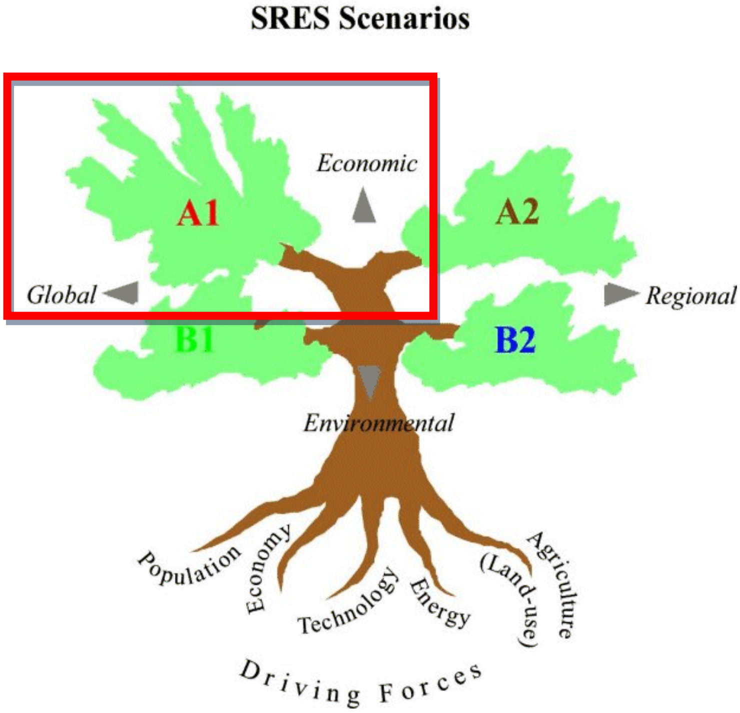
Key Trend	Summary	IPCC SRES SCENARIO				
		A1F1 A1B A1T	**A2**	**B1**	**B2**
Population & Migration	• World Population in 2100 (10^9 people) (1990 = 5.3)	7.1	15.1	7.0	10.4
	• Recent projections show lower expected 2100 populations versus IPCC AR4 scenarios • Urbanisation rates expected to increase across all scenarios • Fertility: Overall trend is for decrease in fertility rates with increasing affluence • Mortality: possible increase from climate change, especially in developing countries in the tropics but possibly compensated by decreased mortality due to less prevalence of cold-related diseases in the north • Migration: most within countries although some badly affected nations may see higher emigration (e.g., South Pacific Island states); even small increases in global net migration rates could have profound effects	Initial increase then slow decrease likely caused by convergence to replacement fertility rates as a result of rising affluence globally; technological innovations imply better access to advance birth control methods and increased migration via enhanced mobility	Continual increase through 2100, possibly caused by continued high fertility rates as a result of lower affluence, especially among developing countries; migration between regions and countries likely to decrease as costs rise; urbanisation pressures likely extreme	Initial increase then slow decrease (same as A1); global migration possibly stable as people choose to "stay put" and make do with what they have rather than seek a better life elsewhere	Continual increase as A2 but at a lower rate; fertility remains higher overall given the slower rise of affluence; global migration lower although increased migration within regional zones very likely, e.g., EU or perhaps new Asian union
Societal Preferences for Food & Fibre	• Food production has increased steadily since the 1960s • Calories per person per day increasing in developing countries • Meat consumption increasing in developing countries, although still less than developed (28 kg/person vs 78 kg/person in 2001)	Less intervention Increased homogenisation of tastes and preferences globally	Less intervention Increased homogenisation of tastes and preferences globally	? Services ? Production Shift away from consumption perhaps to "experiences"	? Environmental Protection Tension between implied lower per capita consumption vs higher population; more regional & local solutions favoured

Key Trend	Summary	IPCC SRES SCENARIO			
		A1F1 A1B A1T	A2	B1	B2
Water	• High spatial and temporal variation in regional availability; wetter in higher latitudes and some tropical areas; decrease in mid-latitude & tropical dry areas • Increased unpredictability • Decreased food security, especially in arid and semi-arid tropics and Asian and African megadeltas • Likely increased competition for water between agricultural and urban uses, both globally and within New Zealand	Strong emphasis on technology implies more efficient water resource use and enhanced security but balanced against increasing demand due to increased affluence	Strong pressures on water security resulting from higher levels of climate change, high population, and lower economic and technological development	More water security via increased environmental emphasis; global focus suggests equitable sharing of water resources	Variable water security resulting from regionalisation exacerbated by population growth; possible compensation from environmental emphasis

Table 15 Modelled global land-use change from 1990 to 2100 across the four IPCC SRES scenario families. For 1990 the range of starting values are shown across all scenarios in each scenario family. For 2100 the top number in each row = estimate from the marker scenario. Bottom values in parentheses show the range of estimates considering all scenarios in each scenario family. All values in million (10^6) hectares (Source: Nakicenovic et al. 2000)

Global Land Use	1990	Land Use Change Between 1990 and 2100					
		A1F1	A1B	A1T	A2	B1	B2
Cropland	1434–1472	n/a	-39	n/a	n/a	-394	+325
			(-826, -39)		(-422, +420)	(-979, -30)	(-582, +325)
Energy Biomass	0–8	n/a	+495	n/a	n/a	+196	+307
			(+3, +1932)		(+67, +396)	(0, +1095)	(+4, +597)
Forest	4138–4296	n/a	-92	n/a	n/a	+1260	+227
			(-464, +480)		(-673, -19)	(274, +1266)	(-116, +227)
Grassland	3209–3435	n/a	+188	n/a	n/a	-1537	+307
			(-1087, +622)		(+313, +1262)	(-1537, +320)	(-491, +823)
Others	3805–4310	n/a	-552	n/a	n/a	-482	-1166
			(-873, +566)		(-1085, -278)	(-983, -482)	(-1166, -137)

6.2 Scenario A1



Scenario A1 suggests a strong dynamic between positive and negative impacts of global development. On the positive side, population stabilisation coupled with substantially higher GDP, globalised worldviews and technological innovation suggest an agile society capable of adaptation. On the negative side, the highly dynamic socioeconomic system requires significant energy and resource inputs to function, i.e. it is "running hot," requires constant monitoring and fine-tuning to continue functioning, and has questionable resilience in the face of significant shocks.

The three variants range in their potential impacts on climate change, mainly due to their different assumptions about energy supply: A1F1 (31% zero carbon energy supply); A1B (65%) and A1T (85%). A1F1 produces the largest change of any IPCC scenario (+4.0 °C), while A1B (+2.8) and A1T (+2.4) produce moderate change. Impacts and risks from climate change therefore vary from severe to moderate.

The variation in climate change impacts as well as technology carries different implications for land-use change. A1F1 would directly trigger substantial land-use change given the magnitude of possible climate impacts, with follow-on effects for biodiversity and ecosystem services. A1B and A1T imply less direct effects from climate on land use but more indirect effects, especially from increased reliance on renewable energy from biomass. A1B produced the highest projected increase in land use for energy biomass (+495 million hectares) of any SRES scenario. Stabilised population pressure should abate direct urbanisation pressures, although increased affluence will increase pressure indirectly to meet lifestyle choices and increasing consumption implied by GDP growth. Conservation uses may suffer somewhat in this scenario as we aim to "fine-tune" the condition and arrangement of ecosystems to produce desired levels of ecosystem services. The science fiction concept of "terraforming" – coordinated eco-engineering of the global-scale ecosphere for human benefit – comes to mind.

The emerging picture suggests continued development of an intensive, rapidly paced, highly interconnected globalised society in which land-use change becomes even more dynamic and unpredictable as a result of both biophysical and socioeconomic forces. Production must adapt quickly to changing conditions or risk becoming unviable.

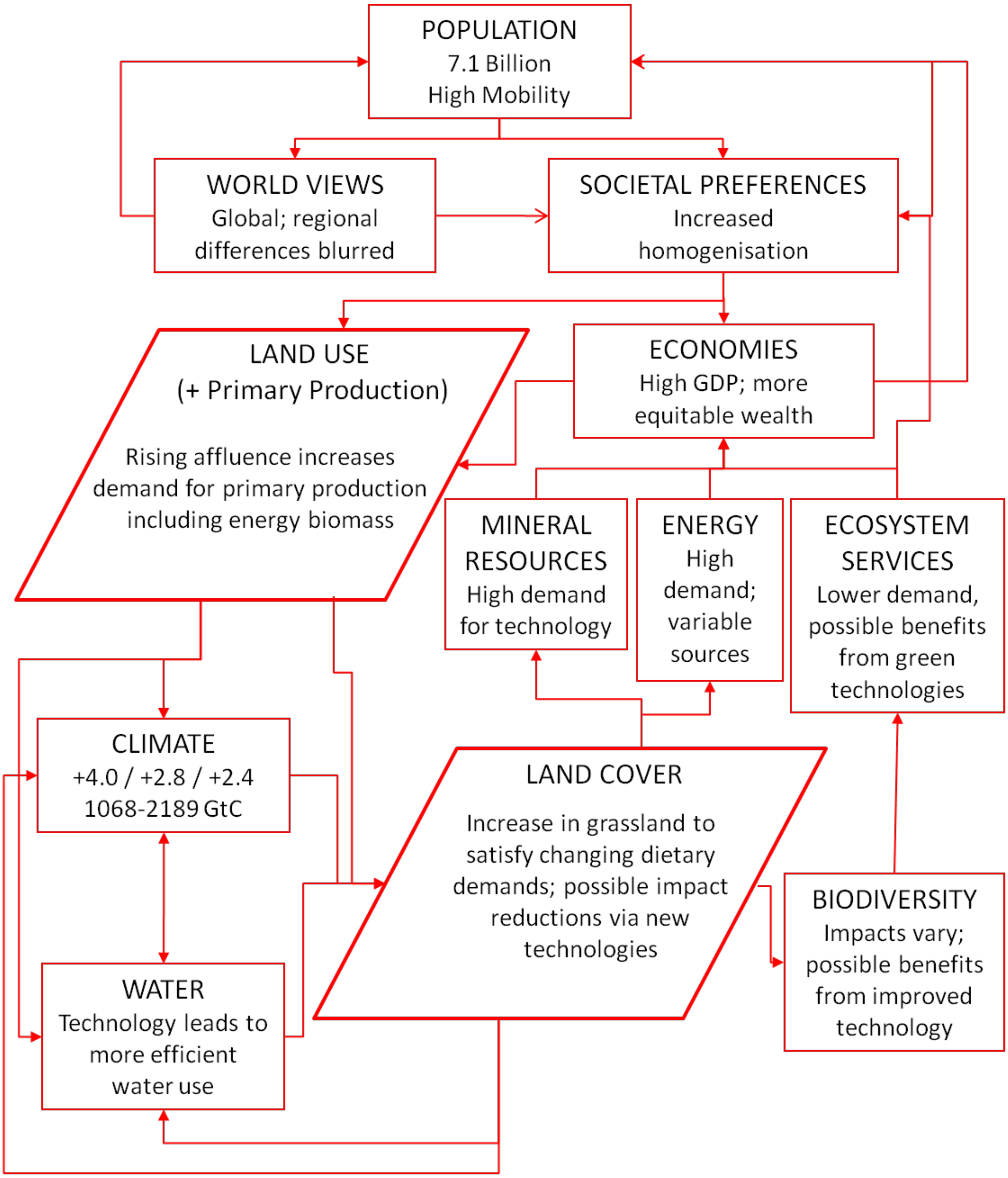


Figure 21 Global system diagram for IPCC AR4 SRES Scenario A1.

