Volume 1

Negotiating our future:
Living scenarios for Australia to
2050

Australian Academy of Science

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Preface

The 21st century looms as a pivotal period in the ongoing human story. This is a tale that has been gathering momentum for centuries as we have made increasingly extensive and intensive use of our planet's continents, islands and oceans to the extent that many parts of the Earth System at large are now showing the strain. As the size and affluence of the human population have grown we have placed increasing demands on natural resources, leading in turn to cascading stresses and impacts upon the natural world that serves as the planetary life-support system for all human societies. Those impacts are evident through climate change, loss of biodiversity and ecosystem resilience, changes to the great natural cycles of carbon, nitrogen, phosphorus and other essential elements, overuse of surface water and groundwater resources and in threats to food security. These developments collectively define the challenge of environmental sustainability.

The social challenges facing the world in general and Australia in particular are as great as the environmental challenges. Demographic, cultural, economic and technological transformations are profoundly altering patterns of living, wellbeing and health around the world in ways that often magnify inequalities. People and societies value fairness and cooperation because they enhance cohesion, productivity and creativity and are prerequisites for social sustainability. Further, a fair and cooperative society recognises the value inherent in cultural, ethnical, behavioural and other forms of diversity. In these senses, a socially equitable society is just as important as an environmentally sustainable one.

The two goals of environmental sustainability and social equity are closely enmeshed. Environmental conditions influence levels of social equity because loss of environmental assets, especially those that impinge on whole populations and regions, causes disproportionate harm to poorer and more marginal groups, entrenching poverty and social unrest, displacing people and widening disparities between the more and less secure. Social and economic conditions influence the environment because they affect human uses of natural resources and the consequent environmental pressures.

These two lodestars of environmental sustainability and social equity encapsulate the set of future challenges considered in this book. Our first goal is to characterise them. Our second goal is to move beyond viewing these challenges as a set of disjointed problems with isolated solutions toward a consideration of how the goals of environmental sustainability and social equity together define an overarching challenge: negotiating an uncertain future in the face of differences in values and perceptions that characterise an open society.

This second goal leads to the idea of living scenarios—shared, ongoing explorations of how the future might unfold, leading to evolving visions for the future that are *plausible* (consistent with natural laws), *acceptable* (consistent with aspirations for human wellbeing) and *workable* (agreed to the extent necessary for action). The book considers how such visions can develop and evolve to support coherent societal responses to the great challenges of environmental sustainability and social equity. What do these challenges mean in the Australian context? How can we meet them? How can we work towards coherent actions as a society? Can these challenges define continuing criteria to guide national foresighting, not just to 2050 but beyond? Might such foresighting become a more formal national project, a great and visionary response to a great and unprecedented set of challenges?

The future will not take care of itself as we worry about the present. Worldwide, countries now have to extend policy formulation frames in both space and time—in space to account for an increasing range of global or transboundary environmental and social influences, and in time to mitigate or respond to future stresses and crises. Australia is no exception. We face great challenges but also have great opportunities to achieve a safer and more socially cohesive future. The ideas and processes mooted in this book will, we hope, stimulate and assist that undertaking.

This book arose from a four-day workshop in late July 2011 at Bowral, NSW, involving 35 participants. The workshop was the culmination of the first phase of a three-year national research project by a consortium led by the Australian Academy of Science, with funding from the Australian Research Council. The title and statement of intent for the workshop was *Australia 2050: toward more environmentally sustainable and socially equitable ways of living*.

The workshop was based on the Dahlem model, a formula that has proved to be an effective way of facilitating interdisciplinary communication and cooperation. As we applied it, this model centred on four interdisciplinary working groups that intensively examined the challenges of environmental sustainability and social equity, using four different foci. These were: i) *system resilience*, its features, determinants and evolution in both environmental and societal contexts; ii) *social and cultural perspectives*, both as drivers of and responses to change; iii) *scenarios for Australian futures*, including processes for scenario development and a set of illustrative scenarios; and iv) *quantitative models*, their uses, development and application to understand processes and constraints on future pathways. Of these four foci, the first two, system resilience and social perspectives, address our aspirations for Australia as a nation and a system. The third and fourth—scenarios and quantitative modelling—offer tools for navigating the future.

For a year preceding the workshop a steering committee (the authors of the synthesis Chapter 1 in this volume) wrestled with the formulation of the basic issues and questions and invited a range of Australians from all states and diverse professional backgrounds to participate.

Prior to the workshop, background papers were prepared to review current knowledge, assess knowledge gaps and provide initial opinions in a range of key areas. These papers were circulated to all participants in advance in lieu of formal presentations of prepared papers. The background papers provided substrate material for working group discussions and led to some lively exchanges of ideas before, during and after the workshop.

At the workshop, the time was divided approximately as one-third spent in plenary discussions, with an emphasis on exchanges between the four working groups, and two-thirds in working groups. Each group had a preappointed chair to coordinate and focus its work and a rapporteur to synthesise the outcomes into a written chapter for this volume. Inevitably, the two-thirds extended their discussions over meals and into evenings. The benefits of a residential setting were readily apparent.

To guide discussions at Bowral, the steering committee formulated a set of framing questions (Box 1). These questions were subjected to critique and development throughout the workshop, particularly because of the existence of multiple visions for an ecologically, economically and socially sustainable Australia. One of the greatest challenges in navigating the future is to reconcile these multiple visions. This emergent focus of the workshop led to the concept of living scenarios, a defining theme in this book.

In this volume, Chapter 1 provides an overall synthesis that also functions as a stand-alone summary. Chapters 2 to 5 are the reports of the four working groups, focusing respectively on resilience, social perspectives, scenarios and quantitative modelling. Chapter 6 is a survey of projections of aspects of Australia's future for the next few decades, drawn from existing resources. The background papers for the workshop appear in a separate accompanying volume. All contributions have been peer reviewed under the guidance of the Workshop Steering Committee.

Michael Raupach, Tony McMichael, John Finnigan, Lenore Manderson, Brian Walker—Project Steering Committee.

Overarching question:

What is our *realistic* vision for an ecologically, economically and socially *sustainable* Australia in 2050 and beyond?

Subquestions:

1. What are the big external factors or constraints which set the ground rules within which this vision must develop (examples of possible factors include population, natural cycles and ecosystem services, societal goals, connectivities and technologies)?
2. On the basis of these factors (or others), what is the *safe* biophysical and social operating space for the Australian social–ecological system, and what thresholds define the boundaries of this space?
3. What realistic scenarios for the evolution of the Australian social–ecological system keep us within this *safe* operating space, what scenarios take us outside it, and what are the consequent *dangers*?
4. If we are likely to be heading into *danger*, in what areas should we be seeking the critical interventions that offer the best *hope* for changing course?

Box 1: The framing questions for the Bowral workshop, as formulated before the workshop. Words with high subjective or value-laden content are italicised.

Acknowledgments

The Project Steering Committee expresses its deep thanks to all participants in the Bowral workshop, who provided the enthusiasm and inspiration that have made this book possible. We thank the Australian Academy of Science (AAS), particularly Fiona Leves, for providing facilitation and support throughout this project. We also thank Professor Kurt Lambeck, former president of the AAS, for his role in initiating the project. We gratefully acknowledge the financial support of the Australian Research Council, through a Learned Academies Special Projects grant.

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Chapter 1

Living scenarios for Australia as an adaptive system

Michael R. Raupach, Anthony J. McMichael, Kristin Alford, Steven Cork, John J. Finnigan, Elizabeth A. Fulton, Nicola J. Grigg, Roger N. Jones, Fiona Leves, Lenore Manderson, Brian H. Walker (Steering Committee)

In thinking about a future that is both environmentally sustainable and socially equitable, two challenges are paramount. The first is to assess a multitude of possible pathways over coming decades, and especially their implications for environmental sustainability and social equity. The second is to find ways to negotiate a pathway, where negotiation implies both steering a path through uncertainties and obstacles, and also agreeing on a shared course in the face of differences in values and perceptions that are a hallmark of an open and pluralistic society.

Negotiating our future: living scenarios for Australia to 2050 *is an exploration of both challenges. In this synthesis chapter we cover five themes: i) Australia as an adaptive system made up of interacting natural and human components; ii) the present state of the Australian system, to provide a brief survey of where we are now; iii) ways of thinking about the future, to distinguish between objective analysis and subjective statements of goals or aspirations and to analyse the idea of a safe operating space; iv) tools for navigating the future, including both quantitative models and scenarios; and v) the concept of living scenarios for Australia as an adaptive system, to consider how such scenarios might be developed and be useful in negotiating the future.*

By living scenarios we mean shared, ongoing explorations of how the future might unfold, leading to evolving visions that are plausible (consistent with natural laws), acceptable (consistent with aspirations for human wellbeing) and workable (agreed to the extent necessary for action). Rather than being preordained and specified futures, living scenarios are maps of the future that can be reworked, adapted and, if necessary, transformed. Living scenarios allow for flexibility and ambiguity; of necessity, they are refashioned in response to changing circumstances. They reflect a rich diversity of opinions, values and aspirations, to identify envelopes of possibilities shaped by the intersection between aspirations and realities. They are tools for achieving an acceptably coherent vision of the future, and a set of pathways towards it. Hence the title of the book.

1 Introduction

Our home planet is vast to ordinary human experience, yet it looks small in many now-familiar pictures of Earth as a blue sphere in the blackness of space. This small sphere sustains a human population that exceeded seven billion in 2011. We humans are making increasing demands on the life-support systems of the planet, not only because of our increasing numbers but also because of generally increasing affluence. Both population and affluence have grown nearly exponentially through the two centuries since the Industrial Revolution, but exponential growth cannot continue forever in a finite system. Already stresses are evident in many aspects of the planetary environment that are critical for life support [1–4] and human health [5]. The world therefore faces a new challenge in the 21st century: that of adapting the human enterprise, strongly shaped by centuries of near-continuous growth, to the realities of a finite planet.

The social challenges faced by societies around the world are as great as the environmental challenges. As the world has become more affluent, it has also become more unequal. Inequity in wellbeing, health and affluence has grown over the last two centuries: the richest are better off than ever before, while for the poorest, global development has been a curse rather than a blessing by many metrics [6–9]. Socially equitable societies providing access to opportunity for all and fostering fairness and cooperation are sources of wellbeing, cultural enrichment, innovation and social stability in a heterogeneous, connected world. There is a great deal of empirical evidence [10] that improving social equity helps societies to do better by numerous measures, including health; freedom from violence; wellbeing; and social cohesion. Social equity is therefore just as important as environmental sustainability. In the 21st century, the finitude of the resources of Planet Earth will mean that neither can be fully achieved without the other.

Both environmental and social trends at this time are being profoundly affected by the dynamics of globalisation. The world is now interconnected to an unprecedented degree by trade, finance, multinational corporate control [11], information technology, social networks, human migration, transfers of plants, animals and their genes, and the spread of infectious diseases and pests. In consequence, new processes and instabilities are appearing in economies, societies and ecosystems. Local disturbances, such as indebtedness, sociopolitical trends, technological innovations or disease outbreaks, can spread and amplify rapidly, with utterly unpredictable outcomes. Tragedies and triumphs become globally shared.

Achieving environmental sustainability and social equity in the context of an interconnected world presents profound challenges for Australia (and, in other ways, for all nations) at the beginning of the 21st century. Responses to these challenges will shape our future over coming decades. However, in attempting to respond, and thus to navigate the future, we face three basic realities that confront every generation: the future is *uncertain*, *contested*, and *ultimately shared*. The uncertainty of the future is experienced everywhere, from weather to politics to the fragility of human existence. The contestability of the future is also familiar from struggles between people and groups of different convictions for control of choices about pathways. Yet as the future rolls inevitably into the present, multiple pathways and choices crystallise into actual events that form shared realities for individuals, communities and nations.

In this book we explore these challenges for the future, with a focus on Australia to 2050. The book has two aims, the first being to investigate ways of assessing the multitude of possible pathways for Australia over the next few decades and especially their implications for environmental sustainability and social equity. The second is to find ways to negotiate a pathway, with its implications for sustainability and equity, in the context of an uncertain future. To 'negotiate' here implies both to steer a path through uncertainties and obstacles, and also to discuss and agree on a shared course in the face of differences in values and perceptions.

This second aim leads us to consider the concept of living scenarios for a future that is both environmentally and socially sustainable. By living scenarios we mean shared, ongoing explorations of how the future might unfold, leading to evolving visions for the future that are simultaneously *plausible* (consistent with natural laws), *acceptable* (consistent with aspirations for human wellbeing) and *workable* (agreed to the extent necessary for action).

The book as a whole was developed at a workshop at Bowral, NSW, in July 2011. The present chapter outlines the key themes emerging from the workshop. Following this introductory Section 1, the chapter is structured in five parts. Section 2 introduces the idea of Australia as an adaptive system made up of interacting natural and human components; Section 3 takes stock of the present state and trends in the Australian system; Section 4 discusses ways of thinking rationally about the future; Section 5 examines tools for navigating the future, including both quantitative models and scenarios; and Section 6 explores the concept of living scenarios.

2 Australia as an adaptive system

Systems with natural and human components

A view of Earth from space is a reminder that our planet functions as a single Earth System [2, 12] comprising the land, waters, air and ecosystems of the planet, together with human societies, cultures, knowledge, economies and built environments. All of these components are tightly connected, influencing and being influenced by one another.

In the two centuries since industrialisation began—a mere moment of geological time—human activities have transformed the natural parts of the Earth System by significantly modifying biodiversity, land cover and atmospheric composition and thereby affecting climate and the great natural cycles of carbon, water, nitrogen, phosphorus and other elements [2, 13]. Climate change is the most prominent of these transformations in current public debates, but it is far from the only one. Both the magnitude and rate of transformation are so great that the epoch since the start of the Industrial Revolution is often called the Anthropocene [14].

Just as the whole Earth functions as a coupled natural–human system, so too does a continent or region such as Australia: its land, waters, ecosystems and the economic and social activities of its human inhabitants all influence and depend upon one another. However, there is a critical difference between the Earth System and a regional system such as Australia. The whole Earth is a materially closed system, exchanging only energy with its space environment by absorbing solar energy and emitting a nearly equal amount of heat energy[1]. By contrast, Australia constitutes a fully open system connected to and embedded within the rest of the world by flows of matter, energy and information. Important connecting flows occur through a shared global climate and environment, the world trade system, a globalised economy, human migration, exchanges of living material (seeds, pests, infectious diseases), regional and global security, and exchanges of knowledge, technologies, ideas and cultures.

Stocks and flows

How can one describe the state of a system such as Australia, and its changes in time? Standard economics use measures of capital stock such as net wealth, and measures of income such as gross domestic product (GDP). However, these

1 There is currently a small difference of about 1.6 Watts per square metre between the incoming solar radiation flux and the outgoing flux of heat radiation. This imbalance is about 0.5% of the gross energy fluxes in both directions. It is caused mainly by the buildup of CO_2 and other greenhouse gases in the atmosphere, and is the 'radiative forcing' that drives human-induced climate change [15].

capture nothing like the full functionality of the system. One way of making a broader assessment is to consider a set of stocks (or assets, or reserves) that can be aggregated into five essential 'capitals' [this volume, Chapter 2]:

- *natural capital:* stocks of the natural resources that supply ecosystem services such as clean water, clean air, fertile soils for food production, and healthy biodiversity
- *built capital:* built environments from cities to homesteads and the infrastructure that supplies their inhabitants with energy, water, food, transport and communications
- *human capital:* the collective mental, physical, biological and cultural capacities of the population
- *knowledge capital:* collective knowledge in minds and encoded in libraries and on the internet, together with the skills to convert the codes into meanings
- *social capital:* the liberties, responsibilities, institutions, governance frameworks and unwritten understandings that enable a society to function effectively, or 'the features of social organisation, such as trust, norms and networks, that can improve the efficiency of society by facilitating coordinated actions' (Putnam, quoted in [16]).

All of these capitals and their constituent stocks are linked by flows and transfers of energy, matter and information. The system thus constitutes a vast network pulsing with activity. Not only is there continual flow and exchange of energy, matter and information through the network, but also the network itself evolves: some parts grow and others fade away, new subsystems arise and others disappear.

For the system to function adequately, sustaining the wellbeing of both humans and the ecosystems that support them, it needs sufficient availability of all capitals. Shortage in any of the capitals impairs the ability of the system to function and evolve [Foran, Chapter 5 in Volume 2]—for example, in terms of social cohesion [Manderson and Alford, Chapter 4 in Volume 2], health [McMichael and Butler, Chapters 1 and 2 in Volume 2] and food security [Stirzaker, Chapter 6 in Volume 2]. All capitals interact with population [Hugo, Chapter 3 in Volume 2], though not through an oversimplified 'more people means more capital' logic.

The different capitals are not necessarily measured in dollars: some, such as social capital, are difficult to quantify other than through comparative indicators yet remain essential for system function. Financial capital in this perspective is not one of the primary capitals but instead is a secondary capital providing a mechanism to facilitate some of the intercapital transactions needed for overall system functionality and development[2]. Examples include the creation of built and knowledge capital from human capital by paying wages and salaries, or the pricing of natural assets such as water and greenhouse gas emissions to maintain overall system functionality by associating their use with a visible cost. Other intercapital transactions are independent of the financial system such as building natural and social capital from voluntary commitment of human capital, or the benefits from natural capital through 'free' ecosystem services.

Feedbacks and emergence

A critical aspect of considering regions such as Australia as systems is that the behaviour of the whole system depends as much on interactions or feedbacks between different system components as it does on the components themselves. Some feedbacks are stabilising, acting to reduce ripple effects from disturbances; for example mechanisms to maintain social cohesion. Others are destabilising and amplify small disturbances into large ones; for example exacerbation of general water scarcity by overallocation, or exacerbation of climate change by more consumption of fossil fuel-based energy for air conditioning.

A consequence is that in a system with multiple interactions and feedbacks, causes and effects are hardly ever simply related. Linear causal thinking (*A* causes *B* causes *C* …) is almost always misleading; rather when a disturbance at *A* causes a response in *B*, interactions through other system components loop back to amplify or attenuate the original disturbance at *A*.

Through feedbacks and interconnections a whole system has emergent properties. These are modes of behaviour that depend fundamentally on interactions between many parts of the system and are not evident if components are viewed in isolation from their connections. In systems with coupled natural and human components, important examples of emergent properties include growth or collapse, reactions to shocks, and 'vicious' and 'virtuous' cycles.

2 Some authors [17] regard financial capital as one of the primary capitals.

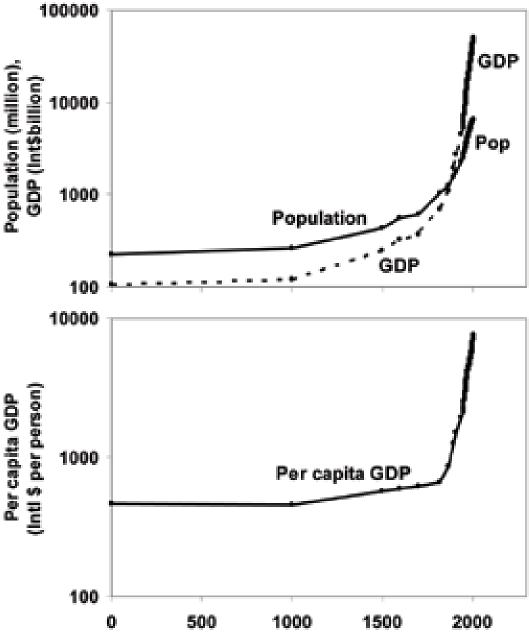

Figure 1: Upper panel: estimates of global population and global aggregate gross domestic product (GDP) from AD 1 to 2008. GDP is in International Gheary-Khamis dollars, a time-independent unit that approximates the purchasing power of $US1 dollar in 2000. Lower panel: per capita GDP over the same period. Data from [18].

Growth and collapse. Figure 1 illustrates the strong, near-continuous global economic growth since the start of the Industrial Revolution around 1800, accompanied by rapid growth in global population [6]. This growth has led to huge but very unequally distributed improvements in affluence, health and material wellbeing, first in developed regions, including Europe, North America and Australia, later in most parts of the developing world, prominently in China and South-East Asia and now in many South American and African nations. Growth has become both self-sustaining and also essential to economic, societal and political stability.

Economic growth is now so ingrained in our thinking that we assume it to be a natural state of affairs. However, the near-ubiquitous growth of the last 200 years is nothing short of astounding in historical terms. For 99.99% of the 2 million-year history of the human lineage on this planet societies grew not at all or only very slowly. We regard growth as business as usual because the 200 years of strong growth (eight human generations or three lifetimes) are long enough to exceed our capacity for direct intergenerational memory [Raupach, Chapter 14 in Volume 2].

Economic growth is a primary example of an emergent property as it depends on the functioning of many parts of the system in concert. Growth is not easy to explain within the framework of classical or equilibrium economic theory. Recent work in complexity economics [19] is starting to view growth as an outcome of interactions between multiple adaptive agents in a complex system that is never in equilibrium because it depends on flows of energy and materials, and never static because both the agents, and also the whole system, are continually evolving in response to the growth itself.

The near-ubiquity of growth over the past 200 years can blind us to the fact that coupled natural–human systems can also collapse, often suddenly and dramatically [20–23]. As with growth, collapse is a whole-system phenomenon and thus an emergent property. Also, like growth, the causes and timings of collapses are not easy to explain systematically. Diamond [20, 21] sees environmental factors as key; Tainter [22] highlights the progressively increasing inefficiencies of growing complexity in civilisations; Wright [23] emphasises quasi-cyclical processes in which the seeds of collapse are sown in bursts of growth as societies fail to take a long view.

Reactions to disturbances and shocks. When hit by a shock (which might be external or internal in origin), a system can respond in a variety of ways: it can recover its original form, adapt, transform into something different but still functional, or cease to function (collapse). A key concept for describing these possible responses is that of *resilience*—the capacity of a system to absorb disturbances and reorganise so as to maintain the same function, structure, feedbacks and therefore identity [24–28]; also Chapter 2 in this volume, and Grigg and Walker in Volume 2, Chapter 7]. Resilience may be desired or undesired from the standpoint of the actors or agents in a system. Two further concepts characterise the extent to which actors can steer the system in directions they want: *adaptive capacity*, the capacity of the actors in a system to influence resilience, and *transformative capacity*, the capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable [24, 28].

Highly adaptive and transformative capacities are keys to survival and prosperity in a rapidly changing world because they confer choice. When shocks happen, a system with these attributes is not simply swept along by events; instead, it has the capacity to move in chosen directions.

Vicious and virtuous cycles. Important social manifestations of emergent properties include vicious and virtuous cycles in social settings [this volume, Chapter 3]—cyclic chains of reinforcing causes and effects with either undesirable or desirable outcomes for the wellbeing of the participants in the cause-effect chains, and for the wider society. Thus vicious and virtuous cycles are amplifying feedback loops, with consequences that are respectively judged as either bad or good.

Vicious cycles arise, for example, around poverty, violence, homelessness, unemployment, low educational opportunities and high incidence of chronic physical and mental health problems. These factors reinforce each other in disadvantaged communities, leading to a spiral of suffering and loss of wellbeing that can propagate in time from generation to generation and also diffuse outward from hot spots of disadvantage to affect a whole society in multiple ways (Australia's current struggle to respond to Indigenous disadvantage being a clear example).

Conversely, virtuous cycles are reinforcing feedbacks that promote desirable outcomes—for example, declines in youth unemployment leading to reduced homelessness, violence and rates of imprisonment and, in turn, to improved wellbeing and opportunity for the children of that generation. Another example is the chain starting with future-oriented and socially progressive (including redistributive or compensatory) policies that lead to more efficient use of natural environmental resources, in turn leading to gains in environmental security and economic prosperity, further relieving pressures on the environment.

Both vicious and virtuous cycles are emergent properties in that they depend upon linkages and connections. They have important implications for social equity [this volume, Chapter 3]. Fostering virtuous cycles and damping vicious cycles requires interventions to foster or dampen connections, without which single-point interventions will fail.

Each of these three examples—growth and collapse, reactions to disturbances and shocks, and vicious and virtuous cycles—embodies an overarching dynamic that governs all emergent properties: the process of *evolutionary emergence* in a complex system through diversification, selection and amplification of selected strategies by replication [29]. This process is not only the engine of biotic evolution, the profound insight of both Darwin and Wallace in the mid-19th century. Much more than that, it is the universal engine of the emergence of complexity, working also in social, economic, technological and social spheres [29, 19].

Evolutionary emergence in coupled natural–human systems, most importantly in our own, can to some extent be facilitated and guided. This is the essence of how we negotiate our future—the central theme of this book. How can we be so presumptuous as to attempt to guide in effect our own destiny through evolutionary emergence? Our toolkit—to be addressed in more detail in later chapters in this volume—is far from perfect but still powerful. It includes building adaptive capacity and transformative capacity [Chapter 2]; facilitation of opportunities for human development, a primary component of equity [Chapter 3]; envisioning the future with scenarios [Chapter 4]; and exploring the interplay between predictable and unpredictable aspects of the future with quantitative models [Chapter 5].

The notion of facilitating and guiding evolutionary emergence in a system in which we ourselves are actors may sound like trying to pick nirvana and then work out how to get there. Rather our emphasis is on the other side of that coin; the aim is to work out the trajectories that we need to avoid and to allow our systems to self-organise among the set of acceptable trajectories.

At the highest level, our ability to guide our own destiny through evolutionary emergence depends on our abilities to perceive Australia as an adaptive system and to utilise wisely the choices that are thereby opened—the reason for the title of this section and chapter.

3 The past and the present

Possible futures are illuminated by knowledge of the past and the present. In this section we review the current state and trend of Australia as a coupled natural–human system and how Australia compares with the rest of the world. Five broad aspects are considered: i) population; ii) the nexus of economic activity, energy use and greenhouse gas emissions; iii) equity and equality; iv) the nexus of health, wellbeing and knowledge; and v) the natural environment. These aspects allow a brief evaluation for Australia of the state and trends of the five primary capitals defined above (natural, built, human, knowledge and social).

Population

A good place to begin is with population [also see Hugo, Chapter 3 in Volume 2], noting that forecasts of population trajectories for Australia have been made for over a century [30]. As shown in Figure 2, Australia's population grew from 3.8 million in 1900 to 22 million in 2010. The growth rate has fluctuated from year to year, typically around 1.5% per year over the past century. The contributions to this high growth rate from natural increase and net immigration were similar at around 2000, with natural increase being mostly larger before then and net immigration after. The contribution from boat arrivals—refugees arriving by boat from South-east Asia—is proportionally tiny in contrast with the massive political potency of this issue [31].

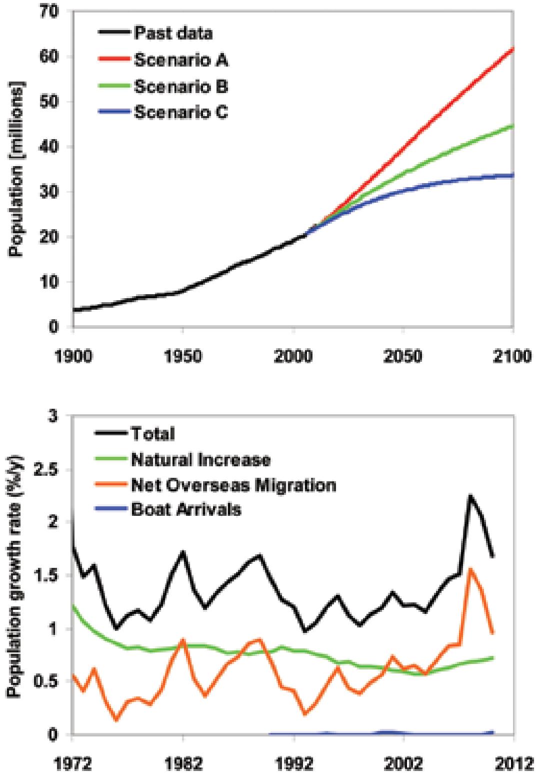

Figure 2: Left, Australian population from 1900 to 2010, with three projected population trajectories from 2011 to 2100. Right, contributions to population growth from 1972 to 2010. Data: ABS [32].

Australia's future population trajectory is up to us to decide, mainly (given near-replacement fertility levels) through the control knob of the level of net overseas migration. By 2100, the population will have reached 34, 44 and 61 million respectively under low-, medium- and high-growth scenarios from the Australian Bureau of Statistics (ABS) [32]; see Figure 2 (left panel). These scenarios differ only in setting the net overseas immigration level to 140 000, 180 000 and 220 000 per year respectively. Significantly, the ABS scenarios do not include an option for holding Australia's population close to the present level.

The nexus of economic activity, energy use and greenhouse gas emissions

It makes sense to consider overall economic activity, energy use and greenhouse gas emissions together because they are closely coupled. The focus on greenhouse gas emissions arises, of course, because of human-induced climate change.

The coupling between economy, energy and emissions is shown in Figure 3 via plots of per capita energy use and fossil fuel CO_2 emissions against income (per capita GDP) for Australia and several other countries and regions[3]. The area of the circle around each point is proportional to population. The resulting wiggly lines represent development trajectories showing how energy use or emissions per person change with increasing income per person (without accounting for international trade, which can have a significant effect [33, 34, 35]).

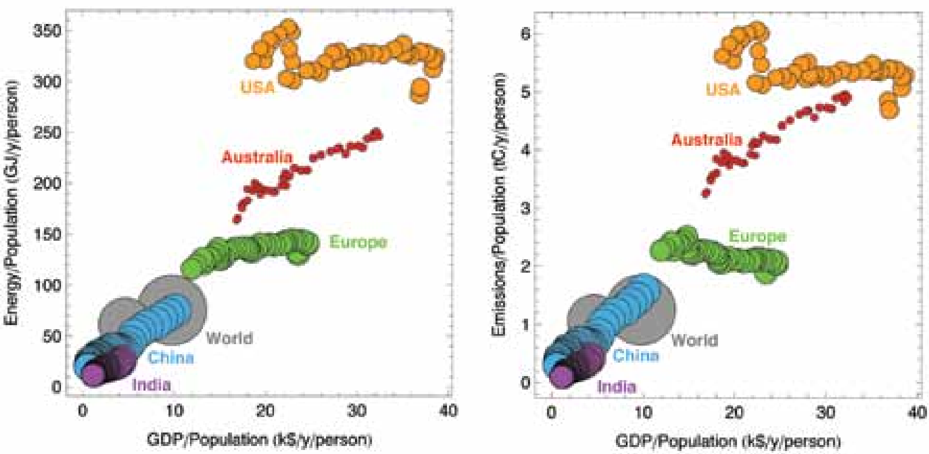

Figure 3: 'Bubble plots' of per capita energy use (left) and per capita CO2 emissions from fossil fuels (right) plotted against per capita GDP (GDP measured by purchasing power parity). For each country or region, each point represents one year from 1971 to 2009, with a size proportional to population. Points for the world are shown for 1971 and 2009 only. Data: International Energy Agency [36].

3 Throughout, GDP refers to gross domestic product by purchasing power parity, in constant-price dollars (US dollars in 2000). We use fossil fuel CO_2 emissions, in tonnes of carbon per year (tC/y) or million tonnes of carbon per year (MtC/y) as an indicator of greenhouse gas emissions, noting that fossil fuel CO_2 accounts for more than half of all greenhouse gas emissions from long-lived (Kyoto) gases.

Figure 3 indicates several significant things. First, there is a striking similarity between the development trajectories for energy use and emissions; they are hard to distinguish at first glance. Second, there is a broad tendency for energy use and emissions to be correlated with wealth, particularly below per capita GDP of around $15 000. The development trajectories in this region cluster in a diagonal band, with countries ascending up this band as they undergo development. The rate of ascent has been very rapid for China, which has now passed the average for the world, and also for India and other developing nations.

Third, Figure 3 reveals major regional differences. The United States and Europe both show signs of levelling off or saturating their per capita energy use and emissions while per capita income has continued to increase (i.e. their trajectories are nearly horizontal). The saturation levels are very different: European energy use and emissions are around half those of the United States for the same per capita GDP. Australia by contrast shows no signs of such saturation; its energy use and emissions have both climbed steadily in lockstep with per capita GDP. Much of this growth is driven by growth in energy-intensive and emission-intensive exports rather than domestic consumption. These differences indicate that institutions, economic structures and energy technologies all influence the relationships between income (or per capita GDP), energy use and emissions.

We now consider three aspects of the trajectories of GDP, energy use and CO_2 emissions.

1. Magnitudes and shares of world totals. Table 1 shows magnitudes and percentage shares of world totals for population, GDP, total primary energy supply and CO_2 emissions for the same nations and regions as in Figure 3, plus the OECD[4] and non-OECD regions (which roughly define groupings of developed and developing nations respectively). Australia in 2009 accounted for 0.33% of the world's population, but its shares of world GDP, primary energy and CO_2 emissions were 3 to 4 times higher, at 1.10, 1.08 and 1.35% respectively. This immediately tells us that Australians per person are responsible for 3 to 4 times the global average GDP, primary energy and CO_2 emissions per person.

2. Recent growth rates. Figure 4 compares average growth rates over the decade 2000–09 (in per cent per year) for population, GDP, primary energy and CO_2 emissions from fossil fuels for the countries and regions in Table 1.

4 The OECD comprised the following nations in 2010: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States.

The most striking feature is the enormous growth in GDP, energy and emissions in China (9–10% per year) and India and other developing countries (5–7 % per year). These rates vastly exceed population growth rates in the same regions. Australia's recent growth rates for all four quantities (population, GDP, energy and emissions) are higher than those of other major developed (OECD) nations. Over 2000–09, Australia had a remarkably high population-growth rate, at 1.5%/ per year—higher than the growth rate for *any* other region in Figure 4, developed or developing. Australian growth rates for GDP, energy and emissions were much higher than developed world (OECD) averages, though less than rates in the developing world. Australian CO_2 emissions from fossil fuels grew rapidly (2.3% per year) through 2000–09 in contrast with the United States and Europe, for which emissions actually declined.

Country or region	Population (million)		GDP (billion $US2000/y)		Primary energy (EJ/y)		Fossil fuel CO2 emissions (MtC/y)	
	1990	**2009**	**1990**	**2009**	**1990**	**2009**	**1990**	**2009**
Australia	17.17 (0.33)	22.1 (0.33)	380.4 (1.14)	703.8 (1.10)	3.61 (0.98)	5.488 (1.08)	71.16 (1.21)	108.8 (1.35)
USA	250.2 (4.75)	307.5 (4.55)	7064 (21.2)	11360 (17.7)	80.18 (21.8)	90.56 (17.8)	1326 (22.6)	1443 (17.9)
Europe	500.1 (9.49)	549.3 (8.12)	9007 (27.0)	12880 (20.0)	67.81 (18.4)	73.1 (14.4)	1101 (18.7)	1041 (12.9)
China	1141 (21.7)	1338 (19.8)	1965 (5.89)	12430 (19.3)	36.49 (9.92)	95.13 (18.7)	655.1 (11.2)	1932 (24.0)
India	849.5 (16.1)	1155 (17.1)	1412 (4.24)	4567 (7.11)	13.26 (3.61)	28.3 (5.56)	161.1 (2.74)	444.5 (5.52)
Non-OECD	4203 (79.8)	5536 (81.9)	11990 (36.0)	32130 (50.0)	170.0 (46.2)	275.6 (54.2)	2631 (44.8)	4454 (55.3)
OECD	1064 (20.2)	1225 (18.1)	21350 (64.0)	32110 (50.0)	189.3 (51.5)	219.3 (43.1)	3075 (52.3)	3328 (41.3)
WORLD	**5267 (100)**	**6761 (100)**	**33340 (100)**	**64240 (100)**	**367.7 (100)**	**508.7 (100)**	**5874 (100)**	**8059 (100)**

Table 1: Population, GDP, total primary energy supply and CO_2 emissions from fossil fuels in 1990 and 2009, for Australia, USA, Europe (EU27), China, India and the world. Figures in brackets are percentage shares of world totals. Data: International Energy Agency [36].

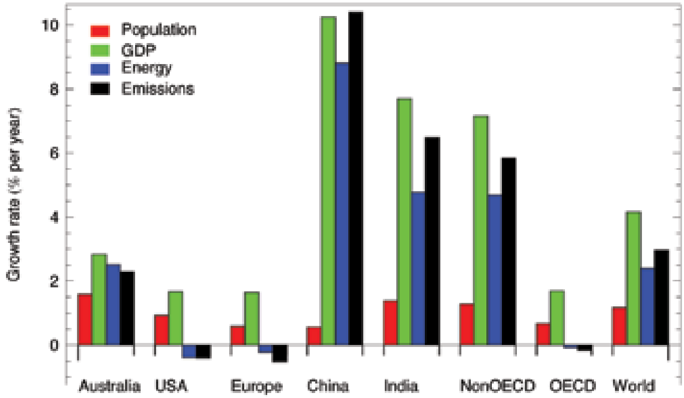

Figure 4: Average growth rates over the decade 2000–09 of population, GDP, total primary energy supply, CO_2 emissions per capita GDP (= GDP/pop.), the carbon intensity of energy (= emissions/energy) and the carbon intensity of the economy (= emissions/GDP) for Australia, the world, OECD (developed) countries and non-OECD (developing) countries. Data: International Energy Agency [36].

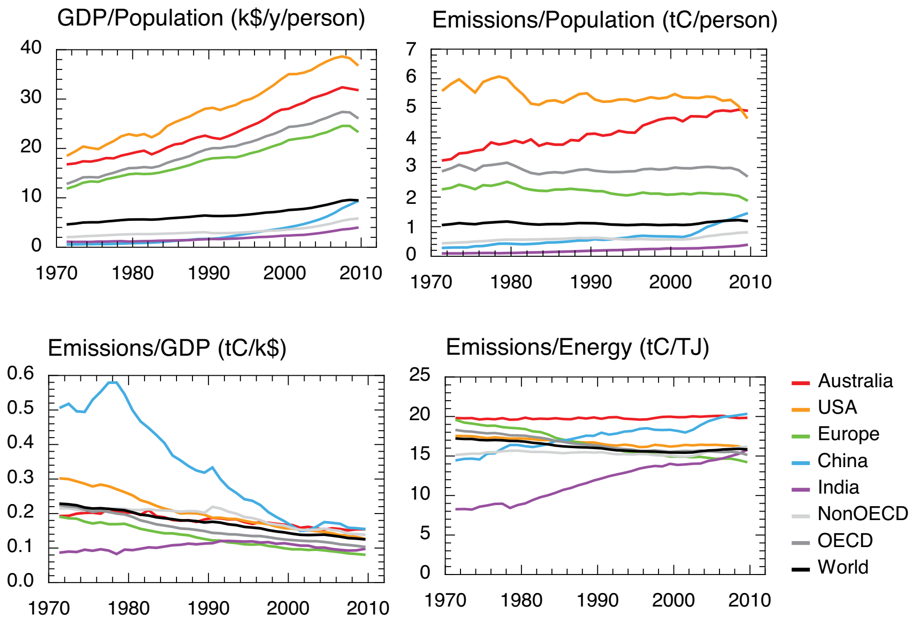

Figure 5: Trajectories over 1971–2009 of several key ratios for Australia, USA, Europe (EU27), China, India, non-OECD (developing) countries, OECD (developed) countries and the whole world. Top left: per capita CO_2 emissions (= emissions/population); top right: carbon intensity of energy (= emissions/energy); bottom left: carbon intensity of the economy (= emissions/GDP); bottom right: per capita GDP (= GDP/ population). Data: International Energy Agency [36].