Table 16 Downscaling of key drivers to New Zealand for IPCC SRES A1 Scenario

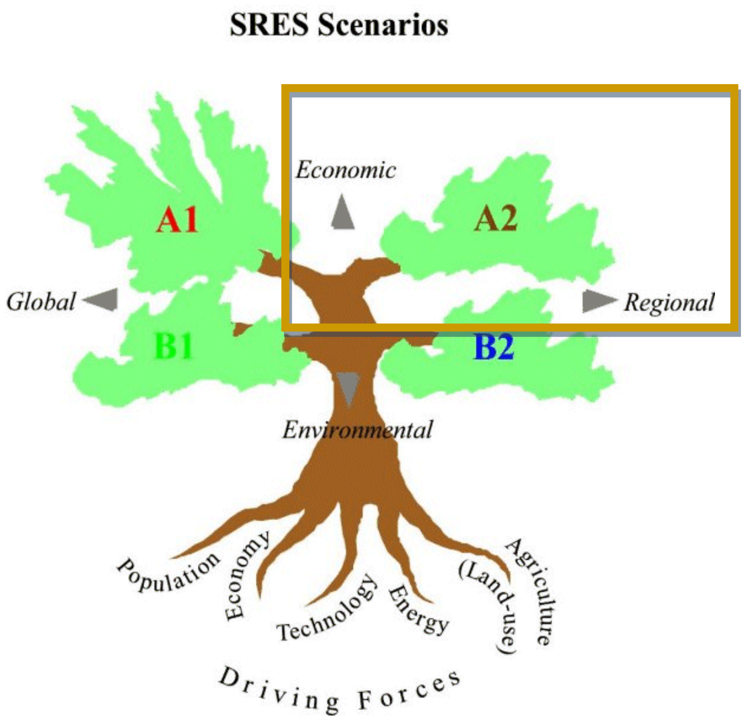
SCENARIO A1	
CLIMATE CHANGE	• Temperature: +2°C to +4°C by 2100 • Rainfall: Mean rainfall remains similar to current conditions, but with increase in intense rainfall events leading to increased flooding • Sea level rise: +0.8m by 2100 leads to increased stress on coastal areas and impact on low lying urban areas
AGRICULTURAL PRODUCTION	• Increasing demand for higher-value products as result of rising affluence • Warming temperatures lengthen growing seasons overall but increase risk from extreme events and pest pressures
BIODIVERSITY	• Low to moderate impacts under A1T, increasingly severe impacts under A1B and A1F1 • Pest ranges and pressures increase overall, higher as well under A1B & A1F1
ECOSYSTEM SERVICES	• Risks to services increase with increasing severity of climate change • Less overall demand to measure and value ecosystem services except for those with high economic value
ENERGY	• Technological advances yield increased energy efficiency • Strong demand for biofuels for both national consumption and export
NATIONAL ECONOMY	• Increasing GDP and GDP per capita • NZ benefits from continued global trade and market access
MINERAL RESOURCES	• Strong global demand triggers new exploration and mining activity • Conflict with conservation uses intensifies
NZ POPULATION AND MIGRATION	• After initial increase, NZ population stabilises between 4 and 5 million persons, which is consistent with the current UN Low and StatsNZ Series 1 projections • Potential immigration pressure from Pacific Island populations affected by moderate to severe climate change in A1T and A1F1
SOCIAL PREFERENCES	• Homogenisation of preferences, especially for food, increases market opportunities for export • Meat & dairy consumption increase globally
WATER	• Increased water demand for agriculture to meet growing market demand • Technological advances increase use efficiency, helping to reduce demand growth and reducing impacts/enhancing quality • All NZ glaciers melt under A1F1 by 2100
WORLD VIEWS	• Increasing free trade as world homogenises • Rising global affluence and shared values creates greater proclivity to aid nations and regions most affected by climate change

Table 17 Downscaled effects of key drivers on triggers and thresholds on land-use change across scales within New Zealand for IPCC SRES A1 Scenario

	NATIONAL	REGIONAL	LOCAL
CONSERVATION	Existing conservation land secure but covenanting of private land slows due to increased competition with new production uses, esp. biofuels Technological advances help mitigate climate impacts but require intensive efforts, e.g., assisted migration	Regions and DOC conservancies cooperating through the use of new technologies to monitor and more quickly respond to biodiversity threats Nonetheless moderate to severe climate change will eclipse the ability to respond in some areas, resulting in further biodiversity decline	Technology gains foster more sophisticated means of local management and monitoring of biodiversity but application is uneven across the country due to high costs
PRODUCTION	Arable (-): Loss to urban Biofuels (+++): Rising demand triggers large expansion on marginal hill-country land Carbon Storage (+/-): Low demand Dairy (++): Rising population, affluence and changing dietary preferences Plantation Forestry(--): Competition from biofuels Horticulture (++): Rising global demand + expanded crop options due to climate change Sheep & Beef (--): Competition with biofuels & carbon	Dairy expansion continues in key regions (Waikato, Taranaki, Canterbury, Southland) Loss of production land around major urban centres continues New regional hubs develop around biofuel processing and production in Northland, Waikato, Gisborne, Hawke's Bay, Tasman, Marlborough and Otago to service domestic and export markets Horticulture expands in northern regions to meet rising global demand	Larger farming enterprises dominate as smaller farms cannot afford new technology Overall, increased technology leads to more intensive production systems and higher outputs per hectare Uncertainty from severe weather events increases risks beyond acceptable thresholds, causing some producers to quit the business; such trends are more pronounced nearer the coast than inland given expected trends in west-to-east climate gradients (e.g., rainfall)
URBAN	Increasing affluence triggers increased demand (e.g., lifestyle blocks); lower population at 2100 implies potential oversupply unless compensated by positive net migration, which is more likely under A1B and A1F1 due to climate migrants	Continued urbanisation, esp. around major centres: Auckland, Hamilton, Wellington, Christchurch, Dunedin Rural areas lose population to urban areas as technological advances lead to increased automation of production	Increasing pressure of peri-urban residential development around major urban centres

UNMANAGED	Unmanaged land decreases markedly as demand for biofuels and/or carbon storage cross suitable price thresholds Fate of unmanaged land under native cover controversial: conservation or production?	Little unmanaged land remains in any region of New Zealand Unmanaged land closer to urban areas more likely to convert to biofuels to minimise distance to markets and keep production costs down	Most local landowners take advantage of new markets and convert their unmanaged land to biofuel production or carbon storage

6.3 Scenario A2



Scenario A2 projects a world that is highly regionalised and heterogeneous, less affluent, and more crowded. Population has not been controlled and has doubled to 15.1 billion in 2100. GDP per capita has not grown substantially over the past 100 years, suggesting a stagnant global economy. There are still some “winners” but nations and regional alliances look after their own interests.

Other than A1F1, climate change and emissions are highest in this scenario. Unlike the other scenarios, A2 does not benefit from lower demands and pressures owing to a very high population or from an adaptive capacity owing to less technology development and less knowledge sharing. As a consequence, climate change will create substantial vulnerabilities across scales, and society at various levels will have less ability to adapt. Many regions could experience chronic resource shortages, leading to poorer conditions or spurring emigration.

Given the very large global and domestic populations, eventually all land suitable for production will be pressed into service to meet increasing demands for food, fibre, and housing. Urbanisation pressure will initially be severe; however, urban areas will eventually stop expanding as measures are taken to conserve productive land for agriculture. Arable and horticulture land uses will gradually expand as the world scrambles to keep up with rising food demands. Dairy sheep & beef production will also increase somewhat, with dairy displacing sheep & beef and sheep & beef reclaiming abandoned or unmanaged land. Biofuel production will be established on marginal lands less suitable for any other use. Forestry will decline slightly. Conservation will suffer as rates of protection decline and then stop altogether, some areas reserved entirely for biodiversity conservation will be diverted to multiple uses, and illegal use of protected lands will increase.

"Bleak" is probably the best word to describe this scenario, given the convergence of these trends. While initially dynamic, land-use change will gradually slow as people in different regions adapt to the new realities of the world.

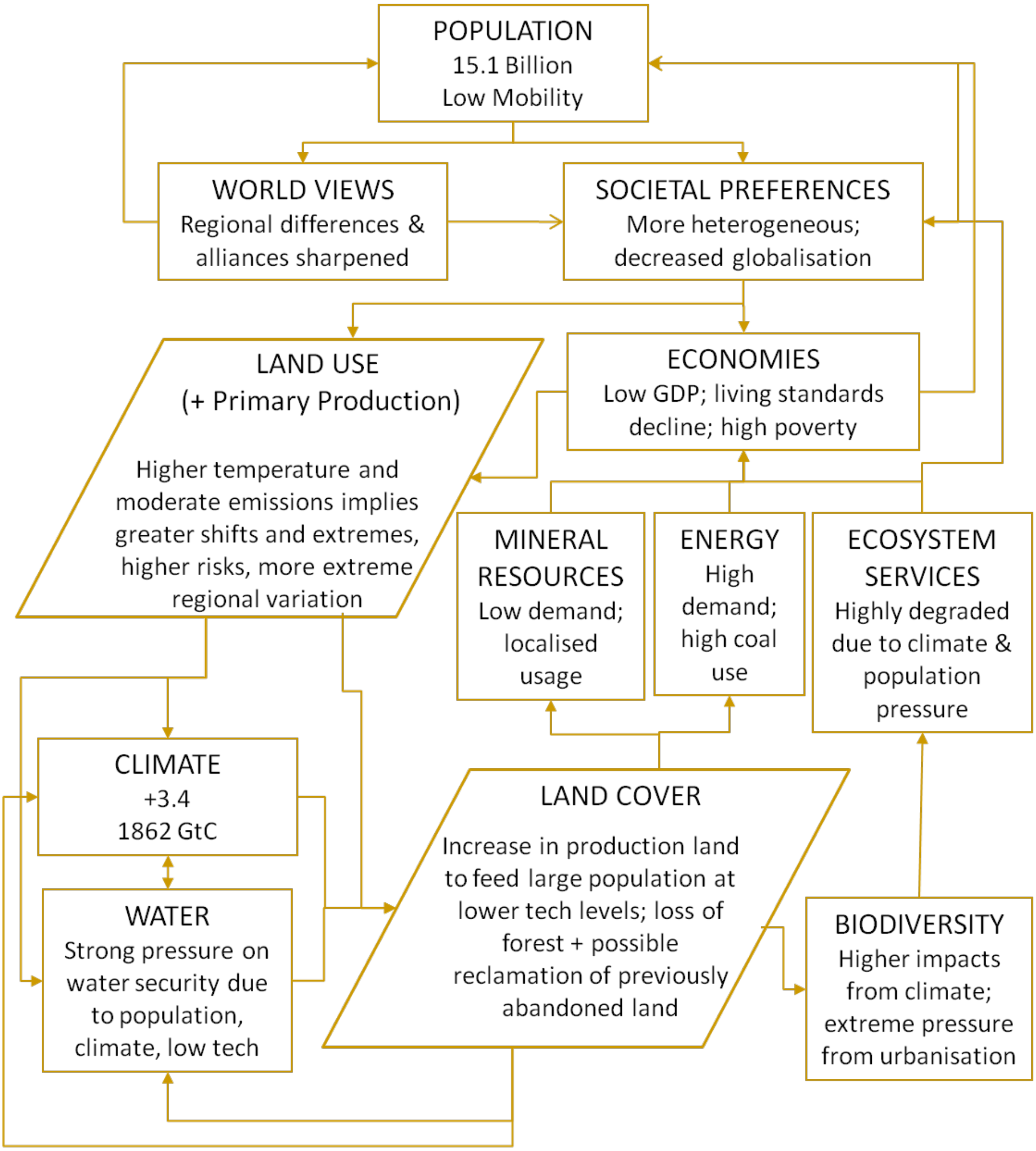


Figure 22 Global system diagram for IPCC AR4 SRES Scenario A2.

Table 18 Downscaling of key drivers to New Zealand for IPCC SRES A2 Scenario

	SCENARIO A2
CLIMATE CHANGE	• Temperature: +2.9°C to +5.8°C by 2100 based on scaling A1B scenario • Rainfall: Similiar patterns as A1 (wetter in the west, drier in the east) but moderately higher magnitudes (1.21) times A1B (see Figure 14) • Sea level rise: not explicitly modelled, but presumably similiar to A1F
AGRICULTURAL PRODUCTION	• Global population increase triggers substantial expansion of production land • Shift in trend from value-added products to products satisfying basic needs NZ becomes more self-sufficient in response to increasing global competition • Climate change and decreased access to globally-supplied inputs (fertiliser, pesticides) due to rising price thresholds reduces yields
BIODIVERSITY	• Climate change, reduced resources and pressure for primary production triggers difficult review to prioritise protected areas; those areas not meeting particular thresholds are converted to suitable production uses • Both range and intensity of impacts of pests and weeds expands
ECOSYSTEM SERVICES	• Tolerance thresholds for poorer service conditions increase as the requirement to satisfy basic needs becomes more urgent • Spatially heterogeneous conditions prevail as various services trade-off to differing degrees regionlaly and locally to meet varying needs
ENERGY	• Range of choice for food, clothing, household good, etc., shrinks due to rising transport costs • Decreased personal mobility resulting from lower energy per capita • Overseas travel and tourism declines relative to current levels
NATIONAL ECONOMY	• Global conditions trigger shift in NZ export markets; Asia becomes dominant market due to increased demand and proximity • Per capita income peaks then declines, leading to lower standard of living
MINERAL RESOURCES	• Decreasing global production due to economic forces triggers extensive recycling efforts and return to “No. 8 wire” mentality • Higher prices for global resources lead to higher levels of resuse/recycling
NZ POPULATION AND MIGRATION	• NZ population towards higher end of projections, e.g., 9 million by 2100 • Density of urban areas increases as land is reserved for food production • Shanty towns appear in major urban centres, especially Auckland
SOCIAL PREFERENCES	• “Food production zones” appear around urban areas to satisfy local demand • Need for increased self-sufficiency triggers a decline in leisure time
WATER	• Water becomes the limiting resource • Establishment of fully costed water markets triggers substantial internal migration as business and people move to areas with affordable water supply
WORLD VIEWS	• Australia-New Zealand links strengthened, common market and currency a strong possibility • Strong Oceania/SE Asia alliances also very likely as they will need access

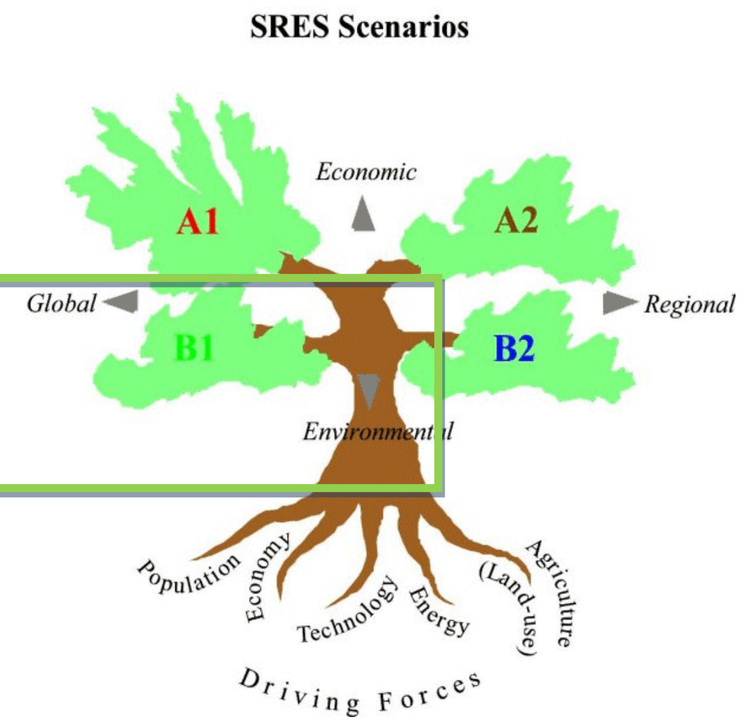
	to NZ food production to help feed their large populations

Table 19 Downscaled effects of key drivers on triggers and thresholds on land-use change across scales within New Zealand for IPCC SRES A2 Scenario

	NATIONAL	REGIONAL	LOCAL
CONSERVATION	Total area of protected lands including conservation estate decreases "Crown jewels" prioritised, including those home to iconic endangered species or still generating substantial revenue from tourism; conservation fee charged to each overseas visitor	Similar to national, protected areas with high production capability are converted As best they can, regions balance uses of remaining protected areas among conservation, recreation, & ecosystem services	Local conservation highly variable and reflects availability of local resources, including physical materials, fiscal resources (especially local council funds), and people's time
PRODUCTION	Arable (++): Expands to meet substantial increases in domestic & export demands Biofuels (+): Expands to meet primarily domestic demand Carbon (-): Shift of emphasis to adaptation triggers shift away from carbon storage towards production Dairy (++): Total area increases but shifts to less productive land, as high quality land diverted to other uses Forestry (-): Reduction in export demand, shift to mainly regional or domestic markets Horticulture (++): Expands to meet substantial increases i domestic & export demands Sheep & Beef (+): Gains from conversion of unmanaged lands; more marginal lands shift to biofuels	Arable and horticulture expand around urban centres to take advantage of high capability soils, proximity to labour, and reduced transport costs Dairy expansion continues in Waikato, Canterbury, and Southland but on less productive land Horticulture expands in northern regions to take advantage of warmer climates and proximity to major ports; possible expansion in some South Island regions as well	Increasing global fertiliser prices raise profitability thresholds, thereby spurring local nutrient recovery/recycling networks Production land uses supporting local markets more interspersed among residential and commercial uses to help reduce transport costs
URBAN	Initial increase in urban area triggered by rising population Eventually total urban area stabilises and increasing population accommodated by higher densities as land is reserved for food & fibre production for local consumption and export opportunities	Recent trends continue such that major urban centres expand Increased demand for localised production and water costs triggers redistribution to warmer, wetter regions	Smaller towns and villages re-emerge as growth areas New land use patterns emerge consisting of clusters of concentrated urban cores surrounded by "production bands"

UMANAGED	By 2100 substantial increases in demand for food, fibre and fuels trigger conversion of all unmanaged land to uses best matching land use capability	No unmanaged lands remain	No unmanaged lands remain

6.4 Scenario B1



In Scenario B1, people live more in harmony with the environment. This scenario shares with A1 a global emphasis, stabilised population (7.1 billion) and increasing wealth. Unlike A1, standards of living (as evidenced by GDP) have increased to lower but presumably more sustainable levels. There is a shift away from consumption to services, and a heightened concern for environmental protection.

Climate change is lowest in this scenario (+1.8 °C), due to lower overall energy demand and a balanced supply between fossil fuels and renewables, as well as shifts in land-use (see below). Risks and vulnerabilities from climate change will consequently be lower than other scenarios. Regional differences, while still present, are likely to be ameliorated compared to other scenarios.

Land-use management contributes to efforts to reduce climate change. Even though climate effects are lower, such efforts lower some thresholds and trigger substantial land-use change. The proactive approach benefits society, the economy, and the environment. Forests, croplands, and other land uses increase the most of any scenario. Grasslands decrease by the largest amount of any scenario (–1537 million hectares), reflecting trends in food preferences to include more crops, grains and vegetables and less meat and possibly dairy. The overall picture implies less pressure on water resources and enhancement of ecosystem services compared to other SRES scenarios. Urbanisation pressures are lower given lower population levels. Conservation will benefit either directly (e.g., new parks and reserves to meet new societal goals) or indirectly (e.g., carbon sequestration).

In summary, Scenario B1 appears to achieve the most balance between continued socioeconomic development and environmental protection. However, it implies the adoption of austerity measures, which requires substantial changes in behaviour that run contrary to long-term societal trends towards greater consumption and affluence.

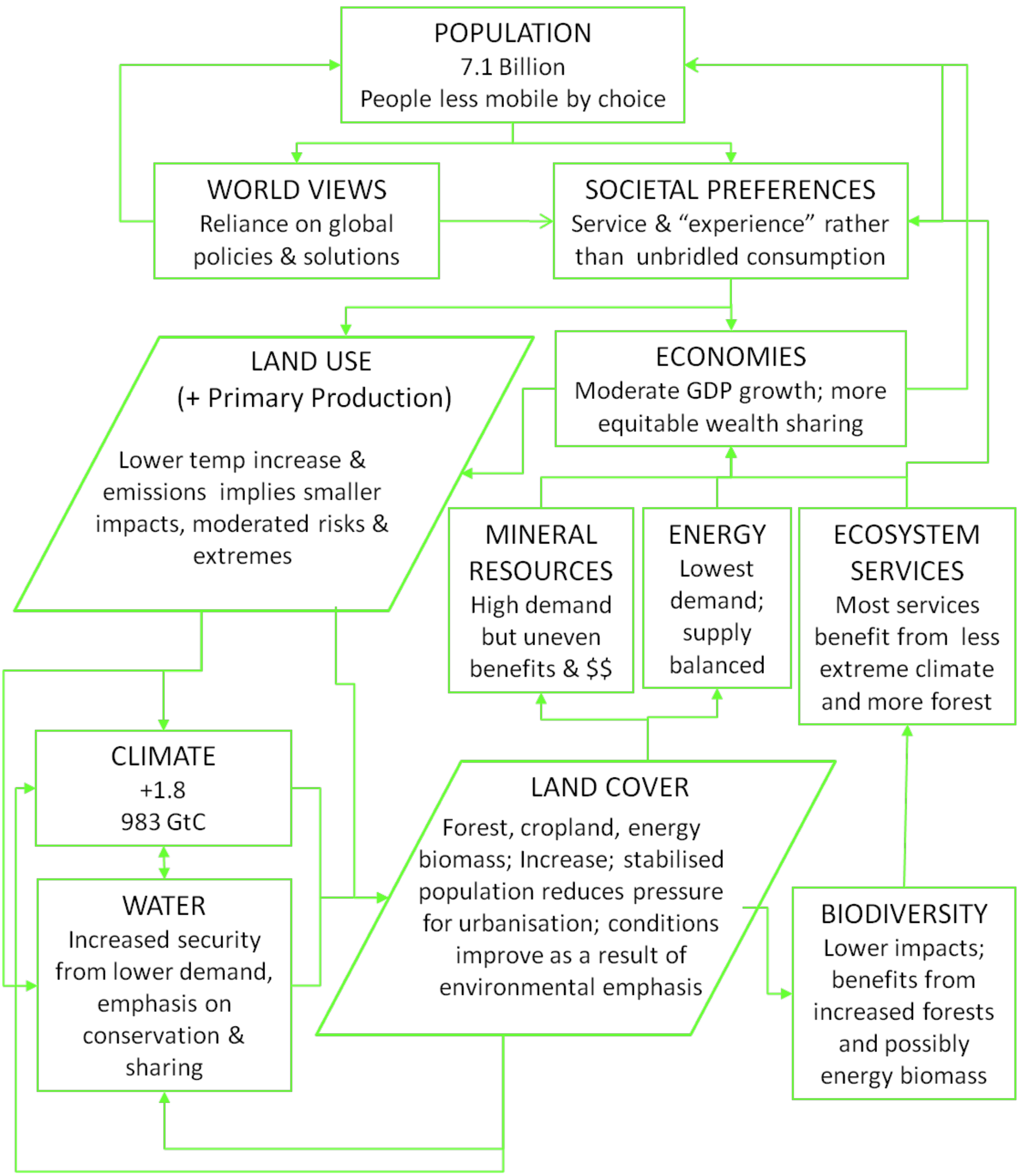


Figure 23 Global system diagram for IPCC AR4 SRES Scenario B1.

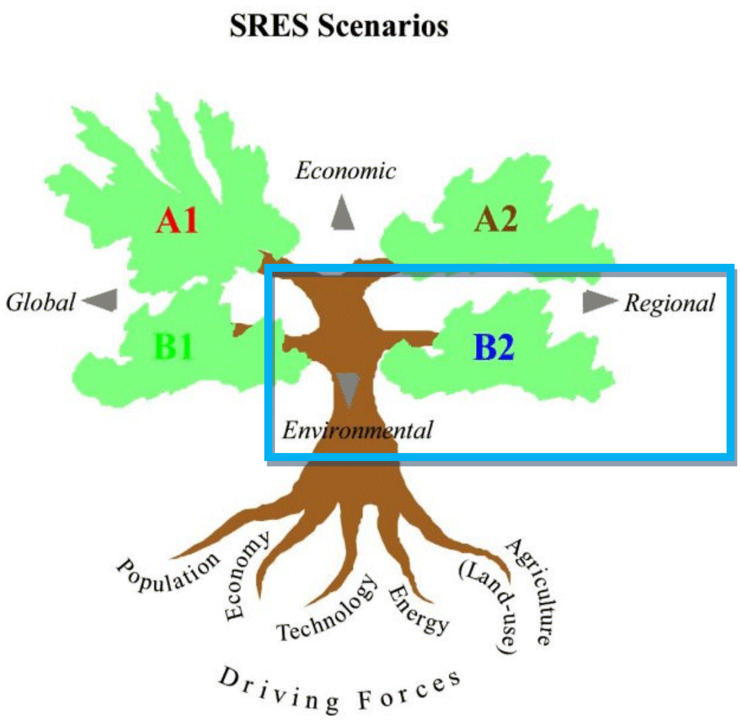
Table 20 Downscaling of key drivers to New Zealand for IPCC SRES B1 Scenario

	SCENARIO B1
CLIMATE CHANGE	• Temperature: +1.3°C to +2.6°C by 2100 based on scaling A1B scenario • Rainfall: Similar patterns to A1B (see Figure 14), resulting in wetter conditions in the west, drier in the east but lower expected magnitude (0.65) of change
AGRICULTURAL PRODUCTION	• Production increases and then declines as world population stabilises • Societal preferences trigger production shifts away from processed foods including meat and dairy to more Mediterranean-style diets rich in grains, cererals, fruits, and nuts • Farming incorporates more environmentally friendly practices
BIODIVERSITY	• Biodiversity enhanced via less risk from climate change and increased societal emphasis on environmental protection • Conservation and restoration emphasised
ECOSYSTEM SERVICES	• All services stabilised and increasing in condition • Explicit valuation of services included in business and national accounting practices
ENERGY	• Lower overall energy use per capita reflecting a combination of lifestyle choices and technologies leading to energy efficiency • Mixture of renewables provide most energy to society
NATIONAL ECONOMY	• Moderate growth and more equitable distribution of wealth • More comprehensive measures such as Genuine Progress Indicator becomes the standard measure of economic success • Higher taxes and/or market-based mechanisms to achieve social and environmental objectives
MINERAL RESOURCES	• Global mineral availability good but expensive given strong demand from technology improvements
NZ POPULATION AND MIGRATION	• Population stabilises between low and medium projections (~4.5–5 million) • Free movement of population between New Zealand and South Pacific Island nations, as NZ offers flexibility to adapt to any lingering effects of moderated climate change
SOCIAL PREFERENCES	• NZ mirrors shift in global emphasis towards a more harmonious relationship with nature and reduced emphasis on consumption
WATER	• Increased water security due to moderated demands resulting from lifestyle choices and technological efficencies • Water management viewed holistically such that all possible uses are considered when making allocation decisions
WORLD VIEWS	• NZ is an active member of global community, both benefiting from and contributing to global free trade in goods, services and knowledge (i.e. technology) • Quadruple bottom-line reporting (cultural, economic, environmental social) standard for all activites

Table 21 Downscaled effects of key drivers on triggers and thresholds on land-use change across scales within New Zealand for IPCC SRES B1 Scenario

	SCENARIO B1		
	NATIONAL	REGIONAL	LOCAL
CONSERVATION	Expansion resulting from increased emphasis on environmental protection, provision of ecosystem services and shift of emphasis from material consumption	Increased emphasis on protection and restoration of degraded ecosystems including lowlands, wetlands and coastal areas is commonplace across all regions	Conservation integrated throughout local development via native plantings and restoration Some areas within urban areas returned to native cover to increase access to and enjoyment of nature
PRODUCTION	Arable (++): Increases to meet shifting dietary preferences Biofuels (++): Moderate increase from shift to renewable energy Carbon (+): Increases for carbon storage and broader environmental benefits Dairy (-): Decreases as dietary preferences move away from meat & dairy consumption Forestry(++): Increases for forestry products harvested in more sustainable practices with longer rotations times Horticulture (+): Increases to meet shifting dietary preferences Sheep & Beef (-):Decreases as dietary preferences move away from meat & dairy consumption	Integrated approaches to land-use planning become common Forested area increases in all regions to supply a variety of uses including wood & fibre for industry, bioenergy and conservation Pastoral land use declines in all regions reflecting decrease in meat & diary consumption; remaining production oriented primarily towards remaining local market demands or to continued production of specialised products for export	Agricultural workforce expands as people pursue farming for both economic livelihood and personal quality of life reasons Increasing shift towards less-intensive production systems; organic farming becomes more the norm than the exception Urban gardening increases in popularity, both individually and via community efforts
URBAN	Initial expansion to accommodate population growth, followed by managed contraction as population decreases and then stabilises, although possibility of net positive immigration may counteract those trends	Smart growth incorporating integrated land-use planning and multi-modal transport is standard	Natural, agricultural and urban areas co-located to allow pursuit of multiple activities (recreation, socialising, gardening) and increase quality of life
UNMANAGED	No unmanaged areas remain; all areas evaluated and valued for their use and function including biodiversity protection, availability of ecosystem services, cultural and spiritual values, etc.	Same as national	Same as national

6.5 Scenario B2



Scenario B2 paints a picture of a world where different nations and regions have taken their own pathways for dealing with climate change, some much more successfully than others. Global population is relatively high (10.4 billion). Overall GDP growth is the lowest of any scenario, but the lower population results in a 40% higher per capita GDP compared with A2. Total energy use is second lowest (B1 lower) but per capita energy use is second highest (A1 higher).