3. Per capita GDP, per capita emissions and emissions intensities. The relationships between GDP, energy use and CO_2 emissions together with population are characterised by the ratios between these quantities [37, 38]. Figure 5 shows the time course over 1971–2009 for four of the most important of these ratios: per capita GDP (= GDP/population), per capita emissions (= emissions/population), the carbon intensity of the economy (= emissions/GDP), and the carbon intensity of energy (= emissions/energy).

Per capita GDP (Figure 5, upper left) increased everywhere over the four decades 1971–2009. The broadly increasing trend was broken intermittently by economic downturns, including a recent dip in developed nations because of the 2008 global financial crisis. By this measure, inequality between nations remains extreme at a factor of 10 between India and the United States, and plenty of countries are much worse off than India. China's growth since the mid-1990s has been extraordinary and its per capita GDP has now exceeded the world average. Australia has had a high per capita GDP through the last four decades, well above the OECD average, and was only slightly affected by the 2008 global financial crisis.

Per capita emissions (Figure 5, upper right) remained steady or slightly decreased through 1971–2009 for many developed (OECD) countries but have increased in developing countries, notably in China since 2000. Australia is exceptional among developed countries, with a significant increase in per capita emissions over the past four decades.

The carbon intensity of the economy (Figure 5, lower left) shows how much CO_2 is emitted for each dollar of wealth created as GDP averaged across the whole economy. To reduce emissions while maintaining economic activity, this intensity has to decrease. Historically it has indeed decreased for the world as a whole and in most countries, but the rate of decrease (improvement) has been slower in Australia than in most other countries.

The carbon intensity of energy (Figure 5, lower right) is a measure of the amount of CO_2 emitted for each unit of energy generated averaged across all energy sources. It is a very conservative number, changing only slowly in time and not varying much between countries because it is determined by the technologies in the energy mix. This intensity has been nearly constant for Australia over 1971–2009, and higher than for any other country represented in Figure 5 except for China in recent years. The carbon intensity of energy in developing countries (China, India and others) has tended to increase as these countries have moved away from traditional local energy sources toward industrial sources, prominently coal.

Globally, emissions decreased slightly in 2009 (by just over 1%) because of the 2008 global financial crisis, reversing a growth at over 3%/ per year that had been seen over the period 2000–08 [39, 40]. However, global CO_2 emissions from fossil fuels experienced near-record growth of 5.9% in 2010 as the world economy recovered from the financial crisis [41].

The significance of emissions is their relationship with human-induced climate change. Targets for keeping risks from global climate change below ‘dangerous’ levels [42, 43] constitute value judgements and are therefore social constructs. The most widely used target, proposed by the European Union in the 1990s [44] and endorsed by the United Nations Framework Convention on Climate Change in Copenhagen in 2009, is to limit warming to 2 degrees Celsius above preindustrial temperatures. Even a 2 degree target will not eliminate climate risks to ecosystems, food production systems and human health, or the risk of crossing climate thresholds that would lock in further warming [42, 43]; therefore, some argue for a 1.5 or 1 degree target [45, 46]. To achieve even a 2 degree target, global CO_2 emissions have to peak within the next few years and then fall very rapidly, by over 3% per year for many decades [47, 48].

The implication of this requirement for the ratios shown in Figure 5 can be seen by writing a simple Kaya identity for emissions [37]:

[emissions] = [population] × [GDP/population] × [emissions/GDP]

To make emissions decline at 3%/ per year the sum of the relative growth rates of the three factors on the right-hand side has to be −3% per year. Over the next few decades, the first factor (population) will continue to grow globally and in most countries—certainly in Australia, according to Figure 2. The second factor (GDP/population, or per capita GDP), will continue its historic growth if the world remains committed to economic growth, a sine qua non of the current world order. That leaves the third factor (emissions/GDP, the carbon intensity of the economy) as the only feasible candidate for achieving emissions reductions. Assuming global GDP growth of the order of 3% per year over coming decades, the requirement is a staggering 6% per year reduction in the carbon intensity of the economy, which can only be achieved with a comparably large reduction in the carbon intensity of energy. This is why the trends in the bottom panels of Figure 5 are a major concern both globally and for Australia: these intensities are highly resilient in an adverse way [this volume, Chapter 2] and have not responded to 20 years of intense international and national efforts to reduce emissions. This highlights the growing divide between scientifically determined emissions targets and the politics of achieving those targets [49].

Finally, figures 3 to 5 indicate why the nexus between economic activity, energy use and greenhouse gas emissions is perceived in fundamentally different ways in the developed and developing parts of the world. In the developing world, particularly its poorest parts, the need to increase living standards and economic wealth is a far higher priority than emissions reduction, which is widely viewed as the responsibility of the developed world. Charlton [50] called this divide ‘progress versus the planet’ and argued that it is the fundamental reason for the failure of recent climate change negotiations, prominently at Copenhagen in 2009.

Equity and equality

Australia’s self-image is of an egalitarian society, ‘Australia fair’ [51]. Yet by many measures, inequality in Australia has increased over recent decades, as in much of the rest of the world. The significance of this fact has been augmented by recent empirical studies summarised by Wilkinson and Pickett in *The spirit level* [10]. They showed that decreasing inequality correlates with improved outcomes in numerous societal indicators, including physical and mental health, freedom from violence, educational performance and social cohesion. These relationships hold both between and within nations.

Equality and equity are different, though related, concepts. Equality is about things being equal or uniform, while equity is about things being fair. Like personal wellbeing, equity is grounded in a social context [52, 53, 16]. Social equity implies that all socioeconomic groups in a society have adequate civil liberties, physical and mental health, longevity, opportunities for employment and education, access to knowledge and culture, and freedom from violence. Conversely, equity is threatened by social stresses associated with vicious cycles [Section 2] around poverty, violence, homelessness, unemployment, low educational opportunities and chronic health problems [this volume, Chapter 3]. These aspects of social equity are not all easily measured, though indicators for many of them are available.

Inequality is more easily measurable than inequity because it is readily captured by numbers. Although equality and equity are not the same, they are linked: high levels of inequality, implying significant levels of poverty and the associated vicious cycles, are strongly inimical to social equity. Measures of inequality are available in the form of income distribution and many other metrics, but in assessing these it is necessary to be aware that choices of measure imply choices about values. This is particularly relevant in choosing between absolute and relative measures [51, p47].

Acknowledging all these issues, we can learn about some aspects of trends in inequality by examining trends in income distribution for Australia, and comparing with other nations. The following data is drawn from an OECD report [54]. Several measures of income distribution are available such as the income difference between the richest and poorest 10% or 1%, or the Gini coefficient—a property of a distribution (say of income) that is zero when the distribution is uniform, and 1 when all the income goes to one person. Increasing inequality is indicated by a higher Gini coefficient.

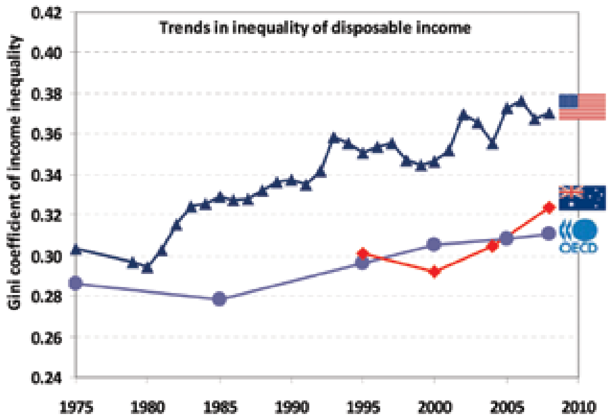

Figure 6: Trends in inequality of disposable income measured by the Gini coefficient for USA and Australia and averaged across all OECD countries. Disposable income equals market income (from gross or pre-tax earnings plus income from savings and capital) after redistributions from taxes and benefits. Figure reproduced from OECD [54].

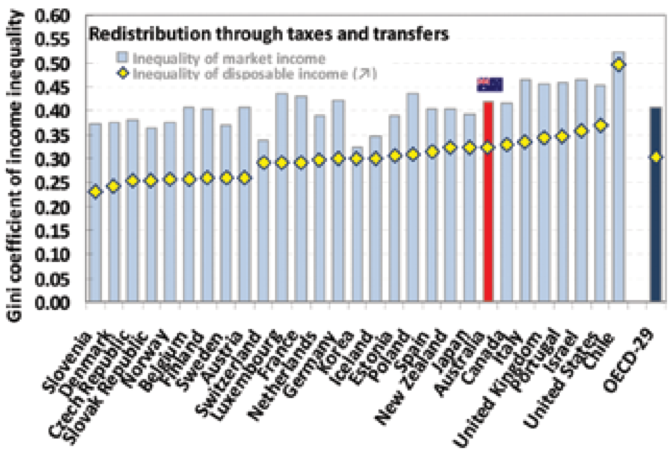

Figure 7: Effect of redistribution of wealth on inequality of disposable income for OECD countries in 2009. Gini coefficients for both market income and disposable income (market income after redistributions from taxes and benefits) are shown by bars and yellow diamonds respectively. The greater the difference, the larger is the role of taxes and benefits in reducing inequality. Figure reproduced from OECD [54].

Figure 6 shows how the Gini coefficient for disposable income has changed over the last few decades for Australia, the United States and all OECD countries. By this measure, inequality in disposable income in Australia is significantly lower than in the United States and higher than the OECD average. It has risen over the last decade in line with trends elsewhere. In 2009, Australia's Gini coefficient for disposable income was the eighth highest among the 29 OECD countries.

For all OECD countries in 2009, Figure 7 shows the extent to which governments reduce income inequality by redistribution through taxes and benefits. The relative amount of redistribution is indicated by the difference between the Gini coefficients for market (gross) income and disposable income after taxes and benefits. For Australia, this difference is lower than for most European countries but higher than the United States. Hence Australia redistributes wealth less than most European countries but more than the United States.

Another measure of inequality is provided by the income ratio between the top and bottom income deciles (the wealthiest and poorest 10%). Like the Gini coefficient, this measure shows a progressive growth of inequality both within and between nations over recent decades. From 1990 to 2007, the income ratio between top and bottom deciles rose from 6 to 9 for Australia and from 13 to 18 for the United States [54, fig 12].

For some major OECD countries, Figure 8 shows the recent (1985 to 2008) growth rates of disposable incomes for the total population and the bottom and top deciles. Among these developed countries, Australia saw the fastest income growth in *all* income cohorts (except for the middle cohort in Spain, where Eurozone indebtedness has since taken a heavy toll). This suggests that the last two decades indeed constitute, at least economically, an 'Australian moment' [55]. Australian incomes for the top decile rose at 4.5% per year, for the bottom decile at 3.6% per year and for the total population at 3.0% per year (indicating relatively slower growth in mid-range incomes). In short, Australia's income growth in all cohorts has been remarkably high among developed nations, with the rich increasing their incomes most rapidly, followed by the poor, who in turn have increased their incomes faster than those in the middle.

At a global scale, drivers of increasing inequality include several major trends [54]: globalisation (trade and financial integration, technology transfers, mobility of products and labour), regulatory reforms (reduced market liberalisation, reductions in employment protection, decreases in minimum relative to median wages), changes in working hours (generally favouring higher earners), changes in household structure (more single-person and single-parent households), changes in income structure (more capital and self-employment income,

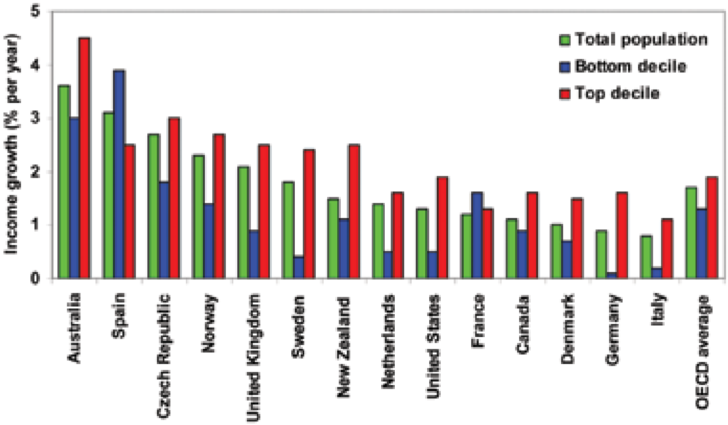

Figure 8: Growth in disposable incomes over 1985 to 2008, in % per year for the total population, the lowest decile (poorest 10%) and the highest decile (richest 10%). Data from OECD [54].

favouring those with assets) and decreases in public transfers of wealth through taxes and benefits as the proportion of taxation on the wealthy has fallen. These trends have acted in different ways in different countries. Most are likely to have been influential in Australia together with a factor unique to Australia in recent years—the impact of the mineral resources boom.

We emphasise again that there is much more to social (in)equity than the measures of (in)equality presented above. Significant issues for Australia include persistent hot spots of disadvantage in many Indigenous communities and in some peri-urban and rural communities [this volume, Chapter 3].

The nexus of health, wellbeing and knowledge

Just as for economic activity, energy use and greenhouse gas emissions, there is a close connection between health, wellbeing and knowledge. It is appropriate to consider them together, as they are vital components of the built, human, knowledge and social capitals associated with people and society.

Health and wellbeing. Personal physical health is a primary component of personal wellbeing. At a higher level of aggregation, the significance of population health is more than the average personal health of the population in two ways: i) adequate population health is an essential component of the health and functioning of the entire coupled natural–human system, and ii) measures of population health are key indicators of the societal asset base for progress towards long-term environmental sustainability and social fairness.
The achievement of good and equitable population health is both a key

objective of any enlightened society and over time a key criterion of whether that society is living in environmentally sustainable, equitable and health-supporting fashion [56] [McMichael, Chapter 1 in Volume 2].

By world standards Australians have good health and life expectancy. Around 1900, average life expectancy in Australia was 55 years for males and 59 for females; by 2009 the figures were 84 years for males and 87 for females. Australia is in the world's top bracket of longevity with Iceland, Japan, France and Sweden [57].

Australia's healthcare system is of high quality by world standards. A tax-based social insurance for healthcare is a great national asset. Nevertheless, ongoing rises in obesity and also in depression and stress (particularly among younger Australians) pose growing risks to future health. Socioeconomic differences in health persist, as do urban–rural differences and, most starkly, between Indigenous and non-Indigenous Australians.

A current snapshot of major diseases (indicating how well or badly we have done in the recent past) [McMichael, Chapter 1 in Volume 2] shows that: i) cancer is Australia's leading broad cause of disease burden (19% of total burden) followed by cardiovascular disease (16%) and mental disorders (13%); ii) the rate of heart attacks continues to fall, and case survival continues to improve; iii) around 1 in 5 adults has a mental disorder at some time in any 12-month period, including 1 in 4 of those aged 16–24; iv) Type 2 diabetes is increasing and it is expected to become the leading cause of disease burden by 2023; v) the incidence of treated end-stage kidney disease is increasing, with diabetes as the main cause.

A profile of current health risks in the general population (as predictors of likely future health gains and losses) is: i) tobacco smoking persists as the single most preventable cause of ill health and death in Australia; ii) 61% of adults and 25% of children aged 5–17 are overweight or obese; iii) sexually transmissible infection rates continue to increase, particularly among young people; iv) use of illicit drugs has generally declined in Australia.

However, these immediately discernible risks are not the whole picture. On a wider-risk landscape, many aspects of safety, health and survival will be increasingly threatened over coming decades by climate change, other environmental changes, sociodemographic stresses and disparities (if unresolved), and indirectly by increases in geopolitical insecurity in Australia's wider region.

Measures of subjective wellbeing (optimism, happiness) reveal contrasting patterns for Australia: while high levels of optimism are reported, so too are significant levels of stress and anxiety, and these levels are rising over time [58]. The truth is more complex than the popular image of a nation of happy-go-lucky people.

The built environment. Health and wellbeing are strongly influenced by environmental factors, including both the state of the natural environment (see next subsection) and also the built environment that provides the immediate habitat and support system for all humans.

A critical global and national trend in the nature and form of the built environment is rapid urbanisation. Around 2010, the world passed the point beyond which more than half of the global population lives in cities and towns. Developed nations are more urbanised than developing nations. Australia is among the most urbanised of nations, with over 85% of the population living in cities and large towns. This has major implications for Australia's development as the current population growth rate of about 1.5% per year is equivalent to adding an extra Canberra to its urban infrastructure every year. Therefore, any of the ABS population scenarios (Figure 2) have major implications for urban expansion and services, including transport, education, health and housing. More fundamentally, patterns of settlement and built environments have great implications for pressures on the (nearby and distant) environment and for social cohesion, equity and health-related behaviours and outcomes.

Education, knowledge and innovation. The title of Donald Horne's 1964 classic *The lucky country* was ironic, coming from the opening sentence of its last chapter: 'Australia is a lucky country, run by second-rate people who share its luck'. The luck arose from Australia's endowments of agricultural and mineral resources. In 1990, Prime Minister Bob Hawke adapted the widely misused tag in his election campaign launch: 'No longer content to be just the lucky country, Australia must become the clever country.'

Is Australia clever? Australia's education system is functional despite failings in hot spots of disadvantage. Its publicly funded research is of high quality [59], despite relatively poor funding. However, the 2011 *Australian innovation system report* [60] showed that relative to other OECD countries Australia has low investment levels in intangible (human and knowledge) capital, referring to innovation-related activities such as skills development, design and organisational improvements. Australia also has very low rates of new-to-the-market international innovations. Private enterprises are more likely to borrow or adapt from overseas than to undertake significant innovation themselves. This and similar studies suggest that Australia is still not very good at being clever and continues to ride its luck.

The natural environment

The natural environment provides the life-support system for human societies and also supports production of goods and services. The benefits of the environment for humankind are often described as ecosystem services [61, 62], of which the Millennium Ecosystem Assessment [61] identified four kinds: production, regulating, cultural, and supporting services. Here we briefly review six crucial aspects of these services for Australia, including natural systems and the production systems supported by them, and ecological and geological natural resources.

1. Water. Australia is a dry continent with water resources that are fully allocated or overallocated in the populated south-east and south-west [63], even in years of average rainfall. This overallocation causes severe stress on ecosystems, particularly in drought years such as the 'big dry' in southern Australia from 1997 to 2009. It also makes water allocation a hot political issue, particularly as governments attempt to return water to the environment. Available water resources in south-east and south-west Australia are likely to decline further as a result of climate change [63]; relative declines in stream flow will be about three times those in rainfall [64]. Declines in water availability per person will be much larger because of a rapidly increasing population. Nevertheless, cities such as Melbourne are demonstrating a capacity for orderly water savings [64].

2. Soil resources. Australian soils tend to be low in mineral nutrients (particularly phosphorus and trace elements) and are easily eroded by water and wind when disturbed. Although the productivity of agricultural systems has been improved over the last century through research and development (R&D), this has been associated with major fertiliser applications in many areas. Soil erosion has transported heavy loads of nitrogen and phosphorus into sensitive estuarine and coastal environments, particularly the Great Barrier Reef [65, 66]. Mining of soil resources, a major problem in most agricultural systems in the 19th and early 20th centuries, continues to be an issue in marginal rangeland systems. Increasing soil salinity and acidification have historically been major problems in irrigation and some cropping areas (Victorian Mallee, south-west Western Australia), with adverse implications for downstream water supplies and ecosystems (for example, the reliance of Adelaide on water from the Murray). None of these long-term issues has disappeared, although other environmental concerns like climate change and biodiversity have displaced them in recent public discourse.

3. Food production. Australia is a global food exporter producing about three times as much as its population needs, mainly in cereals and meat. However, it would be wrong to conclude that food security is not a problem for Australia for several reasons [67]: Australia's population is growing, its water resources are already overstretched and Australian agriculture is highly vulnerable to climate variability and change. The world is experiencing rapidly increasing food demand because of growing populations and shifts in developing countries toward Western-style diets with increased shares of environmentally intensive animal proteins. This has implications for Australian agriculture and its profitability.

There has been a slackening in the rate of improvement in specific yields (production per unit land area and per unit consumption of water and other resources), which historically have increased at over 1% per year in Australia over the last century, driven by intensive research and development. Given the pressures on Australian and global food supplies, there is an urgent need for specific yields to continue to improve through a continuing sustained commitment to R&D [67, 68].

4. Mineral and energy resources. Australia has abundant mineral resources in iron and other metals, fossil fuels and uranium. The wealth from extraction of these resources coupled with demand from developing Asian countries has powered Australia's economy in recent decades and insulated us from the 2008 global financial crisis. Australia extracted 17 360 PJ of geologically stored energy in 2007–08 (54% coal, 27% uranium, 11% gas), of which over two-thirds was exported [69]. Domestic energy consumption (from [69], differing slightly from Table 1) was 5772 PJ (40% coal, 34% oil, 22% gas, 5% renewables, mainly bioenergy). Australia is the world's largest coal exporter, Indonesia being the next. Most of Australia's black coal exports go to Japan, India, Taiwan and Korea [70].

Australia also has abundant resources of renewable wind and solar energy that together contributed only 0.3% of domestic energy consumption in 2007–08 [69]. Serious uptake of these resources is an enormous long-term opportunity. Other countries (Spain, Germany, Denmark, the United States) are showing that it can be done.

How long will Australia's mineral resources last? While estimates vary widely, one authoritative source [69] suggests that at current extraction rates the present economically demonstrated resource will last for about 90 years for black coal, 500 years for brown coal, 140 years for uranium and 60 to 70 years for gas. These times will increase with the discovery of additional reserves and as resource prices rise (increasing the proportion of currently known reserves that can be extracted economically), but will decrease as extraction rates increase. Although the time scales are many decades, they are not infinite, particularly for black coal and gas. On these estimates, and balancing new discoveries and price rises against increased extraction rates, Australia will have used around half of its present resources for black coal and two-thirds of its gas resources by 2050, and most of both will be gone by 2100 [this volume, Chapter 6].

There are also major climate implications. If Australia mines and uses all its fossil fuel resources without carbon capture and storage (CCS), it will contribute significantly to the threat of dangerous climate change. The stark choices are to leave some resources in the ground, to deploy very large-scale CCS (much larger than currently believed to be practical) or to use resources at a rate which, if other nations do as we do, would lead to global warming in the range of 4 degrees by 2100 [64].

5. Terrestrial and freshwater ecosystems. Australian biodiversity is unique and suffering from vulnerabilities and species extinctions at high rates because of habitat loss and fragmentation, exotic diseases, feral animals and plants, overgrazing and overlogging, water diversions, applications of pesticides and herbicides, mineral resource extraction and climate change [71]. Indigenous cultures and heritage values are under direct threat from these losses, and ecosystem function is suffering significant assault in many systems, especially in marginal and water-stressed environments.

6. Marine ecosystems. Australia has 36 000 km of coastline with a 9 million km^2 exclusive economic zone (EEZ) extending out from that coast. An additional 4.6 million km^2 has been recognised under claims associated with Australia's Antarctic territories and extensions of continental shelf areas under Australian control [72]. Globally this is the third-largest marine area of national responsibility and is larger than the Australian landmass (7.7 million km^2). This enormous area stretches from tropical to polar systems, and from beaches to waters deeper than 4000 m, most of which have only been relatively sparsely sampled. Fifty thousand marine species have been recorded off Australia, but this is only a small fraction of Australia's marine biodiversity—scientific cruises still regularly find that more than three-quarters of the species collected were previously unknown [73, 74].

Poleward-flowing current systems run along both the east and west coasts of Australia—the East Australian Current along the east coast and the Leeuwin Current along the west coast. The Leeuwin is unique in that nowhere else in the world does a poleward current flow down the eastern edge of a major ocean basin. These currents significantly influence the productivity of Australian waters by drawing warm, nutrient-poor, low-productivity water southward down the coasts. Australia also lacks large-scale upwelling of cold ocean waters to support productivity hot spots. This means that despite the large size of the EEZ Australia's total fish catch is small by global standards. Production from

Australian commercial fisheries (including aquaculture) has fluctuated between around 150 000 to 250 000 metric tonnes per year since 1985, with aquaculture accounting for a progressively increasing share [75]. Despite the near constancy of production biomass, the total value dropped by 50% in value from 2000 to 2007 [75]. In addition, 25% of Australians fish recreationally, likely landing more than the commercial catch in total, though data is difficult to obtain [75]. Together recreational fishing and marine tourism in general contributed roughly $11.6 billion to the Australian economy in 2006–07, with the total value of Australia's marine industries being around $38 billion and rising by more than 40% through the previous last decade [76].

In comparison to the rest of the world, Australia's marine resources are relatively well-managed [77], with sustainable management regulations to satisfy ecological, economic and social objectives. Earlier trends towards unsustainable rates of exploitation have been reversed for most species and in 2009 the UN Food and Agriculture Organisation rated Australian prawn fisheries as the best-managed in the world. However, pressure on marine resources remains strong as increasing affluence leads to an increasing demand for seafood [78]. In 2005, imports of seafood exceeded the local catch for the first time [75]. Moreover, international demand for seafood means that illegal and unregulated fishing is a significant issue in all Australian waters [79].

Exploitation is not the only pressure on Australia's marine ecosystems. Coastal development and land use have altered nutrient cycles and shoreline habitats (e.g. seagrasses and mangroves) that act as nursery habitats for many marine species. In addition, climate change is causing a strengthening of poleward currents, so Australia's temperate waters are warming much faster than the global average. The poleward extent of the East Australian Current moved 350km further south over the 20th century, leading to a 1.3 to 2.3°C temperature increase in temperate sea surface temperatures [80, 81]. This has implications for marine animals, which can be strongly environmentally influenced. In the west, the warmer waters have seen increased growth of corals at the southern extent of their distributions [82], while in the east there have been examples of the restructuring of marine ecosystems—for instance, the sea urchin *Centrostephanus* has extended its range from New South Wales to Tasmania, destabilising large kelp forests around Tasmania by stripping all the kelp from rocky reefs [83].

Australian marine ecosystems are also unique in that they are dominated by invertebrates. This means that Australian catches are not only dominated by fish, unlike catches elsewhere in the world [77], but they also have a high dependence on calcifying species that are susceptible to ocean acidification. With the increase of CO_2 in the atmosphere, the levels in the ocean have also risen, causing a 30%

increase in the acidity of the oceans with a further doubling of acidity possible by 2100 [84]. Due to lags in the ocean chemical cycles, it could take thousands of years to return to preindustrial levels. The degree of acidification will vary regionally, with the Southern Ocean the most vulnerable, potentially becoming corrosive to shelled organisms by 2020 [85]. But in all oceans it has the potential to cause major disruption to marine ecosystems and the services they provide (for example, climate regulation, nutrient cycling, provision of protein). It is also likely that cumulative stresses on marine ecosystems will act to make the impacts of each more severe and that past exploitation of marine systems may have made them less resilient to additional future stresses [86].

Summary

Australia is an exceptional country in global terms: it has developed-nation affluence, capital stocks and consumption levels, but a developing-nation pattern of growth. Australia's population growth rate is higher than the world average and the rate for major developing nations, including China and India. Its growth rates for GDP, energy use and CO_2 emissions are all high among developed nations.

Australia's present state and trend in terms of the five capitals introduced in Section 2 (natural, built, human, knowledge and social) can be summarised thus:

Natural capital. Australia perceives itself as a land that abounds with nature's gifts, but changes are happening. Australia has water resources that are now overallocated in southern regions and are at further risk from climate change; it has high loss rates for biodiversity; it is using its endowed mineral resources at rates that will see most of them gone within a century; and its impact on global climate is very high in per capita terms. Perceptions of these changes are masked by a historically low population density. Nevertheless, there is abundant evidence that in many ways Australia is unsustainably mining its high endowment of natural capital.

Built capital. With a high GDP and high economic growth rate, Australia has high and growing stocks of built capital. However, rapid population growth and depreciation of existing facilities are both stressing these stocks—for example, in housing supplies and urban infrastructure.

Human capital. At national level Australia rates highly in many measures of the state of its human capital. Most Australians enjoy good health and longevity. Many of the major population health risks are associated with affluence and some are also associated with hot spots of disadvantage within an otherwise affluent society. Measures of happiness and optimism reveal trends indicating that stress and anxiety are significant and rising issues. An increasing burden of health adversity is likely to result if current trends in these key environmental and social conditions continue.

Knowledge capital. Despite a generally good education system Australia has low investment levels in knowledge capital and the national priority placed on advanced knowledge development is low. These factors suggest that Australia is still not very good at being clever.

Social capital. Australia perceives itself has having broadly effective governance mechanisms and functional institutions. By world standards it has low levels of homelessness and interpersonal violence, high literacy and numeracy and good school retention rates. However, inequality is high by OECD standards and increasing. It has been argued [87] that Australia tends to unjustified complacency about its mateship myth and its civic freedoms and is subject to outbreaks of xenophobia. A glaring ongoing problem is the chronic disadvantage suffered by Indigenous Australians.

4 Ways of thinking about the future

The last section surveyed the recent past and the present of Australia as a coupled natural–human system. In the rest of this chapter we turn to Australia's future directions, with this section examining some broad philosophical issues and the next considering more specific tools.

Because many aspects of the future are inherently unknown and unpredictable, thinking about the future requires a different approach to that used in studying the past. In this section we focus not on predictions of specific futures but rather on how to think rationally about the future by exploring four questions: first, what are the giant forces or trends that are likely to shape the future of the world and Australia over the next few decades? Second, how do we handle the inescapable realities that the future is uncertain, contested and ultimately shared? Third, how do we deal with the tension between the objective and the subjective in approaching the future? Fourth, how can we define a future that is safe in the sense of being resilient to shocks?

Giant forces

Despite the uncertainty of the future, it is not completely opaque. Several trends are already evident from the past and the present, as briefly surveyed in the last section with a focus on Australia. Recent big-picture analyses [88, 89] converge in identifying the following global megatrends:

1. *Growth and ageing of population.* Global population continues to increase from its 2011 level of 7 billion, and will exceed 10 billion in the late 21st century according to recent United Nations estimates [90]. Trends towards decreasing fertility are reducing population growth rates, offset by increasing longevity that is also leading to a marked ageing of the population, especially in developed countries. Both trends are associated with increasing affluence.
2. *Increasing affluence, especially in the South and East.* Through unprecedented economic growth, the geopolitical South and East is undergoing a transition [Figure 3, Table 1] that will see the economies of nations like China and India reach a near fully developed state within a few decades. This will have enormous geopolitical implications as power becomes shared more widely, and global environmental consequences as the ecological footprints grow rapidly to match the already large ecological footprints of the North and West.
3. *Increasing environmental pressures.* A human population increasing in both numbers and affluence is placing multiple pressures on the life-support systems of Earth in areas including climate change, water systems, nutrient cycling, terrestrial and marine ecosystems, biodiversity, stratospheric ozone depletion, ocean acidification and more. Finite reserves of non-renewable resources are being exhausted.
4. *Rapid technological change.* Rapid technological innovation will continue, with profound effects on primary and secondary production systems, the knowledge economy and social relationships. Economic sectors based on services and innovation will employ progressively more people relative to primary and secondary manufacturing.
5. *Increasing connectivity and complexification.* Spurred by rapid uptake of new technological possibilities, global networks of information, finance, trade and travel will continue to grow. As a result, levels of societal complexity will continue to increase. Increased connectivity also amplifies the consequences of economic and political instabilities, tensions and conflicts.

All of these trends are now well-established, and have high persistence—they appear likely to continue at least for the next few decades. To this extent, they form a set of giant forces shaping the future. They are deeply interconnected, and far from harmonious. For instance, increasing environmental pressures will eventually collide with growth in human numbers and affluence [1–4]. Increasing connectivity leads to unpredictable amplification of economic and political instabilities, causing shocks with long-tailed or power–law distributions in intensity [91, 92] that disrupt growth in affluence and wellbeing, even to the point of possible system collapse [22].

Care is needed in conceptualising how these giant forces will shape the future because of the tensions between them. For a while, they may act as guides to prediction because of their persistence. However, they also hold the potential for shocks that are inherently unpredictable in timing, magnitude and consequences [93].

Inescapable realities

In navigating a future dominated by the colliding giant forces sketched above, the challenges facing this generation are both general and particular. Earlier in this chapter we emphasised that every generation faces the same generic challenge. While it is tempting to see our contemporary challenge as entirely unique, such a stance is limiting because it denies us the opportunity to learn from ways that generations in the past have faced the task of navigation. Nevertheless, there are unique aspects to the contemporary challenge, brought about by the systemic disruption quality of many current environmental and ecological problems, the global scale of demographic changes, and unprecedented global connectivity.

We also suggested earlier that three basic, objective realities confront every generation in the task of navigation: the future is *uncertain*, *contested*, and *ultimately shared* (in the sense that multiple possible futures inevitably crystallise into just one realised pathway). Each of these attributes has implications.

To grapple with the *uncertainty* of the future, we assess probability and risk. Objective (value neutral) statements about the future are therefore most useful when they come with attached probabilities, either explicit or implicit. Statements without any sense of likelihood are much less useful for thinking rationally about the future because a listener must add their own judgement about likelihood when interpreting such statements, usually based on the level of trust ascribed to the source [94]. Explicit probabilities have been attached to daily weather forecasts since the 1980s. In assessing projections for future climate change, the Intergovernmental Panel on Climate Change (IPCC) has carefully quantified uncertainty with consistent language [15].

Not all objective analyses of the future can yield quantified probabilities. Some are restricted to defining options or possible pathways without saying which are more or less likely. Such analyses are still useful but they leave a key aspect unstated because decisions about pathways require assessments of the risk (likelihood x cost) or opportunity (likelihood x benefit) of alternative choices. There's no way out of this: whether or not God plays dice, we have to.

The implications of probability assessments are profound and the consequences of making wrong choices can be severe. A common mistake is failing to see connections that make future events correlated rather than independent:

mistakes of this sort were part of the mispricing of risk on Wall Street that was one of the triggers for the global financial crisis in 2008 [91].

Quantifying uncertainty, even roughly, does not make it go away. How do we live with it? The answer, broadly, is to ensure that we have enough adaptive capacity and transformative capacity to handle whatever comes at us, and the will to use these capacities. This is why these capacities are keys to survival and prosperity in a rapidly changing world [Section 2].

The *contestability* of the future means that different people and groups place different emphases on what they want the future to look like, leading to different choices about pathways. These choices embody value judgements expressed through subjective rather than objective statements.

Value judgements are carried in the narratives or deep stories that people and groups use to express their convictions [Raupach, Chapter 14 in Volume 2]. Two strong narrative families in contest throughout contemporary public discourse can be labelled the sustenance and expansion narratives. The sustenance narrative stresses the finitude of Planet Earth and the need to protect the environmental commons that maintain planetary life support systems. The expansion narrative stresses the benefits of continued growth in the human enterprise coupled with a belief that technological progress will avert any coming collision between growth and biophysical limits. The deep value judgements associated with these narratives lead to quite different choices about pathways in the immediate future: people motivated by the sustenance narrative are likely to advocate short-term sacrifices to increase longer-term prospects for wellbeing and even survival. Those motivated by the expansion narrative are likely to place higher priority on individual liberties than on regulatory protection of the environmental commons, perhaps seeing such regulation as a threat, and to see the longer-term future as something that will look after itself.

Recognising that the future is contestable does not make it any easier to deal with the contests. How should they be handled? The beginnings of an answer emerge from the third basic reality.

An *ultimately shared* future has implications for the resolution of contests around different value judgements. If everyone shares a common planetary lifeboat then we need ways to agree on a course to be followed to the extent that it is possible to do so, and to live with the remaining disagreements.

The process of reaching such an agreement can be creative, and can make remaining disagreements easier to handle. This is the essence of the living scenarios concept developed in different forms by all four working groups at the Bowral workshop. It is outlined in the last section of this chapter and expanded in different ways in other chapters in this book.

Distinguishing between the objective and the subjective

In *Deep futures* [95], Doug Cocks laid out a philosophy for thinking about the future in which he distinguished between two modes of thought or analysis: what we think is *likely* to happen on the basis of objective analysis and what we *want* to happen on the basis of our subjective value judgements and aspirations. He argued that it is important not to mix these up. Taking a broad view of the subjective question of what people might like to see happening in the future, he argued that a course for the future, for an individual and for a society needs a necessarily subjective working statement of a goal or a vision, and that for a society such a statement should be as broad as possible [95, p135 et seq]. His own statement of a long-term goal is 'quality survival' or 'to see the (human) lineage surviving, and surviving well, [within a] nurturing society'. To translate a broad ambition like this into a well-charted course, Cocks identifies three criteria: a participatory process, the right balance between ambition and modesty, and mechanisms for revision of broad goals.

Cocks's analysis clarifies that both objective and subjective approaches to the future are essential: objective thinking to enable us to be clear about the options available and the constraints imposed by the real world, and subjective goals to guide wise and creative choices. All four working groups at the Bowral workshop grappled with this interweaving between the objective and the subjective.

The system resilience group [this volume, Chapter 2] emphasised that resilience, as defined in Section 2 of this chapter, is a system attribute that is neither desirable or undesirable in itself but simply characterises the extent to which a system maintains functionality under shocks. A system with high resilience can find itself stuck in a state that is either desirable or undesirable from the standpoint of individual, or social goals such as wellbeing or quality survival. The associated desirable-system attributes are adaptive and transformative capacities, because they confer the ability to choose directions consistent with values or goals—and even these are not ends in themselves but rather attributes that enable individual and social goals.

The social perspectives group [this volume, Chapter 3] took a nuanced approach, highlighting the values embodied in concepts of social equity and wellbeing and arguing that these values are widely shared. This group emphasised that 'sustainability is more of a process or a societal journey than a goal defined by specific targets or deadlines'.

The scenarios group [this volume, Chapter 4] emphasised the need for scenario-building to take place in a framework that imposes no value judgements on plausible futures ab initio to avoid excluding possible futures, because their outcomes are contrary to the values of scenario builders. Rather value judgements can be applied at the end of the scenario-building process when scenarios are used to make policy choices.

The quantitative modelling group [this volume, Chapter 5] focused on the role of quantitative models for objectively seeing the future and its uncertainties. However, it also highlighted the role of quantitative models as enablers of community discussion, negotiation and choice—that is, the making of value judgements—through participatory modelling. In this perspective, models provide a common reference point for a discussion around trade-offs between groups with differing objectives, to overcome one of the greatest sources of tension between groups with differing views of the world: the assumption that everyone sees the world in the same way (when in fact they do not), leading to frustration at other groups not understanding the logic of a stated position.