Expected climate change is intermediate compared with other scenarios (+2.4 °C), suggesting an intermediate relative level of risk and impact. Regional trends suggest a greater chance for and disparity among "winners" and "losers" based on a combination of impacts and capacity to adapt. Some regions may cope fairly well or even benefit from climate change, while others will be severely adversely affected.

Taken together, the above trends point to high unpredictability and volatility for land-use change. Land-use projections for B2 show increases in energy biomass, forest, and grassland, and moderate to very large decreases for cropland and other land uses. As for B1, there is an emphasis on environmental protection, which leads to increased use of renewable energy and reduces thresholds for replanting of forests. Urbanisation pressures will be high, given population increases, while conservation will benefit.

More so than others, Scenario B2 will be a very heterogeneous world in all aspects: land use, climate change and climate change impacts, wealth and standard of living, and preferences and lifestyles. The possibility exists for a very segregated society separated more than at present not only by socioeconomic conditions but also by environmental conditions.

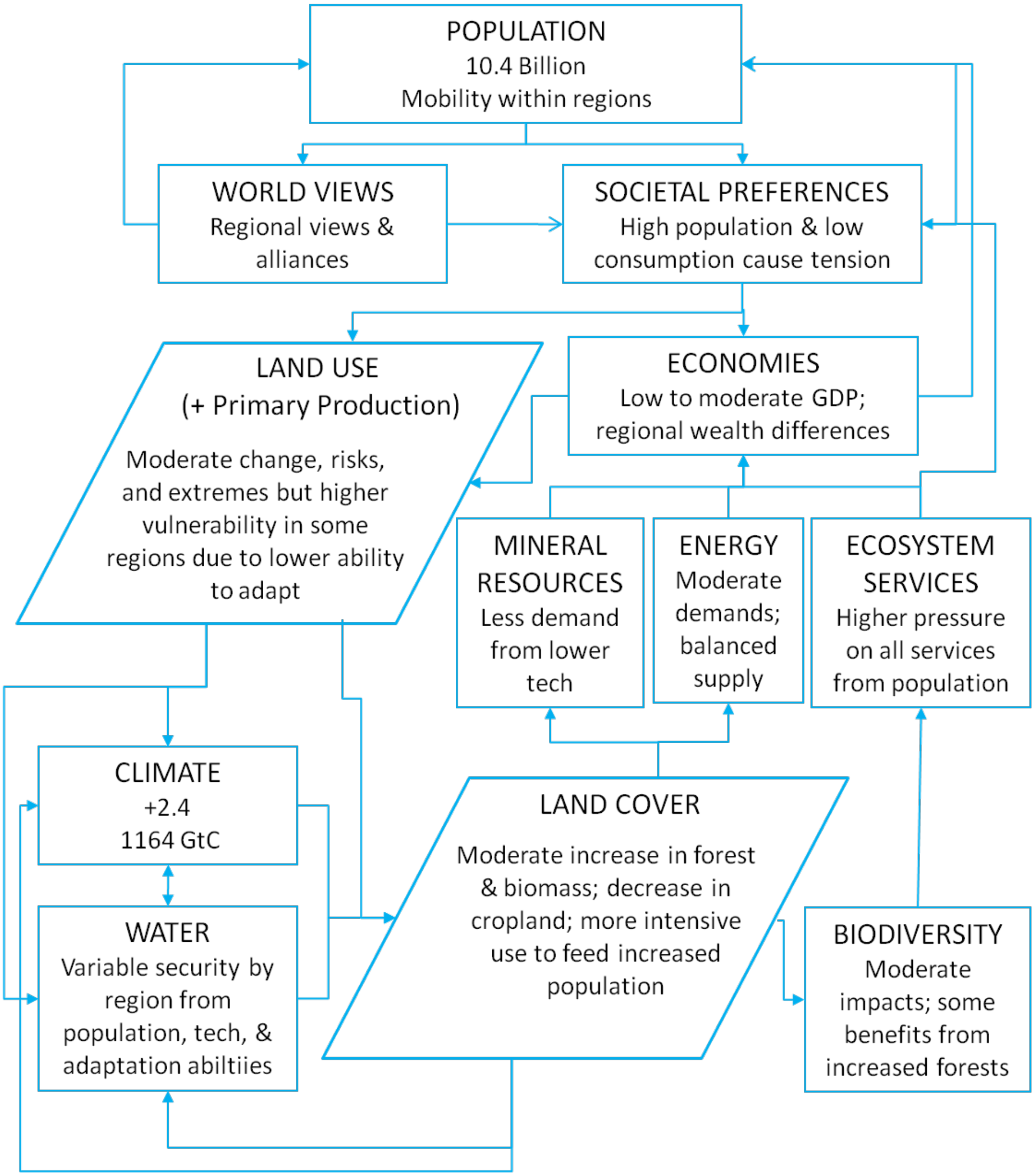


Figure 24 Global system diagram for IPCC AR4 SRES Scenario B2.

Table 22 Downscaling of key drivers to New Zealand for IPCC SRES B2 Scenario

SCENARIO B2	
CLIMATE CHANGE	• Temperature: +2.4°C to +4.8°C by 2100 based on scaling A1B scenario • Rainfall: increases and decreases 0.85 times A1B (see Figure 14)
AGRICULTURAL PRODUCTION	• Increase in production land to meet rising regional market demands • SE Asian markets become more important as regional trade overtakes global trade, spurring emphasis on higher-value agricultural exports
BIODIVERSITY	• Biodiversity declines as most unprotected native land cover is changed to productive uses including biomass for domestic energy consumption • Remaining areas of biodiversity under increased pressure from relatively stronger climate change including pests and weeds but benefit from increased efforts based on increased societal preference on environmental protection
ECOSYSTEM SERVICES	• Provisioning and regulating services under increased pressure and intensification to meet increased production due to populatin increase
ENERGY	• NZ more dependent on local energy production including coal, hydro, wind, and biomass for bioenergy
NATIONAL ECONOMY	• NZ fares better than other countries given strong natural resource base • Primary production becomes a larger share of the national economy
MINERAL RESOURCES	• Reduced access to and reliance on mineral resources given lower level of wealth and income and lower levels of technological development • Coal production increases to satisfy export demands and internal consumption
NZ POPULATION AND MIGRATION	• Population towards the higher end projections, ~ 5–5.5. million by 2100 • Net gain from international migration; while some still seek better opportunities in Australia, many ex-pats return from countries faring worse than NZ and large influx of Pacific Islanders seeking escape from climate impacts
SOCIAL PREFERENCES	• Increased emphasis on environmental protection and enhancement but only for outcomes with substantial economic benefits • Holiday/leisure time becomes more aggregated to allow more time for slower, more expensive travel, usually domestically or to neighboring countries
WATER	• Water resources well-managed but fully allocated • Irrigation increases in some regions to increase production for exports
WORLD VIEWS	• New Zeland party to strong regional alliances and regional free trading zones (OZ/Pacific/SE Asia) • Similiar to A2, an Oceania/SE Asia alliances develops but with less strength as countries can fare better individually given lower population levels

Table 23 Downscaled effects of key drivers on triggers and thresholds on land-use change across scales within New Zealand for IPCC SRES B2 Scenario

	SCENARIO B2		
	NATIONAL	REGIONAL	LOCAL
CONSERVATION	Global trends force a re-think of conservation values and strategies; native land cover increases to provide mixed use (production, biodiversity, ecosystem services); pest & weed control more concentrated as some areas "let go" while others restored for both biodiversity and tourism benefits	Strong trend towards local solutions leads to unevenness in conservation efforts as different locales adapt to changing conditions; more difficult to achieve coordination leading to broader, more enduring outcomes	Patchiness of local efforts, reflecting variation in community and individual preferences and values
PRODUCTION	Arable (++): Increases to meet rising domestic & export demand Biofuels (++):Increases to meet rising domestic & export demand Carbon (+): Small increases through net increase over time in plantation forestry Dairy (+): Increases to meet rising domestic & export demand Forestry(++): Increases to meet rising domestic & export demand Horticulture (++): Substantial increases given export value Sheep & Beef (+):Increases to meet rising domestic & export demand	Horticulture expands in northern regions to meet rising int'l demands & reduce distance to key ports for transport; Heart of dairying shifts further south to Manawatu &Wanganui Marginal lands, mostly hill country, throughout NZ come into use for forestry for fibre or biomass or sheep/beef	Rising global prices and NZ population, coupled with favourable local tax schemes, trigger conversion of suitable lands near urban areas to local food production Farming production systems adopt "best practicable" means to minimise impacts to the environment and ecosystem services
URBAN	Trend towards better local management & reduced sprawl in tension with pressure from increased net immigration as ex-pats return and families take in relatives from regions and countries coping less successfully with climate change	Larger in northern areas due to internal migration and new immigrants settling in warming climates and new opportunities arise to satisfy diversified production exports	Local urbanisation trends continue but towards smaller region cities and towns, rather than larger metropolitan areas as both energy constraints and social preferences limit city sizes

UNMANAGED	Almost all unmanaged land comes under some type of use, primarily forestry, biomass production and sheep and beef, given large amounts are located on higher elevation, hilly land	Most reduced in more northern regions where climates increase productivity; also reduced but to a lesser degree in southern regions	Pockets of unmanaged land remain in remote areas where any use is too difficult and therefore unprofitable

7 Gaps and Limitations

The preceding analysis, while attempting to be comprehensive and current, features several gaps and limitations resulting mainly from the scope of the current study but also reflecting the complexity of the subject matter and the on-going availability of new knowledge and data. Below we briefly summarise those gaps and limitations and discuss how they could be addressed in future analyses.

7.1 Advantages and Disadvantages of Qualitative Analyses

The analysis undertaken in this report was qualitative in nature. It was designed as a scoping exercise to survey recent developments in key trends that influence land-use change. Advantages of qualitative approaches lie in their creativity and flexibility. They facilitate thinking “outside the box” by creating a space in which people can explore alternatives without constraints. New ideas or lines of thinking can be rapidly developed, critiqued, and adopted, adapted or discarded as needed. Disadvantages include an inability to undertake formal sensitivity and uncertainty analyses as quantitative modelling approaches often allow. While qualitative, the current analysis nonetheless provides essential knowledge and current information about key trends that could help underpin further qualitative or quantitative analyses. Ideally it would contribute to a combined approach that draws on linked qualitative and quantitative methodologies, such as the development of qualitative storylines coupled with quantitative scenario analysis and modelling as used in the IPCC SRES scenario development process.

7.2 Key Trends and Drivers

We reviewed 11 key trends, including climate change. The trends reviewed represent some of the major drivers of land-use and land-cover change both globally and within New Zealand. Nonetheless they do not necessarily encompass the full range of trends influencing land-use change. Other trends that could be considered include defence and security, social processes of change, and additional aspects of technological development. Furthermore, different trends affect land-use/land-cover change at different scales, as was demonstrated through/in the analyses in this review. A future review could consider a broader range of trends and evaluate how they change in importance across scales, given that different sets of drivers operate and interact globally, nationally, regionally, and locally.

7.3 Uncertainty

Taking into account the variability of underpinning assumptions, each key trend bounds its own range of possible outcomes. Combining trends into interacting systems potentially compounds uncertainty, given the added variability introduced regarding the number and nature of the links identified. Specific links may be incorrect, while other important links remain undefined. The direction and magnitude of links may be wrong or may vary over time as a result of other known or unknown factors. A formal evaluation of the uncertainty associated with our qualitative downscaling process was beyond the scope of the project. Future reviews would benefit from examining the literature on uncertainty analysis and applying recommended practices. For example, future analyses could incorporate the practice of the IPCC and use formalised statements of uncertainty (e.g., not likely, likely, very likely) with implied associated probabilities to move towards more explicit and robust uncertainty assessments.

7.4 Limited Knowledge of Impacts at Fine-scale Resolutions

IPCC scenarios and similar forward-looking research undertaken to date have effectively defined broad trends and possible outcomes and impacts. However, such broad-scale studies are lacking in their ability to inform outcomes and impacts at finer spatial and temporal resolutions. This is particularly troublesome for land-use change because the consequences of land-use decisions are felt most acutely and directly at local scales, e.g., impact of severe weather on infrastructure, increasing volatility leading to business failure, etc. Research efforts are increasingly attempting to link processes across scales to improve the understanding of the consequences of global and national trends on local conditions and what that implies for adaptive strategies across scales. Such research remains, however, in the very early stages of development.