A safe operating space

A necessary component of a goal such as quality survival is that the life-support systems of Planet Earth keep functioning. Until a few decades ago this was taken for granted. However, new realisations have dawned in recent decades as evidence has accumulated that human activities have significantly affected many parts of the Earth System, including biodiversity, land cover and atmospheric composition [2, 3, 4]. These changes define the Anthropocene epoch beginning with the Industrial Revolution around 1800 and are comparable in magnitude with observed changes in records of the past from ice cores, deep-sea sediments and much other evidence. Changes of this magnitude in the past have been associated with major, abrupt shifts in the state of the Earth System, including climate, the cycles of carbon, water, nitrogen, phosphorus, ocean chemistry and marine ecosystems, and terrestrial ecosystems [2, 3, 4, 45, 46]. Therefore, there are prima facie grounds for concern that human impacts upon planetary functions may provoke abrupt global environmental change at a scale that would threaten the abilities of humankind to ensure quality survival.

To quantify this set of planet-scale biophysical threats, Rockström and colleagues [3, 4] introduced the concept of planetary boundaries that delimit a ‘safe operating space for humanity’. They identified nine axes on which boundaries can be defined: climate change, ocean acidification, stratospheric ozone depletion, atmospheric aerosol loading, modification to nitrogen and phosphorus cycles, global freshwater use, land-system change, rates of biodiversity loss, and chemical pollution. Of these, seven could be quantified (the exceptions being atmospheric aerosol loading and chemical pollution). Of the seven quantified boundaries, the Earth System in its present state is already beyond three: climate change, rates of biodiversity loss, and modification to the global nitrogen cycle. The stated purpose of the concept of planetary boundaries [4] is to 'lay the groundwork for shifting our approach to governance and management, away from the essentially sectoral analyses aimed at minimising negative externalities, toward the estimation of the safe space for human development'.

At the Bowral workshop we attempted to apply and extend the planetary boundaries concept in two ways: application to the Australian region as distinct from the entire Earth and application to social axes in addition to the purely biophysical axes analysed by Rockström and colleagues. The outcomes of these efforts can be summarised as follows.

First, it is necessary to assess the extent to which the idea of a safe operating space is a value judgement that might be contested by people with different sets of values. Few would contest an overall goal such as quality survival, but some are likely to contest the idea that such a goal would be threatened by significant shifts in the state and functioning of the Earth System; for instance in climate and biodiversity. These objections are often based on either or both of two main grounds: rejection of the scientific evidence or an assumption that humans can adapt to whatever changes may occur.

This workshop (and a broader community represented by its participants) does not accept either of these grounds—that is, we accept scientific evidence after proper evaluation and do not believe that adaptation can be infinitely flexible. Our arguments are as follows. First, critical assessment of the scientific evidence is always ongoing, as it should be, and leads to overwhelming support for the view that the influence of human activities on Earth System functions is already significant and will increase if human use of natural capital continues to grow as it has through the last century. For example, see [96] for an Australian assessment of evidence on climate change. Second, the view that humankind can adapt is often based on the argument that humans have adapted to great changes in the past. However, this is not true: past civilisations have collapsed under environmental pressures [21], sometimes creating or exacerbating pressures by their own actions [23]. When past civilisations have succeeded in adapting to pressures they have often done so at the cost of much death and suffering [5]. Further, the present human population of 7 billion is orders of magnitude larger than was the global population in times when societies adapted to major climate fluctuations by migration. Migration of whole societies is no longer an option both because there is no habitable terra nullius to provide a destination and because modern societies are anchored to their built capital.

Can the safe operating space concept be applied to the Australian region in contrast with the globe as originally proposed [3, 4]? There are some difficulties. The working group considering resilience [this volume, Chapter 2] probed the ways in which a safe operating space for Australia might be maintained against various future shocks by promoting both specified resilience (of particular subsystems against specified shocks) and general resilience (of the whole Australian system against a range of shocks that cannot be specified in advance). Quantification of general resilience proved difficult, in part because of transboundary influences. Australia is not a self-contained system, and any attempt to define its safe operating space is conditional on assumptions about the future of the rest of the world, in climate, trade, geopolitical and economic stability, security, health and many other domains.

Can the safe operating space concept be applied in social as well as biophysical dimensions originally envisaged [3, 4]? We can conceive of a socially safe society as one which offers high potential for individual fulfilment and wellbeing and high social equity, because an inequitable society fails to make best use of its social, human and knowledge capital and is prone to conflict at multiple scales from interpersonal to societal [10]. These dimensions of a socially safe society have important differences from the dimensions of a biophysically safe operating space explored by Rockström and colleagues.

Raworth [97] extends the idea of a biophysical safe operating space for humanity to encompass both a biophysical ceiling and a social foundation. Her definition of a social foundation includes 11 priorities, which can be grouped into three clusters focused on enabling people to be i) *well*, through food security, adequate income, improved water and sanitation, and health care; ii) *productive*, through education, decent work, modern energy services, and resilience to shocks; and iii) *empowered*, through gender equality, social equity and having political voice. In this view, a safe operating space for humanity is the space between a biophysical ceiling (a set of limits) and a social foundation (a set of needs for true wellbeing).

Finally, there is an issue with both ethical and practical dimensions in an increasingly interconnected world. How is a safe operating space for Australia intertwined with a safe operating space for others, particularly lower-income, less-advantaged countries?

5 Tools for navigating the future

Models

To peer into the future, humans have used many tools over thousands of years. Predictive powers used to be ascribed to natural phenomena—stars, planets, storms, the flights of birds. Seers in antiquity used intuition and reflection to forecast aspects of the future on the basis of astute observation of their past and present together with some mental map, model or world view of the way the world works. Such forecasts were often insightful but were also fallible, and wise seers were well aware of their limitations. Intuition and reflection on the past remain valuable and essential tools to this day, as does an awareness of their limits.

Wise seers used two basic ingredients in making forecasts: astute observation and a mental map or model. These worked together: observations continually refined the mental map and improved its ability to forecast the future, while the mental map helped the observer to select the significant threads from the tangle of events and chatter filling the world, that is, to observe astutely.

As civilisations developed, these processes became more formalised. Observations were systematically recorded, compared, tested, filtered for reliability and disseminated—the last element in particular being a critical enabler of the rise of the scientific method through the Renaissance and the Enlightenment. Since the rise of networked digital communications and the internet, quality-controlled observations have become instantly and globally available in vast quantities.

Likewise, from the Renaissance onward mental maps diversified from purely intuitive constructs (often static and classically grounded) into an entire ecosystem of theories and models. Some of these were scientific, meaning that they emerged from a process of falsification or refinement based on tests with empirical observations—a broad definition encompassing both the natural and human sciences. Increasingly, these scientific models replaced faith-based competitors as tools for foretelling aspects of the future because they were demonstrably more skilful.

We now have available to us a wide spectrum of scientific models covering a vast range of complexity and generality [this volume, Chapter 5]. At one end of the spectrum are simple, elegant and profound theories (classical, quantum and relativistic mechanics; the standard model for fundamental particles; the theory of evolution through natural selection); at the other end are complex numerical models for large parts of the Earth System, or even the whole of it.

Quantitative models of the future have to grapple with uncertainties of several types. Their results are variously described as predictions, projections or scenarios, terms that imply a nested set of approaches to different kinds of uncertainty. The following meanings echo a usage now widespread in weather forecasting and climate modelling communities [98]:

- A *prediction* is a probabilistic statement from a quantitative model of a system that some particular thing will happen in the system, assuming that external conditions (factors not represented in the model) stay constant, often being set by current conditions. Uncertainties in a prediction are represented by probability distributions that characterise irreducibly uncertain (chaotic) system behaviours or various kinds of model weakness. A weather forecast and forecast of economic growth next year are both examples of predictions.
- A *projection* allows for specified changes in external conditions or factors not represented in the model. This is often done by setting one or more of these external factors to trial values, leading to conditional statements of the form 'if *X*, then *Y*'. Uncertainties in projections include both the uncertainties in specifying the external factors and also the uncertainties in the predictions (in the sense above) of outcomes with given external factors. Examples are climate projections for assumed greenhouse gas emission trajectories [99].
- A *scenario* is an internally consistent narrative about the future developed using a structured approach with clear and consistent logic to consider systematically how uncertainties and surprises in the future might lead to alternative plausible outcomes. Scenarios are not predictions or projections; rather they are explorations of possible alternative futures.

Quantitative models come in many shapes and sizes, ranging from simple conceptual models through single-focus models describing one part of the world (say, vegetation or fish stocks) with high sophistication, to comprehensive or full models describing an entire system [this volume, Chapter 5]. The systems described by models include natural (climate, hydrology, ecosystems etc.), economic (at sectoral, regional or global scales), social (health, income distribution, urbanisation etc.) or, at the highest level, the integration of all of these into a full model for a coupled natural–human system such as Australia, or the entire Earth System. Such comprehensive models are called integrated assessment models (IAMs) [100] and are now developed by large cooperative teams (leading examples are the IMAGE and GCAM models). One application for these models has been to develop scenarios for emissions and other human impacts on climate for the 2007 IPCC Fourth Assessment [99, 101] and the representative concentration pathways to be used in the IPCC Fifth Assessment [102–107].

IAMs for the Australian system are under development, but at the time of writing are not yet at the stage of producing results. Instead, Chapter 6 in this volume presents a survey of quantitative projections for future trajectories of some major components of the Australian system over the next few decades: i) population, society and economy; ii) resources and industries; iii) climate and the physical environment; and iv) terrestrial and marine ecosystems. In summary, these projections show that Australia's population will increase and shift to an older median age. Economic growth is forecast to continue over 2011–50 at around 2.5% per year (a little slower than over past decades) and shift away from primary and secondary industries towards service industries. Recoverable reserves of some major fossil fuels (black coal, natural gas) and minerals (iron ore, bauxite, copper) are forecast to be exhausted in 60 – 80 years at current rates of extraction, and much sooner for other resources (gold, lead, zinc, crude oil). Accordingly, Australia's physical trade balance (including mining, manufacturing and agricultural sectors) is forecast to show continued growth in exports to the mid-21st century, but then to collapse rapidly to around neutral. Trajectories for greenhouse gas emissions are strongly dependent on mitigation policies, including carbon pricing. Climate change will have significant effects that depend strongly on region, but broadly there will be adverse consequences for heat stress on agriculture and urban systems, water availability in southern Australia, incidence of drought and fire, and likely rises in species extinction rates and shifts in ecosystem structure. All of these findings are broadly consistent with the global giant forces reviewed in Section 4.1.

In addition to their use as tools for making projections, models can be important tools for facilitating community engagement in developing policies and plans for the future. Experience in natural resource management as well as other social and behavioural research has found that that the simple delivery of information is a poor means of assisting communities and policymakers in making decisions about the future, and may even be counterproductive [this volume, Chapter 5]. To be more effective, models have been applied as tools for facilitating for community engagement through participatory modelling. This is a process in which modellers and communities work together to develop models and use them to explore uncertainties about the system, possible futures under proposed development trajectories or management methods, and the consequences of different views of multiple participants in the process. Excellent outcomes have been achieved through participatory modelling in fisheries and coastal zone management [this volume, Chapter 5].

Scenarios

As indicated above, a scenario is an internally consistent narrative about the future, developed using a structured approach with clear and consistent logic to consider systematically how uncertainties and surprises in the future might lead to alternative plausible outcomes [this volume, Chapter 4]. Scenarios are important tools because they share meaning at deeper levels than logic-based communication through their basis in narrative [Jones and Raupach, respectively Chapters 12 and 14 in Volume 2].

Our definition of a scenario can be unpacked. A scenario is an internally consistent narrative in the sense that it is based on a storyline or broad qualitative narrative about the future with enough quantitative checks to ensure consistency with laws of nature such as mass conservation (e.g. to avoid postulating more water or energy than nature can supply). Scenarios investigate alternative plausible outcomes of possible uncertainties and surprises in the future by varying these factors systematically among alternative storylines with a clear and consistent logic. An important aspect to be specified logically is an institutional framework and structure of governance that need not be the status quo.

The result of applying this logic is a scenario family investigating different options for the aspect of the future that is varied—for example, choices about governance, the relative weightings given to economic and environmental goals, or the intrusion of plausible but unpredictable factors such as conflicts or economic collapses [108].

Scenario development draws on a range of information, quantitative modelling, expert judgement and creative thinking. These ingredients are combined using procedures that ensure that three key requirements are satisfied [this volume, Chapter 4]: legitimacy (that the information base is reliable and the models used are sound), saliency (that the questions or future uncertainties probed by the scenarios are pertinent) and credibility within specified boundaries (that the scenario is considered plausible by participants in the scenario-building process and by observers).

Scenario families are developed from perspectives that follow from a well-specified focal question. Such questions might, for example, be about pathways for economic growth, resource limits, kinds of governance, or responses to complexity. Different focal questions lead to different scenario families. The first and most important step in scenario development is to clarify the focal question. There may be commonalities between individual scenarios developed in response to different focal questions but the scenarios are unlikely to be the same.

To put these concepts into practice the working group on scenarios at the Bowral workshop considered three scenario families, each including three scenarios, to illustrate different aspects of Australia's possible futures. These scenario families with their focal questions are summarised in Table 2. The specific storylines for the different scenarios given in Chapter 4 of this volume.

Scenario family	Focal question	Scenarios
Climate change	What futures emerge from plausible alternative responses by Australia to threats from dangerous human-induced climate change?	• Business as usual • Muddling through • Clean new world
Governance	What futures emerge from alternative government priorities in fostering economic growth, environmental sustainability and public investment in human and built capital?	• Postmaterialism • Going for growth • Tax and spend
Complexification	What futures arise as a result of failure or success in coping with rapidly increasing societal complexity?	• Failing to cope (overwhelming surprise, ignorance) • Struggling to cope (cognitive dissonance) • Modest gains (attitudinal change)

Table 2: Three scenario families, each including three scenarios to illustrate different aspects of Australia's possible futures, opened by alternative plausible responses to a focal question. See Chapter 4 of this volume for details.

The scenario development process has several important characteristics. First, the storylines that define individual scenarios (such as the nine examples in Table 2) take the form of narratives that are plausible in that they represent possible futures. Second, the range of storylines incorporates a range of possible societal goals likely to be pursued by major actors. Third, scenarios can (and should) incorporate outcomes covering the full spectrum from highly desirable (from a given subjective viewpoint) to downright ugly. Fourth, scenarios require much development to ensure that storylines are self-consistent. Fifth, we reiterate that scenario development is not about prediction; rather it is about systematically exploring possible alternative futures.

Finally, the process of scenario development is interactive and dynamic [this volume, Chapter 4]. Three conclusions from decades of literature on scenario planning are that: i) achieving useful insights requires a structured process that mixes sound research and information with acknowledgment and engagement with the diverse world views; ii) the greatest value accrues to those who have been involved in developing scenarios; and iii) communicating the insights from scenario development requires careful consideration of the needs and receptivity of target audiences.

6 Living scenarios

All four working groups at the Bowral workshop emphasised the importance of interactive, participatory processes in grappling with the future. The scenarios group [this volume, Chapter 4] emphasised that scenario development is fundamentally interactive. The quantitative modelling group [this volume, Chapter 5] highlighted the necessity of participatory modelling for the successful use of models in management and for a more complete understanding of the full range of components in a coupled natural–human system. The resilience group [this volume, Chapter 2] emphasised the need for system-level communication, assessment and planning to promote adaptive and transformative capacities and to draw out compelling narratives of consequences for system resilience in scenarios. The social perspectives group [this volume, Chapter 3] emphasised the need for people to understand their context and to influence decisions as a prerequisite for building social capital, and civil liberty as a crucial element of social capital.

The concept emerging from these ideas is living scenarios—shared, ongoing explorations of how the future might unfold, leading to evolving visions for the future that are simultaneously *plausible* (consistent with objective natural laws), *acceptable* (consistent with aspirations for human wellbeing as embodied in the range of subjective values and goals among those planning their shared future) and *workable* (agreed to the extent necessary for action). Living scenarios are developed by an ongoing interactive process and are owned and accepted by the (successive) participants in that process. They are dynamic, not static, being revised and updated as the future unfolds.

The interactive development of a living scenario can be facilitated and in general requires working with quantitative models to determine what aspects of any proposed scenario are consistent with laws of nature, such as mass and energy conservation, and with available robust rules governing ecological, social and economic dynamics. The models employed can range in sophistication from semiqualitative conceptual models to sophisticated, fully quantitative models that aim to capture the system dynamics in detail.

In concept, several steps are involved in the development of a living scenario:

- A group of people imagine the future using some agreed focal question about the future of a region or the whole Australian system. The result is a large number of imaginable futures.
- This large set of futures is passed through two filters. The first is an objective filter, which uses one or more models of the system to select a much smaller set of futures that are *plausible*, in the sense of consistency with the requirements of natural and social dynamics. It is assumed here that the model is agreed by all participants to be a reasonable representation of objective realities. Care is also required to avoid rejecting futures on the basis of untested, too-narrow assumptions about what is possible or because the futures suggest things that have not happened before.
- The second filter is a subjective filter in which participants apply value judgements to select much smaller sets of futures that are simultaneously *plausible* and *acceptable* according to the subjective values of participants. Because value judgements are involved, it is practically inevitable that different participants in the group will populate the set of imaginable, plausible and acceptable futures in different ways: for instance, some will prefer futures dominated by economic growth with environmental sustenance being of a secondary importance, seeing conversely weighted futures as unacceptable and some vice versa. The initial sets of acceptable futures may not even overlap if the participating group is representative of a broad spectrum of opinion.
- Then follows the key feedback in the living scenario process, that of participatory interaction, dialogue and negotiation. We are all faced with the reality that the future will unfold in only one way; choices will be made and options will become realities. Therefore, alternative visions of the future have to be reconciled and trade-offs acknowledged. In this reconciliation alternative visions of the future move towards being workable together.
- This process is iterative. Shifts in perceived acceptable futures as a result of this reconciliation become new imaginable futures, which again have to be tested for biophysical, ecological and social plausibility using models and again selected for acceptability. After successive negotiations and interactions with models to discriminate between plausible and implausible futures, a set of futures emerges that is simultaneously *plausible*, *acceptable* and *workable* in the sense that they are agreed to the extent necessary for action.

- The final critical element of living scenarios is that they are dynamic and ongoing, being revised and updated as external conditions and internal perceptions evolve. This means that plausible scenarios are not discarded from further consideration because they may lead to unacceptable outcomes: rather, they are kept on the table to anticipate and prepare for potentially undesirable aspects of the future because a failure to explore possible but undesirable futures is a recipe for reducing resilience and adaptability.

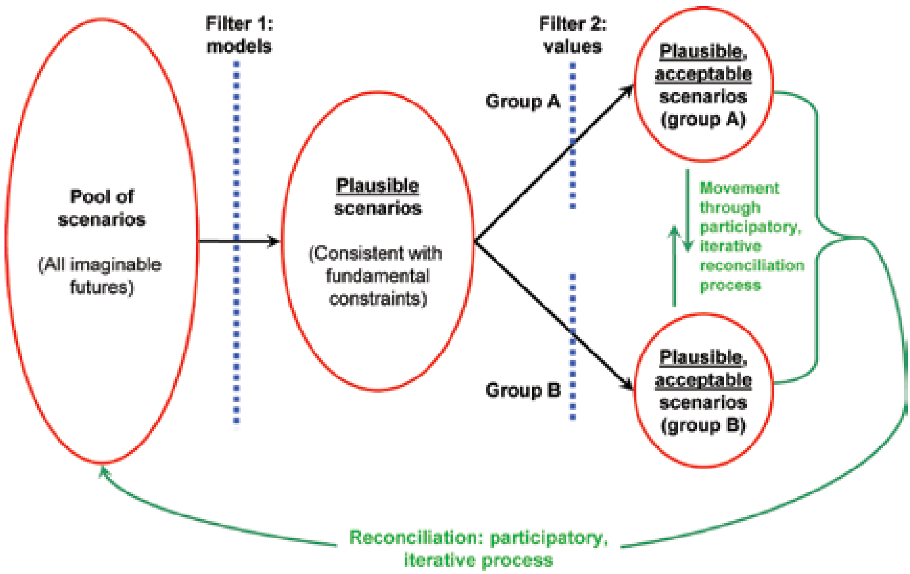

Figure 9: Key elements of a process for developing living scenarios. The key feedback of reconciliation and negotiation, shown in green, leads to shifts in the acceptable futures seen by participants applying different sets of value judgements. Eventually an overlapping set of plausible, acceptable and workable futures is achieved.

We see value and importance in an ongoing process for developing and sharing living scenarios by revisiting or reinventing scenarios after a few years in response to changes in external conditions and the evolving views of participants and the broader Australian community. This would also provide opportunities to learn from previous difficulties and failures. Such an ongoing process carried out with the right degree of public engagement could act to influence views of both participants and the broader Australian community. Given the great and complex processes of environmental and social change and likely stresses upon Australia and its population during this century, this proposed living scenarios process can become a resource for government planning and policymaking.

7 Conclusion

This synthesis chapter has covered five themes: *Australia as an adaptive system* made up of interacting natural and human components; *the present state and trends in the Australian system*, to provide a brief survey of where we are now; *ways of thinking about the future*, including the distinction between objective analysis and subjective statements of goals or aspirations, and the idea of a safe operating space; *tools for envisioning the future*, including both scenarios and quantitative models; and the concept of *living scenarios* for Australia as an adaptive system, considering how such scenarios can be evolve and be agreed.

The culmination of the synthesis is the idea of living scenarios—shared, ongoing explorations of how the future might unfold, leading to evolving visions for the future that are *plausible* (consistent with natural laws), *acceptable* (consistent with aspirations for human wellbeing) and *agreed* (to the extent necessary for action). Rather than being preordained specified futures, living scenarios are maps of the future that are able to be reworked, to adapt and, if necessary, to transform. Living scenarios allow for flexibility and ambiguity; they are tools that are, of necessity, refashioned in response to changed circumstances. They incorporate diverse opinions, values and aspirations to converge on an acceptably coherent vision of the future and a path towards it. Hence the title of the book.

The efforts of the workshop synthesised in this chapter were aimed at supporting coherent societal responses to the great challenges of environmental sustainability and social equity. Through methods like those explored here, can these challenges spark a process of national foresighting—not just to 2050, but beyond? Might such foresighting become a more formal national project, a great and visionary response to a great and unprecedented set of challenges?

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Chapter 2

System-resilience perspectives on sustainability and equity in Australia

Nicola J. Grigg, Brian H. Walker, Anthony Capon, Barney Foran, Rita Parker, Jenny Stewart, Richard Stirzaker, Bill Young (System-Resilience Group)

We assume that sustainable and equitable futures require non-declining human wellbeing built upon a diverse wealth base, including natural, human, built, social and knowledge capital. We hypothesise that human wellbeing is linked to this wealth base via social-ecological interactions: systems of biophysical processes transforming and transporting material and energy, mediated by social processes. Attempts to understand complex social-ecological systems highlight the incompleteness of current knowledge and the illusiveness of comprehensive knowledge of such systems. Resilience assessments provide useful insights into system responses to shocks. We consider past and potential shocks to Australia and the characteristics of social-ecological systems that provide resilience to them. We draw more general insights about resilience in Australia, including identifying signs of systemic drivers of possible futures and the requirements for adaptive and transformative capacities to create diverse options for maintaining wellbeing.

1 Introduction *What is resilience and why does it matter?*

The resilience perspective recognises that our world is a place of dynamic change. Changes occur in an interlinked way, so deliberate actions that aim to bring about a change in a specific area often lead to unanticipated (and potentially unwanted) consequences elsewhere. Unanticipated consequences can manifest themselves on different time scales and in physically different ways to the triggering action. The images in Figure 1, for example, convey consequences of market decisions that are not made explicit at the point of sale. A purchase of asparagus, gold ring or cotton shirt, for example, is rarely accompanied by an appreciation of the

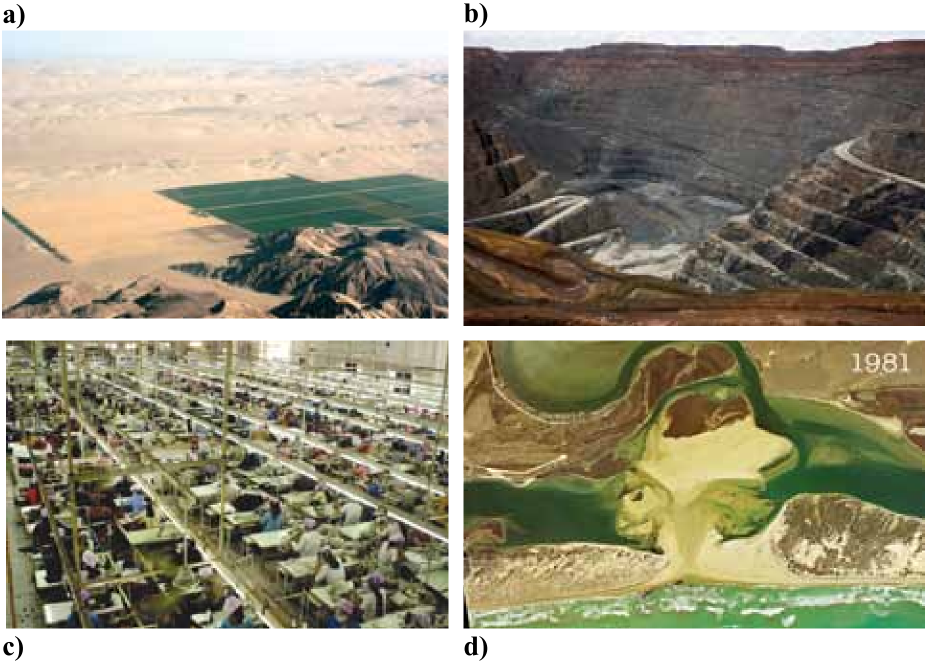

Figure 1: Activity in one part of the system leads to unanticipated (sometimes bizarre) consequences elsewhere via unappreciated connections. The above images show landscapes and human experiences that are instrumental in meeting market demands but are not visible at the point of sale. **a)** Asparagus crops in the Ica Valley, Peru—an example of land use and water decisions in Peru being driven by markets for asparagus in Europe [2] (photograph: Nick Hepworth, Water Witness International); **b)** global demand for gold creates places like the 'super pit'at Kalgoorlie, WA (photograph: istockphoto.com); **c)** Factory conditions under which products are made are not apparent when items are purchased. (photograph: istockphoto.com); **d)** the Murray mouth in South Australia in 1981, closed completely: water use and regulation practices across several Australian states in the Murray–Darling Basin meant that flows to the ocean were inadequate to overcome accumulation of sand at the mouth of the river. The mouth closed again in 2002 and was kept open from 2002 to 2010 thanks to daily 24-hour dredging at a cost of more than $40 million. The dredging ensured ongoing connectivity between the ocean and the Coorong, an important wetland protected under the international Ramsar Convention. Despite dredging, the Coorong reached a salinity of five times that of seawater during this period, with devastating ecological impacts (photograph: South Australian Department of Environment, Water and Natural Resources).

impacts on landscapes and the people instrumental in bringing those items to market. Insights into system resilience point to a set of approaches that enable us to work more effectively within such systems.

This chapter outlines the contribution that a resilience perspective brings to the focus question: *What is our realistic vision for an ecologically, economically and socially sustainable Australia in 2050 and beyond?* Our perspective is informed by the growing body of Australian and international work on resilience. Precise definitions of resilience vary [3–8], reflecting that it is the focus of an active, evolving area of research. We adopt the following definition: *the capacity of a system to absorb disturbance and reorganise so as to retain essentially the same function, structure and feedbacks—to have the same identity* [8]. Resilience is closely related to two additional concepts: i) adaptive capacity—the capacity of agents (e.g. individuals, businesses, communities) to influence both resilience and future trajectories within a system; and ii) transformative capacity—the capacity to transform into a different system (e.g. a domestic transport system reliant on liquid fuels transforming to one powered by diverse energy sources).

Resilience is independent of value judgements about whether system functionality is desirable or not. Adaptive capacity and transformative capacity, on the other hand, reflect both structural characteristics of a system [9] and the ability to steer within or reshape a system to reflect values and subjective judgments. The concept of 'living scenarios' [chapters 1 and 4 in this volume] involves finding ways to explore these interactions between values, system structure, resilience, adaptive and transformative capacities, and potential consequences for future trajectories.

Just as 40 years ago Australia was a very different place from the Australia of today. The Australia of 2050 will be different again. Our vision of Australia is not a static picture: the Australian system (as defined later in this chapter) is continually subjected to a variety of internal and external factors and our responses either amplify or dampen their effects. If there are aspects of Australian life we'd like to be resilient in coming decades, that resilience will not come from trying to prevent or avoid change. Rather, in resilient systems boundaries are probed, novelty generated and selection processes operate that determine which system characteristics are retained and lost over time. The term 'resilience' has become commonplace in policy and planning documents, with various meanings ascribed to it. It is sometimes regarded as a buzzword and dismissed as unhelpful [10]. One aim of this chapter is to provide an account that offers clarity on the meaning and usefulness of the concept.

A potential source of confusion is that the meaning of resilience is context dependent: in an academic paper it can be defined precisely and used in accordance with that definition; more generally (in both academic and non-academic settings), it is useful as a broad concept embracing adaptive and transformative capacities as well as precise definitions of resilience.

Resilience (in the broad sense) matters because, as Australia develops over the next 40 years, our response in the face of disturbances and change will be a key determinant of the wellbeing of the Australian population. The changes anticipated for Australia between now and 2050 include a wide range of key areas:

1. The number of people will increase [Hugo, Chapter 3 in Volume 2]. Total population estimates for 2050 range from 30 million to 42 million [11].
2. The population is expected to reflect a different and more diverse set of values and ethnic origins than in 2012. Aspirations, identity and values change markedly on a 40-year time scale.
3. Employment—both the type of work and how we perform our workplace functions—will continually change in response to technology, the marketplace and aspirations.
4. Where and how we live will change in response to an interacting set of influences, including changing population, employment and energy use [Manderson and Alford, Chapter 4 in Volume 2].
5. Forty years of changing market conditions will influence changes in the education and skills of the population.
6. Australian environmental conditions will change: effects of climate change, water allocation and land-use decisions will all be factors in shaping the 'habitat' for Australians.
7. Physical health and wellbeing are likely to change [Butler, Chapter 2 in Volume 2].
8. Perceptions on safety and security will continue to change and how we go about achieving safety and security will evolve with economic and social implications.

In workshop discussions at Bowral, NSW, the argument was made that the notion of a nation-state has become all-pervasive and unquestioning and yet, as currently operating, nation-states are poorly equipped to handle humanity's planet-scale 'natural security' issues that cross borders. In this chapter, we assume that the nation-state of Australia exists in 2050. In our vision for 2050, we consider Australia's contribution not only to the wellbeing of Australians (the interest of the nation-state), but also Australia's contribution to global sustainability and human wellbeing.

2 Conceptual framework

System feedbacks

When assessing a system's resilience, a key emphasis is to recognise the feedbacks in system interconnections. A system feedback is where a chain of cause and effect forms a loop, so that consequences of a change have an impact back at the source of the change. Feedbacks can either amplify or dampen the effects of change. A bank run is an example of an amplifying feedback: customers withdraw bank deposits, thereby increasing the likelihood of bank default and, in turn, further increasing the number of customers withdrawing deposits. Temperature regulation in the human body provides an example of dampening feedback loops. For example, when body temperatures increase due to exercise it triggers sweating, which results in evaporative cooling.

Feedback loops are not always obvious. For example, it might be expected that changing engine technology to increase fuel efficiency would lead to reduced vehicle fleet fuel demand over time. But evidence over past decades points to a set of 'affluence' feedbacks whereby such technological advances were used to build higher-performance vehicles and accommodate extras such as air conditioning [12]. Hence an action anticipated to reduce vehicle-fuel demand had minimal effect once other system responses provided counteracting feedbacks. The structure of such feedbacks determines the space of possible future trajectories for a system and the speed at which changes occur. When considering response to shocks or other system changes, the capacity of a system to withstand disturbance or to self-organise to retain its character and function depends crucially on system structures like feedback loops.

The fuel efficiency example demonstrates a form of resilience: in the current system configuration, making vehicle engines more fuel efficient sees other aspects of vehicle fuel-use increase (e.g. air conditioning), and so fleet-fuel requirements remain largely unchanged. Fleet-fuel usage is 'resilient' to changes in engine fuel efficiency (this is known as the 'rebound' effect in a system [13, 14].) This example highlights an important point: resilience is not necessarily desirable. It is a property of a system, and whether resilience of a particular system is desirable or not is a normative judgment. Hence our focus is not on 'maximising resilience'; if seeking to build resilience, what aspects of the system do we wish to be resilient to what kind of shocks? Assessments of specified resilience make this question a central focus.

Framing resilience

We frame questions of resilience in three ways:

1. *Specified resilience*. What aspects of Australia are resilient to what kinds of disturbances? Specified resilience is about identifying particular aspects (e.g. food security, access to employment) and their response to particular shocks (e.g. the resilience of crop production to drought or steep rise in fuel prices). Assessments of specified resilience can be focused on desirable or undesirable attributes (e.g. resilience of unemployment levels or cane toad populations to strategies for alleviating these problems).
2. *General resilience*. General resilience is about identifying characteristics that bring resilience to many aspects of a system from all kinds of disturbances. Anticipating and assessing all the potential shocks or system changes in store is not possible, and we will never understand all potential threshold effects. Yet some system characteristics, such as human health, confer resilience to multiple shocks of different kinds. For example, a population of fit, healthy individuals is better able to cope with a diverse range of shocks than a population overwhelmed by debilitating health issues. Again, assessments of general resilience are independent of normative judgments of desirability.
3. *Adaptive and transformative capacity*. How might we achieve some 'steerability' in the face of inevitable change? To go beyond assessing resilience is to act to influence it. Adaptive capacity is the capacity to adapt to and shape change, and 'is related to the existence of mechanisms for the evolution of novelty or learning' [3]. Where assessments of resilience highlight resilient, undesirable states, questions of transformative capacity become important: what enables us to fundamentally change system function? For example, what would enable a system founded on coal (infrastructure, employment, social and economic structures enabling coal mining, transport and burning) to be transformed into one founded on renewable energy? In a rapidly changing world there are often benefits to embracing continuous transformational change—seeing the future not as some state to reach and then make resilient, but as a trajectory that will require significant ongoing changes as natural and social environments change.

Sustainability and wellbeing

Our purpose is to ensure questions of resilience contribute to a broader vision for sustainable and equitable ways of living in Australia in 2050. In choosing a working definition of sustainability, we recognise the large range of possible definitions and approaches. We choose a definition that provides a useful base for our discussions, but we hold that definition lightly, acknowledging the rich potential for alternative perspectives. We deliberately choose a viewpoint that sees sustainability from a human perspective, defining it as a condition of non-declining human wellbeing for current and future generations [15].

Acknowledging also the difficulties in defining wellbeing [16], we adopted a practical working assumption that wellbeing is not possible without a foundation built upon various forms of capital: human, natural, built, social and knowledge capital at the very least (to be discussed in more detail later). We noted also that wellbeing cannot be separated from its social context: 'wellbeing is not the state of individual bodies, but of bodies in society' [16]. There are serious implications of being too prescriptive about definitions of health, let alone wellbeing:

> In particular, alternative ways of valuing the duration of life, the quality of life, the burden of ill-health, or inequalities in health incorporate critical but not necessarily obvious or well-accepted judgments about whose life or what kind of life has meaning and worth. It is, therefore, important to examine—empirically and normatively—how the use of summary measures of population health can shape, improve, or distort decisions...[17].

Wellbeing is certainly about more than bodily health and encompasses a rich suite of individual and collective human experiences (physical, psychological, social, cultural and spiritual). Although wellbeing is subjective and context-dependent, and so resists precise definition, we assume that underpinning conditions, necessary but not sufficient for wellbeing, can be characterised usefully. Hence our emphasis on diverse forms of capital.

On the matter of articulating our vision for sustainability from a resilience perspective, we link the above working definition of sustainability to a broader and more conceptual definition: 'sustainability is the capacity to create, test and maintain adaptive capability' [18]. This definition places the emphasis on enabling a diversity of options for the future, rather than prescribing what those options should be.

System representation

Applying these definitions within a systems view, as required for assessments of resilience, is a challenge. Recognising the importance of interconnections very easily leads to calls for a complete 'end-to-end' comprehensive model of 'Australia'. Such an end-to-end model is a useful pursuit; however, we are seeking insights available to us from existing knowledge, models and data. Fulton stressed that the quest for a single, all-purpose model is rarely as useful as developing 'a range of approaches to capture the feedbacks and delays and multi-scale interactions' [19].

The Australia Stocks and Flows Framework (ASFF) is a very detailed model that tracks stocks and flows in the physical economy [12, 20]. The framework involves a chain of calculators that capture the flows of material through the system that is Australia. It is indicative of the fundamental underpinning links between population, infrastructure, transport, land use, industry, services and trade: Australia as a 'system of systems'. It is important to note, however, that there is no explicit representation of feedbacks in the ASFF, and the authors of the ASFF were very careful to emphasise the reasons for and implications of their choice. They drew particular attention to the challenges of handling feedbacks that lead to rebound effects, stating that 'managing the rebound effect within the physical economy is one of the greatest challenges to national policy design, whatever population and development options are chosen for Australia's future' [12].

Many of the feedbacks that concern us in the Australian system are mediated by social processes reflecting the political and economic situation, goals, values, preferences and choices. In other words, as soon as we wish to consider the feedback structures that inform resilience, we must work with system feedbacks between social and biophysical processes. Biophysical modelling practice has traditionally been to omit the social feedbacks, wanting the rigour of physical conservation laws to provide bounds on future possibilities. This biophysical approach has placed an emphasis on characterising the feasible, the reachable space, clearly independent from normative judgments about what is desirable (e.g. not prescribing human responses such as goal maximising).

Rather than seek to provide a comprehensive description of 'Australia' and what a complete model of Australia needs to include, we offer examples of the types of resilience insights we would seek to draw out from such comprehensive models. We seek to foster an appreciation for the feedbacks and nonlinearities in the Australian system, as it is these system properties that inform our search for a 'safe operating space' [21] [Chapter 1 in this volume]. We use a number of different entry points for looking at the Australian system: given an example of a shock to one part of the system (e.g. drought in south-eastern Australia), we do not provide a comprehensive analysis of its effects, but illustrate the kinds of system interconnections that come into play and discuss how assessing system resilience can enrich system understanding.

Wealth, capital and Australia as a 'system of systems'

We suggest that it is desirable for Australia to have a resilient, evolving capacity to create options for our future. Our conceptual framework assumes options for our future can only be built from a healthy wealth base comprising different forms of capital and that this wealth base in turn can only be sustained via a set of systems that maintain and build that wealth. Such a conceptualisation was an important foundation for the Millennium Ecosystem Assessment [22].

We refer to many forms of capital to characterise Australia's wealth base. We adopt a broad definition of capital as 'any form of wealth employed or capable of being employed in the production of more wealth' [23]—a definition that embodies transfers and feedback between forms of capital. These forms of capital are drawn upon and used in a number of interacting systems—a system of systems—and the capital stocks are in turn sustained, increased or depleted as a result of interacting system processes. For example, knowledge capital can be put to work to build governance systems that in turn create social capital that fosters environmental stewardship behaviour that in turn leads to an increase in natural capital stocks. This conceptual framework is illustrated in Figure 2, and examples of the different forms of capital are listed in Table 1.

Natural capital	**Built capital**	**Human capital**	**Social capital**	**Knowledge capital**
Biodiversity	Transport	Health	Equity	Data
Land	Utilities	Education	Safety	Information
Water	Housing	Security	Agency	Knowledge
Mineral resources	Commercial infrastructure	Choice	Trust	Wisdom
Atmosphere	Industrial infrastructure	Agency/ voice	Leadership	Collections
Climate	Agricultural infrastructure	Identity	Social networks	Artwork/music
Energy sources	Public infrastructure (including public spaces)		Institutions	History
	Telecommunications		Communication practices	Folklore
	Defence infrastructure			

Table 1: Categories and examples of forms of capital (wealth employed or capable of being employed in the production of more wealth) comprising the 'asset base' for Australia. The lists are not intended to be comprehensive nor non-overlapping (e.g. 'agency' can refer to individual or collective agency).

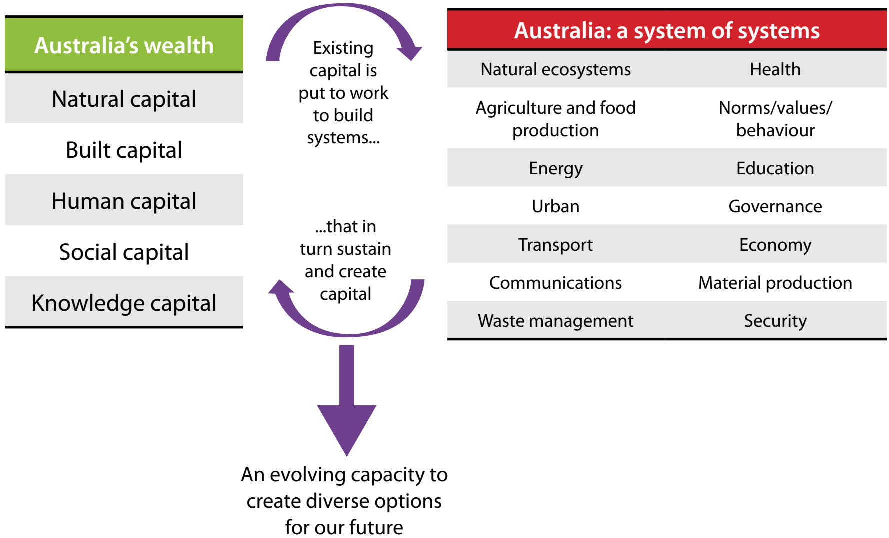

Figure 2: The left side shows forms of capital contributing to Australia's wealth. The right side indicates the system of systems that mediates flows of capital. Our capacity to create and choose between diverse options for our future emerges from the interaction between the two: capital is combined to build systems whose processes in turn sustain (and create) capital. It is this evolving capacity to create future options that we seek to make resilient.

It may appear confusing to have 'natural capital' and 'natural ecosystems' on different sides of Figure 2, as surely they are the same thing? The distinction is that natural capital refers to a snapshot of the state of the physical stocks in our natural ecosystems, whereas the ecosystem itself includes not only the natural capital but also the system of interacting processes that determine the direction and rates of change of the physical stocks. The systems on the right-hand side of Figure 2 determine the dynamics, including any nonlinear responses.

3 In search of a safe operating space

Specified resilience

Assessments of specified resilience investigate particular shocks and characterise system structures that build or erode resilience of identified system functions or attributes. Just as resilience is a property of the system, independent of judgments about whether that resilience is desirable or not, so too it is important to note that resilience is not a binary quantity, where a system is either resilient or not. It is only useful to make comparative statements, highlighting how one system configuration is more or less resilient than another.

Specified resilience assessments address the question: resilience of what, to what? Two case studies are described in the following sections to illustrate the kind of insights that can be explored in specified resilience assessments. The first case study contrasts the resilience of Australia and East African nations to drought. To be clear, we consider the resilience of food security to drought. Drought is an example of an external shock on the system. The second case study considers a shock that is amplified by internal system dynamics: the growing public health crisis associated with Australian lifestyle choices. We consider the resilience of the health of the Australian population to a combination of obesity-causing pressures.

Case study: resilience of food security to drought

The Millennium Drought was a period between 1997 and 2009 characterised by extreme rainfall deficit in South Eastern Australia [24]. The drought imposed a significant, prolonged shock on the Australian system. It led to multiple crop failures over consecutive years and severe, accumulating local impacts, but at the national scale there was relatively little impact on GDP, national food security and other measures of national wellbeing. Looking at irrigated agriculture in the Murray–Darling Basin, the reduction in irrigation in 2006–07 was 33% of 2000–01 irrigation volumes, but the gross value of production in 2006–07 was 20% less than 2000–01 production (adjusting for the confounding impact of commodity price changes [25]). Water trading and related governance mechanisms saw water diverted to higher-value uses: the gross value of water more than doubled, providing income to those who could forego their need for water and sell it on the market and providing buffering to those who risked losing high-value perennial crops had they been unable to buy water [25].

In East Africa, prolonged La Niña conditions affected two consecutive rainy seasons, with catastrophic consequences for over 12 million people in Somalia, Djibouti, Ethiopia and Kenya in 2011 [26]. A cascade of impacts unfolded in the region: failed crops, increased food prices, food shortages, mass movement of people, upsurge in infectious diseases and increased death rates and violence. Famine was declared by the United Nations in five regions of Somalia, and a situation report on 25 August 2011 by the UN Office for the Coordination of Humanitarian Affairs stated: 'An augmented multisectoral response is critical to prevent deaths and the total collapse of livelihood and social systems.' [27].

Drought and crop failure triggered conditions ripe for nationwide collapse within only two years in East Africa, and yet a decade of drought and crop failure has not had anything like that impact in Australia. Analyses of the response to drought in Australia have pointed to the multitude of adaptation options that were adopted by the Australian agricultural sector [28], thereby contributing to resilience: water trade (both entitlement and allocation trading); access to groundwater; capacity to alter the mix and levels of production; switching from growing local produce to brokering imported produce (e.g. in the case of rice); altered farm management practices and technological change; off-farm sources of income; and Australian Government assistance programs providing income support and business assistance. Not all of Australia was in drought at the same time, which also provided alternative production options.

It is now widely appreciated that water trading enabled effective water allocation in ways that centralised prescriptions could not. The drought also shifted irrigators' expectations, and they now make risk management strategies for water shortages an integral part of their long-term planning. Future reforms that address problems of water trade restrictions and carryover rights may further increase the availability and flexibility of response options [28]. The design of drought assistance interventions has profound implications for system resilience. For example, 'a subsidy that helps drought-affected graziers purchase fodder to supplement their degraded forage stocks encourages them to maintain stocking rates despite effects that degrade natural capital in the system', and 'an alternative subsidy is one that helps offset the transport costs associated with agisting cattle to distant ranches unaffected by the drought'. This tactic helps ameliorate the plight of graziers during a time of drought while fostering resilience in the system, so that even if they are increasingly driven by the economic performance of their system they are less likely to drive it into an undesirable state [29].

The adaptive capacity that saw Australia through the drought was the product of previous investment in financial, human and social capital at scales that ranged from the individual (e.g. investment in farm infrastructure, local knowledge and experience, financial savings) to national (e.g. investment in water governance structures). Drawing on that adaptive capacity over the drought years came at substantial cost, particularly at the local, individual scale. The system as a whole, as measured by GDP and national food security, came through relatively unscathed as a result of substantial drawdown in social and ecological capital.

Worsening indicators of wellbeing in rural communities, including mental health, social inclusion, suicide, community stability, family relationships, education and debt levels, were documented before the drought, and it is clear that rural communities are facing multiple pressures that were further exacerbated by drought [30, 31]. Such declines suggest an ever-decreasing resilience to shocks such as drought, and unless there is investment in recovering adaptive capacity, our rural communities will become increasingly vulnerable. Similarly, iconic ecosystems, such as the Coorong wetlands in South Australia, were altered dramatically, with devastating impact on fish, birdlife and supporting food webs (and local livelihoods dependent on that biodiversity) [32]. Such impacts would not have been as severe under different water management practices across the Murray–Darling Basin [32, 33]. The rains of 2010 and 2011 have seen bird numbers increase dramatically after two decades of decline, although numbers are still below bird counts at the start of the annual birdlife survey in 1983 [34]. The long-term health of such valuable ecosystems remains in question.

A specified resilience assessment of Australia's response to drought and our capacity to monitor and respond to trends in that resilience would be a wise investment in the face of an anticipated future change: a potential long-term drying trend. The impacts of such a change would include reduced and erratic produce outputs and economic crisis conditions for many regional economies. If we are to transform the system to cope with such a scenario, that opportunity only exists in good times, so an unwillingness to act in such times prevents resilience building. More typically, it takes a crisis to trigger substantial changes, and time lags and inertia in this system mean that crisis-induced reactive changes will necessarily be constrained to fewer, more limiting options.

Case study: resilience of the health of the Australian population to obesity-causing pressures

Drought and long-term drying are examples of specified, external shocks to Australia. We turn now to an example of a shock that emerges from the interaction between external factors and internal system dynamics. Reported obesity prevalence increased steadily from less than 8% of the adult population in 1980 to 23% in 2006 [35]. Obesity is linked to a series of health consequences such as diabetes, hypertension, heart disease and some cancers. The economic costs of obesity in Australia were estimated to be $58.2 billion in 2008 [35]. Since 1990, the health expenditure in Australia as a proportion of GDP has increased from 7.9% in 1999–2000 to 9.4% of GDP in 2009–10 [36]. Trends in obesity and related chronic diseases are contributing to those increases and place pressure on budgets in other sectors. In short, increasing obesity is triggering a cascade of health, social and economic consequences. The increasing prevalence of obesity has been effectively linear over the past 20 years [35] and, in the absence of other information, it might be assumed that both the trend in obesity and its health consequences could be reversed, following the same linear trajectory back to where we started.

In practice, however, a set of feedback loops at many places and scales creates a more complex picture. Within the human body there are metabolic processes that see increases in body mass index (BMI) aligning with well-identified stages in metabolic syndrome—a combination of medical disorders that increase the risk of developing cardiovascular disease and diabetes. Representing the processes in a simulation model, Zhou et al. [37] mapped out a set of stages in the unfolding of diabetes and its consequences. Each stage represents a threshold from which reversal becomes increasingly unlikely (from glucose intolerance to insulin dependence and irreversible consequences such as blindness or amputation). Step jumps in direct medical costs are associated with each threshold crossed—for example, the need for dialysis requires an 11-fold increase in cost over the costs for diet-controlled Type 2 diabetes [38]. On top of direct medical costs are the effects on employee productivity, caring costs and other social costs to the individual. Hence an apparently smooth and reversible increase in BMI gets amplified through the individual's system to yield a nonlinear response in health impact and other costs at the individual and societal level.

Published analyses have shown that the observed trend in weight gain is due to an energy imbalance of 100 kilocalories per day, leading to recommendations that appear trivial to achieve: walk an extra 15 minutes each day and eat a few less bites at each meal [39]. Yet such apparently achievable recommendations are remarkably difficult to implement in practice due to feedback loops that reinforce increasing weight gain [40]. The sedentary nature of work, leisure and travel, and the ready availability and low cost of energy-dense food are all contributing to this obesity-causing, or obesogenic, environment [41]. Feedbacks come into play at the individual level, leading to an entrenched dynamic with multiple associated thresholds, further reinforced at a population level by other society-level dynamics and feedback loops [42–44]. For example, the irreversibility at the individual scale results in population-level time lags: even immediate, strong action will not see a reversal along the path we came as the health impacts already triggered need to run their course and work their way through the system.

In this example there is no single external, specified shock. The profound impacts are a product of internal and external system dynamics. To build resilient population health in the face of these pressures, the system itself needs to be transformed; we address this in a later section.

Tracking measurable changes in resilience

Our two examples—drought and obesity—illustrate insights that can be explored in specified-resilience assessments. Ideally, such assessments would provide some means of monitoring changes in resilience and learning from them over time when determining priorities and making trade-offs between decision options. Comprehensive measures of resilience will continue to elude us, but there are some aspects of resilience for which measurable observables can be used to indicate directions of change. A danger in doing so is that as soon as such indicators are accepted and come into use, it is difficult to avoid responses that amount to optimising for that measurable quantity or even gaming the system. For example, examination systems in universities lead to strategic score-maximising exam techniques contrary to the exam purpose of demonstrating and evaluating learning. Similarly, the Disability-Adjusted Life Year indicator (DALY) for quantifying the burden of disease has deficiencies and limitations that are well acknowledged, yet its appeal and ease as a metric mean that important decisions around provision of health services are now reliant on DALY calculations [16, 17]. Furthermore, there are risks of overly narrowing our vision. It is unhelpful to expect that all indicators should be improving at all times; a characteristic of a resilient system is the ability to draw on reserves and buffers periodically and to swap one form of capital for another in order to adapt and continue functioning as before.

It would be helpful to have measures that quantify the resilience of many aspects of Australian system. The Australian Bureau of Statistics (ABS) offers a list of Measures of Australia's Progress (MAP) that provide indicators that can be reported on [45]. The MAP publications seek to address the question, 'is life in Australia getting better?' and provide a selection of statistical data on the social, economic and environmental dimensions of life in Australia. Currently, the MAP assessments report on 17 'headline progress indicators' (six social, five economic and six environmental indicators), supplemented by hundreds of additional indicators. Included in the supplementary indicators are time series of various capital assets, for example, which reveal trends in total and per capita stocks (e.g. total 'cultivated biological assets'—orchards, vines and breeding livestock—have been in decline for the reporting period 1999–2009, residential dwelling stocks have increased over that period, but per capita residential dwellings peaked in 2006 and have been declining steeply since). While these time series are useful for identifying trends in important capital stocks (identified in Table 1), they say little about resilience. Measures of resilience need to indicate capacity to absorb shocks and unexpected changes.

Specified resilience assessments necessarily address the question: resilience of what, to what? and these questions guide the choice of appropriate indicators. For example, indicators of resilience of Australian food security to drought could include: measures of the availability and access to water trading, the access to groundwater, the availability of opportunistic cropping options, the availability of alternative employment options for agricultural workers, the access to imported food and the potential for water-use efficiency gains.

Counterintuitively, note that an intervention that increases system-wide water-use efficiency can decrease resilience to drought, as it removes the availability of this water-saving option in times of future drought! Increasing water-use efficiency only increases resilience if the water saved remains available in a form that can be drawn down in times of need. To give an urban example, if the water savings obtained by upgrading to water-efficient technology simply get taken up by an irreversible increase in population and dwellings, the next time there are water shortages there will not be the option to find more water via those water-efficiency savings. Governance mechanisms that see efficiency measures implemented within a system cap with good water accounting offer protection against water savings being taken up by system rebound effects. The system boundary assumed in any quest for efficiency is also important. To seek to increase efficiency assumes that there is a 'loss' in the first place, and this is not always the case. A loss of water from a leaky irrigation system is not a loss to the ecosystem as a whole.

Focusing only on specified resilience provides a partial analysis: increasing specified resilience in a particular subsystem can lead to perverse outcomes elsewhere, including a decrease in general resilience for the system as a whole (e.g. ensuring woolgrowers were resilient to fluctuations in international wool price via the Wool Price Reserve Scheme ultimately led to collapse of the Australian wool market and an enormous stockpile of wool) [46]. The next section considers the question of general resilience, including the associated challenges of providing measurable indicators of general resilience.

General resilience and adaptive capacity

Reviewing existing assessments of specified resilience reveals insights that are more generally applicable. Some of the same characteristics that foster resilience in specific cases appear in other situations, leading to the recognition of system properties that foster 'general resilience'. General resilience is not only about coping with large shocks. It is also about retaining a capacity to absorb any shocks, and as resilience declines it takes a smaller and smaller shock or disturbance to trigger an unwanted system shift.

Assessing general resilience is not easy because it does not define the resilience 'of what' explicitly; it assumes there are unknown thresholds that might be crossed and so has to do with a broader coping capacity of the system. How effectively can the system respond to the consequences of an undefined and unexpected disturbance and recover its functionality?

In this section we focus on the general resilience of system states that are desirable. The attributes of a system that confer general resilience overlap considerably with adaptive capacity, so the discussion that follows encompasses general resilience and adaptive capacity. The following questions frame the options for assessing and building that capacity:

- What are the characteristics of the range of external and internally generated surprises Australia may have to face?
- What important characteristics of a system provide resilience to many or all such shocks?
- What indicators are useful for tracking changes in the above characteristics?
- What is possible here and now to build adaptive and transformative capacity?

Architecture of surprise

To characterise the kinds of shocks and disturbances, we refer to a recent conceptualisation [47] that describes the range of shocks in an 'architecture of surprises', falling into three kinds: 'long fuse, big bang'; 'multiple whammy' and 'ramifying cascade'. These are useful qualitative descriptions rather than mutually exclusive categories. The 'long fuse, big bang' arises when the antecedent stresses accumulate slowly over time, creating conditions that generate an impact that is far more sudden. The 'multiple whammy' occurs when stresses interact synergistically to create a combined shock that is markedly different in character to experiencing the stresses independently of each another. The 'ramifying cascade' is the consequence of system connections, where a perturbation in one part of the system propagates to have impacts in other connected parts, or even other systems. Examples relevant to Australia are shown in Table 2.

Long fuse, big bang	Multiple whammy	Ramifying cascade
Financial crisis. Antibiotic resistance. Obesity.	Local drought coupled with international food crisis. Global financial crisis at the same time as a local environmental emergency (e.g. cyclone or bushfire). Pandemic coupled with staffing shortages due to retiring baby boomers.	The knock-on effects of successive energy or resource peaks. The successive effects of a long-term drying climate. Effects of chronic disease.

Table 2: Examples of each surprise archetype

One challenge that arises with the 'long fuse, big bang' variety of surprise is that it provides little motivation for preparatory action, especially because those who do nothing have a distinct competitive advantage against those who choose to act (e.g. doing nothing means that effort can be devoted to maximising immediate economic returns). Such a situation forces a response after the impact, rather than an anticipatory response. In trying to encourage a preventive response to such surprises, a useful strategy is to seek actions that provide immediate benefits as well as offering some insurance in the face of impending surprise. The quest for such co-benefits and the lens of general resilience can be useful approaches to draw on when choosing to invest in prevention; they do not ameliorate fully the forces that select against preventive action, but do contribute in that direction (particularly if uncertainty is cited as a reason for a wait-and-see approach).

The 'multiple whammy' also presents difficulties as it is unusual to be able to anticipate the interactions between shocks arising simultaneously from different sources—there are enough uncertainties with anticipating impacts from single stresses without delving into synergistic interrelationships between stresses and their outcomes. Furthermore, decision-makers in one sector tend to make it a priority to anticipate consequences that they may be directly responsible for, and incentives to look further afield are limited. Comprehensive analyses of multiple possible combinations become rapidly unfeasible. Again, actions to build general resilience offer a constructive approach that does not require deterministic prediction of an unlimited space of imaginable combinations of stresses.

The 'ramifying cascade' category of surprises is of particular interest. The 'long fuse, big bang' and the 'multiple whammy' surprises will in themselves tend to trigger cascades and, in the previous section on specified resilience cascades, were apparent in both impacts and approaches to resilience building. As with the 'long-fuse, big bang' surprise, there are systemic selection pressures against investing in preparatory or preventive measures against ramifying cascades, even if the cascades of connection are apparent. And like the 'multiple whammy,' it is generally not easy to anticipate the specifics of how a perturbation will manifest itself as it propagates through a network of connections, although connections may be clear with hindsight.

General resilience attributes and challenges

Defining and assessing general resilience for a particular social-ecological system is one of the weakest areas of resilience theory. It was given high priority in a January 2012 Resilience Alliance workshop to identify the research requirements for advancing the theory and practice of resilience.

We view general resilience as being determined by a number of attributes [Grigg and Walker, Chapter 7 in Volume 2] [48]. These include a system's diversity, modularity and connectivity, including the nature of feedbacks. They also include the system's governance mechanisms—polycentric, distributed, adaptive governance confers resilience. The presence of learning mechanisms that allow for experimentation and safe failure also contributes to resilience.

General resilience is also determined by the amounts and quality of multiple kinds of capital in a system. These include stocks of natural capital, built capital, human capital and deliberate reserves such as sovereign wealth reserves, and additional forms of capital such as knowledge capital, financial capital, and—very importantly—social capital. Redundancy in capital stocks is also important for providing buffering capacity.

Some of the challenges associated with building general resilience in the face of global change include [49]:

- Cause-effect relationships that are separated by large distance in the Earth System, as illustrated by the examples in Figure 1; such relationships are sometimes referred to as teleconnections [1]. Furthermore, cause-effect relationships are often counterintuitive in highly connected systems with feedback loops.
- Impacts of decisions taken by one generation will be felt by future generations. For example, greenhouse gas emissions to date lock in committed future global warning, irrespective of future decisions [50].
- Learning and knowledge-building tend to be separated into disciplines (e.g. physics, biology, hydrology, ecology, economics, psychology, law). Equally, problem-solving and decision-making within particular sectors or industry don't necessarily consider impacts outside the sector or industry.
- Handling cumulative impacts from distributed, diffuse sources raises particular challenges. For example, individual purchasing decisions aggregate to global impacts on land, water resources, biodiversity, climate, economy, employment conditions, yet each individual contribution to those impacts is measurably insignificant.
- The interplay between individual and collective interests: 'individually reasonable behaviour leads to a situation in which everyone is worse off than they might have been otherwise' [51] (tragedy of the commons and similar social dilemmas).
- Concentrating on resource-use efficiency without taking a broader systems view leads to the rebound effect, where improvements in efficiency inadvertently lead to greater overall rates of resource consumption [13, 52].

Building general resilience to ‘long fuse, big bang’, ‘multiple whammy’ or ‘ramifying cascade shocks’ requires an ability to recognise and address these challenges.

Tracking measurable changes in general resilience

The MAP reporting provides indicators recommended by Alford et al. [Chapter 3 in this volume]—levels of violence, homelessness, youth and long-term unemployment; life expectancy; levels of retention in formal education; numbers in prisons; diet and obesity; participation in civil society—all of which affect general resilience [Chapter 3 in this volume]. The MAP indicators are a useful starting point when considering indicators of general resilience, but do not provide sufficient insight to address the challenges listed above. What developments in indicators could address the challenges particular to quantifying general resilience? What system attributes confer adaptive and transformative capacity, and so the ability to choose; how can these be measured?

The aim is to monitor change in general resilience, whereas the MAP reporting is a response to the question, ‘is life in Australia getting better?’ Statistical snapshots over time reveal changes that are relevant to the ‘is life getting better’ question, and can alert us to important trends. If we are seeking to infer resilience to future shocks, however, we need indicators that shed light on system attributes and dynamics. For example, trends in obesity are clearly apparent in the MAP reporting. However, important information about the feedback loops that reinforce and perpetuate these trends cannot be gleaned or inferred from these snapshots. Alford et al. [Chapter 3 in this volume] emphasised the importance of system effects, referring to ‘virtuous’ and ‘vicious’ feedback loops, ‘hot spots’ and lag times. It is useful to be able to interpret statistical snapshots within a broader framework that explicitly accounts for these system effects, for it is these effects that strongly determine resilience. These system effects are usually only made explicit in models, whether conceptual or mathematical.

The difficulties associated with prescribing measurable snapshots of wellbeing are well described elsewhere [16]. A particularly relevant issue is that the same indicator value can translate into very different on-ground outcomes in different contexts. In the case of the DALY metric, for example, individuals with identical physical symptoms experience very different outcomes shaped more by their context than measurable aspects of their medical condition. Perceptions and experience of wellbeing are interwoven with cultural and environmental context, and important meaning is lost as soon as indicators neglect such context dependence.

Learning mechanisms are significant contributors to general resilience, but typical education and training indicators do not capture key aspects such as Year 12 retention rates, proportion of population with higher education qualifications and participation in work-related training. Some important attributes are less tangible, including: are we operating in social systems that routinely monitor and evaluate performance in light of our values and goals; do we alter organisational or societal behaviour and decisions in response to lessons learned; as individuals to what extent do we reflect on our own actions and make decisions based on past learning (learning from experience, rather than learning by participation in formal or informal education programs)? Do government policies and rewards systems (in all sectors) encourage learning and experimentation (rather than reinforce behaviours)? Are we 'enhancing the development of integrative perspectives across the Australian knowledge system' [53]?

What evidence is there that indicates our priorities and effectiveness around learning as a society? For example, Australia has a system for royal commissions that is invoked in order to learn from significant events such as the Victorian bushfires or Queensland police misconduct, whereas nations without such mechanisms for public inquiry may not have equivalent opportunities to learn. Although the term 'lessons learned' is often used, lessons are not actually learned until they are acted upon and implemented. In this way, both the existence of a royal commission system and evidence that society learns and changes as a result of such inquiries could be indicators of our effectiveness around learning as a society. Similarly, the adoption of adaptive management practices reflects openness to learning from past decisions and new information and adapting decisions and actions accordingly.

Measures that identify critical weak points in vital systems are useful indicators of resilience. For example, the 'average' condition of roads may not be as important as identifying the weakest bridges in the road network when it comes to assessing the resilience of population mobility or delivering aid materials in the face of natural disasters such as cyclones, bushfires or industrial accidents. In other words, it is not simply the amount of built infrastructure, but attributes such as connectivity and redundancy that matter. Any measures of connectivity need to be reported within a context for any meaningful interpretation: telecommunications connectivity can confer resilient access to knowledge or assistance in the face of the unexpected, or it can erode resilience if it increases exposure of the population to destructive cyberattacks.

The above measurable quantities are observations of 'what is' or 'what has been'. When evaluating preventive actions, particularly in areas of health and security, the most successful actions and initiatives can be the least visible, as their success is the avoided 'what might have been'. Almost by definition such measures require a model in order to make a comparison between the measured 'is' and the imagined 'might have been'. Measures such as DALYs do something like this in that they represent an estimated 'years lost' relative to 'ideal' life years (estimated via a model based on statistical evidence). This seems possible when the 'might have been' is an expected, normal outcome for which there is an abundance of data. In the case of security or preventive health initiatives, it is a harder task to characterise the avoided undesirable or catastrophic 'might have been'.

The art of synthesising and interpreting indicators is important and challenging. The more complete, rich and comprehensive the list of indicators, the more difficult it is to find a tractable synthesis yielding a coherent, insightful message. A common theme throughout our workshop deliberations was the need to 'make connections', particularly those connections that link the biophysical and social domains. In scientific inquiry the combinatory explosion of potential links requires intelligent judgment—Poincaré pointed to the fact that combinations can be so numerous that 'a whole lifetime would not suffice to examine them' and that creative insights come from seeing the fruitful possibilities among a sea of 'sterile combinations' [54].

In summary, useful system-level indicators would make it possible to identify amplifying or dampening feedbacks; offer insights into connectivity and its potential impacts; aggregate from individual to society-wide attributes in meaningful ways; reflect the effectiveness of participation in actions such as learning or democratic processes; make the benefits of preventive measures more tangible; and clarify implications of optimising for efficiency (e.g. trade-offs between efficiency and resilience, rebound effects). There is little ready access to tangible, working examples of such indicators. However, indicators of this kind can be found in the comprehensive data sheets in the Balancing Act triple bottom line analysis of the Australian economy, and the report contains useful spider diagrams, structural path analyses and other ways of conveying an integrated picture [55]. The challenges in monitoring changes in general resilience are well-identified and tractable, and development of improved indicators is highly feasible. A fruitful start would be to identify 'attributes of potential concern' that are evaluated over time: start with best judgments of what is likely to be significant and update them as we learn. The Australia *State of the environment report 2011* reviews the condition of environmental and cultural systems in terms of their resilience [56]. This provides a useful point to build upon in specified and general resilience assessments for Australia, along with other Australian resilience assessments [57–62].

Building general resilience here and now

Building resilience in any deliberate manner requires a capacity and willingness to communicate, assess and plan at a system (and system of systems) level. A common response to calls to link across systems is that 'we can't include everything'; an obvious truism, but connecting 'everything' to 'everything' is not the only way to take a holistic or systems approach. Reviewing available approaches reveals that years of effort in facilitating 'systems thinking', tackling 'wicked' problems or more generally fostering cross-sectoral connections have yielded a diverse mix of methods. Examples include system dynamics [63], participatory modelling [64–66] and transdisciplinary inquiry [67].

Analytical, technical and methodological differences aside, a common attribute of these many approaches is the ability to bring multiple perspectives to light. Counterintuitively, opening up to a greater diversity of perspectives can bring about a more constructive mode of interaction. For example, the impacts of mining operations on the salinity of rivers supplying water to agriculture in the Hunter Valley, NSW, triggered adversarial tension between mining and agricultural interests in the 1980s. These tensions were resolved constructively when the competing interests of stakeholders were acknowledged and the problem was reconstructed as a technical/governance issue that enabled changes in regulatory arrangements and mining and water storage operations [68]. When representative perspectives are acknowledged and on the table, which is a form of recognition of stakeholders' voices necessary for any meaningful engagement, exchanges can be lifted from a position of conflict to one of curiosity (particularly if such conflicting perspectives are explored in a 'safe' dialogue, game or simulation environments). The ability for stakeholders to take others' perspectives enables the discovery of insights that resonate across many points of view. A focus on living scenarios [Chapters 1 and 4 in this volume] enables such perspective-taking.

How can these many approaches contribute to the question of building general resilience? Whether the problem lies in the biophysical or social domain, envisaging and creating solutions is invariably a social process and all of the aforementioned approaches reflect this; the approaches are processes for engagement and collective decision-making. The most appropriate places to integrate these processes are in governance systems.

Governance refers to the institutions and processes through which collective decision-making is implemented and made accountable. Important dimensions of governance are signalling (information flows used to inform decisions), structure and function (the network of mechanisms and processes for interpreting signals and implementing decisions), and framing (what is visible and so included and what is not seen and so excluded in the way problems are framed). [69].

For example, intensive agricultural production results from framing, signals and decision-making that are focused on maximising economic efficiency at each stage in food production chains. The impacts of the resulting agricultural practices on the environment and health are 'externalities' that are well-appreciated and understood but are poorly accounted for in agricultural decision-making frameworks structured to optimise a narrow set of indicators [70, 71].

A contrasting example is the use of microcredit lending practices [72]. Where traditional banks look only to physical capital as collateral, microfinance operations explicitly consider other forms of capital—most notably social capital—when making lending decisions. Joint-liability group lending makes a small loan to an individual, but a group of individuals is jointly responsible for the loan's repayment. A woman with no collateral according to traditional banks has recognised social capital: existing close ties and trust networks in her local community. It is a measure of success that microfinance institutions have survived, replicated and expanded so rapidly in regions judged as non-viable by traditional banks [73]. Evaluations of microfinance give a more complex picture and offer insights into the metrics issues discussed earlier [74], including the challenges of evaluating and linking across multiple criteria such as poverty reduction, profitability, and social and environmental impacts [75–77].

The choice of frame affects what is possible. A frame that ignores impacts on social capital, health and wellbeing leads to outcomes that are measureable and highly successful within that frame (global-intensive agricultural systems have produced ever-increasing yields at ever-decreasing costs), but ignores the more connected system picture of environmental, health and social outcomes. A frame that includes social capital has enabled the existence of microfinance institutions that are enjoying tangible success even though their measurable benefits are hotly debated.

Relating these examples back to the aim of building general resilience, food production systems that maximise efficiency are resilient entities in that they survive, persist and dominate developed-world food production, but they come at the cost of less resilience in areas of environmental, social and population health. If governance systems are to account for such cross-linkages in decision-making processes, then the required framing, signalling and structures need to be open to less-tangible impacts; microfinance institutions are an example of this.

Higher-level strategies for building general resilience begin to look as follows: put in place governance systems that are open to diverse perspectives and are capable of holding uncertainty; enable stakeholders to appreciate and learn from those diverse perspectives (including enabling governance systems themselves to adapt in response to insights learned); and enrich such learning by developing meaningful ways to monitor, model and interpret the impacts of decisions, including impacts on 'attributes of potential concern'. The rationale is that general resilience involves an ongoing willingness and capacity to innovate and change. Change needs to be informed by learning, and change occurs more readily if there is broad support for it (witness the difficulties in passing controversial legislation); both of these requirements are served by systems that foster stakeholder engagement and learning.

A key learning task is to co-create wise responses to situations that involve social dilemmas and trade-offs. Much has been written on workable governance systems that enable sustainable stewardship of common pool resources [78–80]. Graham Marshall has drawn on that literature and highlighted opportunities in Australia given governance trends in Australian natural resource management [81]. Recent decades in Australia have seen a move towards market mechanisms for delivering public policy objectives in an effort to separate politics from the on-ground implementation and management for desired outcomes (e.g. for on-ground action funded by government schemes such as the Natural Heritage Trust or the National Action Plan for Salinity and Water Quality). Marshall highlights prospects for improved decentralised structures for effective collective action.

Marshall makes a strong argument for two useful guiding principles for such structures: nesting and subsidiarity. The principle of subsidiarity decentralises tasks to the least-centralised entity that has the capacity to conduct the task. A nested or polycentric governance system is 'a system where citizens are able to organise not just one but multiple governing authorities and different scales' [79]. The blend of subsidiarity and nesting principles ensures good local engagement and attentiveness to local knowledge, but also enables cross-scale interactions so that 'when small systems fail, there are larger systems to call upon—and vice versa' [79]. Of particular interest to resilience is that polycentric arrangements foster a diversity of local approaches that amount to multiple local-learning experiments and also provide some inbuilt buffering against system-wide failure. Furthermore, Alford et al. [Chapter 3 in this volume] emphasised the importance of context: polycentric, decentralised governance is better equipped to adapt to local contexts. Recognising potential trade-offs between the capacity for 'exploitation' (e.g. production, efficiency, execution) versus 'exploration' (e.g. experimentation, flexibility, innovation) in governance structures is important. Working at only local or global scales, with one prioritised at the expense of the other, is less effective at navigating complex problems than maintaining a balanced capacity for both [82].

A further advantage of working with multiple governance scales is brought to light when looking at the difficulties of global-change problems. Ostrom asks: 'must we wait for global solutions to climate change before taking actions at other scales?' and makes a strong case for the fact that in addressing global problems such as climate change, relying entirely on international efforts is a questionable approach [83]. Internationally coordinated efforts are needed ultimately, but they are not sufficient and they will only come into being and endure if supported by governance structures nested at other scales. The perception that system-level change requires a choice between top-down or bottom-up actions is false. The relevant systems' insight to take from contrasting top-down and bottom-up actions is to infer the extent to which they either oppose or support one another—those that mutually support each other have a higher chance of persisting and enabling successful change. These considerations lead to questions of system change and transformation.

Transformational change

Transformational change is more than a change in trajectory within an existing system, but rather a transition to a different system structure, with different processes, interconnections and feedback loops. Altering the set of feedback loops that currently reinforce an obesogenic environment is a change that would in turn entrain other changes at different scales and parts of the system: a system transformation.

A deliberate, prescribed transformational change at the scale of the whole system (whatever the focal scale might be) is likely to be too expensive and risky to be acceptable. The change needs to be initiated in the form of experiments and novel enterprises at fine scales, in line with the idea of 'safe arenas' for experimentation advocated by the transition approach to development [84]. Many will fail (and are expected to fail), and those that succeed will feed back to the focal scale and spread, resulting in a gradual, more evolutionary form of transformation; one that is more likely to be acceptable. Such a process needs help from higher scales (primarily government), but all too often the existing rules and constraints on use of support funding (drought assistance packages etc.) result in help not to change, rather than help to change [8].

Transformation vignette

The following hypothetical 'transformation vignette' is illustrative rather than prescriptive. It reaches across several sectors; when an entry point is chosen (e.g. transport) it naturally entrains other sectors and subsystems, all with potential feedbacks and consequences of their own. The vignette starts with a description of the current influences on the way Australians choose to spend their time and money.

Household incomes have risen over past decades and such income rises enable a range of options, including decreasing working hours, increasing savings and increasing expenditure. ABS reports suggest that of these options the most adopted response has been increased expenditure [85, 86]. On a daily basis marketing messages inform (and persuade) us on the ways in which our lives can be improved by spending money on advertised goods and services; these messages permeate our free-to-air television, appear on all pages of our newspapers and magazines and arrive regularly in our virtual and physical mailboxes. Reporting on the health of the economy looks to the retail sector and asserts that weak consumer spending is highly undesirable. Options for spending our money on material consumption are highly visible and have become a key motivation driving individual work habits.

ABS surveys of transport use [87] point to growing car dependence: between 2000 and 2009 the proportion of households with no registered motor vehicles decreased from 11% to 8%, while the number of households with three or more motor vehicles increased from 2% to 19%. Of people who travel to work, 80% do so in private motor vehicles, while 90% of day-to-day (non-work) trips are also in private vehicles. The picture is that Australian households are earning more, spending more and commuting more: each of these factors contributes to a widespread experience of time impoverishment [88]. At the same time, our built infrastructure is dependent on energy-intensive climate regulation (air conditioning and heating systems), the goods we buy carry a high ecological footprint [89, 90], the total material requirement of the Australian population has trebled since 1975 [91] and our mobility patterns have been founded on affordable fuel and the cost-free right to emit greenhouse gases. Cumulative impacts of lifestyle choices on our health are well-documented and seen in trends in obesity, chronic disease and psychological conditions associated with stress and depression.

Going against these trends confronts an individual with systemic barriers. Choosing not to own a car confronts the reality that most work, social and community interactions are premised on a high level of individual mobility, achieved by private vehicle ownership since there are few alternatives available. An individual who seeks to reduce the ecological and social impacts of their purchases finds that retail outlets are oriented towards supplying information on price per quantity, and information such as embodied energy and water requirements or the employment conditions of those producing the goods are generally unavailable to the consumer without considerable extra investment of time and effort.