7.5 Lack of a Clear “Stopping Rule”

Similar to the IPCC SRES scenario process, the on-going availability of new and updated information and data means the report is by definition out-of-date at the time of publication. No specific criteria exist that suggest an optimal point at which to stop. One could always include just one more new study or report to improve the breadth and quality of the analysis and make the report as up-to-date as possible. Undertaking consistent and periodic reviews and analyses, such as the IPCC climate change assessments or the IEA’s World Energy Outlook, can help overcome such limitations by building up a longer term picture of how various key trends are evolving. Such an approach becomes even more useful if former scenarios and projections are re-evaluated in light of new data or information.

7.6 Preferences and Views

The analysis considered world views and societal preferences for food and fibre and their potential consequences on land-use change, but only very broadly. Future reviews would benefit from a more comprehensive and thorough analysis that included a wider range of preferences and a more detailed analysis of their potential effects on land-use change.

7.7 Reconciling Global and New Zealand Trends

Global trends have inherent assumptions or implications for New Zealand. In some cases, New Zealand is explicitly characterised (e.g., population projections by various world agencies). In other cases, New Zealand is combined with other countries, typically with at least Australia or sometimes regionally (e.g., Asia Pacific) or politically (e.g., OECD), given limited data or knowledge or the priorities of a particular project or researcher. Future research could explore in more detail the similarities and differences in trends produced by international organisations such as the OECD, FAO, UN, etc., versus those produced by national organisations such as MAF, Statistics New Zealand, MED, etc.

7.8 Relative Importance of Key Trends

When evaluating key trends, we did not rank or otherwise assess their relative importance. We treated each key trend as equivalent in terms of its potential effect. In reality that is almost certainly not the case, as some key trends will have more substantial influence on future land-use change. Even more likely, different trends will wax and wane in importance over time. The dynamics of various productive land uses in New Zealand is a good example of these effects. Changes in markets, technologies, preferences, and economic and biophysical conditions have caused shifts in production over the past 40–50 years. As discussed above, more quantitative modelling would facilitate sensitivity analyses that could help determine which trends exert more influence on future land-use change.

7.9 The Technology Wild Card

Assumptions about technology reflect the level of confidence in human ingenuity and our ability to overcome potential resource limitations or adapt to new circumstances. Projections of future technological trends can markedly alter the direction, magnitude, and character of future scenarios. The IPCC SRES scenarios treatment of the technological development of energy systems highlighted the potential strength of such effects. For example, consider the effects of technology in the A1 versus A2 scenario families. The A1 scenario family assumed generally high rates of technological development, leading to the highest rates of energy use but also to the highest level of economic development measured in terms of GDP. However, within the overall family, differing assumptions regarding the types and rates of technology and emphasis across different energy sources led to substantially divergent outcomes for emissions and, consequently, for climate change. The A1F1 scenario led to the highest emissions and projected temperature increase of any scenario, while the A1T scenario led to the second lowest emissions (B1 being lower) and moderate temperature increases, while still accommodating substantial global economic growth. In contrast, the A2 scenario family assumed slow technological development, leading to lower GDP growth (total and per capita), relatively high and inefficient rates of fossil fuel use, and therefore relatively high emissions and projected temperature increases.

As explained earlier, our review did not focus on specific technology but rather on technology as an aspect of each key trend. In that sense our assessment was broader than the IPCC assessment, which focused as described above primarily on energy technology, and paralleled discussions of technology in a more general sense. Technology has been considered or in some cases explicitly modelled relative to agriculture (e.g., increased crop yields, resistance to drought or other stress), water resources (e.g., more efficient and cost-effective irrigation, desalinisation), resource use (e.g., extraction of lower quality ores, improved reuse and recycling), and human health (increased longevity, improved quality of life) to name a few. For example, in one modelling study (see Ewert et al. 2006) technological improvements to crop yields ranged from 25% to 163%. Future assessments would benefit from a more complete and rigorous treatment of technological development, especially more explicit pathways that must eventuate to realise different outcomes, as opposed to relying on vague or, at best, heuristic assumptions of “progress.”

7.10 Age of IPCC SRES Scenarios

The current analysis is based on the IPCC SRES scenarios developed approximately 10 years ago. Future analyses can and should be able to take advantage of new scenarios developed in conjunction with the IPCC’s Fifth Assessment Report (AR5). The process for developing new scenarios is briefly described below.

In 2006 the IPCC decided they would not directly coordinate and approve the development of updated scenarios in their next review process (AR5). Instead the IPCC indicated that the scientific community should coordinate the scenario development process, with the IPCC helping to catalyze the timely production of new scenarios for possible use in AR5.

In September 2007, experts met in Noorwijkerhout, The Netherlands, to consider plans from the scientific community regarding development of new scenarios. Attendees at the meeting included experts in integrated assessment modelling (IAM), impacts, adaptation and vulnerability research (IAV), and climate modelling (CM). A key aim was to overcome the limitations of the sequential scenario development process used in AR4. Given the long development times, the sequential process resulted in substantial lags between early and late phases of scenario development, which generated inconsistencies given the continual availability of new information as discussed above. Instead, the scientific community desired a more flexible, parallelised scenario development process (Figure 25) that could be completed more quickly, thereby reducing lag effects, and that also promoted more interaction and integration among the IAM, IAV, and CM communities. Attendees agreed on a parallel process of scenario development centred on “Representative Concentration Pathways” (RCPs).

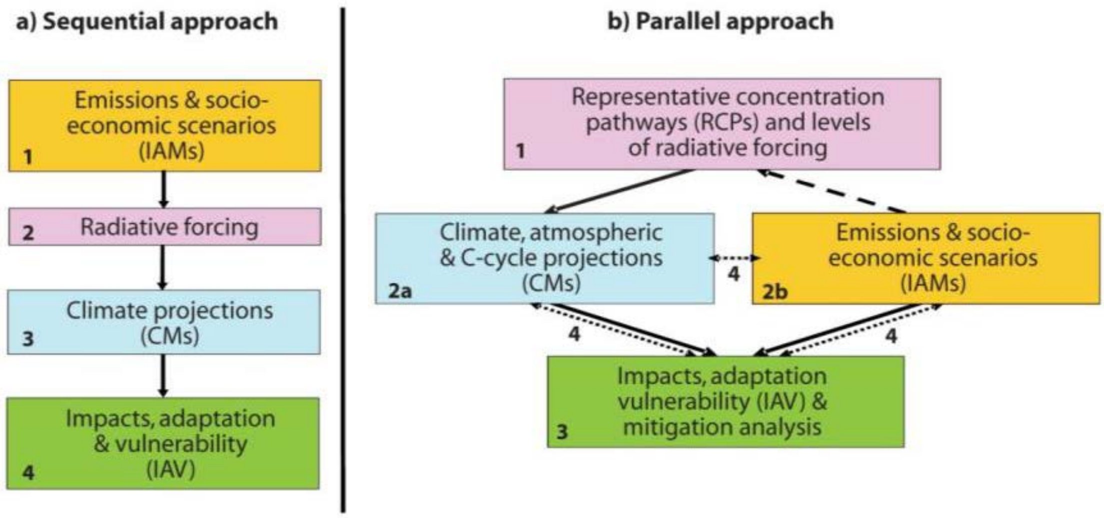


Figure 25 Climate change assessment approaches: (a) The sequential modelling approach used for AR4 and its predecessors; and (b) The parallel modelling approach proposed for AR5. IAMs are Integrated Assessment Models; CMs are Climate Models; IAV is Impacts, Adaptation and Vulnerability Research; and RCPs are Representative Concentration Pathways (Reproduced from **http://www.ipcc.ch/activities/activities.htm**).

RCPs provide time-dependent projections of atmospheric greenhouse gas concentrations (Figure 26). The trajectory taken over time is important, as is the final concentration or stabilization level. It has been decided that four RCPs will be produced in advance of the AR5: one high pathway for which radiative forcing reaches >8.5 W/m^2 after 2100 and keeps rising; two intermediate "stabilization pathways" in which radiative forcing is stabilized at approximately 6 W/m^2 and 4.5 W/m^2 after 2100; and one pathway where radiative forcing peaks at approximately 3 W/m^2 before 2100 and then declines. RCPs will also incorporate more detail than previously in "near term" scenarios that cover the period to about 2035, and extend in a more stylized way to 2300, whereas the IPCC AR4 scenarios stopped at 2100.

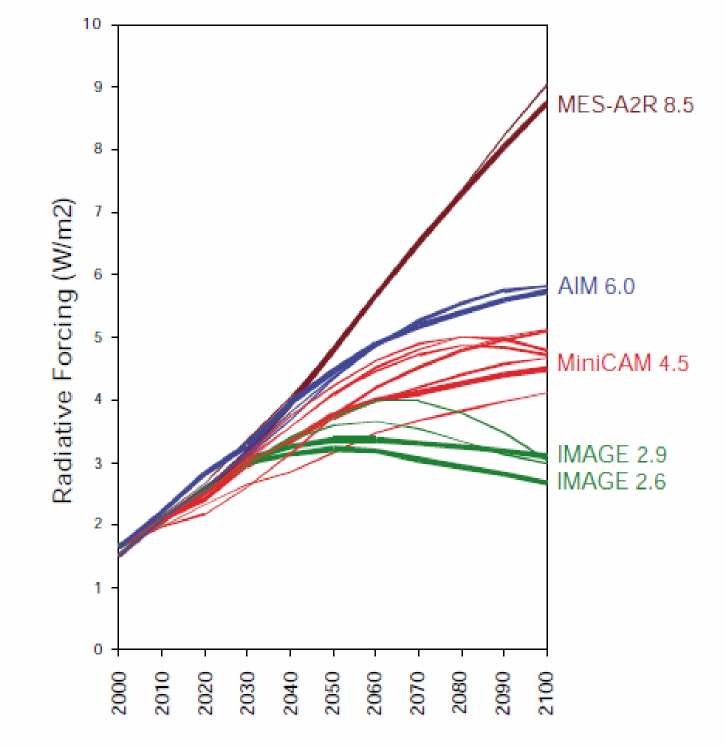


Figure 26 Radiative forcing for the RCP candidates (coloured lines). Names refer to the integrated assessment-modelling group responsible for producing the RCP (Source: Moss et al. 2008).

The schedule for delivery of various scenario "products" strongly influenced the IPCC's decisions on the scheduling of AR5 (Figure 27, Figure 28).The early identification of a set of RCPs facilitates coordination of new integrated socioeconomic, emissions, and climate scenarios. The primary rationale for beginning with RCPs is to expedite the development of a broad literature of new and integrated scenarios by allowing the modelling of climate system responses to human activities to proceed in parallel to emissions scenario development.

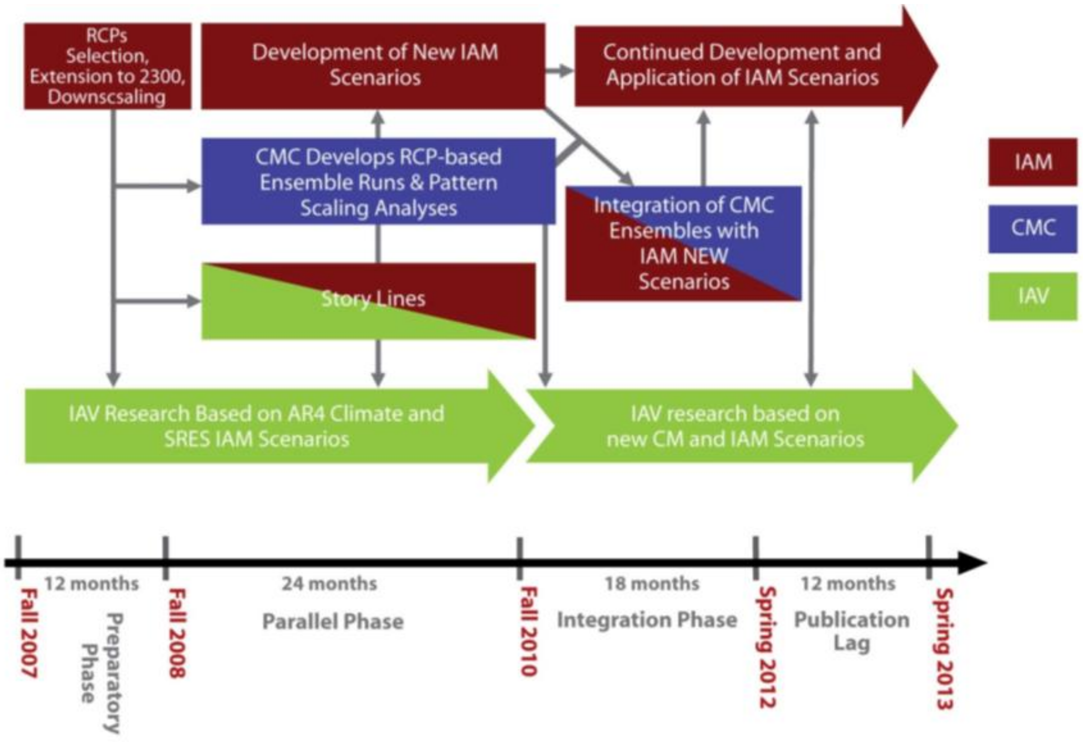


Figure 27 Timeline and critical path of scenario development proposed for AR5.