The choice to 'downshift' and work fewer hours is perceived as risky, as those who work longer hours accumulate greater visible rewards (full-time income, more frequent promotions, more workplace recognition, higher superannuation savings and a more materially rich lifestyle). The result is that while individual changes of this nature are possible and deliver individual and social benefits, it requires a level of time, effort, foregone income and persistence that is not required if one simply aligns oneself with 'the way things are'. Our social norms, workplaces and public infrastructure have co-evolved with individual lifestyle choices, and without intention such co-evolution has led to a form of system resilience that places subtle and surprising pressures on individual options and choice.

That co-evolution led to built infrastructure and social systems that are very successful at meeting the lifestyle choices and preferences of current and previous generations. What will enable social systems and infrastructure to continue to evolve to reflect the changing needs and aspirations of current and future Australians? Needs and aspirations consistent with environmental sustainability and social equity include:

- climate-resilient infrastructure with low ecological footprint
- a high degree of autonomous mobility that is decoupled from fossil-fuel dependence, urban congestion and loss of air quality
- meaningful work that doesn't erode quality of life, individual health or contributions to family and community, and builds capital that can be drawn upon in old age
- systems and structures to allow purchasing choices to be informed and influenced by embodied impacts of purchases (e.g. impacts such as ecological footprint and the working conditions of those producing the goods).

What governance and infrastructure systems could be put in place to foster a 'safe operating space' (i.e. ensure environmental and health impacts are kept within acceptable bounds), yet enable a diversity of options for individual lifestyle choices within those bounds? Rather than imploring to people's better nature to do the right thing, or imposing centralised prescriptions (such as prohibition), the aim is to create systems so that going along with the status quo naturally builds capitals necessary for health and wellbeing rather than eroding them. It would be counterproductive to require uniform agreement on beliefs, world views and behaviour: individual diversity, imagination and creativity are vital for general resilience and adaptive and transformative capacity. We suggest a mutually supporting combination of top-down adaptive governance structures and bottom-up innovation, imagination and exploration is needed.

There are synergies where actions in one area can deliver co-benefits to other dimensions of the larger picture. We consider the potential implications of two key interventions: i) governance mechanisms that make current externalities (such as ecological footprint, health impacts or volunteer contributions) tangible and visible in our economy, and ii) investment in integrated city planning and mass transit systems that enable high levels of individual mobility independent of fuel affordability. Both these interventions are consistent with key recommendations of the Prime Minister's Science, Engineering and Innovation Council report into energy-carbon-water intersection [53]:

- *Recommendation 1.* The Expert Working Group recommends that consistent principles for finite resource use be developed and implemented for energy, water and carbon. These principles will ensure that 1) markets transmit full, linked, long-term costs to society; 2) accounting is comprehensive and consistent with natural constraints and processes; and 3) markets work together with non-market strategies, including implementation of robust governance arrangements, promotion of behavioural change and effective regulation of use.
- *Recommendation 4.* The Expert Working Group recommends the development of a national Resilient Cities and Towns Initiative, to foster resilient, low-emission energy systems, water systems and built environments by focusing jointly on technological developments in supply and on adaptation in demand as Australia's urban populations grow.

Cascading changes that could flow from these interventions are as follows. Alternative transit options could facilitate greater mobility and social inclusion for those currently unable to drive (youth, elderly and disabled citizens). Increased selection for low-impact goods and services (made possible by labelling and pricing mechanisms that account properly for social and environmental costs) not only reduce harmful environmental and social impacts but open up employment options associated with providing such information and delivering goods and services that compete well on these grounds.

There are potential benefits to Australian agricultural systems. The pricing of externalities such as environmental impacts of production, coupled with anticipated price rises in fuel and fertiliser, could trigger an increased uptake in nutrient recovery options from urban-waste streams for application in agriculture. Such changes would lead to reductions in eutrophication of rivers, estuaries and coastal waters that are currently the disposal sites for urban-waste streams, while also renewing the viability of peri-urban agriculture (assuming that cost structures favour applying recovered nutrients locally rather than transporting nutrients large distances). Opportunities for peri-urban agriculture make possible a whole set of options that are currently difficult to realise in urban environments: new urban employment options, shorter supply chains for fresh produce in cities as well as dedicated 'green infrastructure' planning in cities that sees further cascading benefits from vegetation (reduced-heat island effects, more comfortable urban microclimates, increased urban biodiversity, vegetated wetlands and riparian zones for treating and mediating stormwater run-off, flood mitigation, higher amenity values, and options for communal garden allotments).

A shift away from private vehicles and towards mass transit systems would see a greater emphasis on access to services within walking distances from transit hubs, which would increase daily levels of exercise and stimulate a greater diversity of neighbourhood hubs providing access to goods, services and transport. Pricing of environmental, health and social impacts of food would see selection against highly processed food in favour of locally produced food. Similarly, pricing these externalities in other material goods may lead to greater opportunities for smarter collective access to equipment such as vehicles, lawnmowers, power tools and specialist appliances (rather than the current emphasis on individual ownership).

These kinds of structural changes can, counterintuitively, make possible a lighter dependence on high incomes and associated long work hours. This last suggestion is a stretch and may not be realised, but based on our experience we would not be surprised if the experience of learning collectively how to do with reduced material consumption actually increases the availability of (and confidence in) lifestyle options that are less dependent on material affluence (with another potential co-benefit of redressing imbalances in over- and underemployment). Such a transformation would be extremely significant: analyses of transitioning to a low-carbon economy in Australia show that it is unlikely without physical consumption levels that are roughly half that assumed in base-case modelling scenarios [92].

Shocks are not necessarily negative, and can bring opportunities. The Canberra bushfires in 2003 caused devastating loss of life and homes. There are stories from fire victims who used their immediate loss as an opportunity to build a better-quality home matching the needs of their household [93]. It has also been argued that the opportunity to rebuild to deliver environmental benefits was largely lost due to 'the McMansion effect' and urban development practices [94]. Our capacity to turn shocks into opportunities depends on existing stocks of capital as well as support systems we construct and maintain: insurance, financial savings and social structures that are activated in traumatic times. These are elements of general resilience and adaptive capacity, and investing in these capacities in times of plenty creates the potential to turn shocks into benefits. There is also some argument for creating shocks. Planned shocks can be a way of safely testing and building resilience, avoiding lock-in, and turning shocks into an 'expanding cascade of good'. Examples of recent Australian planned 'shocks' have been the floating of the Australian dollar, the mandate for compulsory superannuation and establishing water markets.

Descriptions so far have dwelt on potential cascades of co-benefits from interventions. Unintended consequences will also occur. For example, if Australia were to require social and environmental costs to be made explicit on trade imports (e.g. via import taxes or duties), what cascading impacts would occur beyond Australia? How would the design of such interventions interact with impacts on wealth distributions and trade relationships in other nations, and how would these impacts feedback to the Australian economy (e.g. via reduced demand for mineral exports)?

Narratives of transformation

System transformation is a key ingredient of living scenarios and narratives. Resilience analyses have a clear role to play in bringing narratives of transformation to life, first in highlighting interconnections and unanticipated consequences, and second in distilling resilience principles in a way that makes it easier for them to come into common parlance. As an example, for many years a message from the resilience community has been to 'embrace uncertainty'. Such calls risk being greeted with ridicule or scepticism unless they can be made tangible and relevant to people.

To this end it is useful to supplement formal scenario exercises with intuition-building vignettes/games/models that provide the seeds for new narratives about the future. The role of ensuring such games and models reflect plausibility lies with biophysical modellers [Chapters 5 and 6 in this volume], with resilience perspectives applied to draw out useful system-level intuition among stakeholders and decision-makers across a diversity of sectors. Examples could include:

- Experience unanticipated consequences: invite participants to choose an intervention in a game or model system, only to have them learn that system feedback loops, time lags or social dilemma situations lead to counter-intuitive outcomes.
- Experience situations where, unless preventive or anticipatory action is taken, system dynamics and thresholds mean that reactive responses in a 'wait and see' mode are too late to provide any desired outcome (or available options are far more limited than anticipatory, preventive measures).

- Make efficiency/resilience trade-offs and rebound effects real for people.
- Foster diverse perspective taking and allow an appreciation of alternative ways to frame problems (e.g. participatory modelling games allow people to take the role of others in the system and so expand their understanding of factors that shape decisions by others).

Games, models, narratives and scenarios can provide experiences that create new understandings and encourage exploration and innovation in the face of future challenges. Historical analyses are also valuable for these purposes [95, 96].

4 Conclusion: an evolving process to enable future options

Our vision for a sustainable and equitable Australia in 2050 draws on a resilience perspective that informs both the nature of the goals we pursue and the manner in which we pursue them. Enabling a diversity of future options is, almost by definition, a core goal from a resilience perspective. Resilience is not an end in itself, but rather a perspective that can offer useful guidance at a system level.

There are a number of implications for governance. Our deliberations lead us to conclude that the processes used to tackle problems are more important than getting locked into prescribing specific answers. Processes that enable a developing, evolving understanding of system dynamics and responses to them (e.g. as in management strategy evaluation and adaptive management approaches) are required. Such governance processes can only come into being and thrive if there is an explicit value placed on learning. Learning crucial to resilience includes:

- learning where there are resilience/efficiency trade-offs, rebound effects, thresholds and system limits, monitoring our relationship to these over time and using that knowledge to evolve priorities for decision-making and actions (specified resilience)
- identifying and tracking ‘attributes of potential concern’ that indicate general resilience and discovering effective ways to monitor and either build or reduce general resilience as the situation requires
- learning ways to identify when transformation is called for and creating transformation options in a timely manner. The need is not to transform to a specified, predetermined new system, but to identify new acceptable trajectories that are open to ongoing adaptations when required.

Decision-making and actions that value learning and adaptability and are at ease with high uncertainty require leadership and social networks that allow such governance structures to persist. An electoral environment that rewards immediate short-term goals to consume rewards certainty over uncertainty (and punishes leaders who change their mind in response to altered circumstances) and is unlikely to foster such leadership or networks. These aspects of the electoral environment cannot be prescribed and planned, but investment in incubating environments that allow the evolution of skilled leadership approaches and useful social networks is possible.

Suggested strategies would draw strongly on the expertise represented in the other Australia 2050 workshop groups. Challenges in communication were highlighted throughout the workshop. Accumulated experience among many participants across all the groups tells a familiar story: comprehensive analyses of biophysical systems, scenarios for our future and well-articulated options for decision-making have been carefully prepared and presented to government and the Australian public over many decades. Some of these efforts have been publicly rejected (e.g. [97]), and more generally those responsible for such analyses have come up against significant barriers in seeing their analyses embraced readily to inform decision-making. This was an important experience voiced by many researchers in the room.

A response to these challenges is to adopt more active, participatory approaches. It is not sufficient to conduct detailed analyses or model runs and present graphs and 'answers' for people to digest, no matter how rigorous, careful and insightful such results are. In the crafting of decisions in response to system problems, delivering predetermined 'solutions' to stakeholders is rarely as effective as approaches that engage stakeholders in an iterative dialogue that enables the exploration of multiple perspectives and options for future trajectories.

In conclusion, our vision is one that reflects an awareness of system realities and makes deliberate choices to expand the options for creating a 'safe operating space'—we want to foster environmentally sustainable and socially equitable ways (not prescribe any single way) of living.

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Chapter 3

Social perspectives on sustainability and equity in Australia

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Future trajectories for Australia will be influenced not only by biophysical factors but also by changes to social structures and the abilities of communities to respond and adapt to new environments. The confluence of biophysical and social factors is especially worrying in peri-urban and regional areas where exposure to climate change impacts and existing social stresses are high. However, while there may be clearly desirable zones for achieving social equity and environmental sustainability, it is harder to say where thresholds for social disarray might occur due to the complexity of social factors, system dynamics and individual perspectives.

1 Framing

Introduction

Our future generations can no longer be assured of being better off than the current generation, challenging traditionally held beliefs in the value of progress. There are signs that values are shifting away from prioritising consumption. Concerns about 'limits to growth', which have previously been seen as a minority view, have now entered the mainstream.

While Australians face a range of challenges on climate change, biodiversity, population and desired economic growth, science can provide clues about how these challenges will evolve. These are complex issues and the better we appreciate their complexity the better equipped we are to inform government policy, private sector action and personal values. This appreciation can also shape aspirations and behaviour to ensure desirable outcomes by 2050. To achieve desirable change we need to better understand social perspectives on these issues and to better integrate biophysical and social structures in long-term planning, policy and programs.

Social perspectives are important as they allow us to better understand the processes of change and how people make decisions about the future. They also add context about pathways toward preferred outcomes and about drivers for change that might be missed by approaches that concentrate solely on biophysical and economic considerations. In addition, the inclusion of social perspectives helps incorporate multiple world views and heterogeneous social fabric into the process of envisaging Australia's future.

The diversity of world views inherent in such a large-scale imagining of possible futures for 2050 is one of the challenges and opportunities in bringing a social perspective to what otherwise might be solely a biophysical science approach to mapping future spaces. The diversity of views and skill sets among the authors of this chapter has been a key strength in enabling us to understand the current situation and debate alternative factors that might drive change and alternative images of the future.

During the Bowral, NSW, workshop we developed a new understanding of how social perspectives may contribute to the idea of 'safe operating spaces' and 'thresholds of concern'[1] in which desirable futures may exist. We have drawn on elements of systems thinking to identify potential policy and social 'hot spots' that have important implications for change either because they have long-term, locked-in consequences or because they are positioned at the confluence of major drivers of change. It is important to incorporate a number of social processes when modelling or developing future scenarios so that an integrated model of the biophysical and social realms can be developed.

Developing definitions and a shared understanding

A particular challenge in introducing social perspectives to understanding future trajectories is developing a shared understanding of what we mean by a desirable future. The framing notions of social equity and environmental sustainability may be contested or interpreted in different ways. Are they coupled? How do decisions that affect one impact the other? And how do they relate to other normative goals of economic prosperity and human wellbeing, which may also be interrelated?

Social Equity. First, what is social equity? One goal of social equity may be to reduce the proportion of people who are marginalised, excluded, lacking capability or, in the most reductive way, regarded as unproductive. But social equity may also be evidenced by a reduction in social stresses and fewer people in poverty, implying that the distribution of resources, goods and services has improved. Another approach would be to assume that a goal of social equity is for society as a whole to be no worse off than we are today; in other words, the aspiration is one of intergenerational equity (given that one of the markers of social inequity is cycles of disadvantage). Another approach might be that social equity allows for fulfilment of potential. Bringing together these various viewpoints, we can summarise by saying that social equity includes access to opportunities to fulfil potential without barriers that result in social stress.

There are important differences between the related concepts of social equity and social equality. Social equity implies fairness and justice without necessarily imposing uniformity of outcomes or equal distribution of resources. Concepts of social equity are important because in modern democracies an inequitable society is prone to conflict. People need to live productive and meaningful lives and in doing so they avoid greater personal and societal costs. Both Sen [2, 3] and Nussbaum [4] have made this same argument through a capabilities approach, emphasising 'what people are actually able to do and to be' [4]. As illustrated in the *Human development index* (1990), there are clear social and economic advantages of wellbeing and equity. By redressing inequity and attending to capabilities, human capital can be harnessed for individual and nation state advantage [5].

Environmental sustainability. Sustainability has a multitude of definitions and meanings depending on context; in this section we will note some general principles and issues for consideration.

First, we recognise that sustainability is more a process or even a societal journey than a goal defined by specific targets and deadlines. If sustainability is a long-term process then the vision for environmental sustainability needs to enable alignment by successive governments and consistent support by stakeholders. This provides some guidance as to how we might frame an environmentally sustainable view of the future as one that is acceptable by the majority of the population rather than one particular prescriptive or political vision.

Boundaries are important to consider in relation to sustainability in Australia. A key question to ask is whether we are aiming for Australia to be sustainable compared to other nations or if we are asking for Australia to contribute to global sustainability? The perspective we choose will affect issues such as population policy, the import of goods, energy resources and consumption, community resilience and Australia's contribution to climate action among other issues. However, if we recognise sustainability as a long-term process, then eventually we must realise that meeting an environmentally sustainable view of the future requires thinking not at a national level, but in a global context.

Complexity of social factors. Social complexity is important in framing more sustainable and equitable pathways. Our societies are characterised by two types of tensions that strongly influence their evolution: i) individual aspirations vs. collective experiences and ii) short-term perceptions vs. long-term expectations.

In many instances individually beneficial decisions do not contribute to social equity or environmental sustainability at the larger scale. Likewise, decisions that appear rational and beneficial in the short term might lead to detrimental outcomes later on. The well-known 'tragedy of the commons' encapsulates both of these tensions with unfortunate consequences in terms of social equity and environmental sustainability [6, 7, 8]. These tensions affect the ways in which policy and social change affect trajectories and how policy decisions are represented, interpreted and accepted.

2 Visioning

Scope

In our discussions we approached the question of achieving environmentally sustainable and socially equitable ways of living in Australia in 2050 through a four-step collective process. First, we made explicit *assumptions* about the system under study by drawing out constraints and continuities that would characterise Australia in 2050. We then placed Australia within the global context and identified major and long-term *drivers* of change that would be difficult to influence. Within this context we identified *shapers* as trends or opportunities that we might be able to influence through policy levers or social change within a reasonable timeframe. Finally, we debated the notion of applying the concept of a safe operating space to the social realm and identified indicators that would act as early warning signs for change in an undesirable direction.

Assumptions, continuities and constraints

In thinking about Australia in 2050 we assumed that some aspects of Australia's territory and its political system would continue largely unchanged. First, we assumed a stable democracy would continue (and that it will continue to be regarded as desirable) and that radical cultural change would be unlikely and beyond what we were considering in our desirable future.

Second, we acknowledged that Australia is a complex social ecological system with inherent feedback loops. Hence no component of this system can evolve in isolation. As a consequence, many changes that aim to improve environmental sustainability will have an impact on social equity in Australia. We also assumed that the Australian society would continue to work towards the protection and extension of life for everyone living in Australia. As a consequence, we discarded any scenario that would imply intentional harming, marginalising or eliminating of some components of the Australian social fabric.

Finally, we placed a constraint on the present by stating that current patterns of spending and consumption, social organisation and structures were no longer sustainable and that current policies and industry conditions would contribute to an unsustainable future [this volume, Chapter 1]. To ensure an environmentally and socially sustainable future, Australia requires change.

Global context

Looking to 2050 and beyond, we identified a number of interacting global trends and processes that are likely to present significant challenges and opportunities for Australia.

The first of these drivers is climate change. Climate change is likely to see rising temperatures, shifts in seasonal rainfall patterns, greater climate variability and more extreme events such as high rainfall events, inland floods and coastal inundation, cyclones, droughts and heatwaves [9, 10, 11]. The pace and extent of changes are uncertain, and may occur as a series of steps or shifts rather than smooth trends. Significant shifts in specific climate system elements cannot be ruled out, such as in the Indian monsoon, which could result in significant and relatively rapid changes in regional climate and food production. National, regional and global actions to reduce greenhouse emissions and adapt to climate change will also continue to evolve [12]

Global economic realignment is already underway, with a decline in the relative importance of the major western economies and the role of the emerging economies increasing, including Brazil, China, India, Indonesia, Mexico, Turkey, South Africa and South Korea. This realignment will influence global trade and investment flows, economic governance (such as oversight of finance markets), social and cultural connectivity and norms, technology costs and trends and evolving geopolitical priorities and outcomes. It will also continue to have significant implications for Australia's economic positioning in the world, including world demand for our major exports. Furthermore, the ability of Australia to respond to global economic changes may be limited by factors such as the decision-making of multinational companies.

Global and regional food security trends are uncertain but appear likely to decline over coming decades, with potentially higher trend prices and more frequent price spikes [13, 14]. Population growth and rising incomes will increase demand for foods both in terms of volume and variety while also increasing competition for land (such as for urban settlements). It is possible that improved technologies, off-farm food production (such as urban gardens) and improvements in food access and related policies could substantially offset these pressures, but the net result is uncertain.

Demand for energy resources is also expected to continue growing, with prices increasing subject to resource availability and the impact of carbon policies on coal, oil and gas. The idea of peak resources such as peak oil, but also peak coal, would see a potential trend of resource scarcity turn into a 'shock' as we edge closer towards depletion [15, 16, 17]. This may also be true of other resources such as fresh water and nutrients, placing further pressure on matters related to food security.

Geopolitical tensions and non-state terrorism risks appear unlikely to decline over the next few decades and could become more acute. Significant tensions appear likely in our geographic region, with probable direct and indirect impacts in Australia. Terrorism that targets Western icons in Australia and our region cannot be ruled out, and we may see increased inward business migration or tourism as people search out a safe haven in Australia.

Climate change policies promoting forest-based carbon sequestration may increase competition for land, exacerbating food security issues, while attribution of extreme climate events to past Western energy use may motivate terrorist acts [18, 19]. Food security and climate change will drive changes in demand and prices for agricultural commodities and lead to the emergence of novel institutional arrangements (such as long-term output contracts providing greater price certainty).

System effects: feedbacks, hot spots and lag times

During the Bowral workshop we applied several different lenses to analyse system-level changes that would lead to plausible futures. First, we concentrated on identifying particular *feedbacks*—'vicious' or 'virtuous' cycles—that would characterise the evolution of Australia towards 2050 within a global Earth vision. Then we managed to identify hot spots that presented significant urgency or importance for decision-making. Thirdly, we focused on changes that would be characterised by particularly long lag times (also known as slow variable-driven dynamics), limiting the set of possible future trajectories and thereby reducing the degrees of freedom for change to 2050.

We identified several indicators of social stress: level of violence, homelessness, youth and long-term unemployment, declining life expectancy, declining level of retention in formal education, increasing numbers in prisons, poor diet and obesity leading to increasing levels of chronic diseases, and increases in the numbers of people living in absolute and relative poverty. These symptoms all come with costs on the population through government remedial measures. In addition, indicators of stress include increasing economic inequalities and decreasing participation in civil society, indicated by such measures as abstention from voting or reflected in declining capacity to express views and influence broad social choices through mass media or other channels.

Obvious vicious cycles compound these indicators. Declining levels of retention in formal education are highly likely to lead to increasing youth unemployment, in turn leading to increasing inequality, probably increasing homelessness, violence and numbers in prisons. Those who are unemployed, imprisoned, homeless or involved in violence are more likely to have children who are not retained in the formal education system, perpetuating or even accentuating the cycle. People who are unemployed are more likely to be homeless. People who are homeless are less likely to participate in the formal processes of society, reinforcing their alienation. Those who are homeless are probably more likely to be the victims of violence. Richard Wilkinson's cross-country comparisons show that increasing inequality is associated with shorter average life expectancy [20]

In terms of virtuous cycles, increasing retention in formal education may lead to a decline in youth unemployment, in turn reducing levels of violence and other crime, so reducing the numbers of people in prison. Strategic investments in job creation in areas with high levels of unemployment have the potential to modify the social environment, making the area more attractive for further investment. People in employment are more likely to afford healthy food and are therefore less likely to develop chronic disease at a relatively early age. So strategies to improve rates of education and employment that reduce inequality and homelessness are associated with improved average life expectancy. Reducing inequality is also likely to lead to increasing participation in both formal and informal decision-making processes. Conscious strategies of involving communities in participatory processes for decision-making in turn reinforce public engagement and social cohesion.

In 2012, the most marked instances of inequality are seen between non-Indigenous and Indigenous Australians and between rural or remote Australia and poorly serviced peri-urban areas at the fringes of our cities. Peri-urban areas usually combine poor services with low levels of retention in education, consequent higher levels of youth unemployment and long-term unemployment, higher levels of violence and other crime, above-average probability of imprisonment as well as higher levels of accidental death and injury resulting from lifestyle choices and the need to travel further by less safe means. Some parts of rural Australia have suffered disproportionately both from extended drought and structural changes, with reduced employment opportunities in agricultural activities leading to reduced demand for services, leading in turn to the withdrawal of services and a spiral of decline. The poor provision of education leads to young people being less educated and more likely to be unemployed. Poor health services contribute to lower life expectancy. These problems reinforce the pattern by increasing the probability that people will leave the area. Areas of concern in remote Australia are particularly associated with the spatial congruence of fast-track development associated with mining and energy industries and entrenched disadvantage amongst Indigenous groups (e.g. in the Pilbara, WA). The models of governance applied in Australia's remote regions are arguably inappropriate, with the characteristics of a 'failed state' [21].

The projected increase in Australia's population is likely to accentuate problems in the peri-urban regions. While the lowest level of projected population in 2050 could be accommodated by urban infill, densification and the development of regional urban centres, more realistic projections will result inevitably in a significant increase in people living in the peri-urban fringes of major cities. These areas are therefore to be considered as hot spots in which indicators of social stress are most likely to reach alarming values. As a matter of fact, recent immigrants and poorer Australian-born residents are already and disproportionately located in peri-urban areas. This pattern is likely to continue, so cultural segregation will be an additional factor influencing social cohesion and shaping public services in these places. Strategies taking advantage of incoming flows of population to encourage the revitalisation of regional centres and rural areas could, at least in principle, reduce the stresses that are currently apparent there.

These social trends are linked to pressures on ecological systems. The Millennium Ecosystem Assessment (2005) concluded that major drivers causing the loss of biodiversity were: habitat transformation (particularly from conversion to agriculture), overexploitation, biotic exchange, nutrient loading and anthropogenic climate change. Population growth and urban sprawl contribute indirectly to reinforce these factors. Loss of biodiversity in such areas as coastal wetlands is accentuated by the expansion of the land area used directly and indirectly by humans as the urban and peri-urban population grows. The rate of release of greenhouse gases has been historically roughly proportional to population levels and wealth so we would expect population growth or increases in household wealth to lead to a proportionate increase in emissions. In practice, the current trend is for emissions to increase more rapidly than the population because those in outer-urban areas generally travel further by less-efficient transport technologies, so their transport-related emissions are above average. There is also an increasing reliance on energy-intense resources for heating and cooling rather than harnessing design. For example, whereas 5% of dwellings in south-east Queensland were air conditioned in 1980, the figure now is 65 %.

The timescale for restoration may be even longer for biodiversity loss; it will not be possible to restore a species at all if it becomes globally extinct, while it may take many decades to restore if it has only disappeared from a specific region. Destruction of habitat may be irreversible. If a specific habitat can be restored, the time scale is likely to be decades. Similarly, it may not be possible to eradicate an introduced species, as illustrated by the failure to restrain the spread of cane toads or eliminate rabbits, despite commitment and huge efforts in both cases [22]. Chemical pollution may take decades to clean up. So the three forces that have driven the loss of biodiversity in recent years all have long time lags and are all continuing, while they are now augmented by climate change.

Safe operating space

The notion of a safe operating space in the biophysical world implies that thresholds exist beyond which the system approaches collapse [23]. In social contexts, the concept of 'safe' might relate to an acceptable level of social equity

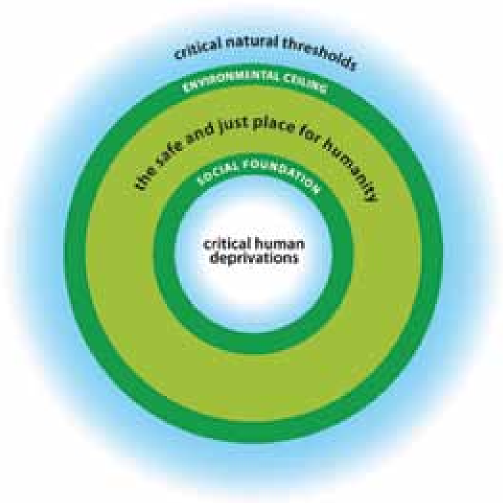

Figure 1: (from Raworth 2012): Identifying safe operating spaces from a social perspective.

or levels of adequate individual and social wellbeing. Yet the concept of a ‘safe operating space’ with respect to social dimensions has not been applied, and we do not have an understanding of where the limits for social breakdown might be.

The main difficulty in translating the concept of a safe operating space to the social context is in applying the concept of threshold limits for social collapse. The social system is adaptable and resilient, and people’s perceptions about what is normal and acceptable also change. Notions of acceptable social conditions have varied dramatically over human history, and regimes in the past would not be considered safe or acceptable now. The other risk in attempting to define a safe operating space is in making value judgements about what aspects of the Australian community might be perceived as ‘safe’. There is a set of possible safe spaces that sit between social inequities and critical biophysical thresholds, as described by Raworth (2012) [24] in Figure 1:

While this maps a potential space figuratively, we consider it is very difficult to define ‘safe social operating space’ quantitatively, and possibly counterproductive. Social thresholds appear difficult or impossible to identify a priori, and individuals and groups demonstrate significant capacity to adapt or normalise highly unsafe circumstances (even where this appears ‘maladaptive’ at larger social scales or longer time frames). We find it useful to identify a working set of social warning signs that would serve as indicators of a loss of resilience.

These may also provide a basis for identifying social practices or institutions that would enhance general social (and political and economic) resilience.

In developing this approach, we argue that the knowledge of how ecological systems behave might not translate directly to social systems. Applying ecological change process mechanisms to social systems might be useful since both biophysical and human systems display highly non-linear interactions and dynamics. But it is usually only in hindsight that we can identify the critical transition point. Furthermore, the notion of what might be 'safe' as opposed to preferred—a value statement on how we would like to live—is also problematic. Rockström's notion of safe operating space is the physical space that is safe for humanity—but clearly, there are many different types of spaces that humanity can operate within, without leading to human extinction.

Warning signs for social inequity

Even if we have trouble identifying specific thresholds, it seems possible and desirable to monitor indicators of social relations and processes to detect trends that are more or less desirable. In this way a shift in the social indicators could act as a warning sign that society is moving towards unsafe operating spaces. Minimally, increases in indicators that we associate with social inequity, as outlined above, are also early indicators of the erosion of a safe operating space. Increased unemployment, homelessness, mental health problems and crime, loss of food security and growing inequalities—and political instability—are all warning signs of real pressure on the social (and economic and political) system. In expanding on this, these social indicators may include:

- increasing violence, where behaviours that are expressed have a poor public outcome and impact on human rights. These include gender-based violence, child abuse, and random and directed interpersonal violence
- increasing unemployment, especially long-term unemployment and youth unemployment, in the absence of programs to address these trends
- increasing housing insecurity and homelessness, and increases in the various social, economic and health determinants of homelessness
- decreased levels of literacy and numeracy among specific population groups and at a national level
- decreases in school retention
- declining life expectancy

- rising incidence of chronic and non-communicable diseases, including conditions associated with stress, poverty and environmental factors (such as diabetes and heart disease, but also chronic obstructive pulmonary disease and asthma)
- decreased food security, including access to food, how food is distributed, and declining food production.
- decreasing civil engagement and, conversely, rises in community expression of tension and intolerance (extremist organisations, racism, vilification, and so on)
- increases in all crime and the percentage of the population in prison
- declining liveability—congestion, distribution of housing, and employment
- low viability of regional areas as indicated through population trends or levels of disadvantage through these and other indicators
- intergenerational disadvantage as expressed through the continuation of poor social indicators across time, within specific populations and in aggregate.

Enablers of social capital

We can also expand our view by shifting focus from ideas of individual equity to issues around social capital. Social capital includes a range of contributors, but key concepts relevant to building social capital in this context include understanding the bigger social ecological system, being able to express opinions and having mechanisms in place for difficult decision-making [25].

Having an understanding of the social ecological system means people are aware of how they fit within a larger system. This could be expressed through their interactions with nature and concerns for the natural environment, or understanding issues about food production and security. To maintain a functional social ecological system into the future, people need to be conscious of dependencies and interconnections. Queensland has taken a lead role through the decision to include sustainability principles in the core curriculum and to require appropriate practices to be followed in schools through the Queensland Environmentally Sustainable Schools Initiative.

Continuing to be able to express opinions is the second of these enablers. This comprises an ability to publish or to comment, and might be expressed through having diversity in media ownership and editorial content, the degree of flexibility or regulation in media and advertising, and continued opportunities through social media for people to contribute to debates.

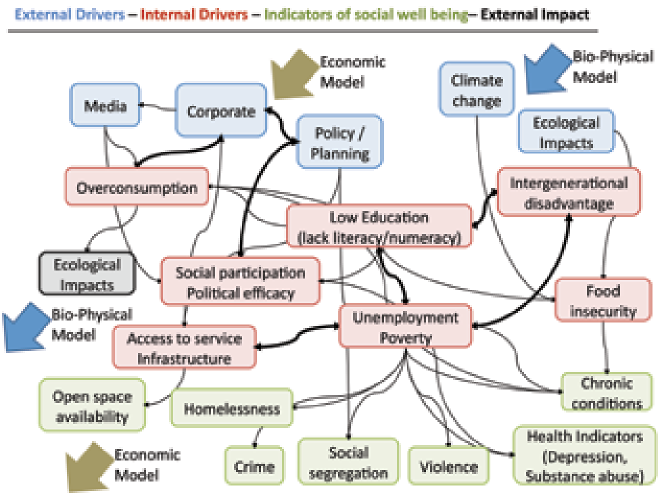

Figure 2: Conceptual model of the different social processes that might impact on future trajectories for Australia. The directed links within the diagram show how the different concepts may affect one another (main link are displayed as think arrows). The blue and brown large arrows show how this conceptual model is driven and feeds into the biophysical and economic processes.

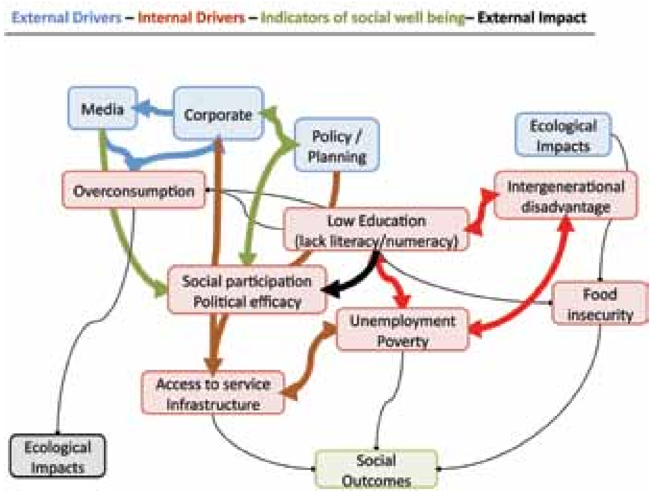

Figure 3: Conceptual model of the different social processes, as in Figure 1 in which some virtual and vicious cycles are highlighted. The reinforcing or stablising feedback loops within these cycles have the capacity to drive the system either to stability by damping the effect of drivers, or outside a safe operating space by amplifying them. The connections between these factors in the model provide a base level on which we can overlay different values and structures such as individualism, community orientation or government-led change. As well as understanding changes to indicators, we can also use this to understand the effects of shocks to the system.

The third enabler is to have effective mechanisms for difficult decision-making. An example is the community engagement of the Douglas Shire at Port Douglas, Qld, around drinking water. Port Douglas used to get drinking water untreated from the Daintree, but after a developer subdivided lots, residential development plus informal squatting meant water started to show dangerous levels of *e. coli* and would need to be treated. The cheapest way was chlorination, but doing so would affect the 'clean green image' of the area. Other options include technologies like microfiltration, but that would have increased costs by 50%. Either way, it was a difficult decision for the Cairns Regional Council. With community advocacy from the Friends of Douglas Shire, the council therefore commissioned engineering studies of four alternative treatments, and communicated these with the community through libraries, brochures, the media and public forums. The community voted for the cleanest, but most expensive technology. The decision was politically sustainable because the choice also allowed people to comment and the community 'owned' the decision. In contrast, the decision-making process used to decide on the use of recycled and treated water in Toowoomba, Qld, was much less effective as it primarily employed only two options, one of which was no change. Being able to take difficult decisions and take action is a way in which better community outcomes can be enabled.

Understanding social and economic processes

Researchers struggle with describing the dynamics of social processes, but it is possible to characteristic some social processes and to find interventions within the system. The following diagrams (figures 2 and 3) provide insight in what type of social processes might be considered in seeking to understand potential future trajectories for Australia and map how this works.

Phase changes occur in social systems at multiple scales across different time frames as well as more gradual change. For example, the fall of the Berlin Wall is an iconic change caused by a gradual build-up of underlying changes that were difficult to observe beforehand or even explain in an uncontested way afterwards. Changes within Australia that affect gender relations, and particularly reproduction, are arguably another example, as are the social changes that have flowed from the internet are a dramatic instance. There is strong evidence of cohort effects in the development of world views over successive generations, resulting in long 'waves' of expressed values linked to demographic shifts across age cohorts. Depending on the nature of the inquiry, establishing or replicating what has caused certain effect to emerge in models or simulations can be difficult and we consider existing national or global-scale simulations exploratory (rather than conclusive) at this stage. Other aspects of social and economic processes are amenable to simulation, such as the operation of social networks, and of markets and associated patterns of resource use and consumption, using national and global economic models.

This supports a view that we can identify plausible future end states with a reasonable degree of confidence, although we may not be able to identify causal pathways to these states with confidence. Modelling to determine future trajectories, as discussed in other chapters, may be most useful when served by a strategy where the role and impact of social factors or variance can be explored through how the models might be used for different end states, rather than factoring changes 'within model'—that is, through the formal programming of causal societal processes.

There are at least three important roles for modelling in the development of futures scenarios. First, modelling can help to check consistency within scenarios and the coherence of distinctions across scenarios. Second, modelling serves to populate scenarios and make them tangible—for example, by incorporating information on population levels, average incomes and income inequalities, distribution of settlements, travel time, fuel prices, environmental conditions and social indicators such as those identified above as potential warning signs. Finally, modelling can be used to establish milestones and time frames within the social and physical dimensions of scenarios. For example, when a new technology or standard is implemented, a model can anticipate how this might be introduced and thus identify when things need to change for an outcome in 2050 to be feasible. We expect careful use of multiple models to develop coherent scenarios, rather than a single model or fully coupled set of models.

3 Understanding societal change

While we can describe and model social and economic processes, the roles that individuals play in creating change are also important for understanding how societal change might happen. Factors relating to individuals that may either contribute to or inhibit change include values, feedback and learning within the system and how people perceive the future and their roles in creating it.

The role of values

To what extent will Australians act to foster a future nation where environmental sustainability and social equity are valued goals progressed through collective social action? Such an outcome will require changes in the values and attitudes of many individual Australians towards the future, such that they make decisions that promote sustainability and social equity not only in their own lifetime, but also in the longer future. It will also require that Australians, as a national community, have a coherent capacity for making and implementing decisions on a large scale and about often-difficult issues. Although people can be very different, in terms of culture, demographics and socioeconomic characteristics, the social processes through which they form and change values, attitudes and behaviours operate in much the same ways.