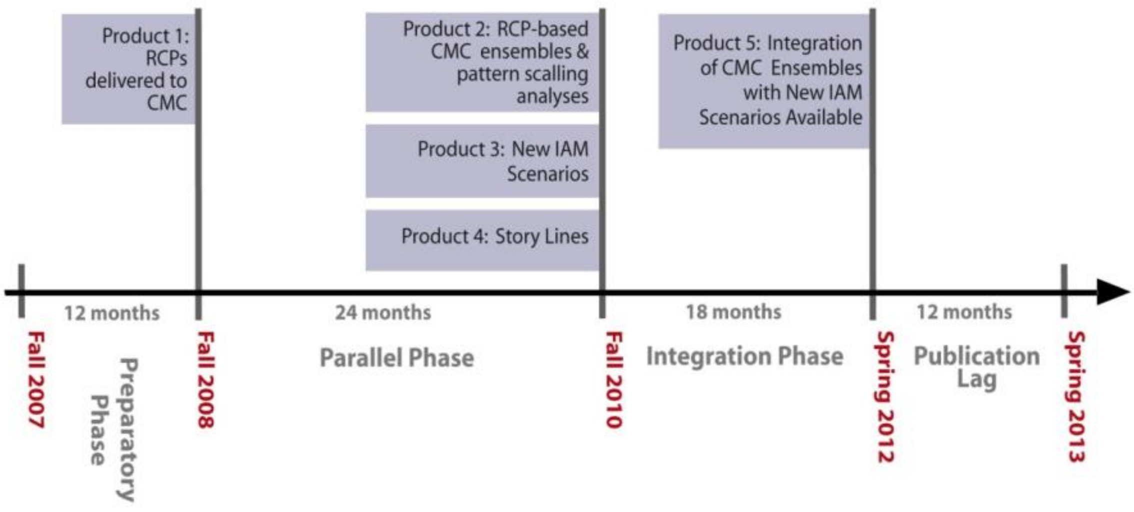


Figure 28 Timeline of key scenario development products proposed for AR5. RCPs are Representative Concentration Pathways; IAM is Integrated Assessment Model; and CMC is Climate Modelling Community (Source: http://www.ipcc.ch/activities/activities.htm).

8 Conclusions

In this study we undertook a systematic, integrated, multi-scale assessment to scope potential implications of climate change and its interactions with other key trends for triggers and thresholds of land-use change. Specifically, we aimed to address 3 questions:

1. To what degree could climate change influence triggers and thresholds of land-use change, either individually or combined with other key trends?
2. To what degree, if any, will those influences vary among the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) scenarios?
3. Conversely, to what degree does climate change not influence land-use trends, e.g., much of the conservation estate is fixed, long lifespan of major infrastructure?

Our approach used a systematic "downscaling" framework organised along two dimensions: future scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) as part of its 4th Assessment Report (AR4 Scenarios) versus major land-use categories (conservation, production, urban, unmanaged) across multiple scales from global to local (Figure 3). Downscaling involved assessing the implications of processes operating at broad scales and resolutions at finer scales and resolutions. We applied that approach qualitatively to identify how various cultural, economic, environmental, and social trends could affect triggers and thresholds of land-use change in conjunction with climate change.

Below, we summarise the findings for each of the three questions individually and overall. This required addressing the concepts of triggers, thresholds, and reversibility as outlined earlier in the report. We used the systems diagram in Figure 5 to organise our discussion of each question.

8.1 Question 1: Degree of Influence of Climate Change on Land-use Change Individually and in Combination with Other Key Trends

Climate change and other key trends will affect triggers and thresholds of land-use change in complex ways both individually and collectively as a result of various links and feedbacks among them. Research to date clearly demonstrates that the direction (positive or negative), magnitude, and spatial and temporal patterns of potential effects on land-use change vary substantially, depending on:

- knowledge of the individual processes underpinning each trend including climate change
- specification of the model used to characterise the system of interactions among climate, economy, society, environment and cultural, i.e. the nature of the links and feedbacks among those key trends and how they interact to generate patterns and processes across various scales and hierarchies
- assumptions regarding future trends and how they influence the trajectory of the integrated system, either individually or collectively.

Effects of Climate Change

Overview

Climate change affects the biophysical conditions of the land (i.e. land cover), which in turn influences human decisions about how the land is used (i.e. land use) (Figure 5). Climate affects the type and distribution of land cover by affecting abiotic and biotic aspects of the environment. Climate affects geology, geomorphology, and soils via processes such as weathering that determine nutrient status of soils and precipitation that determine hydrological regimes. Climate is also a key factor affecting habitat suitability for most species. Natural climate cycles related to variations in the earth’s orbit and orientation drive changes in land cover by altering the suitability of different places for different species through long-term cycles such as glaciations, punctuated by episodic events such as volcanic eruptions or, more dramatically, impacts of large meteors. Land-cover changes in turn feed back into the climate system and contribute to the regulation of climatic conditions in a state that supports life.

While climate models have to date mostly focused on average conditions (e.g., temperature, precipitation), more recent analyses and models suggest that changes to minimums, maximums, and extremes and frequencies of events could be more critical for influencing changes in land cover and by extension land use. Maxima and minima represent thresholds that bound the range of suitable conditions for different types of land cover and by extension associated land uses, e.g., the niche of different species, the productivity of land for different types of production, or perhaps the hazard risk posed to urban development. As climate changes, some of those thresholds will be crossed, triggering changes either via natural pathways, sociocultural and economic pathways, or via combinations of both. Some changes could be reversed, others will be permanent, at least relative to the time horizon of interest. Below we discuss potential impacts to triggers and thresholds of land-use change for each of the four major land-use themes in response only to climate change.

Conservation

Climate change will trigger shifts in ranges based on individual species sensitivities to factors such as temperature, rainfall, wind, etc. Such shifts will also alter inter-species interactions, resource regimes, and eventually result in the reassortment of ecological communities to varying degrees. While a full assessment of the impacts to ecological communities is beyond the scope of this project, some broad trends emerged from the review.

Climate change will shift species ranges farther south and/or to higher elevations as annual minimum temperatures exceed thresholds that usually prevent certain species from surviving in a particular area. As a result, alpine and sub-alpine environments will contract, and, depending on the magnitude of change, some species adapted to colder environments could literally run out of room. Conversely, changes to the magnitude and frequency of high temperatures will also limit or diminish heat-intolerant species. Milder climatic conditions overall will alter competitive interactions and increase the likelihood of establishment and spread of new weeds and pests. Some existing pests and weeds will also likely benefit through range expansion and enhanced growth and reproduction. The interplay of responses to new climatic regimes will repeat itself across the landscape in complex and surprising ways. The resulting changes will likely be difficult to reverse, even if climate eventually returns to recent historical conditions. Whether future societies desire to restore biodiversity to current conditions or whether they accept the new conditions that prevail is another important question, and one that cannot be answered.

Against this backdrop, ecological communities in protected areas, which are fixed spatially, will undergo changes in composition. Some species will be significantly challenged to adapt, especially if the rate of climate change proceeds faster than their ability to migrate given natural abilities or landscape conditions, i.e. habitat fragmentation. In some cases local conservation efforts could result in failure despite best efforts. In addition, increased pressure from weeds and pests will further challenge efforts to maintain ecological integrity as new exotic species become established or existing exotic species become more prominent. Such trends could trigger a call for a more dynamic and flexible system of protection to help prevent further biodiversity losses, especially irreversible losses resulting from the global extinction of a species.

Production

Climate change will shift agro-ecosystems across scales as the result of combined effects of temperature, atmospheric CO_2 concentrations, precipitation, extreme events, and pests and weeds (see Table 3 for a summary). Resulting changes will be spatially heterogeneous and as a result will trigger changes in land use both globally and within New Zealand as producers everywhere respond to evolving market conditions.

Research to date suggests that developed countries will fare better than developing countries, given lower expected biophysical impacts from climate change and increased ability to compensate through productivity gains. Regional differences could become more pronounced so that food security decreases in developing countries. Negative or lagging production trends in developing countries where New Zealand has sizeable export markets (e.g., Indonesia, India, Malaysia, Philippines) would trigger increased demand for New Zealand products.

Climate change within New Zealand is expected to be more moderate compared with climate change globally. If those trends prove accurate, climate change would likely have less influence on the mixture and distribution of productive land uses than other key global trends such as population and economic development. This suggests that recent trends would continue, i.e. dairy and other higher value exports would continue to expand, especially if overall potential productivity increases due to warmer temperatures and enhanced CO_2 concentrations.

Based on modelling by NIWA, areas in the west and north will likely fare better as warmer and wetter conditions expand the range of choice for productive land use and potential productivity. Other regions, especially those in the east, will fare relatively worse, given hotter temperatures, decreased precipitation and more frequent and severe droughts, and increased year-to-year variability that would increase the likelihood of business/farm failure. Risk and severity of flooding could increase. At local scales, land managers will face increasing complex and uncertain conditions as they try to adapt to changing conditions.

Urban

To evaluate the effects of climate change on urban land use, consider the effects on existing versus new urban areas. Existing urban land uses can be adapted to suit new conditions, converted to other uses, or abandoned. Taking into account past investment, adaptation would likely be the most cost-effective option in most cases through alteration of land-use patterns in existing urban areas or modifications to built infrastructure. Conversion or abandonment of existing urban areas to other uses will occur where the level of risk to infrastructure and human life from events such as flooding crosses unacceptable thresholds.

Regarding new urban areas, climate change will influence choices regarding location, design, or both. Because future urban areas could be designed to function under a range of climatic conditions, the majority of influence will be on design rather than location. In some areas, the hazard risk from climate change will become so large that avoidance is the best option, e.g., preventing future urban development in areas along the coast that are likely to be affected by sea level rise.

Unmanaged

Climate change will affect unmanaged land directly by altering land cover. Ecological communities and ecosystems (e.g., land cover) on unmanaged lands will change as climate changes via natural ecological processes such as succession. In some cases, conditions on unmanaged land could passively evolve towards a state of high ecological integrity and native dominance and thus contain high native biodiversity values. In other cases, unmanaged lands could become overrun with pests and weeds. The actual changes that occur will depend on many factors, including the conditions at a particular location and the context of the surrounding landscape.

Climate change will also trigger changes in the value of unmanaged lands for different managed uses, resulting in its conversion to the most profitable use. The likelihood of conversion will be highest where societal responses to climate change create economic value where none existed before, such as carbon sequestration on land previously perceived as unproductive or perhaps unprofitable. The IPCC SRES scenarios showed substantial variability in impacts on “other” land uses, depending on assumptions about trends in energy, population or lifestyle preferences.

The reverse process is also possible. Climate change may render certain areas currently used for production as unprofitable for reasons explained earlier, leading to land abandonment.

Effects of Climate Change in Combination with Other Key Trends

In addition to climate change, our report considered 10 key trends and their effects on land-use change. As demonstrated by the IPCC SRES scenarios, assumptions about key trends such as population, economic development or energy use substantially influence scenario evolution and lead to significantly different outcomes both qualitatively and quantitatively. Below we summarise the combined effects on land-use change of those 10 trends in conjunction with each other and climate change. As above, we first provide an overview of the interactions among the various trends, and then provide more detail on the consequences for the four major land-use themes.

Overview

The 10 key trends interact with each other and with climate to change land use through complex pathways and feedbacks (Figure 5). Population is a critical factor, as total population affects the amount of land needed for different uses. As population changes, the demand for housing, commerce and industry, social services, recreational facilities, etc., changes, affecting land values and triggering corresponding changes in land use. The magnitude of demand for land is not necessarily linearly related to population size. World views and societal preferences reflect people's attitudes towards the use of the land and what is acceptable and unacceptable. Such considerations reflect the global versus regional and economic versus environmental considerations that shaped the overall structure of the IPCC SRES scenarios. It is interesting to note that population trends in the IPCC SRES scenarios were determined exogenously and therefore could not change in a scenario regardless of what transpired.

Population, societal preference, and world views interact through economic markets and non-market mechanisms to allocate and distribute land uses to fulfil different purposes and meet different needs. The market predominantly determines dynamics among production, urban and unmanaged land uses. Markets operate within broader spheres, reflecting societal preferences and world views manifested as various restrictions, controls, or incentives operating across various scales, e.g., free trade agreements, economic development plans, subsidies, taxes, zoning, etc. Shifts among productive uses depend on many factors, including – but not limited to – prevailing and expected commodity prices, availability and price and of suitable land, attitudes and preferences of land owners and managers, and availability of suitable infrastructure. Conservation uses result from market (e.g., purchase of land) or non-market mechanism (e.g., covenants).

Land-use changes in turn drive changes in climate, water, and land cover. Land-cover changes have consequences for biodiversity and associated ecosystem services, energy (production and consumption), and mineral resources. Changes in the provision of mineral resources, energy, and ecosystem services, together with improvements to infrastructure, influence land values, factors of production, and costs of goods and services. Together, they feed back into the market and influence future land-use decisions. The link from ecosystem services to societal preferences represents consideration given to the maintenance of services by society. Perceived current or future degradation of a service could influence societal preferences, leading to new land-use regulations designed to reverse or decrease any degradation. Climate change represents one example of such a feedback loop. Concerns about future climatic conditions have prompted action to alter human influence on the climate through reduction in greenhouse gas production via use of energy and various land-use activities and drive carbon sequestration through land cover change. As a result, markets are being developed to include consideration of ecosystem services in economic decision-making.

As highlighted in the review, future trends for population, water resources, energy, etc., were highly variable and uncertain. Nonetheless, an interesting overall pattern emerged. Biophysical resources such as climate, water, minerals, energy, ecosystem services, and biodiversity are declining in terms of quantity and/or quality. This suggests that sometime this century we will cross various thresholds of resource availability. As a result, costs will increase significantly and availability of goods and services will decline, triggering significant changes in land-use both globally and within New Zealand.

Conversely, future trends in population, economics, societal preferences, and world views varied markedly. These trends represent different assumptions about human behaviour and are therefore more malleable.

Having considered the overall system and the interactions among them and with climate change, we now outline their combined effects on triggers and thresholds of change for each of the four major land-use themes.

Conservation

New Zealand has one of the highest rates of protection of terrestrial and freshwater areas in the world and is a biodiversity hotspot with many endemic species. Just over a third of the land area is protected. Over the past 20–25 years the total area of land legally protected for conservation has slowly expanded through additions to the conservation estate, designation of regional parks and local reserves, and covenanting of public and private land. For example from October 2010 to May 2011 the total area of land covenanted through the Queen Elizabeth II National Trust increased by 1000 hectares.

Climate change could accelerate the designation of land for conservation as society seeks to secure – or at least minimise impacts to – biodiversity, assuming that biodiversity protection remains a relatively high priority on New Zealand's societal agenda. The increasing recognition and potential economic value of ecosystem services could also trigger additional lands being designated for protection, albeit for the primary purpose of service provision rather than biodiversity conservation. In the short- to medium term, overall concerns about biodiversity loss beyond those from climate change both globally and within New Zealand will likely continue to drive expansion of the protected areas network. Increasing demand for bioenergy crops could generate opportunities for positive associated conservation benefits by increasing the extent of habitat for some species, provided the dynamics of harvesting and restoration are properly managed.

The suite of key trends will also produce pressures competing with conservation. Pressure from established invasive species, both existing and potential, is likely to increase as a result of more favourable climatic conditions, although in the regionalised scenarios (A2/B2) reduced global trade and/or increased environment focus could help reduce the likelihood of new incursions. Overall, the expectation is for an increase in biosecurity efforts, including prevention, eradication, and control. Put another way, climate change will likely trigger the need for greater investment in biodiversity "infrastructure", given the substantial influence of pests. Due to the extent and remoteness of many protected areas and the level of management required for effective management, conservation in New Zealand is energy intensive. Substantial increases in energy prices could render some conservation efforts prohibitively expensive, such that some protected areas receive no pest control. Increasing global costs for some mineral resources could increase pressure to allow mining on conservation lands.

A particularly critical consideration for conservation is the effect of future population trends both within New Zealand and globally. As discussed earlier, Statistics New Zealand projections for the 2061 New Zealand population range from 4.8 to 6.7 million. The UN's 2010 long-term projections for New Zealand in 2100 range from 4 to 9 million, while those for the world range from 6.1 to 15.8 billion. Any increase in population will be accompanied by corresponding increases in demand for resources including land. The expected increase in the percent of older people will also trigger demand for more community services, which will compete with conservation for limited public funds.

On the other hand, the trends in societal preferences and world views are towards more support for conservation of both biodiversity and associated ecosystem services. If those trends continue, support for conservation could increase. For example, increasing consumer demand for environmental accountability in production could lead to new market opportunities for ecosystem services that will yield co-benefits for biodiversity. Community conservation initiatives, which are already prevalent across New Zealand, could become even more popular, especially among the growing population of older people.

Following conventional wisdom and accepting the UN Medium projection as "most plausible," New Zealand and global population by 2100 would be roughly 6.3 million and 10.6 billion people, respectively. Under such a scenario, while we might not expect a loss of existing conservation lands, it seems likely that the rate of designation of conservation lands will decline and perhaps eventually stop altogether.

Production

Taken in combination, the key trends could trigger a substantial shift in production both globally and within New Zealand. However, the high degree of variability as evidenced in the SRES scenarios makes it difficult to determine exactly what shifts would occur, where, and to what degree. Referring again to the system diagram (Figure 5) and following the flows from the top (population), the broad trends with highest relevance for production include:

1. increasing global and New Zealand population increase the demand for food, fibre and, increasingly, energy
2. shifts in world view, especially trends towards regional alliances leading to free trade agreements and zones, expand market opportunities for agricultural commodities including in some countries with rapidly expanding populations
3. rising affluence in many countries, triggering shifts in preferences for diets higher in dairy and meat content, expectation of greater mobility leading to greater energy demands, and higher rates of material consumption, although some countries will continue to struggle to satisfy basic needs
4. increasing prices for factors of production (e.g., energy, equipment, pharmaceuticals) from increased global economic competition
5. reduced supply of land for production, resulting from increases in urban and, at least initially, conservation land uses, leading to intensification of many lands and the reclamation of unmanaged (abandoned) lands in some areas
6. altered weather patterns due to climate change shift production patterns in complex ways, with crop choice expanding in areas experiencing warmer and wetter conditions
7. water security issues resulting from climate change effects on supply, increased demand to satisfy increasing population and affluence, intensification of competing demands, and effects to water quality from changing land use/land cover
8. changing land cover patterns reflecting changes in climate, water resources, and land use and influencing supply of minerals, energy, biodiversity and ecosystem services
9. increased costs for energy and some minerals, of which phosphorus could be especially critical for New Zealand
10. continued increase in emphasis on management of ecosystem services, leading to development of markets for some services and shifts in land use towards provision of desired ecosystem services (e.g., "service farmers")

11. uncertainty about technology and innovation and whether they will progress and/or expand quickly enough to meet emerging challenges.

Taken together, the key trends paint a very complex picture with potentially substantial repercussions for triggers and thresholds related to production both globally and within New Zealand. More detailed consideration of potential impacts on production land uses is considered in Section 8.2 below in the context of the 4 IPCC SRES scenarios.

Urban

Urban land uses will continue to expand as a result of continued population growth and continued societal preferences leading to more people living in urban versus rural communities. Given this backdrop, the key questions are: how much will urban areas expand and where will they expand? The answers to those questions will depend on

1. the total amount by which population grows
2. the additional land area required to house the added population and provide associated urban uses for employment, services, recreation, etc.
3. how land use policies and planning and market forces interact to influence the overall outcome, which includes consideration of other current and potential land uses as shown in Figure 5.

Regarding question #1, the range of future population projections provides significantly different answers. In the UN low projection, global and New Zealand populations eventually stabilise and then decline somewhat from current levels. Under the medium projection, population in both cases rise ~45% by 2100, and in the high projection they both more than double by 2100.

Migration is also a key but poorly understood consideration. Current research suggests that most climate-change-induced migration would remain within countries or within alliances, allowing migration among countries, e.g., the EU. However, currently ~1 million New Zealand citizens live overseas, and presumably some of them would return if conditions in their adopted country deteriorated past particular thresholds in standard of living. Even the recent trend of net positive migration from New Zealand to Australia could reverse if climate change causes severe water stress in Australia. In addition, Pacific Island nations are likely to be more vulnerable to climate change, and migration within those countries would not be an option if the sea level rose enough to make them uninhabitable. New Zealand could therefore experience an influx of those seeing respite from worsening conditions in the South Pacific.

Regarding question #2, urban uses currently account for ~ 1.3% of total land area in New Zealand, including estimates of rural residential land use. Assuming future urbanisation reflected historic land consumption patterns, future populations of 4.0, 6.3, and 9.5 million in 2100 would require, respectively, –8%, +45%, and +117% more land than currently, or slightly less than 1.3%, 1.9%, and 2.8% of New Zealand's total area. While not large in absolute quantity, urban areas are not evenly distributed. They tend to be situated in low-lying and coastal areas in close proximity to highly productive soils. Assuming most new residents locate near existing urban centres, land surrounding existing towns and cities will continue to increase in value and expand as land prices cross thresholds that trigger a conversion to urban use in both the medium and high scenarios. The low scenario is interesting in that the population initially increases before starting to stabilise and then decline, leading to the distinct possibility of abandoned urban lands.

Regarding question #3, several competing factors will influence the final outcome. Rising affluence tends to lead to expanded urban areas as people desire and can afford larger homes on larger lots, often in peri-urban areas. In contrast, some cities and towns across New Zealand are starting to promote “smart growth.” Smart growth aims to reduce the extent of urban expansion by 1) in-filling existing urban areas, 2) targeting higher dwelling densities of new residential areas, and 3) promoting co-location of mixed uses to foster less commuting times and reduce the need for additional transport infrastructure. Urban planning in New Zealand is also starting to take account of climate change and plan accordingly to reduce future risks from it. Therefore planning and zoning will influence those trends to some extent, especially if spatial planning as now mandated for Auckland becomes more widespread.

Unmanaged

The implications of climate change and other key trends on unmanaged land will be complex and predominantly localised. Landowners and managers will respond to changing biophysical and socio-economic conditions and decide what to do with land currently left unmanaged. A wide range of outcomes for unmanaged lands, included in the “other” land use category, is possible globally, as evidenced by the IPCC AR4 scenarios.

Given all the key trends and their interactions, the most likely trend in New Zealand will be a reduction in unmanaged lands related to new opportunities for economic uses, particularly those related to conservation ecosystem services, or energy. Interestingly, a change in land use from unmanaged to conservation may not result in any change in land cover. A primary example would be covenanting of existing native bush, in which the land cover remains the same while land use changes.

8.2 Question 2: Variation of Effects Among Four IPCC AR4 SRES Scenarios

The impacts of climate change and the other key trends varied substantially among the four IPCC SRES scenarios (Table 13). This result is not surprising, given the IPCC scenario analysis by design intended to explore fully a “possibility space” defined by two main considerations: the emphasis of future growth (economic versus environmental) and patterns of societal cooperation and coherence (global versus regional).

Combining the two considerations and applying them globally generated four storylines that broadly defined the four IPCC SRES scenario families (A1, A2, B1, B2). Each scenario family also included assumptions about trends in population, economic development, technological development, emissions, and bioenergy. These trends were defined *a priori* and did not evolve as scenarios progressed. In modelling terms, they represented exogenous inputs that remained invariant during a model run.

The resulting scenario model runs highlighted sub-global (regional) similarities and differences. All scenarios exhibited spatial heterogeneity and regional variation. Furthermore, the patterns, magnitudes, and types of changes varied among and within scenario families. The implications for land-use change were complex. Areas such as the Mediterranean, equatorial Africa, parts of Asia, and parts of North America carry a higher risk of experiencing more severe impacts.

Globally, projections of land-use change varied substantially both across and within scenario families (Table 22). The large variability reflected differences in both underlying *a priori* assumptions and among the structure and assumptions of the models used in the scenario process. Within scenario families, the difference between low and high projections for changes in a land-use category averaged 998 million hectares (minimum = 329 million hectares for energy biomass in A2; maximum = 1929 million hectares for energy biomass in A1). Across the four scenario families, the difference in projected changes for individual land-uses averaged 893 million hectares (minimum = 67 million hectares for low estimates for energy biomass; maximum = 1850 hectares for low estimate for grasslands). In other words, the range of variability of projected changes in land use averaged around 1000 million hectares globally.

The large variability, especially with respect to croplands, forests and grasslands, has potentially interesting and contradictory consequences for New Zealand in terms of future land-use dynamics. On the one hand, as a relatively small country New Zealand could be subject to dramatic changes in future land-use patterns, especially with regard to production uses, as the global economy adapts to changing conditions (climate or otherwise). On the other hand, disruptions and shifts in future global land-use patterns coupled with less benign climate impacts locally (i.e. compared with other countries) could result in New Zealand becoming a relatively stable and productive player in the global primary production. This could lead over the long-term to more stable land-use patterns, as land in New Zealand is adapted to the most profitable use.

Table 24 Projected changes in global area of land uses from 1990 to 2100 in the IPCC SRES scenario families.
All values in millions (106) of hectares. † indicates cases where the marker scenario estimate = the high or low estimate from the scenario family. n/a = not available

	IPCC SRES Scenario Family					
Land Use Category	**A1**	**A2**	**B1**	**B2**	**Mean across Families**	**Range across Families (Max minus Min)**
Cropland						
Low	-826	-422	-979	-582	-702	557
Marker	-39†	n/a	-394	+325†	-36	719
High	-39†	+420	-30	+325†	+169	459
Mean within Family	-301	-1	-468	23		
Range within Family (High minus Low)	787	842	949	907		
Energy Biomass						
Low	+3	+67	0	+4	+18	67
Marker	+495	n/a	+196	+307	+249	299
High	+1932	+396	+1095	+597	+1005	1536
Mean within Family	810	231.5	430	303		
Range within Family (High minus Low)	1929	329	1095	593		
Forest						
Low	-464	-673	+274	-116	-245	947
Marker	-92	n/a	+1260	+227†	+349	1352
High	+480	-19	+1266	+227†	+488	1285
Mean within Family	-25	-346	933	113		
Range within Family (High minus Low)	944	654	992	343		
Grassland						
Low	-1087	+313	-1537†	-491	-700	1850
Marker	+188	n/a	-1537†	+307	-260	1844
High	+622	+1262	+320	+823	+757	942
Mean within Family	-92	787.5	-918	213		
Range within Family (High minus Low)	1709	949	1857	1314		
Others						
Low	-873	-1085	-983†	-1166†	-1027	293
Marker	-552	n/a	-983†	-1166†	-675	614
High	+566	-278	-482	-137	-83	1048
Mean within Family	95	-542.5	-36	-339		
Range within Family (High minus Low)	1439	807	501	1029		

8.3 Question 3: Lack of Influence of Climate Change on Land-use Change

While climate change will be a key trend influencing land-use change going forward, it will not be the only trend, nor will it always exert an influence. Other key trends such as population, energy, minerals, water, preferences, etc., also affect land-use change. In some cases those considerations will outweigh climate change, e.g., urbanisation will continue regardless of climate change as population increases. Based on the literature reviewed, trends in water security and energy could exert more influence on land-use change than climate change, at least in the short term (20–30 years).