The values and attitudes people hold and the ways they behave are strongly influenced by the values, attitudes and behaviours of other people in their social networks [26]. Individuals are influenced by cultural and community values, by others who they trust and by information from trusted sources. People's behaviour tends to conform to norms or expected patterns of behaviour among their own trust network—friends, peers and family or other people from the same ethnic, linguistic, political or faith group. Indeed, the hallmark of interpersonal trust is whether a person behaves in the way that another person expects, based on tacit norms that are prevalent in those people's shared social setting. But because the trust networks of any individual person are multifaceted and change as new relationships develop, people's values, attitudes and behaviours are quite dynamic. Communication technologies and social networking media mean that people are less reliant than they once were on face-to-face interactions to develop trusted interpersonal relationships. As a consequence, peer networks are increasingly becoming disembodied, relying on remote and mobile technologies to connect people. Opinion leaders or trendsetters are important catalysts for change in other people.

People who aspire to move into a new or different social group whose members hold different values or have different and perhaps unfamiliar ways of behaving to their own will tend to change their norms or ways of behaving to match those of their chosen new social group. Such changes are important to being accepted and trusted by members of their chosen new social group, since trust is less likely to develop between people who have very different values, attitudes and ways of behaving. Similarly, people are more likely to change their way of behaving if others around them have made that change, either because people don't want to be singled out or seen to be different, or because change occurs from the sharing and co-production of new knowledge.

Feedback to individuals

Feedback to individuals about the consequences of their actions is a powerful influence on behaviour. Changed behaviour of individuals is reinforced by feedback from others—positive feedback indicates approval or acceptance of an individual by their social group and reinforces the individual's commitment to the behaviour. Negative feedback about unacceptable behaviours can equally lead to changes in behaviour. The more visible behaviours are, the greater the potential for positive or negative feedback from others to influence future behaviour. For example, the number of businesses that participate in Earth Hour, which involves their leaders and people turning off superfluous lighting, grew very quickly. The perception of businesses that do not turn their lights off during Earth Hour as uncaring or irresponsible towards the environment is very high, given that the event focuses the attention of a large number of observers. Many fewer businesses turn their superfluous lights off routinely, when the potential for negative feedback is less.

The most immediate feedback from people's actions comes when they directly perceive the consequences of their own action through negative or positive impact on things that they value. However, many people do not directly experience the impact of their actions. For example, we rarely experience personally the impact that our decisions have on environmental quality.

To influence action, information needs to be understood. Understanding derives from a person's prior knowledge, experiences and beliefs. Hence incorporating social ecological system processes into school-based education (as described above for Queensland) is important to develop the cognitive knowledge that allows people to understand the impact of actions on the environment. However, if information is to influence people to change their behaviour, that information also needs to be trusted.

People trust information when it is conveyed to them by sources they consider credible such as media sources that they are familiar with and trust, friends or close colleagues. People may not have direct experience of the trustworthiness of an information source, but put trust in its reputation. Reputation is established by credible processes that are based on people's experiences and by learning about whether something lives up to its claims. Such processes and mechanisms for establishing reputation that have developed as society has come to rely less on face-to-face communication and direct experience include certification of goods and services as 'green', consumer reviews of products and services, and the feedback processes—for example, in eBay that invite buyers and sellers to rate the quality of their transactions.

Information has its most powerful impacts on values, attitudes and behaviours when it is not contestable. However, this is rarely the case. The great differences among people can mean that information and opinion conveyed by the media, public commentators, politicians, local opinion leaders, scientists or spiritual leaders influence the behaviour of some people and not others. The impact depends on each individual's own value orientation, cognitive understanding of the message being transmitted and acceptance of the evidence base or values on which it is based.

Notwithstanding the information available, if people are to change their behaviour they need to encounter no substantial barriers to change. Barriers to such change can result from financial cost or to indirect costs (in terms of time, for instance). For example, changing from electric to solar hot water involves a financial up-front investment that can be prohibitive even though there is a promise of later savings in electricity bills. Other factors affecting people's capacity to change include the extent to which everything an individual requires in order to make a change is within their control, or if it requires other people to act. Cooperative or enabling action by other individuals, corporate or governance bodies will increase an individual's capacity to change. For example, the provision of bike paths and bike sheds by governments is making cycling more feasible for individuals; kerbside recycling bins and collection trucks make household recycling feasible and easy for individuals; innovation, low-cost production and widespread availability in shops of water tanks and kitchen compost bins overcomes cost and accessibility barriers. Incentive schemes introduced by government are also designed to increase capacity and uptake of change (e.g. subsidies for replacement of ageing appliances with new energy efficient appliances). Some incentives come directly from market forces. For example, rising petrol costs meant that the potential cost-savings from changing to smaller or more fuel-efficient cars were an incentive to many people; car-share schemes have also experienced recent growth.

Efficacy and agency

A final key factor that determines whether people change their behaviour towards the environment is efficacy. Efficacy is a function of people's agency—their sense that their individual actions will make a difference—and their attitude to the future, either optimistic or pessimistic [27]. Therefore we find that individual perspectives about the future can be optimistic or pessimistic in terms of their ability to influence, and optimistic or pessimistic in their expectations about how the future may evolve.

If we think about those leaders who inspire change, we might expect that they are people with high agency and an optimistic attitude to the future. Activists may feel pessimistic about future trajectories. Both those groups feel that their own actions will make a difference and the difference is worth making. On opposite poles are people with low agency who have a pessimistic attitude to the future.

They feel disempowered to act and are pessimistic about whether any action will make a difference. These differences are not fixed, depending for example on the particular issue being considered. For example, biodiversity conservation is impacted by many pressures, has long time lags between pressure and response, and any action at an individual level rarely makes a discernible difference. These factors can result in individuals having low efficacy on biodiversity conservation issues, even if they are change leaders in other sectors such as reducing water consumption.

On the other hand, low efficacy is entrenched among some social sectors. Entrenched low efficacy (the sense that an individual's actions can make no difference to their situation let alone in the wider world) is a mark of social exclusion. Individuals who are income poor, with low education and poor access to information (due to poor literacy, low income, lack of English etc.) are most likely to have entrenched low efficacy. If people's persistent experience is that nothing they do can make a difference to their own situation, they become despondent or depressed. Learned helplessness is an associated response. These psychosocial states impact negatively on individuals' capacity to buffer the impacts of sustained biomedical stress, which in turn readily proceeds to chronic disease conditions [28, 29]. In addition, social exclusion limits people's access to financial, social and other capitals (information, skills, social connections to more efficacious people etc.), limiting their capacity to change their behaviours and the prospects of them being exposed to trusted people who have different ways of behaving and might influence their own directions. As previously explained, this vicious cycle promotes entrenched intergenerational disadvantage. The consideration of preferred future trajectories is important in creating a prosperous Australia that is socially equitable and environmentally sustainable. Understanding the social dimensions in conjunction with the biophysical characteristics adds an understanding of how we might create desirable future spaces.

4 Prospects and conclusions

Future trajectories need to take into account unlikely societal scenarios. History is full of surprises. For example, experiences of the Great Depression gave rise to the New Deal and income support for unemployed people. Mobilisation for World War II and the subsequent Marshall Plan (rebuilding war-torn Europe) contributed to the Colombo Plan and the birth of international aid and development assistance. In more recent years, Australia has seen material shifts in biodiversity loss and a scaling-up of government and philanthropic resources for voluntary conservation activities. We have also seen sustained shifts in attitudes towards climate change and some acceptance of policies that result in slower economic growth in order to achieve a largely non-economic goal. Yet there are other examples of inertia in attitudes and institutions, even in the face of significant contextual change. Income support and other policies that relate to unemployment, for instance, were designed in a time when most unemployment was short term and do not fully address the personal and wider societal costs of long-term unemployment and the skills and other dimensions of labour market re-entry.

For social and other scientists, a next step is to build scenarios of the future at both local and national levels and to use consultative approaches to engage populations in decision-making to set in place the policies, strategies and programs to realise the preferred future. Australians are increasingly mindful that the biophysical and social worlds intersect and that changes in one domain compound changes in another. They are also well able to contribute to decision-making beyond the conventions of the election of governments. Addressing the future and selecting strategies to ensure humanity continues to live within a safe operating space requires increased attention both to the organisation of information and the mechanisms of engagement.

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Chapter 4

Towards scenarios for a sustainable and equitable future for Australia

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A scenario is an internally consistent narrative about the future, developed using a structured approach with clear and consistent logic to consider systematically how uncertainties and surprises in the future might lead to alternative plausible outcomes. Scenarios can share meaning at deeper levels than logic-based communication through their basis in narrative. Scenario development draws on a range of information, quantitative modelling, expert judgement and creative thinking. These ingredients are combined using procedures that ensure that three key requirements are satisfied: legitimacy (that the information base is reliable and the models used are sound), saliency (that the questions or future uncertainties probed by the scenarios are pertinent) and credibility within specified boundaries (that the scenario is considered plausible by participants in the scenario-building process and by observers). A crucial starting point in scenario development is the specification of a focal question. To exemplify these concepts, we consider scenarios arising from three different focal questions, respectively concerning approaches to climate change, governance and complexification. Finally, we consider processes that could potentially engage Australian society in using scenarios to navigate the future, thereby aiding a national strategic conversation about the issues driving change in Australia over the next 40 years and their relevance for human wellbeing.

1 Introduction

A realistic vision for a nation needs to include more than abstract values and hopes—it must also consider how those values and hopes might influence natural environments, human settlements, jobs, technologies, political systems and the like. That requires the consideration of the plausible ways in which the future might unfold.

Considering how the future might unfold is challenging. This is because we cannot always be certain how current trends in the social, economic, political, environmental or technological spheres might continue or change, what new trends might emerge and how these trends might interact with one another. It is also difficult because the full range of plausible futures includes elements that many people, including those who set policy, find uncomfortable to consider or discuss. This complexity and uncertainty can seem overwhelming, and many decision-makers simply extrapolate the future based on trends of the past. This amounts to assuming linear change and expecting to be able to predict the future—both of which have been shown to be frequently untenable assumptions.

There are, however, ways in which we can engage with the future productively. We can achieve this engagement by undertaking a systematic consideration of what has been learned from the past, present knowns and unknowns, and future possibilities. Some of these possibilities we can be confident about and others might come as surprises and shocks to many people. We need a mixture of research and informed imagination in order to consider issues of this nature. Almost always, we require some form of scenario—an internally consistent depiction of a situation, and how that situation might have come about. Strategic plans, political policies and many computer models, movies, novels and newspaper editorials present scenarios of some sort, some more rigorous and logical than others.

Some scenarios, such as imagined reconstructions of a crime, may concern the past, but in this chapter we use this term to refer to imagined but plausible futures. Our definition of a plausible future is one in which the events and trends envisaged do not break any rules of physics and are logical even if some events or trends might not seem likely given past experience and current understanding. It is important to note that 'improbable' is very different from 'implausible'; in fact most scenarios in their entirety are highly improbable because there is a miniscule chance that they will play out exactly as presented. However, they can still be plausible. For example, a scenario that imagines Australia becoming a totalitarian state might seem highly improbable, but it might be plausible if a defined set of events and trends unfold. On the other hand, a scenario in which salinisation of Australian soils or the nation's decline in biodiversity were quickly reversed through revegetation of catchments over a period of a few years would be implausible because revegetation and the hydrological and population changes needed for this to occur cannot take place in such a short time frame.

The discipline of scenario planning uses highly structured approaches to develop narratives about the future that have clear and consistent logic and draw on a range of information, expert judgment and creative thinking. Scenarios created through these approaches combine stories and knowledge: stories create and maintain powerful mental associations, while formal and informal knowledge is drawn from a wide range of sources to develop plausible narratives. These scenarios systematically consider how the uncertain aspects of the future might develop to create alternative plausible futures. They have many purposes, including raising awareness of future possibilities, developing well thought-out strategies to achieve desired futures and/or to prepare for possible challenges and opportunities.

This chapter explores the use of scenarios as a way to address the framing question: what is our realistic vision for an ecologically, economically and socially sustainable Australia in 2050 and beyond? In the following pages we will consider how a scenario planning process can help to identify factors that might influence the future and therefore the types of visions that might be possible and the constraints on achieving those visions. We will also consider the role of scenarios in defining the elements of a 'safe operating space' and explore how these elements might change under different assumptions about the future. Ultimately, scenarios provide a basis for considering what interventions might be needed and when they might be needed for us to avoid undesirable aspects of the future and achieve desirable ones. The scenarios we present here are not developed sufficiently to address these questions in detail, but we have carefully considered how they could be addressed by people across Australian society—a process that we argue is vital for developing visions for and achieving desirable futures.

A key objective of scenario development is to facilitate strategic conversations—dialogue among diverse groups, as unconstrained as possible by agendas or blinkered thinking, about future possibilities and the consequences of currently discernible trends over the longer term. Approaches to the development of scenarios, and the use of scenarios as thinking, planning and management tools, have been refined for more than five decades in many counties and settings [1, 2, 7]. Jones [Volume 2, Chapter 12] discusses theory and practice with respect to scenario development, and Cocks [Volume 2, Chapter 13] gives an example of a family of scenarios for Australia's future. In this chapter, we will consider processes that could potentially engage people from across Australia and all parts of Australian society in developing and considering scenarios for their futures. We also reflect on the sorts of issues that are likely to frame different families of national scenarios for different purposes and audiences.

We believe that it would be worthwhile to generate a national strategic conversation about the issues driving change in Australia over the next 40 years and their relevance for human wellbeing. However, no scenario developed over the course of a four-day workshop could hope to achieve this, so we have aimed to lay the foundations for a larger process by developing a range of exemplar scenarios. Our hope is that these exemplars will illustrate the approach and indicate paths for future work involving more detailed scenarios. In the following pages we will also suggest how this start can be used to help generate a national approach to living scenarios—scenarios that are regularly reviewed and modified by different stakeholders as new knowledge and different needs emerge.

2 A central issue: the knowledge–action gap

As we have discussed above, uncertainty about the future is a major challenge. So too is the so-called knowledge–action gap, the sometimes large separation between the knowledge that scientists accumulate and the ability of the public and its leaders to understand, interpret and use that knowledge [8]. There are challenges on both sides of this gap. On the one hand, scientists struggle with a tension between their role as objective researchers and thinkers and their desire to contribute not only data but opinion to public debates [9]. Among non-scientists, meanwhile, the difficulty of distinguishing between objective information and assumptions and beliefs can often result in confusion about what is known and what is surmised. Sometimes scepticism and distrust of science and scientists can be the result.

There can be no better example of the consequences of not dealing with the knowledge–action gap than the current global indecision and lack of action over climate change. Independent assessments of the scientific literature have shown that among many thousands of research publications there is no credible disagreement with the conclusion that the Earth's climate is changing in ways that require urgent action. Yet the doubts expressed by a small number of individuals have contributed to stagnation of action to address climate change in most countries [10, 11].

Why is it so hard to bridge the knowledge–action gap? Recent research has focused on the challenges of communicating complex environmental issues that emerge over long time periods to publics that do not have specialised scientific knowledge and are focused on immediate threats. For example, it is difficult to talk about the future threat of climate change or environmental degradation and still expect people to be prepared to take urgent action now [12, 13]. Some psychologists argue that the reaction pathways in human brains evolved to respond to threats that are imminent, immoral, intentional and/or instantaneous [12–14]. Such responses equipped our ancestors with the ability to deal with dangerous animals and with rival humans who sought to do them harm, but they appear to fail for threats like climate change that emerge slowly and cannot be readily blamed on immoral or intentional actions by others. Some regularly occurring aspects of climate, however, such as winters and droughts, seem to trigger appropriate responses in humans. Amerindian populations, for example, evolved a regional trading system about 600 years ago to cope with extended droughts [15]. In Australia, severe climatic events, such as drought and floods, elicit strong responses from the public and governments while debate rages about whether any action should be taken about climate change, which has the potential to exacerbate the effects of droughts and floods greatly [16].

Any attempt to communicate about possible futures must take account of the diverse ways in which people share information and opinions. Vivid stories, movies and the like have the potential to help people experience the future's issues now and bring together emotions and beliefs with various forms of information. There are examples of how effective this can be in indigenous populations, who use storytelling much more frequently than modern Western societies. Knowledge of tsunamis successfully transmitted over many generations by some indigenous populations in Thailand, the Andaman Islands and the Solomons enabled extraordinarily high rates of survival compared to other groups (17, 18).

Scenario planning has several potential roles in bridging the knowledge–action gap. The obvious role is in helping people to jointly construct coherent visions of alternative futures, which they can then use to help make informed comparisons between different decision options based on long-term implications brought forward into today's consciousness.

A second role of a well-structured scenario planning process is to identify the assumptions made by participants and the broader set of stakeholders as well as the range of beliefs, attitudes and relationships among people who influence or are influenced by the issues that the scenarios focus on. For the participants, this can be one of the most valuable parts of the process, because they increase their awareness of their own ways of understanding the world as well as those of others.

A third role is to allow participants to explore the future implications of different ways of understanding the world. These ways of understanding include many different types of knowledge, one of which is scientific knowledge, and a good scenario-development process can help stakeholders test not only their own ideas about how the future might unfold but also the scientific knowledge about the present and its implications for the future. This is a mechanism for increasing trust and confidence between stakeholders.

Joint development of scenarios as a way of exploring alternative futures has been shown to work very well in groups of a few people to more than 50. Later in this chapter we will ask how it might be applied to whole societies. Engagement and strategic dialogue on a societal scale is a huge challenge but perhaps one that is essential if we are to address the societal-scale challenges that Australians are now facing and will continue to face into the foreseeable future. Interestingly, some of the trends that are contributing to those challenges also offer hope for dealing with them. For example, globalisation, ubiquitous electronic communication and developments in technologies for data capture and analysis offer the chance of achieving society-wide dialogue that was impossible in the past.

3 The use of scenarios to explore future options

A scenario is an internally consistent representation of the future that is in some way plausible (as defined above), or at least not implausible. Scenarios often have a strong narrative element; that narrative can be communicated in a variety of ways, including text, pictures, video, storytelling or drama. The narrative is used to assist decision-making in a way that allows a new story to be told or that realises an existing narrative. Scenarios are developed around both evidence and values, both of which give insights into how the future might unfold.

There are three strong conclusions that arise from the decades of existing literature on scenario planning: i) achieving useful insights requires a structured process that employs sound research and information, acknowledges and examines diverse worldviews and assumptions, and addresses prejudices, mental filters and other quirks that hinder creative and wise foresight; ii) the greatest value or benefit of scenarios accrues to those involved in scenario development; and iii) communicating the insights gained from scenario work requires consideration of the needs and receptivity of target audiences.

To achieve useful insights, provide value to participants and be credible to diverse audiences, scenarios need what Cash et al. [19] describe as legitimacy, saliency and bounded credibility:

- Legitimacy describes the nature of the information used, whether it is reliable and survives scrutiny, peer review and testing (including obeying laws of nature).
- Saliency refers to the inclusion of prominent, information and narrative elements that are generally recognised as pertinent.

- Credibility refers to the reception by participants and observers, which thus influences the likelihood that the scenarios or scenario-building process will contribute to decision-making.

There is a delicate balance to be achieved with respect to these criteria, especially credibility. Scenarios that may seem credible to some audiences may not to others, and credibility can change with time. For example, several scenarios about the future of South Africa, with and without apartheid, were developed in the 1980s. The scenarios were initially seen as not credible by many South Africans but were gradually accepted by more people and eventually influenced high-level decisions in government [20, 21]. Similarly, extreme climate change scenarios developed in the early 2000s for the Pentagon were designed to stretch the bounds of what decision-makers thought was credible [22]). These scenarios have influenced books, movies and essays in the media about possible extreme outcomes of climate change such as a new ice age in the Northern Hemisphere or increased risks of hostilities driven by movements of climate change refugees [23]). Earlier scenarios by Royal Dutch Shell considering the possibility that oil prices might rise [24[and by the US Air Force considering the possibilities of travel to the moon [25] are further examples of scenarios that questioned what was thought to be credible at the time. In Australia, scenarios developed in 2004 by the Business Council of Australia considering the possibility of China shifting its market focus away from Australia [26] were greeted with some scepticism by many readers, and yet this is frequently discussed today as one of Australia's worst fears (along with a collapse in the Chinese economy). Similarly, various scenarios considering the possibility of Australia having a different system of government (e.g. [27]; Cocks, this volume) might seem unlikely, but it was not long ago that the collapse of communism in eastern Europe seemed a slim and distant possibility [(3]), the likelihood of a hung parliament in Australia was thought highly unlikely [28] and the chance of a slump in the US economy seemed almost unthinkable (despite some logical arguments from leading economists that this was actually quite probable [29]).

The key point of these examples is that the credibility or otherwise of a scenario is not established on the basis of what people will readily accept but by what can be argued with clear logic. Often scenarios are considered incredible by some readers because they rely on some triggering event or trend that the readers find unlikely, but once that event has occurred readers can accept the subsequent logic. This is why it is important to be clear about enabling assumptions and sequences of events in scenarios so that they provide roadmaps with forks in the road, and milestones. Not only do these event sequences allow the scenarios to become useful in the future once it appears that a previously unlikely scenario might be unfolding but they also allow planning for multiple plausible futures to include investments that are only required once certain trajectories of change become apparent.

Although academics and practitioners have developed many different approaches to scenario development, the core of most approaches include processes:

- to agree on what question is being asked about the future
- to gather and consider information about past and emerging trends and likely important drivers of change
- to identify and acknowledge different perceptions and ways of thinking (e.g. values, world views, assumptions, mental models) that might influence the framing of the scenario question, the interpretation of information or visions and preferences for different futures, and which might themselves contribute to the ways in which the future unfolds
- to decide which trends and issues should be focussed on in the scenarios
- to refine and challenge the scenarios
- to draw conclusions from the scenarios as a trigger for action.

The authors of this chapter have experience with a range of different approaches to scenario development, including that developed by Royal Dutch Shell (Figure 1), the Intergovernmental Panel on Climate Change [30] and the Millennium Ecosystem Assessment [31]. Most of our deliberations at this workshop revolved around the framework shown in Figure 1.

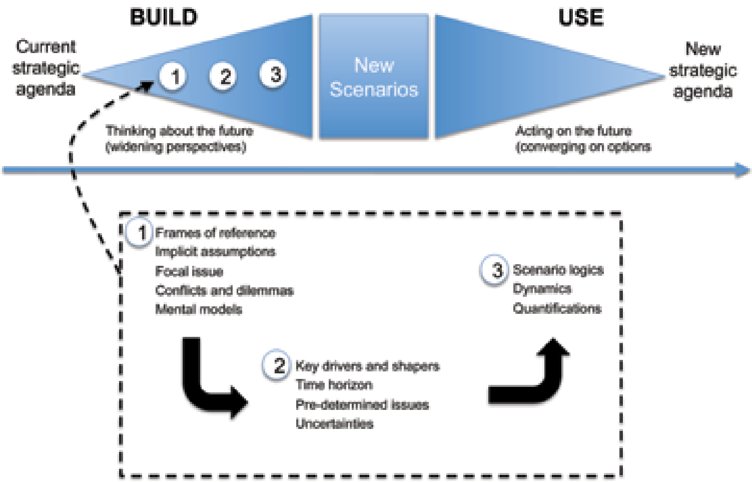

Figure 1: The components and stages in a typical approach to scenario planning (adapted from Royal Dutch Shell [32]).

4 Clarifying the question

The first and arguably most important step in scenario development is to formulate a clear focal question about the future. This challenge is not unique to scenario planning—all dialogue about the future is likely to be less productive without clarity and agreement on its focus and purpose. This does not mean that all participants in scenario planning must agree on aims and visions for the future—but they should agree on a common question that they are all addressing.

During the Bowral workshop, members of the scenarios working group agreed that the framing question for the workshop needed to be further clarified and focused to make it tractable in a scenario planning process. To do this, we agreed that several subsidiary questions should be addressed:

- What is meant by ‘an ecologically, economically and socially sustainable Australia’?
- Who should answer this question? Many current Australians will be dead well before 2050, yet many Australians who will then be alive are currently too young to participate. Many aspirations vary by generation, although fundamental needs such as food, shelter and the desire for opportunity and self-expression will surely endure. How can or should we (the workshop participants or even the whole current Australian population) identify a single vision for an ecologically, economically and socially sustainable Australia in 2050, given the numerous competing visions that might fit these criteria?
- There may be numerous possible ways in which Australia might be ‘sustainable’. Can we identify the limits within which alternative acceptable futures should lie?

One way to address these questions in a scenario planning process is to define a desired future, or a suite of desired futures that lie with a ‘safe operating space’ and develop scenarios that consider the steps that are likely to generate those desirable futures, given our understanding of the obstacles and solutions we perceive as helping or hindering those pathways. Such scenarios are often called normative (because they seek an agreed societal norm).

Another way to address the questions listed above is to explore the range of plausible paths into the future. This approach would consider how trends that are already established, trends that are only just showing indications of emerging and trends or events that could emerge as surprises might interact. Considering this range of plausible futures that Australia might experience would facilitate discussion not only of routes to desirable futures but ways to avoid undesirable ones. Desired futures could be identified by considering which of the plausible futures look appealing after the scenarios have been constructed. In the rest of this chapter we refer to scenarios developed by considering multiple plausible pathways into the future as ‘explorative’.

We decided to investigate both normative and explorative approaches. Our scenario development process, therefore, identified two focal questions that relate to the two types of scenarios investigated:

- Assuming that we can loosely define a set of attributes that should be part of desirable futures (see following section), what steps might be required to ensure that those attributes are maintained within acceptable levels by 2050?
- What factors might influence change in the ecological, economic and social sustainability of Australia between now and 2050, what factors and influences are relatively certain versus relatively uncertain, and how might uncertainties play out in a range of ways to generate a plausible range of desirable and/or undesirable futures for Australia?

5 Assumptions, conflicts, dilemmas and mental models

Thinking about the future, whether by using scenarios or another tool, is likely to be hindered if participants are unclear about their own values, beliefs and assumptions and about those of others. Unless prompted, people rarely consider their underlying assumptions even though these assumptions strongly influence what they think is desirable or undesirable and plausible or implausible. Assumptions often become widely accepted without anyone questioning whether they are supported by evidence [33]. People often assume uncritically that the events of the past will continue in the future [34)]. It can sometimes be a shock to realise how differently the values and beliefs of others can be [35]). Exploring these issues can sometimes be insightful, revealing new understandings, both of ourselves and others, and furthermore revealing the existence of flaws in thinking that have been termed ‘predictably irrational’. In the best cases this process of exploration can illuminate differences of opinion, minimise resolve and even avoid conflicts [35].

Ideally, a process would exist that collects and disseminates the assumptions of a wide range of Australians. In the absence of such a process participants at the Bowral workshop made a start towards identifying key assumptions relevant to the scoping question (Table 1), which we hope will form a foundation for others to build on.

Issue	Examples of diverse viewpoints (some better supported by knowledge and information than others)	
Economic growth	High rates of conventional economic growth (GDP) are vital for Australia's future.	Assumptions about the importance of continued economic growth at all costs are questionable.
How to measure progress	Conventional measures are adequate and will continue to be so.	A sustainable Australia requires reduced consumption of natural resources and progress that is defined by social and environmental considerations as well as economic ones (which might include lower rates of conventional economic growth).
The future of emerging economies	The economies of China and India will continue to grow and benefit Australia for at least several decades.	One or both of these economies could collapse or decrease their connections with Australia.
Nature of the Australian nation	Australia will remain a social democracy within its existing physical boundaries and with a political system similar to today.	Various (seemingly highly unlikely) possibilities of changes to Australia's federal system, destabilisation of our democracy or even annexation of some parts of Australia by other countries.
The nature of the Australian character	A future Australia will value fairness, equality of opportunity and tolerance of diversity.	We might see deliberate or unintended shifts in values.
Resilience and adaptive capacity	Social and biophysical resilience and adaptive capacity are declining, both nationally and globally, and this makes Australia vulnerable to future shocks.	These are difficult terms to define and anyway people always find ways to cope with major challenges.
Natural resources	Several natural resources are at or near their peaks or are already declining and this has the potential to create significant hardship for Australians if not addressed very soon.	There is no need to panic about resource scarcities because as one resource declines markets and/or innovation will find alternatives.
Role of markets	Market forces will alleviate scarcities (e.g. via technology, or substitution) and solve most problems of sharing of wealth.	Fundamental limits apply to capacity of market forces to solve environmental and social problems.
Climate change	Climate change can be managed by incremental change.	It requires an urgent, global response.

Role of science	Science on the whole is credible and valuable and can provide useful working hypotheses.	Science cannot be trusted and/or is too uncertain to contribute to major problems facing society.
Decision-making	Decision-making should be based on a thorough risk analysis (informed by science).	Political realities and pragmatism should be the main determinants of decisions.
The state of the world generally	We are heading irreversibly into catastrophe as safe operating boundaries are breached.	There is still room to move and time to act.
Australia's population	A medium to high rate of population growth is in Australia's interests.	Australia's population is already too high for sustainable use of natural resources and ongoing maintenance of high quality of life.
	Australia needs a population policy and plan.	Population issues can be resolved without a long-term policy.
Short-term versus long-terms goals	Short-term decisions are more important than long-term strategic decision making.	Australia risks becoming increasingly vulnerable to future shocks and to missing future opportunities unless it invests more in long-term strategic thinking.
Hope for the future and engagement in shaping the future	Nihilism (despair for the future, living for the moment as if tomorrow might not come) and/or fundamentalism (searching for meaning in fundamental belief systems).	Activism (hope for the future and engagement in shaping a desirable future).
Value of intellectual pursuits	Research, innovation, philosophy and other intellectual pursuits are vital for Australia's future.	Scepticism about the value of intellectual pursuits and in some cases anti intellectualism.
Authority	Respect and support for authority.	Scepticism and distrust of authority.
Social composition	Australia will flourish with a population drawn from diverse ethnic and cultural backgrounds.	Tolerance for people from different backgrounds is limited; excessive diversity is harmful.

Table 1: Examples of key issues about which there are diverse assumptions, views and beliefs across Australian society. Issues such as these need to be identified and discussed when considering options for an ecologically, economically and socially sustainable future Australia. Although they might be sources of disagreement, acknowledging them allows their implications to be explored in future scenarios, whereas ignoring them works against cooperative action towards a better future.

The competing assumptions that are evident in debates about Australia's future reflect different beliefs and values. In many of the cases included in Table 1, different viewpoints might apply in different situations. Examples of these differing viewpoints include varying views about approaches to economic management, optimism or pessimism about the capacity of technology to solve environmental problems and contrasting opinions about how large Australia's population could or should be. Some argue that in most of these cases differences of opinion persist because there has been too little dialogue about the future and what would need to happen for different perceptions of the future to be valid. For example, when the consequences of increasing Australia's population without drastically changing current consumption patterns are analysed, it becomes clear that for larger populations to be socially, ecologically and economically sustainable there will need to be major changes in attitudes, technologies and settlement patterns [37, 38]. These possibilities can be built into scenarios so that ways of achieving hoped-for future changes can be explored along with the implications of those changes.

In other cases addressed in Table 1, differences of perception are based on differences in understanding and access to information. Sufficient science exists to reduce these differences but it needs to be communicated and accepted by the public [39]. The overwhelming majority of scientific evidence indicates that there are serious issues to be addressed with climate change that cannot be addressed through incremental adjustments to policies and practices. However, there is considerable 'cultural resistance' to science within society, especially when non-scientific ideologies are represented as common sense and are transmitted by trustworthy sources [40]. Further, even many highly educated people exhibit fundamental misunderstandings about climate. Sterman [5] found that when presented with a very simple systems model of how atmospheric carbon dioxide (CO_2) is regulated, many university students do not appreciate that a slow reduction in carbon dioxide (CO_2) entry into the atmosphere over the next 40 years will not lead to a corresponding reduction in atmospheric CO_2 levels (and hence climate change), because atmospheric CO_2 levels will continue to rise as long as the rate of entry exceeds the net rate of removal by natural CO_2 sinks on land and in the oceans [41, 42].

Table 1 includes viewpoints like the example above that could be made clearer by promoting open dialogue between scientists and wider society. A scenario development process would normally seek to identify which assumptions about the future can be made with relative certainty, which are uncertain and which are potentially critical. A major challenge for scientists is to convey what is relatively certain and what is uncertain without causing confusion and undermining confidence in the science and the scientists [8, 39]. While it is relatively easy to sort relative certainties from uncertainties among the staff of a company or among a community group whose members have similar values and beliefs, Table 1 illustrates how hard it is likely to be at a national level. And yet, unless some agreement can be reached about fundamental issues like whether there is a need to address climate change, it is impossible to achieve agreement on ways forward towards desirable futures. Therefore, when we discuss possible approaches to living scenarios later in this chapter, we propose processes for using scenarios to allow stakeholders to explore the evidence behind different assumptions and the potential future implications of basing decisions on different viewpoints.

6 Defining an ecologically, economically and socially sustainable Australia

Agreeing on what might constitute an ecologically, economically and socially sustainable Australia in 2050 is a particularly challenging task for a national consideration of alternative futures for Australia. All working groups at the Bowral workshop addressed this question, drawing on the professional opinions and experience of the workshop participants and on a range of other published and unpublished information on the attitudes of Australians. Our discussions took place in the knowledge that debate about the meaning of 'sustainable' has raged for decades. As this debate has continued, there has been increasing agreement that human social and economic systems should be considered as being inseparably coupled with ecological systems [43]). It is only recently, however, that there has been serious interdisciplinary discussion about definitions and measures of aspects such as equity, wellbeing, resilience and adaptive capacity in the context of coupled social-ecological systems [44–46] .

For the purposes of our scenario development process, we have drawn the following conclusions:

- It is neither possible nor advisable to define a single vision for a desirable future Australia (in fact, there is merit in allowing the development of scenarios to help explore alternative definitions and concepts).
- It is, however, possible to define the main elements of desirable futures and also to identify elements that would be undesirable in any future.

Australians are likely to hold many, sometimes competing, views about the elements of an ideal future. Focusing too strongly on any single conceptualisation of these elements is likely to stifle diversity, innovation, resilience and adaptability. This in turn will complicate any efforts to adjust our development trajectory as the future reveals itself. Conversely, acknowledging and seeking to understand and value a diversity of views are likely to contribute options as we seek to adapt to change and maintain social and ecological resilience.

Nevertheless, it is possible and advisable to consider some core attributes we might want our future to include. Identifying these core attributes is important because it helps reveal the values, beliefs and hopes of different people and may also draw out hidden assumptions that we make about the future. Once a set of core attributes is identified it can be used to promote dialogue to refine the desired set and to guide steps to achieve those desired elements now and in the future.

Drawing on the intergroup dialogue at the workshop and the reports from the working groups in this volume, we suggest that core elements of an ecologically, economically and socially sustainable Australia include:

- good individual and population health (mental and physical)
- equity of opportunity for a good life
- freedom
- satisfaction.
- security (including not just safety, but also confidence that people have access to the other aspects of wellbeing in this list)
- social relations
- material sufficiency
- sense of purpose
- ongoing, mutually beneficial, contact between people and the natural environment
- mechanisms for engaging all relevant parts of society in making major, especially complex, decisions.

However, we recognise a need to engage a much wider subset of the Australian population in a dialogue about what the components of this list should be.

7 Drivers and shapers of change

Having defined some core elements of an ecologically, economically and socially sustainable Australia (as we perceive them), we consider below what factors might affect those elements in the future. Table 2 lists key likely drivers of future change developed through our own deliberations and discussions with other workshop groups.

Some trends can be considered to be essentially unavoidable (i.e. they are already in place and it is very unlikely for them to be reversed) whereas others could develop in more than one direction. Those that are both uncertain and likely to be critically important in at least some situations are often referred to as critical uncertainties. These are usually the focus for scenarios.

Category	Details
Key Drivers (external—difficult to rapidly influence):	
	World trade (source of wealth and power to some, makes humanity a planetary force, a powerful driver of resource consumption and potential environmental catastrophes). Globalisation and technological change (essential for our survival and prosperity; increasing connectivity and specialisation; dissemination of power and awareness to the global community; greater cooperation to deal with widespread disasters or decreased resilience due to complex, interconnected bureaucracies?).
	Climate change.
	Fossil fuel depletion and rising energy costs.
	Other resource depletion—food/potable water/other.
	Global population (7 billion, rising to 9 billion by 2050—aspirations for improved quality of life). Poverty and inequality (15% of world population enjoy 80% of world GDP; 43% live on less than $2 per day; inequality in the developed world is increasing).
Shapers (can be influenced domestically):	
	Australian population growth.
	Community, corporate and political awareness of key issues.
	Social complexity.

Shapers (can be influenced domestically): (Continued)	
	Search for improved quality of life.
	Social and political organisation.
	Innovation and technology.
Unavoidable constraints:	
	Drivers of climate change are already changing significantly, which implies that climate is changing and will continue to do so (although uncertainty still exists with respect to some details of how this change might emerge in different places over different time scales).
	Peak of global oil supply is here or close or has been passed [47] Global biodiversity is declining, many ecosystems and species are seriously damaged.
	Global population growth to at least 8.5 billion.
Critical uncertainties:	
	Rate and severity of climate and other environmental change (e.g. character of tipping points—i.e. thresholds at which major irreversible change initiates).
	Attitudes of decision-makers towards science (e.g. urgency to achieve an equitable and ecologically and socially sustainable Australia—how quickly do we need to achieve targets if major impacts are to be avoided?).
	Increasing complexity of society or simplification[1] (deliberate or as a collapse).
	Geographic centre of economic and/or other power (e.g. how far might economic and other power move to the east, which countries—such as Brazil, Russia, India, China or others—might rise to be globally influential economic forces?).
	How Australia deals with population (proactive, reactive, targets for rate of growth, where and how people live).
	Rate of development and relevance of technological contribution to solutions.
	Future governmental focus (e.g. form and scale of economic growth, environment, compromise).
	Access to essential resources (e.g. food, water, energy) from within Australia and globally.

Table 2: Drivers and shapers of change and more or less certain factors influencing possible futures for Australia

8 Scenarios

How scenarios address the framing question for this workshop

What is our realistic vision for an ecologically, economically and socially sustainable Australia in 2050 and beyond? As explained in the Introduction to this chapter, a scenario development process helps us identify what factors might influence the future, explore how those factors might play out under different assumptions about the future, and consider what interventions might be needed to encourage desirable aspects of the future and discourage undesirable ones. While participants in a scenario development process might have existing visions of an ideal future, the process helps to draw out the often different visions that exist and explore the assumptions, beliefs and values behind them. Developing multiple scenarios based on different visions, assumptions and factors that might shape the future allows participants to explore the consequences of different views and different interventions.

Often it will become apparent that multiple alternative visions can be achieved simultaneously, in which case scenarios can be used to explore what interventions might be needed to achieve this harmonious outcome. Sometimes different visions might clash, in which case scenarios can be used to explore how such clashes might arise and how to minimise them. Often participants in a scenario planning process reassess their assumptions and realise that some of their future expectations are not possible or not desirable because of hidden side-effects. Equally, participants often discover that there are possibilities that they had not thought of or had previously thought were not possible.