Water security looms large as a key issue for the 21st century. Substantial changes to the pattern and magnitude of water supply both globally and within New Zealand will have more immediate consequences than changes in weather patterns. For example, vulnerable environments such as alpine areas house glaciers that provide substantial year-round supply of freshwater to many areas. Large allocations to agricultural uses might need to be curtailed or water usage charged for, at all or at much higher rates.

Energy security is also a serious concern, both in terms of adequate supply to meet rising demand and in the role of fossil fuels as a major contributor to increases in greenhouse gas concentration in the atmosphere. The evidence suggests that conventional fossil fuel production has already hit a peak or plateau or will do within the next 5 years. This has spurred exploration and production in more challenging locations that carries higher risks (e.g., the recent oil spill in the Gulf of Mexico), questions about the viability of biofuels as a substitute for fossil fuels (including the ethics of feeding cars versus feeding people), and pursuit of lower net energy fuels such as tar sands. Energy security will be a critical trend to monitor, as society cannot not function/as we know it cannot without adequate energy supply at affordable cost.

Finally, returning to our conceptual model, climate change is not likely to influence certain land uses, given the irreversible nature of those uses. The two main uses in that regard are conservation and urban. Conservation uses will tend to endure because they reflect substantial societal commitment to preserving and maintaining native biodiversity as well as recreational opportunities. Climate change will affect land cover, even if the land remains under conservation. As discussed earlier, impacts to land cover will challenge our ability to maintain the assets for which land was conserved in the first place. This, in turn, could affect society’s desire and commitment to set aside land for conservation.

Similarly, urban land uses will on the whole remain the same despite climate change. Certain areas may become non-viable, but mostly in reaction to catastrophic events such as severe storms or flooding. This situation may change if climate forecasting techniques improve so that risks can be better quantified. Otherwise, some urban areas will experience substantial investments in infrastructure to adapt to climate change.

8.4 Summary

This review examined the effects of climate change and other key trends on triggers and thresholds of land-use change, both individually and collectively. The literature on climate change and each of the 10 key drivers is substantial, so we could only undertake a partial review of each trend to identify potential issues or aspects to consider. Despite these challenges and limitations, the review yielded important insights into possible implications of different cultural, economic, environmental, and social trends on triggers and thresholds of land-use change. We offer the following summary for consideration organised at two scales: global and New Zealand.

Global

- A basic model of land-use change considers transfers among conservation, production, urban, and unmanaged land uses. While conceptually simple, this model provides a sound framework for thinking about land-use change. It reinforces the finite nature of global land supply and highlights the need to monitor and anticipate irreversible changes that limit future land-use options. Some permanent changes may be desirable, such as urbanisation or designation of conservation areas, while others may be undesirable, such as impairment or permanent loss of productive capacity due as erosion or desertification.
- Globally, the historical trend has been for conservation and urban land uses to increase in area over time, while trends in production land uses have been more variable and reflect country-specific, sub-national, and local conditions. Production land uses are declining or stable in many developed countries and increasing in many developing countries, usually via conversion of natural ecosystems. Global trends in unmanaged lands are also variable. Shifts from a managed land use to unmanaged land, often referred to as land abandonment, have occurred or are occurring in some global areas, e.g., forest regrowth in the eastern United States, abandonment of agricultural land in higher elevation environments of Europe, or areas undergoing desertification in Africa and China.
- Climate change will influence land-use change globally over the coming century as a result of differential shifts in temperature, precipitation, winds, frequency and severity of extreme events, and changes in distributions of non-native species (i.e. pests and weeds), which could significantly impact on conservation and productive land uses.
- Other key trends reviewed in this report will also affect triggers, thresholds, and reversibility of land-use change in complex and unpredictable ways. Taken individually, each key trend, including climate change, could evolve independently in a manner that challenges global and national governments and societies to respond, mitigate, and adapt. There is an increasing likelihood that two or more key trends will co-evolve and the resulting impacts will overwhelm the ability of society, globally or otherwise, to cope adequately, leading to substantial land-use change. On the other hand, land-use change could be one mechanism that society implements to adapt to global change (climate or otherwise).
- Global population trends have a large effect on land-use change because they drive demand for urban and productive land-uses. Assumptions about population trends in the IPCC SRES scenarios had significant implications for land-use change, including the allocation of productive land-uses. Recent projections out to 2100 exhibited similar variability (6.177–15.805 billion). Continued growth or eventual stabilisation and decline of population each have their own set of issues and associated consequences for land-use

change and complicate efforts to anticipate trends in triggers and thresholds of land-use change, at least over the long term.

- Societal preferences and world views will also significantly impact on land use through demand for various goods and services. Significant shifts in these trends can trigger significant shifts among production land uses, as evidenced by the large variation in IPCC SRES scenario projections for croplands, grasslands, and forest.
- Trends in water resources warrant careful monitoring, as significant impacts on land-use change could manifest themselves sooner than climate change. Regional variations could trigger moderate to substantial rearrangement of primary production patterns and/or affect productivity of existing productive areas.
- Recent developments in the energy sector are worrying. Recent analyses found that production from existing major oil fields is declining more rapidly than previously thought and that some countries may be overestimating their reserves, in some cases by significant amounts. On the one hand, this could lead to a global reduction in energy production and a corresponding reduction in energy per capita much sooner than expected. Conversely, it could spur massive investment in locating and developing existing undeveloped energy sources (oil, natural gas, coal) and/or alternative energy sources, including biofuels. Development of additional fossil fuels sources would only exacerbate climate change unless accompanying means to capture or divert increased carbon emissions were implemented. In terms of land-use change, the IPCC SRES scenarios consistently projected increases in land area devoted to bioenergy production, although the magnitude of the increase varied. Overall, an inability to meet current or expected increases in global energy demand would trigger significant changes in land-use patterns as countries, regions and localities adjust to a lower energy world.

New Zealand

- Similar to global trends, urban and conservation land uses have increased over time. Urban growth typically results from expansion onto productive lands, especially around major urban centres. Low-density residential development (i.e. lifestyle blocks) also reduces productive capacity. While not large in magnitude, such losses have differentially affected the most productive soils, i.e. soils with Land Use Capability classes from 1 to 3.
- Gains in conservation lands (i.e. protected areas) often, but not always, represent transfers from unmanaged land that has retained high native biodiversity values. Key processes include identification and protection of significant natural areas by councils as part of the Protected Natural Areas Programme and private covenanting schemes.
- Unmanaged lands are decreasing as a result of transfer to conservation, as discussed above, or in some cases expansion of production. Trends are often difficult to quantify, given the limited availability of information on land-use change.
- Impacts of climate change in New Zealand are expected to be relatively moderate compared with other countries in terms of the extent, frequency, and severity of changes. Assuming moderate changes, growing season would lengthen and productivity increases as a result of warmer temperatures and increased CO_2 concentrations. Wetter conditions in the west and south (Figure 14) suggest potential for higher productivity, especially in major dairy regions such as the Waikato, Taranaki, and Southland. Drier conditions in the north and east (Figure 14) may create limitations for some forms of production. Projected changes to seasonal precipitation patterns (Figure 15) suggest that the exact nature and magnitude of impacts will be localised.

- As demonstrated by the IPCC SRES scenarios, land-use outcomes differ significantly, depending on external assumptions (e.g., differences among SRES scenario families regarding population trends, economic development, etc.) and internal specifications of the system studied (e.g., large variation among projections within SRES scenario families from different models). Therefore the future pattern and intensity of cropping, dairy, forestry, horticulture, and sheep & beef production in response to global and local market and commodity price changes are highly uncertain. Nonetheless, several overall trends emerged that will influence triggers and thresholds of change among production land-uses:
  - Demand for renewable energy will increase as conventional energy sources inevitably decline over the coming century, triggering conversion of land to biomass production. By 2100, New Zealand will need to meet most of its energy demands domestically, given likely decreases in net global energy supply resulting from resource depletion, increasing population, and increasing per capita energy consumption rates, especially among developing countries. The most likely outcome will be conversion of unmanaged lands, some existing forestry land, marginal, hill country, low production pasture lands suitable for plantation of trees or other woody species See Hall and Gifford (2007) for details on possible transition pathways.
  - In the short term, continued increase in global population and changes in societal preferences, especially increased affluence in some developing countries, will drive further expansion and intensification of dairy land. Medium- to long-term trends will become increasingly uncertain, given increasing variance in trends of population, affluence, and societal preferences.
  - Demand for land for crops and vegetable production should remain stable or increase to meet increasing domestic demand resulting from population growth. Displacement by urbanisation could trigger crop displacement of pastoral production on high capability soils near urban areas.
  - Similar to dairy, demand for horticultural products for export should continue to grow in the short term. Given existing land-use patterns, increases in area would most likely occur via transfers from pastoral uses in areas with existing infrastructure to support expansion.
  - Assuming the above trends eventuate, sheep & beef production and forestry will both experience a “squeeze” from bioenergy and dairy production, with the former displacing higher elevation, more marginal productive land and the latter displacing lower elevation, higher producing land. Declines in both seem likely over the long term as a result.
- Increasing interest in ecosystem services could result in the establishment of thresholds aimed at sustaining their condition and function. Such thresholds could influence future land-use dynamics by limiting the extent and intensity of land uses in different localities, depending upon the goals and objectives set. The recent cap on nutrient loads in the Lake Taupo watershed represents an early example of changing thresholds for ecosystem services leading to land-use change.
- The fate of unmanaged land presents an interesting consideration. While magnitudes differ, the area of “other” land uses declines by 2100 in all the IPCC SRES scenarios. It seems reasonable to expect a similar trend in New Zealand with regard to areas of unmanaged land. Increasing demands from a growing population, combined with more

affluent lifestyles under some scenarios, will trigger increased demand for production. Additional demand can be met by expanding the area under production, increasing intensity of land use, or increasing efficiency through improved technology. Conversion of unmanaged land represents the only way to expand the total base of productive land to accommodate increases in productive land uses. Unmanaged lands, however, can also support native biodiversity to varying degrees. Therefore conversion of unmanaged land could, in some cases, lead to further decline in native biodiversity, if conversion results in the loss of native land cover. On the other hand, uses such as carbon storage would improve outcomes for biodiversity and associated ecosystem services, as “conversion” in this case would result in the protection and possible enhancement of condition of native cover.

In the final analysis, what do the trends in climate, population, economic development, energy, etc. mean for triggers and thresholds of land-use trends in New Zealand? To answer this question, it is most useful to partition the future into a short (~20 years), medium (~50 years), and long (~100) term.

In the short term, New Zealand will continue to experience population growth. This will lead to further urbanisation and continued conversion of adjacent areas from various forms of production. Conservation will also continue to follow recent trends so that total protected area will increase, primarily through the covenanting of private land that retains sufficient native biodiversity values. Recent production trends should also continue, as affluence in many developing countries will continue to rise and raise demand for dairy, meat, and horticultural products. Dairy will continue to expand in those remaining areas of highest suitability. Sheep & beef production should also fare well and retain its share of the landscape if recent trends in rising affluence continue.

In the medium term, the increased uncertainty and variability surrounding many future trends will create a situation perhaps best characterised by Shell International as a “zone of extraordinary opportunity or extraordinary misery” (Shell International 2011). While originally applied in the context of energy futures, this idea is broadly relevant. It represents the notion of a critical transition period during which decisions made or not made and actions taken or not taken will have long-lasting and significant repercussions. Globally, we appear headed for such a transition phase, which would mirror the time period during which the IPCC SRES scenarios started to diverge substantially, including land-use change forecasts. The mid-21st century is also when the forecasts of the World3 model used in the Limits to Growth also began to diverge substantially.

Within this “zone,” we can safely assume that bioenergy production must increase to offset decreased global supplies of fossil fuels due to production declines and increased competition with developing nations. This will trigger changes in marginal lands throughout New Zealand to bring additional supply on line. Commodity markets will likely become more volatile and lead to increasing uncertainty for industry and farmers. Given the less favourable forecasts for several southeast Asian countries, New Zealand agricultural and forest products could still be in high demand, although export destinations may shift substantially. Depending on the global response to climate change, climate impacts could start to alter patterns of domestic production significantly, or at least to increase adaptation costs.

In the long term, despite their age, the IPCC SRES scenarios remain a good guide to possible future conditions out to 2100, given their coherent structure and rigour of development and application. As highlighted throughout this review, the four scenario families paint highly divergent pictures of the world in 2100, with significantly different consequences for land-use change. More recent information about trends in climate change, energy, ecosystem services, minerals, and societal trends adds further layers of complexity, which reinforces the need for further research regarding triggers and thresholds of land-use change.

9 Acknowledgements

The New Zealand Ministry of Agriculture and Forestry's Sustainable Land Management and Climate Change Research Fund supported this research under Contract C09X0903, administered by the New Zealand Foundation for Research, Science and Technology. The authors wish to thank Brett Mullan (NIWA) for contributions to the section on global climate modelling and downscaling to New Zealand. We also thank Bob Frame, Alexander Herzig, Michael Krausse, Levi Timar, and Peter Verburg for their thoughtful and valuable review and comments, Anne Austin for editorial oversight, Nicolette Faville for assistance with graphics, and Kerril Cooper for report quality assurance and control.

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