The process that our working group went through during the Bowral workshop illustrates how different views about what is most important can cause a dialogue to fragment if we are not careful and respectful of others' views. It also illustrates that it not necessary to agree on one set of scenarios when exploring future possibilities and that there is likely to be benefits in exploring different priorities in different families of scenarios. In this way, our process is likely to reflect what might occur at a national level, and it offers some ways to deal with differences of view.

1 In this paper we use the term complexification to refer to the processes that increase the complexity of social-ecological systems, often to the point of gridlock. Current and recent examples might include complex governance structures and formal and informal institutional arrangements that apparently led to the global financial crisis of 2008, the political gridlock in the USA that is inhibiting the taking of many major national decisions, and the slow progress in Australia and elsewhere towards addressing climate change, looming shortages of fossil fuels and other major issues, partly due to the complexity of information and the difficulty most people have in understanding who to believe and who not to believe.

The process leading to our scenarios

Our working group included people from diverse backgrounds. However, despite our pre-existing familiarity with scenario planning principles, it was difficult for us to reach consensus on the most important critical uncertainties. This was partly due to the brevity of the workshop but also because of genuinely held differences of opinion about the most important drivers of change and the most effective ways for scientists to contribute to dialogue about intervention.

Some participants considered that the implications of climate change, combined with pressures arising from peak oil and the need for transition to alternative energy sources, were pre-eminent. These participants argued for a suite of national scenarios that focus on the likely consequences of urgent, emergency action to address climate change and compare these with the likely consequences of alternative policies. Such scenarios, it was argued, should starkly present scientific consensus about the consequences of business as usual and of alternative policies.

Others recognised the need to have scientific viewpoints on likely future scenarios documented, but considered it was important to also explore other factors likely to influence ways in which Australian society will cope with emerging future challenges and opportunities. For example, what consequences might arise from policy options founded on beliefs that climate change, energy, population and other challenges can be addressed incrementally? How might options for addressing future challenges be driven by broader attitudes about equity, democracy, economic growth and the roles of government and private sectors? These participants shared concerns about the risks of climate change but argued there is strategic value in Australians discovering for themselves the implications of different future options, because being engaged in putting the pieces together is likely to lead to greater acceptance of the need for action than even the most rigorous scientific evidence presented as a fully formed scenario. They suggested that scenarios developed jointly by scientists and other people who hold competing views, beliefs and sources of information, all striving to hear and understand alternative viewpoints, could make a major contribution to achieving this goal.

These differences of approach will seem small to some and large to others. They are likely to exist in the broader Australian communities and they will surface in any national strategic dialogue. Many who hold strong views will seek to communicate their understanding through scenarios and other avenues, while others may prefer future options to emerge through cooperative exploration of the future. We conclude that both types of approach need to be encouraged.

We also recognised that both strategies could be used as inputs to inform the other. Therefore, we developed three families of example scenarios, mapped with varying detail. These arose from consideration of different critical uncertainties as being most important (Figure 1).

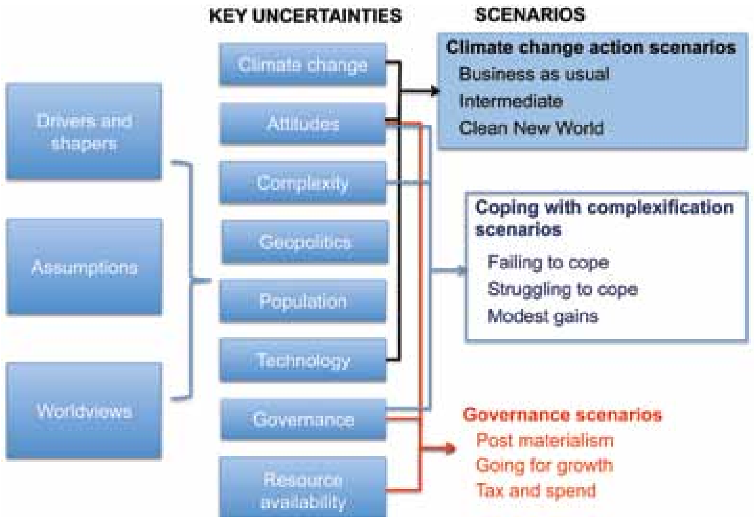

Figure 1: Evolution of three 'families' of scenarios, focusing on different combinations of critical uncertainties.

The approach demonstrated in Figure 1 is one of developing scenario families. This approach is well-established in the scenario planning literature. Scenario families are usually developed around critical uncertainties (i.e. different scenarios within a family explore different ways in which critical and uncertain drivers and shapers might develop). This approach is a type of systematic risk assessment—it allows us to consider the range of possibilities and what might be needed to prepare for them and/or influence which ones eventuate. In some situations, scenario families might strictly explore all combinations of critical uncertainties. For example, the UN's *Millennium Ecosystem Assessment* scenarios explore all four possible combinations of two critical uncertainties (degree of global connections and degree of proactivity in environmental policy). [31, 48] In other situations, scenarios might only focus on combinations of critical uncertainties that appear most useful and interesting. The scenario families shown in Figure 1 are of the latter type—each family explores different combinations of critical uncertainties but only some combinations of those uncertainties.

The climate change action scenarios

The climate change action family of scenarios investigates both of the focal questions identified earlier in this chapter to some degree, but especially the first one: assuming that we can loosely define a set of attributes that should be part of desirable futures (see following section), what steps might be required to ensure that those attributes are maintained within acceptable levels by 2050?

These scenarios arose from the assertion within the Bowral group that climate change is the most critical issue facing Australia and that action is needed urgently if highly undesirable futures are to be avoided. A related assertion is that undesirable climate change will threaten many, if not all, of the attributes of an economically, ecologically and socially sustainable Australia. A further key assertion is that there is a disconnect between science and policy that must be addressed because the interactions between climate change and other major long-term issues, such as peak oil, overconsumption of a range of resources, and population growth (Table 2), can only be effectively addressed if science is understood, trusted and able to join other ways of thinking in contributing to both biophysical and social processes.

These assertions and the other assumptions made in these scenarios (see below) can be contested, and indeed are, by some stakeholders. Part of the purpose of scenarios is to explore the implications of a range of world views, both to test their credibility and to see what implications there might be in the future if they turn out to be correct. Ideally, in the development of national living scenarios competing viewpoints would also be tested in this way.

Key assumptions associated with the climate change action scenarios are that:

- Science sounds increasingly urgent warnings of the need for real action to mitigate and adapt to the impacts of climate change.
- Politicians and corporations interpret this in the light of political reality, which weakens the action recommended science.
- The real risks to the community are underestimated (these hazards include an increasing possibility of catastrophic outcomes, and the elimination of options to take a graduated response, if current policies are maintained).
- Inaction today effectively locks in adverse outcomes for decades ahead.
- The convergence of these issues is unprecedented, requiring radically different thinking.

These scenarios address the focal question by exploring what steps might be required to reach a desired future in which climate change has been controlled and its undesirable implications for ecological, economic and social sustainability have been minimised (dubbed the 'clean new world' pathway). To do this, and to improve community understanding of the challenges, the pathway thought to be desirable by the group was compared with two other possible pathways—a business-as-usual pathway, and an intermediate pathway that adopts some of the measures proposed in the desirable pathway, but is constrained by trying to balance a range of competing agendas and not giving priority to what is needed to address climate change ('muddling through').

These scenarios are highly normative. That is, they are based on strong and clear ideas about what needs to be done and how this might be achieved. Figure 2 shows how the three climate change action scenarios link to three global trajectories that help to determine what options Australia has.

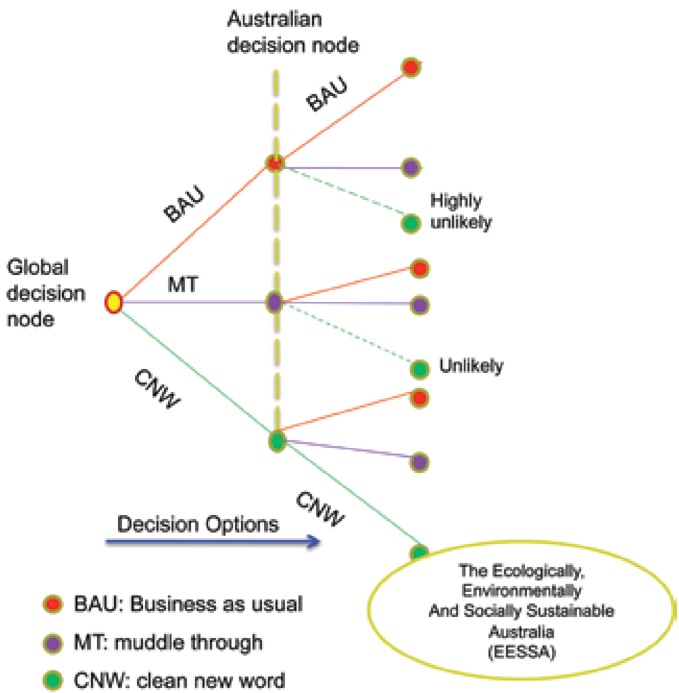

Figure 2: Relationships between the three climate change action scenarios that compare an emergency action pathway (clean new world) with two alternative pathways. This family of scenarios is based on the view that keeping the increase in global mean temperature within +2oC by 2050 will give Australia a good chance of being ecologically, economically and socially sustainable. The clean new world scenario achieves this. It is regarded as highly unlikely that an ecologically, economically and socially sustainable Australia (EESSA) could be achieved by Australia (green circles) if the world continues on a business-as-usual trajectory. EESSA is also considered to be unlikely under the intermediate 'muddling through' scenario.

The preliminary narratives for the three scenarios are shown in Table 3.

Scenario	Narrative summary
Business as usual	
	There is strong focus on economic growth, driven by resource exports and global trade, especially with China and India; biophysical limits are given secondary consideration. Two-speed economy intensifies, as does social inequality. High population growth continues, driven by immigration; this locks in a 4-degree world. Increasing natural disasters, urban degradation and infrastructure decline. There is intensified energy and resource nationalism, internal militaristic response (e.g. north-west Western Australia threatens to secede). Extremist politics start to dominate, foreign aid contracts, defence increases, there is a de facto alliance with China. Complexification increases, national resilience decreases but some local resilience increases. Coal is king, with coal and gas-to-liquids technology attempting to meet oil supply shortfalls, and intense conflict between coal seam gas and food supply needs.
Muddling through	
	Initially, there is partial acceptance of biophysical limits, including climate change, but short-termism dominates. By 2020, the ongoing intensification of extreme weather events convinces a frightened public and government to shift towards clean new world policies and technologies. Technological breakthroughs increase. Then, about 2030, a major catastrophe occurs in South Asia generating many new refugees; this is perceived in Australia as very threatening. While most clean new world policies continue, there is strong support to exclude refugees. Australia becomes more overtly nationalistic.
Clean new world	
	Strong global and national acceptance of biophysical limits accelerates energy transformation, urban redesign and quality public transport, enhancing energy security and decarbonisation. Greenhouse gas emissions peak by 2015, making it likely that the world's average temperature will not increase by more than 2 degrees, promoting health. Required speed of change demands new governance frameworks, to allow for emergency action. Attention is given to population policy, but disagreement continues. Reliance on China and India continues (but Asia also shifts to green technologies). There is increased global cooperation, especially around energy, climate and IT; military shifts towards peacekeeping and emergency relief. Rural decentralisation opens up agricultural and employment opportunities. Resilience increases, social and economic systems become more simplified. Per capita resource use is limited, contracting availability of consumer goods. Average wages fall.

Table 3: Narrative summaries for the three 'climate change action' scenarios

8.1 The governance scenarios

The governance scenarios also address both focal questions, but especially the second: what factors might influence change in the ecological, economic and social sustainability of Australia between now and 2050, what factors and influences are relatively certain versus relatively uncertain, and how might uncertainties play out in a range of ways to generate a plausible range of desirable and/or undesirable futures for Australia? These scenarios focus on how different foci for government policy in the next few decades might influence what can be achieved with respect to ecological, economic and social sustainability (Figure 1). These foci are:

- greater emphasis on protection of, and respect for, the environment and on giving people the chance to develop their own potentialities at a smaller group level than in contemporary society (postmaterialism)
- economic rationalism and marketisation (going for growth)
- public investment to build neglected sectors of society ('tax and spend')

The underlying assumption in these scenarios was that the strongest determinant of future Australian development is the philosophy adopted by governments. These scenarios illustrate how some stakeholders in Australia's future might want to explore alternative scenarios in a different way to that illustrated in the climate change action scenarios (Table 4). These governance-focused scenarios drew on thinking by Doug Cocks, who has subsequently documented a similar set of scenarios (see Cocks, Chapter 13 in Volume 2).

Scenario	Narrative summary
Postmaterialism	
	Summary. An Australian Government that has been in power for a long time is concerned with setting the parameters for society within which the environment will have greater protection and respect and people can develop their own potentialities at a smaller group level than in contemporary society. Overarching policy positions: 1) capping energy throughput for society as a whole; 2) capping material throughput; 3) stabilising population as soon as possible. *Risks:* Strong pursuit of this agenda could result in stagnation of the economy and failure to be adaptive enough and sufficiently responsive. *Benefits:* High chance of greatly enhanced environment quality and a socially harmonious society.
Going for growth	
	Summary: An Australian government adopts a strongly economistic (economic rationalist) approach to development, promoting marketisation and reduced regulation. *Risks:* Increased material and other forms of inequality, leading in the worst case to a highly disadvantaged underclass and considerable social tension. *Benefits:* High and sustained economic growth (as conventionally measured). In the best case, the trickle-down effect could improve material (but not environmental or social) living standards, even for the poor, and even if inequality increases.
Tax and spend	
	Summary: The election for a long period of a government strongly committed to a philosophy of tax and spend—in ways that use tax revenues to promote strong public investment in sectors of society that Australia currently has difficulty resourcing (e.g. maintenance of health, education and welfare infrastructure, selective support of science and technology, promotion of approaches to social cohesion). *Risks:* Economic stagnation with good access to public services outweighed by lower capacity for private consumption. *Benefits:* High access to public services is a basis for an equitable society.

Table 4: Narrative summaries for the 'Governance' scenarios.

There is a range of other possible scenarios in which an Australian government might take more direct control than those above (e.g. a theocracy, fascism). These currently seem unlikely, but some in society advocate them and Australia would be unwise to not at least consider how they might arise.

The coping with complexification scenarios

Like the governance scenarios, the coping with complexification scenarios also address both focal questions but especially the second. These scenarios focus on how increasing complexity of everything might influence what can be achieved with respect to ecological, economic and social sustainability.

The assumptions behind these scenarios are that:

- The growing complexity of life, decision-making and external pressures is driving Australian society towards the point where it might fail to cope.
- The attitudes that governments and society have towards complexity make a big difference to how we respond as a nation.

These scenarios (Table 5) illustrate yet another way in which some stakeholders might enter the dialogue about Australia's future.

One of the major determinants of how a society manages complexity is through its attitude to knowledge. Kitcher [49]) refers to two extremes of participation in knowledge that contribute to decisions. One is the commitment to equality, in that everyone has the right to make up their own mind and the other is to skill, where the division of labour means that expertise rests in various groups. Clearly, knowledge requires some degree of specialisation, but neither of two extremes on the spectrum of specialisation is desirable—having scientific 'experts' decree decisions, or a free-for-all where anything goes. Society runs into trouble if there is no clear public division between evidence-based knowledge and belief. Both democracy and free speech are held to be universal rights, but reason in decision-making can be impaired if these rights are exercised to try to impose belief over evidence [49].

The practice of science in a democratic society therefore needs to combine values and science (used in its broadest sense of the natural and social science, humanities and the arts) in a reasonable manner [9]—that is, to use reason in addressing complex issues. The working group all subscribed to this broad ideal, agreeing that scenarios were the best tool with which to address such issues. Reason is applied according to the guidelines set above where underlying assumptions are examined, evidence is supplied and openly reviewed, and scenario participants all have the right to express their opinions and the duty to listen to others. However, the group could not agree on the mix between science and values in all cases, nor could it agree totally on whether scenarios needed to be generated as part of decision-making or could be generated externally as one of the specialised activities mentioned above.

This is a central issue of complexification and we find ourselves in the situation where we believe that scenarios are suitable tools to use, but we remain unsure about the best method to use to go forward. This suggests that learning by doing should be part of the process of developing and applying such scenarios.

Scenario	Narrative summary
Failing to cope (overwhelming surprise/ignorance)	
	There is a large decline in quality of life through failure to manage several external and/or internal drivers. Governments and other institutions are so overly complexified that they cannot act effectively. There is a confluence of 'wicked' problems that are synergistic in diverse ways. Society is strongly adversarial, further preventing action. This scenario concerns a combination of major external and internal influences, blindness to them and lack of preparedness.
Struggling to cope (cognitive dissonance)	
	Australia struggles with institutional breakdown (schools, judiciary, corrections, public services, infrastructure). It copes partly because it started with a high level of resilience, though this is declining in this scenario. Community resistance to higher taxation means Australia is unable to find resources to deal with collective problems. Lack of resources keeps appearing as the key issue (people talk about improving efficiency but this cannot solve the problems). There is a slow degradation of resources and society. There is a failure of government to understand this is a complex system that cannot be managed by one-dimensional policy responses and that all policy action is ultimately experimental and this implies a willingness to be prepared to monitor outcomes, review and improve policy.
Modest gains (attitudinal change)	
	Governments recognise the complex nature of the problems we are facing. They are aware of the constraining impacts of social adversarialism at levels from political to group identities of all sorts (gender, ethnicity, religion). Strong policy responses at multiple levels address the socialisation of children and revamp the parliamentary system to give more emphasis to multiparty committees and other mechanisms for bipartisan action on key issues. Experimentation and adaptive management are used to find new policy approaches.

Table 5: Narrative summaries for the 'coping with complexification' scenarios.

9 Living scenarios

The three families of scenarios developed here are different from one another in several ways, but it also must be acknowledged that they represent a narrow set of views and values. For example, many of the views that are aired in the clean new world scenario within the climate change action family of scenarios might look similar to those in the postmaterialism scenario in the governance family. In the process of developing living scenarios it will be important that other world views are articulated and explored through detailed scenario planning processes, so that they are understood and their logic and potential implications for the future are tested.

Three other key insights emerge from the process we ran at this workshop. The first is that there is a strong need to better engage Australians to think deeply and in a more informed way about the interacting ecological, economic and social challenges facing the nation in the near and medium-term future. Many unproductive debates exist because people have competing information, assumptions, world views and mental models that filter out messages that are unwelcome, uncomfortable or inconvenient. There is increasing evidence that most people are biased towards optimism [50]. We need a process that encourages people to acknowledge and respect their different viewpoints and explore how Australia might develop if different pathways are followed.

The second insight is that any group of Australians, even if highly informed about factors that could affect Australia's future, is unlikely to agree on a single set of critical uncertainties around which to develop scenarios to inform progress towards an ecologically, economically and socially sustainable Australia in 2050. Different people will have different perceptions about how drivers of change operate and interact and they will see different uncertainties as being more critical than others. They will also have different values and beliefs that will lead them to think that different factors are more worthy of being addressed than others.

The third insight is that no family of scenarios, or multiple families, developed by a subset of Australians and passed on to others is likely to have the impact required to get people thinking deeply about future prospects and possibilities for this nation. Scenario planners have long known that the greatest benefits of scenario development are the insights gained being involved in the process.

Therefore, we propose a process that iteratively develops families of scenarios that are relevant to different groups of people and engages Australians from all parts of society in exploring the implications of alternative decisions and development pathways (Figure 4).

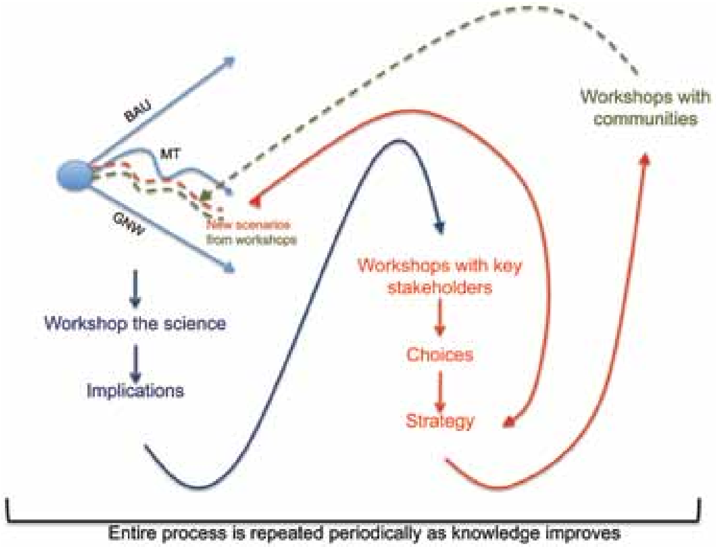

Figure 4: A possible approach to developing a national suite of living scenarios.

To start the process, we propose that one or more families of scenarios be developed by a core group of participants representing a wide range of expertise and awareness of societal viewpoints and beliefs. This group is charged with getting the process going: the start-up process would require the participants to access as wide a range of viewpoints as possible, including a diversity of biophysical and social science inputs. These families would be designed to identify and address critical uncertainties identified by participants and what participants anticipate will be important to different parts of Australian society. These starting point scenarios should include all elements of a scenario development process, as discussed in ‘The use of scenarios to explore future options’ earlier in this chapter. They should be developed sufficiently so that they provide insights into future challenges and opportunities and objectively inform readers of the relevance of scientific and other inputs. They should provide building blocks that subsequent participants can use to test their own ideas and/or add to and modify to develop their own scenarios.

The starting point scenarios are intended to provide a framework that can be built upon by other stakeholders and the broader community. They should be accompanied by guiding information and by information about processes, so that other groups of people can use them as a basis for developing their own strategic conversations and, if relevant, their own scenarios. This would require strict identification of what is known with high confidence (e.g. physical laws, or social and ecological processes, such as population growth or decline in habitat for biodiversity, that we know will take a long time to be slowed or reversed regardless of what interventions or shocks might arise), and clear consideration of the uncertainties involved in future possibilities that we have less confidence in.

This process of identifying levels of confidence is itself a key part of the strategic dialogue that should take place in the living scenario process. It allows participants to identify their assumptions and examine them critically. It should encourage respect for others' views about how the future might unfold, while acknowledging that all future outcomes depend on strings of events, each of which has its own level of uncertainty. The development of scenarios allows participants to explore different strings of events and to consider their implications openly and collaboratively. Hopefully, the process will identify how multiple desired outcomes might be achieved by common decisions and interventions. Where incompatibilities might arise, the process can flag these early and ways to deal with them can be developed before major tensions arise.

To get the material to the point at which it can support diverse strategic conversations, we suggest that these starting point scenarios and supporting material be subsequently workshopped with a variety of stakeholders and then with broader communities. These processes must take account of the latest understanding of social psychology and learning processes so that they truly engage and empower people from across Australian society. There could be times when different scenarios would be developed and revised by small stakeholder groups than when scenarios were workshopped with communities. For example, stakeholders selected for their expertise in certain areas might participate in developing scenarios for a specific decision requiring specialist knowledge. On the other hand, some scenario development and revision with broader community groups might be designed to increase awareness of issues and diverse viewpoints and to prepare community members to take part in more specialised scenario development if they are interested. This is the reason why, in Figure 4, there are two loops back to the scenario diagram, one from stakeholders and one from communities.

What are living scenarios? They would be reflexive [Volume 2, Chapter 12], in that they would allow participants to learn from one another and from evidence and incorporate that learning into new scenarios, and they would have a formal role in tracking ongoing progress in exploring, defining and establishing an ecologically, economically and socially sustainable Australia. For example, a set of living scenarios for Australia's future might be a national-scale suite of stories. These stories might be part of public discourse about Australia's medium- and long-term futures and contain narratives that are retold and modified over time are taken, and used to inform regional-scale scenario planning efforts, and are used by key decision-making groups to help to define and refine their own strategic goals.

Ways in which such living scenarios might be used include:

- An industry group may take a broad set of national goals and use them to explore how their own interests in terms of development and trade may fare under each alternative.
- A coalition of security interests might look at how national and regional security might unfold with different narratives, and then feed that information back into the narratives themselves to then enrich the explorations of others.
- Regional and metropolitan communities might explore what they value about their lifestyles, what values are shared across different communities, and what assumptions, beliefs, hopes and visions underpin core values, and they might then consider how these core values might be made resilient to future changes (and also what transformations in some aspects of these communities might be required in order for the core values to be retained).

10 Synthesis and discussion

Like the man who discovered he had been talking prose all his life, we have all been scenario planners from childhood. Faced with a what-to-do question, we imagine plausible (and implausible) possible futures—scenarios—and feed those imaginings into our decision-making processes. When we raise scenario building to the status of a cognitive technology, we are trying to both enrich and manage this powerful input, particularly as a tool for making more rational decisions for collectives of all sorts, from communities to corporations to countries.

The present paper does three things: first, it canvasses a variety of methodological principles and guidelines for building useful scenarios when time and resources are short, as they always are. Second, it demonstrates the comforting maxim that a small group of involved people can relatively easily and quickly generate a wide variety of perspectives (facts, attitudes, constraints, opportunities etc.) that bear on important long-term issues. In this case, the four workshop groups—scenarios, modelling, resilience and social science—uncovered a wealth of ideas that the Australian community needs to be aware of as it tries to guide itself towards a good future for all its citizens. Third, this paper makes a start towards exploring the very important follow-on question: how do we go about making this happen? The process proposed, living scenarios, requires much more thought and development but which we suggest will pay major dividends for the effort invested. Recommendations for this type of approach have emerged from other working groups at this workshop and the idea is addressed in Chapter 1 of this volume.

At the centre of the issues being addressed in this chapter is the relationship between science and values as expressed in a democratic society and how this relationship is exercised. Into this we bring the question: What is our realistic vision for an ecologically, economically and socially sustainable Australia in 2050 and beyond? The authors of this chapter recognise that scenarios can play a valuable role in both helping to articulate this question and in addressing potential courses of action. Scenarios are driven by both narrative and evidence: the narrative aspect gives them very strong meanings in a social context, whereas evidence is provided to ensure they remain plausible.

Having a meaningful dialogue around scenarios within the democratic context is still a difficult undertaking. Kitcher [49] proposes four levels of engagement that can be developed within the scenario context:

- Level 1 requires well-ordered science to make claims of consensus around specific issues. This involves making the process of investigation and of the value judgements used in exploring the science as transparent as possible.
- Level 2 would involve a detailed and precise account of current courses of action; exploratory scenarios in the language of scenario types.
- Level 3 would explore ethical frameworks within which to devise policies for apportioning measures.
- Level 4 discusses, under terms of mutual engagement, how we are prepared to balance current actions against the risk of future suffering.

Kitcher also nominates four negatives that need to be overcome [49]:

- Present competition among scientists and in fields of science is constrained by historical contingencies that no longer reflect human needs.
- The flaws of democracy are inherited by existing systems of public input. The formal process of scenario development can address this.
- Privatisation of scientific research will probably make matters worse. Markets have insufficient vision to fully address human and environmental needs. This can be pursued through a wider investigation of economic welfare where access to goods and services are seen as means rather than ends.
- Current scientific research inadequately addresses the poor. Yet the value-base behind science includes equity, fairness and access.

The Bowral workshop discussed all of these matters, particularly the interactions between science-based and values-based views about the future, and how they could be addressed. The Level 1 process is the body of scientific knowledge brought into the scenario process. Level 2 broadly fits the climate change action scenarios. The governance scenarios fit into Level 3 as they explore how different values play out. The complexification scenarios range across all levels.
The question remains: how can we bring together these issues in a meaningful, well-ordered way? The development of dynamic, reflexive scenarios that explore how our knowledge and institutions may evolve is not easy, but it is vital.

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Chapter 5

Exploring futures with quantitative models

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When a group of scientists discusses models, they can expect some shared understanding of what this term means. When the general public hears the word models, it conjures up a range of images, from fashion icons to miniature trains, but rarely the kind of internally consistent formalised reasoning meant by scientists. In this chapter we show that models and modelling are more familiar and less arcane than people think. All humans use models, consciously or unconsciously, because models are the guidebooks that help us navigate the world we live in. However, as the modern world has become more interconnected and complex, the intuitive models that have served us for millennia are increasingly guidebooks to the past, and of declining value. Here we argue that in a modern world that is so much a product of advances in science, the most reliable guides are models based on scientific principles. We also emphasise the importance of broad participation in the modelling process and discuss ways of achieving this at national scale.

1 Introduction

The collision of science and intuition

Fundamentally, all models are simplified versions of reality. We use them as learning tools when reality itself is too difficult to handle [Boschetti et al., Chapter 8 in Volume 2; Perez, Chapter 10 in Volume 2]. To be useful, they must reproduce the aspects of the world we are interested in with sufficient accuracy to let us ignore many complicating factors without being led catastrophically astray. Scientific models are distinguished from other models in that they must conform to scientific understanding of real-world processes and the laws of nature (e.g. conservation of mass and energy), and as such are internally consistent. This constraint does not exist for the intuitively formed models used to guide day-to-day behaviour and participation in society, which derive from 'world views'. World views are a form of intuitive (subconscious) model, described by Cocks [Volume 2, Chapter 13] as, '…a coherent system of fundamental beliefs that describe some reality of interest… a thinking tool, a cognitive technology, which provides a first-stop mental model when seeking understanding (What's happening?) or when making decisions (What-to-do?)'. Defined in this way, world views are synonymous with 'narratives', which Raupach [Volume 2, Chapter 14] describes as strongly, even viscerally, held beliefs about the way the world works or ought to work.

People get their world views (or narratives) from many sources—parents, peers (e.g. friends, sporting teams, ethnic groups), education, experience and religion. Peer group pressure is a major determinant of behaviour [1] and in the modern age self-reinforcement of personal views and prejudices through the internet is increasingly important [2]. We tend to sympathise with those who have similar world views to our own [3, 4]. This is because, while world views help us understand our world and anticipate change, they are mostly used as filters that guide our interpretation of other models—either scientific models or the world views of others. Conflict between non-scientific world views, often those that are held unconsciously, and the deductions of scientific models can be a major source of misunderstanding or even conflict.

Intuitive models based on secular ideologies and religion, which might have served humans well when they were dealing with conditions on relatively small scales (e.g. day-to-day activities of hunter-gatherer societies [5]), often failed past civilisations that outgrew their resources [6] and are proving to be ill-suited to dealing with the sheer scale of modern activities. It is no longer sufficient to use commonsense models based on collective past experience, because no previous generation has faced the limits of the natural world at a global scale. Technological development has allowed humanity to shape the modern world to such an extent that we now appear to have entered a new geological epoch, the Anthropocene [7]. Moreover, technology has changed the way people interact, while simultaneously allowing them to satisfy their aspirations in ways that were undreamed of when the decision-makers of today were growing up and setting their mental baselines. Science has a transformative explanatory role in dealing with potential future change because, unlike other means of comprehending the world, it is continuously subjected to testing against reality. Scientific hypotheses must in principle be falsifiable through comparison with observations [8] and, as new information becomes available, be refined or even overthrown and replaced [9]. This scientific method is the foundation of the modern world. We argue that models conforming to the scientific method are a critical component of any effective means of shaping policy meant to address challenges associated with our collective future.

In the following sections we will explain in more detail what we mean by scientific and quantitative models, what they are for, what is in them, how we use them, and give examples of models in action. First though, it is instructive to expand on the kind of conflict that we as scientific modellers often encounter when our assumptions and predictions conflict with deeply held world views. We can do this through a simple example. Let us start with perhaps the simplest model of our world, as a planet where people are a part of the system. A visual representation of that idea is the sphere of the natural world with all our social and economic engagement played out upon it (Figure 1). To most scientists, this simple picture would seem unexceptionable. However, large slices of humanity may find it uncomfortable or confronting. Psychologists have found that humans fall roughly into two ways of thinking about the world—those who think it is just and those who do not [10]. Moreover, some major religions and early Western thought explicitly place man outside the natural order [11]. This has meant that when other models (e.g. scientific ones) have proposed a connection between the two and that resources are limited, this has led to confusion or dismissal ('Why do that? We didn't have to worry about it in the past…' or 'That can't be right, it is here for us, the world wouldn't play tricks on us like that, that's not fair…') or even to bitter or deadly disagreement [12]. Such confrontations did not happen when human populations were small, because the bounds of the natural world seemed distant and beyond the horizon of any impacts people might have had upon it. Societies saw no need to anticipate what those impacts might be. Today is different. Population has expanded to the point where we have a global civilisation and the natural boundaries of our planet are tangible.

In the past it was not uncommon for civilisations to expand to a point where they encountered local boundaries [6, 13]. However, even then, humans rarely extrapolated their intuitive guides—their local models of their interaction with the world—to the point where available technologies and cultural behaviours had

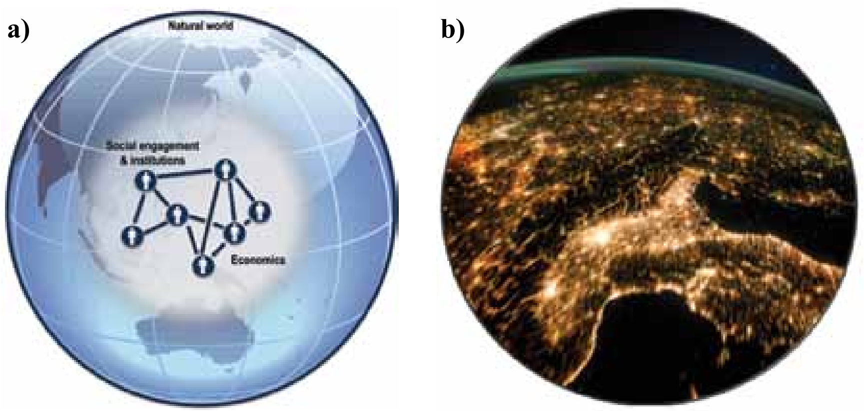


Figure 1: Conceptual model of how the social and economic systems play out within the bounds defined by the natural world that supports them: **a)** as a schematic diagram, and **b)** as demonstrated by a photo[1] of central and eastern Europe at night taken from the International Space Station in February 2011. It shows the thin band of the atmosphere arcing across the top of the image and light spilling from cities (highlighting the hot spots of human economic and social activity and contrasting strongly with the dark waters of the Mediterranean and Adriatic).

impacts on the limits of living space, food supplies or social structure. Lacking this anticipation and warning, civilizations collapsed when they passed boundaries (natural or social) and could no longer support themselves [14]. Taking the fate of those past cultures as a warning, modern society is realising that it is important to think about what happens when the demands of global civilisation reach social and ecological boundaries. However, there are many different versions of how people think this collision will unfold, especially through the next few decades.

In the developed world two versions of the future dominate—the 'sustenance' and 'expansion' narratives [Raupach, Chapter 14 in Volume 2]. The sustenance narrative assumes that our global social and economic system will collide with the bounds of the natural world and that a devastating shock will result (Figure 2a). In contrast, the expansion narrative assumes that something—for example, technological advances—will act as a buffer, preventing this collision (Figure 2b). The many acrimonious arguments about climate change, population growth and economic development that are occupying society at present are rooted in the fact that people do not share the same world view and so are coming to different conclusions about how the world will respond to this collision. This tension can also be exploited by vested interests that spread misinformation exacerbating any differences [15]. A direct result of this has been a persistent and potentially growing gulf between what science predicts human actions will mean

1 The original rectangular photo from NASA has been remapped on to a circle here for comparative purposes, but has not been modified in any other way.

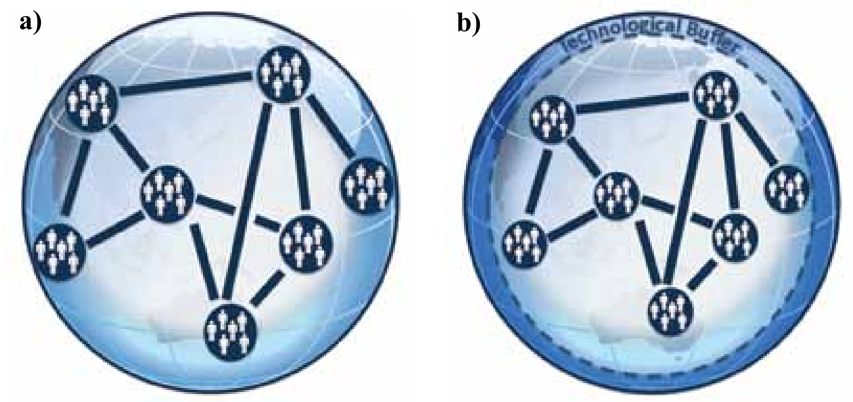


Figure 2: Simple alternative models of the future response to changing population size: **a)** the social and economic system reaches the bounds of the natural world, and **b)** some buffer (e.g. technological innovation) prevents the social and economic system from colliding with the bounds of the natural world.

for our future climate and wellbeing and the appreciation of the general public (or at least some parts of it) of these scientific realities.

Anthropogenic climate change provides an example of the clash of narratives at global scale, but equivalent conflicts are playing out daily at smaller space and time scales in Australia over issues such as sustainable water allocation in the Murray–Darling Basin or sustainable use of old-growth forests or fish stocks. As detailed in later sections of this chapter, we can learn from the use of quantitative scientific models in these smaller-scale questions to show us how to best employ models to address the larger global questions.

Quantitative models

Scientific models do not have to be quantitative, though many are. So long as they follow real-world constraints, qualitative (descriptive) models can still be internally consistent and scientific. However, for the purposes of this chapter we will focus on quantitative models.

Most quantitative models are sets of linked mathematical equations that encode scientific understanding of how nature or society operates. The real world is so vast and complex that building even highly simplified representations of it can be a major scientific enterprise. Large computer models that describe the evolution of oceans, atmosphere, sea ice and terrestrial ecosystems are used to predict weather and climate. On the other hand, very simple models of these same systems, consisting of just a few equations, can give important insights that may be lost in the detailed models. In practice, to maximise learning we employ models that span a range of complexity.

Finally, an absolutely fundamental attribute of scientific and quantitative models is that they must be explicit [16]. Their assumptions—the algorithms that encode the scientific understanding and the data behind the model inputs—must be clearly stated and available for scrutiny. This is a crucial difference between the models we will discuss in the rest of this chapter and people's internal world views and narratives whose assumptions are rarely exposed to the light of day.

2 What are models for?

Most non-modellers assume that the purpose of a scientific model is prediction. This is only one use of models, albeit an important one; Epstein [16] lists 16 reasons for modelling, apart from prediction. Even prediction can mean something quite different to scientists and the general public. The default assumption of most people is that a prediction involves a definite, deterministic statement such as 'A will happen and B will not', whereas science is used to predicting probabilities: 'There is a 65% chance of A happening and a 35% chance of B happening'. Probabilistic prediction, however, is becoming more familiar; for example most weather forecasts are now stated as probabilities.

When models represent the interaction of the natural world and society, prediction in any sense becomes much more problematic. The strongly contingent nature of human decision-making means that the exact form of the future is essentially unpredictable. This does not make models useless, however.

An important feature of such systems is that, although specific details are unpredictable, there may be a stable statistical spread of outcomes in the long term that have predictable average behaviours. It is easiest to characterise these behaviours if there is a broader context to the predictions. This context is provided by scenarios (internally consistent stories about how some aspect of the system, such as the level of globalisation, may evolve into the future) to which we can assign some likelihood or preference. Chapter 4 in this volume explores scenarios in much more detail, but the intersection of scenarios with quantitative models is illustrated well by Figure 3 (from [17]). This plot shows the evolution of global temperature to 2100 for four trajectories of greenhouse gas concentrations that correspond to scenarios of how the world's economy might develop, given plausible assumptions about rates of globalisation, economic development, the success or otherwise of global mitigation agreements and so on [18].

Quantitative modelling played two roles in producing this figure. First, we see that the temperature curves have bands of uncertainty. This reflects not only the fact that the climate has chaotic elements but also that there are some facets of the climate system we are unsure of or cannot model completely faithfully. Consequently, we can only predict a range of resulting temperatures for each greenhouse gas trajectory. Nevertheless, we can specify this range quite well and assign definite probabilities because the planetary dynamics that control the climate obey laws of nature and well-understood scientific relationships. Second, the scenarios of global economic development that lead to each projection of possible greenhouse gas concentrations are produced by integrated assessment models (IAMs), which contain descriptions of social processes like economics and demography. Although social processes are much more difficult to capture in quantitative formulae than physical ones, they are still bounded to some degree by the laws of nature as well as by other constraints such as path dependency (where making some choices about development paths excludes others).

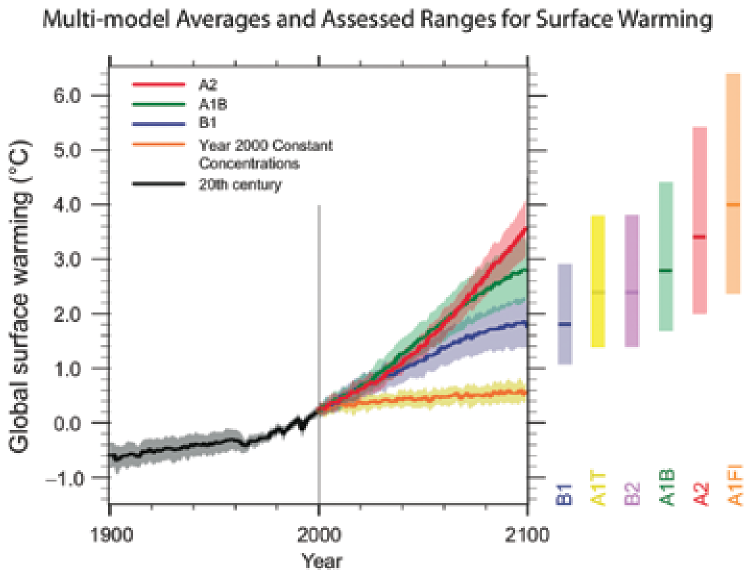


Figure 3: Trajectories of average global surface temperature to 2100 corresponding to scenarios of global development and their consequent greenhouse gas emission trajectories (shaded bands around the trajectories indicate one standard deviation of individual model averages). The bars on the right indicate the best estimate (solid line within each bar) and likely range assessed for six illustrative IPCC emissions scenarios (drawn from hierarchy of individual models as specified in [17]). Redrawn from Figure SPM-5 in [17].

Of equal importance to prediction is modelling to gain understanding. We can build models that reveal the essential processes behind observed phenomena without necessarily being able to predict their occurrence. For instance, plate tectonics explains the nature and location of earthquakes, but so far has not allowed us to forecast their occurrence. Similarly, over the last decade computer models of social networks have provided important clues as to how ideas, opinions and fashions spread through society without being able to tell us whether one idea is more likely to be adopted than another [19].

A third reason for modelling is as a test bed, to check the consequences of choices we may make as a society without suffering any dire consequences.

We have only one world, which means (for example) that we cannot compare the result of increasing greenhouse gas concentrations in the earth's atmosphere with the behaviour of a parallel world where the concentrations are held steady but everything else behaves as on the Earth[2]. Consequently, for most of the manipulations of the world's natural dynamics and societal relationships that humanity is currently performing, modelling is the only way we know to test the likely results or to explore alternatives. A fourth reason for modelling—one that is aimed squarely at the conflict between different world views—is to use models as a forum for wider social discussion. Models can allow us to compare the alternative futures that could result from choices we make today, and in the next few decades, without prejudice or priority being given to any one world view. In this way, the trade-offs, unintended consequences and constraints of any potential future can be explored. New ideas can be generated about how to deal with the many challenges now facing Australia and the globe. Used in this way, models can allow us to expand and anticipate the time and space horizons of our planetary boundaries. They can help us avoid the sleepwalking into disaster that has characterised almost all past encounters of human civilizations with natural boundaries of geography and resources.

Within the bounds of these four purposes for modelling there are many ways to use models to help us understand the dynamics of our world or to plan for the future. One of their most important applications is to define the reachable space within which society can make choices. Laws of nature and path dependency together mean that our past and present choices have already excluded a large number of potential futures; the remaining (constrained) set of possible futures are the reachable space. We can define this space because the physical world must obey the laws of nature (even if social choices are more unpredictable)

2 However, comparison of the Earth with Venus (runaway greenhouse effect) and Mars (negligible greenhouse effect) has been very useful in understanding this particular aspect of planetary physics.

so that the future consequences of choices made today are bounded. For example, the increase of almost 50% in atmospheric greenhouse gas concentrations since the start of the Industrial Revolution commits us to a climate warming of more than 1 degree Celsius, even if all emissions were to cease tomorrow (compare the end point of the flattish orange line in Figure 3 with the starting value in 1900). We can also make the form of this reachable space clear by spelling it out in terms of key indicators such as employment, affordable energy, water, healthcare, the state of the environment and so on. This use of the models is vital because these consequences are rarely obvious when we consider a complex system like Australia and Australian society.

A powerful new concept in applied modelling is to invert the concept of a reachable space and use modelling to define the boundaries of a 'safe operating space' for a society. The safe operating space can have biophysical, economic and social dimensions. Rockström et al [20] have discussed biophysical planetary boundaries defined by assuming that we wish to keep the planet's climate in a state close to that of the late Holocene, the climatic state in which all human civilization evolved. Defining the social and economic bounds of the safe operating space is a more difficult task [Finnigan et al., Chapter 9 in Volume 2] and will not be attempted here. Instead, potential classes of information required in determining a national safe operating space are listed in Table 1.

Component	Information types & attributes
Physical climate system	Temperature
	Rainfall
	Sea-level rise
	Extreme weather events (storms, extended heatwaves)
	Probability of large bushfires
	Ozone levels
	Ocean acidification (pH, aragonite saturation state)
	Nutrient cycles (soils & waterways)
	Water* (surface & groundwater)
	Aerosols (smoke, dust, industrial)
	Level of chemical contaminants
Ecological system	Land cover of different vegetation types
	Land use* (crops, grazing land, forestry, conservation, recreation, mixed & urban areas)
	Biodiversity (species distributions, extinction rates)
	Ecological community composition & structure
Social and economic	Wellbeing
	Inequity
	Income (levels, unemployment rates, employment diversity)
	Human capital (health, life expectancy, education, level of crime)
	Social capital (voluntarism, sense of community, harmony, resilience, quality of life, freedom of expression, spirituality, access to recreational pursuits & green space, place attachment)
	Infrastructure (transport, services)
	Housing (availability, homelessness)
	Cultural diversity (multiculturalism)
	Economic system (market-based, independent reserve bank)
	International trade (demand, exports, imports, exchange rates)
	Government (federal–state democracy, fiscal neutral policies, expenditure, taxation receipts)
	Resource state & production (renewable, non-renewable)
	Domestic demand (preferences)
	Demographics (population size, age, household, labour)
	Technology (efficiency, uptake)
	Emissions
	Policies

* These include the provisioning of humans with food and water

Table 1: Components of a future world that need to be considered when defining a safe operating space for Australia.

3 The contents of models

It is convenient to separate quantitative scientific models into four types: models of the natural world, economic models, social models and integrated models that attempt to bring features of all these together in a unified whole. In this section, we will briefly describe the history and modern developments of each type of model.

Natural world

There is a long history of modelling the dynamics of the natural world at different time scales: from the epochal time scales of geological processes, to the decades, to millennia over which climate is defined, to the days and to the hours over which we predict the weather. Along with these different time scales come different spatial scales, from the global to the regional to the local. Modelling the biophysical world is the area of application where natural science has hitherto been most comfortable and successful.

There are as many different kinds of biophysical model as there are different scientific disciplines. Within the context of climate change the best known are global climate models, or GCMs. These models (e.g. Australian Community Climate and Earth-System Simulator (ACCESS) [21]) are constructed using equations governing the large-scale circulation and thermodynamics of the atmosphere and oceans. They are continuously being improved and expanded to include more components of relevant processes such as the carbon cycle. GCMs are used to investigate the climate impacts of potential future emission scenarios and they produce global maps of ocean and atmospheric properties (e.g. temperature fields). The spatial resolution of these models is becoming finer all the time. The latest generation of GCMs resolves the entire globe at scales as fine as 50 km. Within Australia, ocean-forecasting models now resolve water movements and properties like temperature and salinity to scales of 10 km, with finer-scale models under development around the coast. Similarly, ocean–atmosphere models resolve Australia's landmass down to less than 4 km. Processes happening at scales finer than those the model resolves directly but which influence the resolved calculations through feedback mechanisms are typically represented by simplified relationships or 'parameterisations'. These are often empirically derived; for example those for cloud cover, convection or albedo. The outputs of GCMs are mapped on to finer scales for specific regions using finer-scale models that sit (or 'nest') within the larger model (e.g. Figure 4). These finer-scale models are then used to explore some of the regional implications of potential future environmental shifts, but are also used in more day-to-day assessments such as the fate of yachts lost at sea or the dispersal of air pollution.

The living components of the natural world have also attracted the attention of many modelling efforts. Land-use models are not only used to incorporate the influence of land surface processes (e.g. photosynthesis, evapotranspiration or hydrology) on climate, but are applied regionally to assess the implications of changing agricultural practices [22], catchment management [23] and urban or coastal development [24]. In the marine realm, models of habitats, food webs and entire ecosystems have been used to explore the implications of conservation and fisheries management decisions [25]. These ecological models span a wide range of process detail, depending on the questions they have been designed to answer. The most sophisticated include processes such as primary production, nutrient cycling and the breakdown of waste, movement, predation, competition, growth and reproduction.

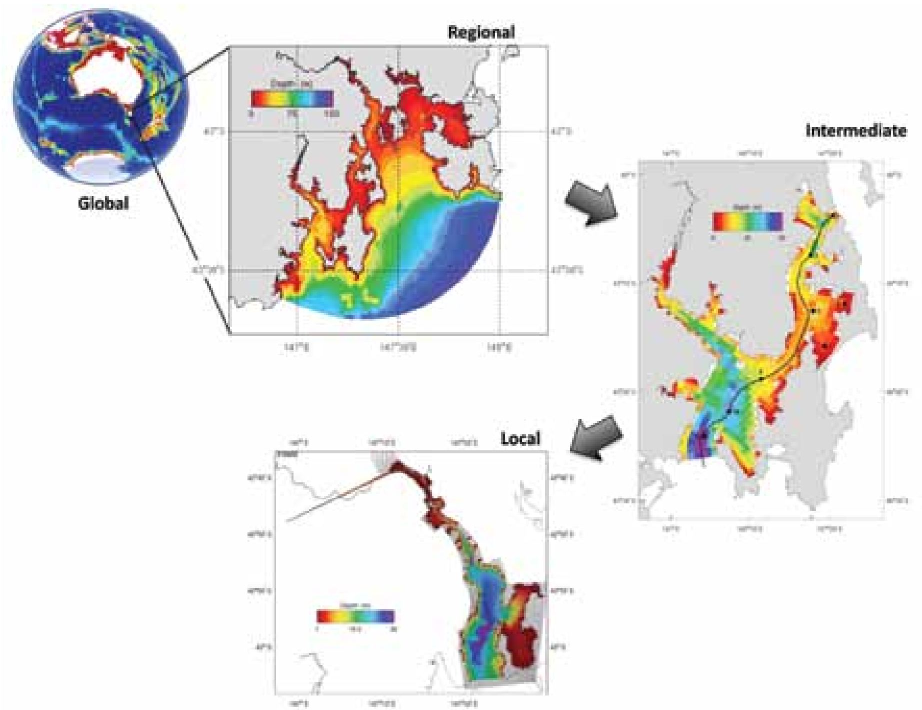


Figure 4: Example for the Derwent River region, Hobart, Tasmania, of downscaling from climate models to regional models—in this case of ocean properties (e.g. temperature, current flow etc.) for marine planning and management on finer scales (modified from [26]).

Economic systems

Economics—perhaps the most quantitative of the social sciences—is also a discipline comfortable with modelling. There are economic models focused on the many different aspects of the economic spectrum. Macroeconomic models address the entire global economy or deal with naturally coupled subsystems such as energy or agriculture. Models of market behaviour are used to try to understand the unpredictable and stochastic behaviour of trade in all sorts of commodities. Financial or 'fiscal' models are tools used by treasury departments to assess the impacts of taxes or regulations on national accounts. The increasing use of models to perform risk analysis or to automatically guide share market investment has become widespread. This last application of economic modelling has attracted a great deal of criticism in the wake of recent market booms and busts [27, 28]. Unlike models of the biophysical world, economic models are not based upon fundamental laws of nature and therefore need careful application and interpretation to avoid being misused.

Macroeconomic models (with assumed internal microeconomic behaviour) are perhaps the most common form of model currently used to inform policy decisions in Australia. They can cover the entire economy, when they are referred to as computable general equilibrium models, or just part of it, such as the agricultural or energy sectors, when they are termed partial equilibrium models. At their largest these models are dynamic, multisectoral (covering more than 50 industries) and multiregional (spanning all Australian states). They are used to explore interacting regional economies and the effects of technology and policy decisions on competitive markets, labour and capital flows and household consumption [29]. These models can be coupled with other aspects of the system (e.g. models of international trade, changing resource productivity) to form the basis of IAMs. (discussed further below).

Agent-based models[3] (e.g. where individual components of trading networks are tracked through time) have also been used in economics [30], but are not nearly as widespread as equation-based general equilibrium models. To date, agent-based models have focused more on microeconomic decision-making than macroeconomic processes, but this is starting to change. However, in combination with social aspects of the system (discussed below) agent-based models can explore behaviours outside the realm of the classical CGE models and so are likely to also find a place among the suite of models required to fully explore and communicate the implications of alternative futures.

3 Agent-based models compute the behaviour of many interacting individuals or small groups and how they change through time and allow their average behavior to 'emerge'. This is in contrast to analytical models that solve equations for aggregate or average behaviour directly.

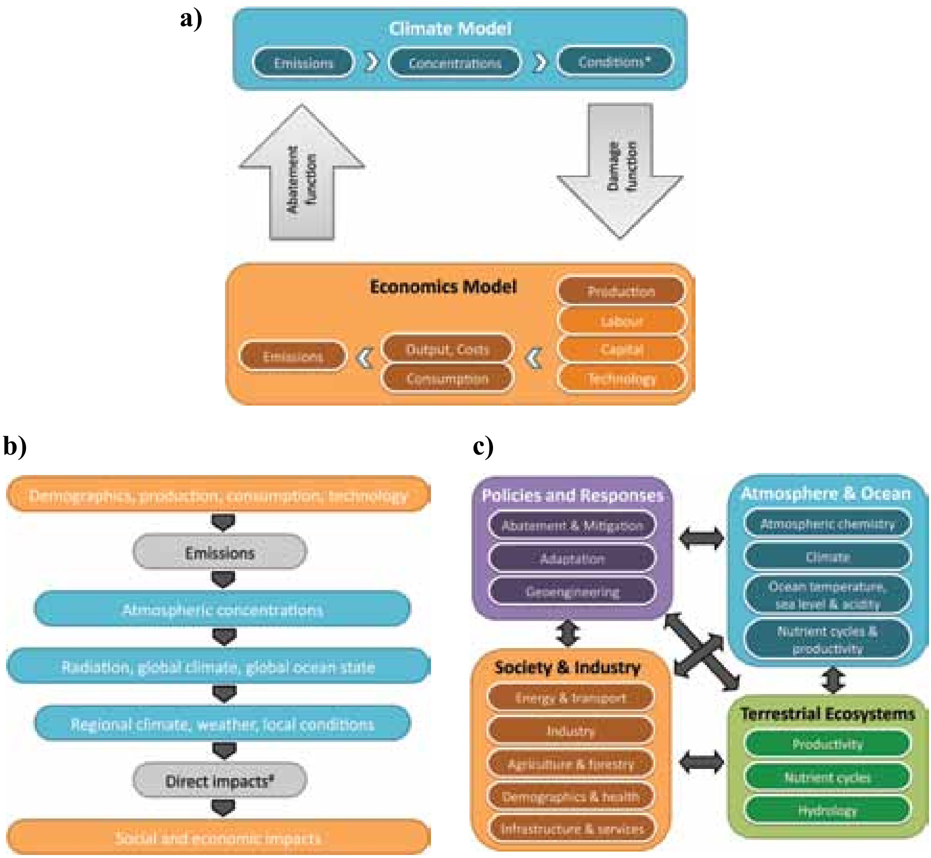
Social systems

Modelling is less common in the rest of the social sciences. This is in part because it has been argued that human behaviour is too unpredictable or involves too many influencing factors to be predictable [31]. However, approaches to simulating social dynamics taken from complex systems science, such as agent-based modelling and network theory, are changing this view [32; Finnigan et al.,Chapter 9 in Volume 2]. Quantitative models of social systems have been used to explore information sharing [33] and innovation [34], decision-making under social constraints [32], and to explore a range of issues, including drug use [35], crime fighting, traffic flow, marriage rituals and the segregation of neighbourhoods [36]. Nevertheless, a significant gap remains between such conceptual models, used to gain insights into real-world systems, and applications of these principles in models of direct interest to businessmen, government policymakers or the general public.

Integrated models

In the last decade-and-a-half a new, more integrated modelling approach has developed that links models of the natural world, economics and social dynamics to produce IAMs. To date these have been applied primarily at two spatial scales, the global and the regional. The missing scale is the national scale, the one that particularly concerns us here. National-scale models are largely in their conceptual infancy [37] and require some processes and properties (e.g. dynamic governance or policy-industry-environment feedbacks) not typically included at either the regional or global scale.

The earliest IAMs were applied at global scales in the 1970s [38], but their use intensified in the 1990s [39]. Most global models of this kind have been used to project greenhouse gas emissions (e.g. the scenarios used by the Intergovernmental Panel on Climate Change (IPCC)—the emission trajectories leading to the different coloured lines in Figure 3) and to consider the welfare and economic costs of alternative trajectories (which is what policymakers have typically asked about most). IAMs seek to couple human behaviour, as represented by socioeconomic determinants and policy, with the behaviour of the atmosphere-ocean-climate and living ecosystems. The aim is to deduce the biophysical and socioeconomic impacts of human behaviour as well as possible societal and biophysical responses. Broadly speaking, they compute the impacts of changed climate—for example, temperature and rainfall changes, on agriculture, industry, human health and other components of the economy. They then work out how the resulting changes in economic activity alter the emissions that drove the changes in the first place, thereby coupling the climate and economic components of the Earth System (Figure 5a). The first climate-related IAMs were only vertically integrated, following the chain that links the causes and consequences of climate change (Figure 5b). By 2000, horizontally integrated models (Figure 5c) were being constructed to assess what might constitute sustainable development; these models had an enriched structure with more complex linkages and feedbacks, such as direct human modification of ecosystems and CO_2 fertilisation of plants, yielding more complex structures.



* Conditions include atmospheric, terrestrial and ocean properties (e.g. temperature or rainfall).
# Direct impacts cover impacts to natural ecosystems as well as cultivated crops and forests.

Figure 5: Schematic diagrams of IAMs: **a)** the general concept of the model structure that includes both climate and economics; **b)** vertically integrated models (which are effectively one-way flows); and **c)** more interconnected horizontally integrated models. These figures are modified from figures in [39, 40].

At regional scales, dynamic fully coupled models of the entire system have been in existence since the 1970s, though they have really only come into relatively common use in the last 15 years as computing power has reached a point where their use has become tenable. Early models (e.g. of resources associated with rivers or lakes [41]) often exceeded available computing power and largely fell out of favour until the 1990s. Since then they have incrementally regrown, from multispecies (predator-prey) and primary production (plant or plankton) models to models that include regional-scale physical factors (and exogenous large-scale environmental forcing), much of the food web of a region and some representation of the dominant human activities [42]. Within the marine realm these models can now span processes, from the micrometre scales of bacteria to tens of thousands of kilometres (for ocean basin or global scales), and processes that act on seconds to centuries. Somewhat surprisingly, modelling terrestrial dynamics at an equivalent level of complexity has lagged in practice in the aquatic domain, but this situation is now being redressed [43]. This means that there is already some solid experience with the kinds of challenges that will be faced when building national- or continental-scale models.

Dealing with model uncertainties

Building fully integrated system models pushes scientific understanding to the limit—not all processes are equally well understood and new ones are uncovered as the models are put together and gaps are identified. It also pushes the bounds of complication (i.e. the size of the models and the number of parameters) and complexity (feedbacks and non-linear system behaviour). This can make these models uncertain and potentially difficult to work with.

Although experience with quantitative modelling is least well-developed for social systems, where uncertainty is greatest, in truth there are uncertainties in all the domains. However, the presence of uncertainty should not lead to inaction; risk is about the weighing of the likelihood of an event occurring and the impact it may have if it does. Issues in the real world may become more pressing and difficult to remedy if precautionary action based on risk assessment does not occur. Likewise, uncertainty should not see the abandonment of models, as science has over 50 years of experience with how to deal with such uncertainty.

Three main sources of uncertainty are dealt with on a regular basis by scientific modellers. First is the uncertainty associated with the trajectories of a dynamic, or chaotic, but well-characterised system—this is reflected in confidence bands around mean trajectories, like those presented in Figure 3.

Another aspect of uncertainty has to do with the future state of properties we know to be important but have no way of projecting with confidence. Future political and societal decisions, such as those regarding policies and behaviours around emissions levels, are an example. These decisions will have a substantial impact on the factors that influence the Earth System by the end of the century, but we have no way of knowing now what they will be, and there are very many options. This kind of uncertainty can be represented by 'what if' scenarios—illustrated by the different scenarios and resulting bands of potential outcomes presented on the right of Figure 3. The importance of these first two kinds of uncertainty can also be different as we move further into the future. For instance, the uncertainty about near-term climate states within the next couple of decades is mainly a result of the chaotic nature of the biophysical system. While there is a small degree of uncertainty about exact values, in broad terms fundamental physical laws and inertia in the system mean the trajectory is actually fairly well-constrained. This is why all of the trajectories for the different scenarios in Figure 3 have a good deal of overlap until 2020–30. After that point, however, uncertainty about the social and regulatory responses comes to dominate, leading to the large deviations between the ranges of outcomes in the long term (e.g. compare B1 and A1F1 in Figure 3).

Lastly, there is uncertainty due to gaps in knowledge about the system—processes that are poorly known or even ones that we do not realise exist as yet. Operationally, we can deal with this kind of uncertainty by building models incrementally (as mentioned above for the integrated models), adding new components as new information on connections or processes becomes available. A complementary approach is to use multiple alternative models to capture different ideas of how the system works, and examine the implications of each of the alternative forms under all of the suggested potential future developments or policies. If the outcomes are effectively the same across a range of model representations, then there is increased confidence in the robustness of the conclusions drawn. The IPCC provides guidelines around how to express this confidence—from 'low' when there is limited evidence or low agreement between experts through to 'high confidence' when there is a lot of rigorously examined (robust) evidence and high levels of agreement [44].

Even if uncertainty persists and the outcomes are different across alternative model representations, the range of resulting outcomes can still be used to provide information on the range of potential future scenarios that must be considered. These scenarios can in turn be used to paint broad contexts for management decisions—and models—at smaller scales that recognise the uncertainty at the larger scale.

There is a tight relationship between scenarios and models when both are used to their best effect. Scenarios can provide context for a model, effectively saying 'if the part of the world you can't represent in the model does this, what would be the response of all the bits you can model?' Models can ensure that the broader pictures of the future that scenarios help to paint are internally consistent and not in breach of natural laws. Chapter 4 in this volume provides a detailed discussion of four potential future scenarios for Australia. In addition, some contextual geopolitical scenarios are provided in Table 2. These kinds of scenarios would dictate assumptions about trade, spending patterns, competition for resources and so on that would be included in any national-scale integrated models.

Climate drive threatens SE Asia: There is increasing demand for water due to growing populations and industrial expansion. Changes in regional climate could contract the water supply and make it more variable. China has a 2000-year history of water-control programs and controls the headwaters of major rivers feeding India, Bangladesh and SE Asia.			
Least violent outcome	**Business as usual**	**Most violent outcome**	**Implications for Australia**
All the nations in the region agree to basin-wide sharing and allocation of water. Simultaneous improvements in efficiency of water use.	China continues to steadily divert more water from SE Asia into water-poor regions of China (likely refraining from redirecting waters destined for the subcontinent for diplomatic and security reasons). Even if SE Asia can improve efficiency, rise in tensions is likely.	China aggressively diverted water from all the headwaters to its water poor regions. Significant tensions arise between China and both India and Vietnam (possibility of war and nuclear exchange).	Level of instability affects Australia's trade, productivity and border security (massively increasing people movement and refugee pressures).

Table 2: Potential geopolitical scenarios that could be used as context for a national-scale IAM. Note that these are not forecasts, simply alternative views of how the world may unfold.

Unification of the Muslim world:

Many pressures for change in the Middle East and Africa (fast-growing populations, millions of unemployed youth, education gaps, a rejection of modernism and the West due to past support for local dictators). Many different unifying concepts proposed (e.g. democracy vs. religious caliphate, many antithetical to Western powers).

Presence of nuclear weapons programs could exacerbate nervousness of other nations (e.g. Israel) regarding the outcome.

Least violent outcome	Business as usual	Most violent outcome	Implications for Australia
Israel and the USA may take decisive (and early) action to neutralise the nuclear threat, simultaneously preventing accommodation between Shia and Sunni interests and supporting key oil-producing Arab states so that they do not participate in any aggregate body (or caliphate).	Not all Muslim states (or key oil producers) fall, so smaller aggregate body formed. Heterogeneous make-up of the Muslim world. Israel may still destroy Iranian nuclear facilities and Pakistan may still suffer at least partial collapse, particularly in the north where large bandit regions of Taliban may form.	Broad geographic caliphate forms. Nuclear exchange between Israel and Iran disrupts global oil production; antiMuslim sentiment leads to suppression of Muslim minorities in China, Russia and Europe. Potential US pre-emptive strikes on Pakistan's nuclear stockpile; stand-off with India (over weapons) leading to Indian push into Kashmir and Afghanistan, resulting in a further stand-off with China (which may support Pakistan and enter Afghanistan against India).	Some trade implications. Could cause shocks to fuel supplies and large-scale people movement.

4 What models can already tell us about the future

While national-scale integrated models do not yet exist, quantitative models of component parts of the Australian system are already being used to give some indication of what the future might be like in Australia if we continue as we are—a scenario often described as 'business as usual'—or switch to other management and development options. A full exposition of all available model outputs would take a book in itself. In lieu, an illustrative summary of projected futures for many aspects of the Australian system is provided in Chapter 6 of this volume. Further discussion of projections of some aspects of Australian society and industry also appears in volume 2.

5 The importance of broad participation in the modelling process

To date, communication of scientific knowledge of climate change and what is causing it has not been universally successful. As a result, there has been confusion surrounding the topic in the community as a whole and full use of the information has not always been made in decision-making. This has led to tension between people with alternative views on the topic and has also led to a sense of bewilderment and frustration about why it can't be clearer. This confusion and frustration has come about, at least in part, because of an assumption held by many physical and environmental scientists that simply delivering additional information is sufficient to provide understanding and cause behavioural change. Experience in natural resource and coastal management as well as social and behavioural research and sustainability science has found this approach is actually largely ineffective [45], and can even harden existing opinions [46,47].

Learning, and any resulting behavioural changes, are a product of complex cognitive and social processes [48, 49], all of which are enhanced by free and open dialogue, trust, airing of conflicting viewpoints, participation, sharing of control and responsibility, direct experience and reflection [50]. Knowledge is also distinct from information. Information is interpreted data and factual statements [51]. On the other hand, knowledge, much of which is tacit and unspoken [52], is the capacity to act effectively, which is rooted as much in experience, contextual bounds and social values as it is in supporting evidence [53]. This makes effective knowledge transfer much harder than is naively assumed [54].

So far in this chapter we have described three reasons for the value of modelling: for prediction, to gain understanding and as a test bed. Our fourth reason for modelling introduced the idea of participatory models as forums for discussion and the resolution of competing ideas. Using models in this way brings together the concepts of scientific modelling and innate world views and uses all kinds of models, from the simplest representations to the most detailed. Shared storytelling and conceptualisation of problems are features of all human cultures, and models can be used as a framework for discussions, to formalise and channel these activities to help communities find solutions to divisive problems, even when different members of a group hold conflicting objectives. This approach has been used successfully in a broad range of areas; for example at regional scales to address the management of natural resources (such as fisheries [55], catchment management [56], integrated coastal zone management [57]), and social challenges (e.g. inner-city drug use and prostitution [35]).

Experience with applying participatory processes that are anchored by scientific models (not just world views) has shown that, like a system of interconnecting cogs (Figure 6), the approach leads to the democratisation of knowledge and can build understanding and elicit options and opinions from a broader spectrum of the community and lead to more effective governance. It is a means of bringing together expert advice (e.g. scientific, ethical, technological, or economic) and community-held world views to both educate and be educated by the process. Furthermore, any actions taken are more robust, because the inclusive nature of their germination means all parties feel ownership and there is greater compliance, as the need for hard decisions is recognised and steps are taken together rather than being imposed by one body on another. This participatory approach also supports more adaptive management, as new perspectives or suggestions from experts, governance bodies and the community can be fed back into the models, either to update them with new information or to investigate the potential outcomes of the new alternatives. The models become the common arena for discussing ideas; an arena that is not static but can evolve with new understanding and new ideas, forming the foundation for 'living scenarios' as described in chapters 1 and 4 of this volume.

For a 'living scenarios' approach such as that just described, to succeed there must be trust in the tools used to define the scenarios. In the rhetoric presented in the media around debates on topics such as the use of shared resources like the Murray-Darling Basin, positions based on science and the use of models are often attacked and misunderstandings over the use of the models – or open distrust – are often clearly evident. One of the sources of this distrust is a lack of exposure to, and experience with, models. It is an often-heard statement that 'I'm not a modeller, just a simple <insert profession of choice>. This perception is typical

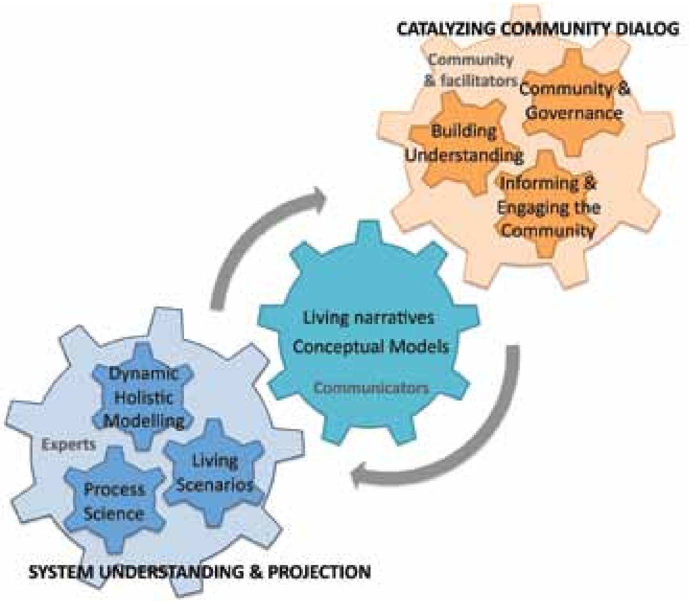


Figure 6: A schematic representation of the interconnected processes that can be used to plan alternative futures. At the lower left there is the science-based foundation, using observationally and theoretically based understanding to build models to make projections of the future given constraints of human behaviour, social institutions, development objectives, resource use, technologies and policies. This understanding is shared (communicated) more broadly using stories and simpler conceptual models. The resulting dialogue (upper right of the diagram) may also be based around models of different forms (from purely conceptual to more quantitative), supporting understanding and engagement as well as feeding into governance. Ultimately, these feed back to the dynamic system models in the lower left (both in terms of updated scenarios via increased understanding of the human dimensions of the system and how they may respond, which can be explicitly incorporated into the models).

because people are unaware of how they themselves use models, particularly mental models, to make decisions. One way of simultaneously increasing this awareness and providing an explicit sense of familiarity with the use of models is to provide people with an opportunity to directly interact with them. Simple models stripped to the essential basics of system function can offer a means for anybody to interact them from their definition (i.e. identifying what should be included) through to hands-on exploration. This can help people appreciate the strengths and limitations of models (they are not crystal balls). Moreover, these simpler models provide the means for people to explore via direct experience a version of the system and so gain a deeper appreciation for how the system functions and the way feedbacks can lead to unexpected outcomes or delays in actions. This kind of understanding increases the willingness to use models to help frame discussions around alternative futures, societal objectives and what are acceptable levels of impacts. Models can also supply a means of gaining experience with how complex systems respond when put under stress, helping to accelerate the evolution of intuitive mental models and making them more useful in the modern world [Boschetti et al, Chapter 8 in Volume 2]. Moreover, they provide a means for individuals to explore the strengths and weaknesses of their world views and, as a result, potentially modify them.

The transparency provided by simpler models must be maintained when using more complex models to make projections about future system states to inform regulatory bodies and policy makers. Economic (and other) models are already widely embedded in governance. For broader, more inclusive system models to be used the same way they must be transparent and interpretable, so that the credibility of their outputs can be judged based on an assessment of their key assumptions and their ability to represent critical processes. Additionally, the models must provide information to decision-makers in forms they are already familiar with and with absolute clarity—an ill-posed framing can unintentionally constrain direct model-based conversations (e.g. ignoring potential costs associated with a business-as-usual scenario and overlooking the opportunity for benefits under alternative policies).

Before moving on to sketching how such a participatory model-based process might be implemented at a national scale, it needs to be stressed that this approach is not something that flows only in one direction (as shown in Figure 6). It is intentionally a two-way interaction. While allowing for broader understanding of systems, it also facilitates an information flow back to system modellers on missing components of the system. Of all the parts of a social-ecological system, the parts that are most difficult to model at present are those dealing with human behaviour. However, the responses and adaptations of people within a system will almost certainly be a key component of its future direction and degree of resilience. By watching how people from a broad variety of backgrounds (and cultures) make decisions when exploring simpler models, scientists can build new understanding. This new information can be used to further refine or expand the system representation captured in more complex models or as the basis for new sets of contextual scenarios to consider—either broadening the options to be explored or identifying where choices may more firmly lock society into a more constrained set of future paths.

6 Making national-scale modelling real

While participatory approaches have seen widespread use in many Australian jurisdictions, a national-scale engagement process of the kind envisaged here would not necessarily be easy. While similar approaches have been highly successful at local or regional scales, such as in the Ningaloo–Exmouth region of the Gascoyne, Western Australia [57], a national-scale effort faces new challenges.

The most obvious challenge is building the models that will form the basis of the approach, both the underpinning models and the models for use in the engagement process. While a full implementation of the participatory approach means that a broad audience should be consulted to determine key system components, existing experience affords us a good idea of the scope of the models and likely components (Figure 7). While simple models of this system could be drawn up fairly rapidly, in terms of a complex IAMs no such model yet exists at a national scale. As mentioned previously, models with similar conceptual breadth of scope have been applied at regional scales and are beginning to be implemented on a global scale [59]. Experience from these other models shows significant scientific and computational challenges will need to be met to incorporate the new processes before a complex national-scale IAM is a reality. Taking these lessons on board, research organisations have prototypes under construction.

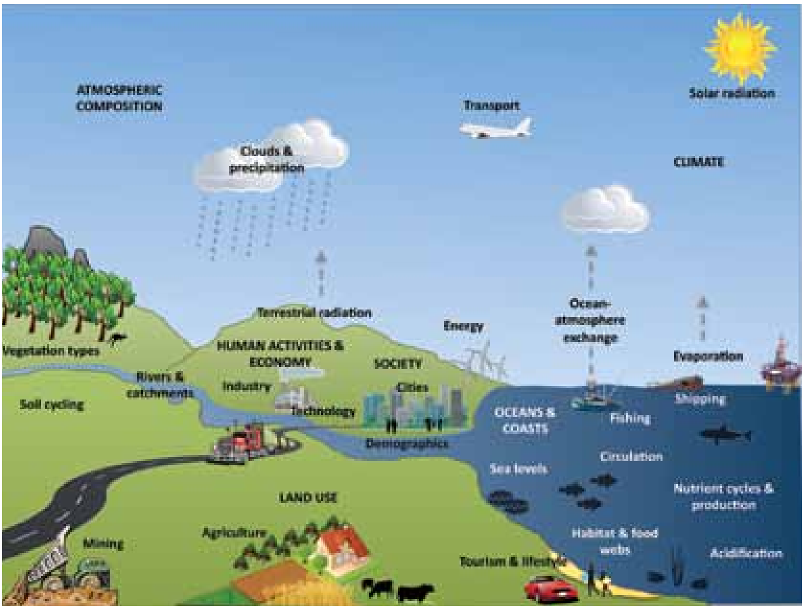


Figure 7: A diagram illustrating likely required components for a national scale IAM.

If the kind of living scenario approach discussed above (and elsewhere in this volume) is to be implemented nationally, building the models is only one aspect of the challenge. Another pressing problem will actually be how to be participatory at a national scale. There needs to be further reflection on past experience at broader scales (e.g. by state governments) and whether it is a concept that remains appropriate at such broad scales. We can also look to experience in the private sector. Even if it is concluded that the method is valid, then seeking individual involvement in the process of defining the model components, specifying desirable system states and participating in ongoing iterations of model evaluation and refinement is not feasible at national scale. It is not actually feasible even at a regional scale for all but the most-sparsely populated areas of Australia's interior. Fortunately, Australia's historical handling of natural resource management can provide insights into what a framework for successful participatory engagement at a national scale might look like.

As acknowledged above, participatory approaches to decision-making have been used in many Australian jurisdictions. An example of such a process that is successful on very large scales (beyond regional and state scales) is the hierarchical consultation process at the heart of Australia's federal fisheries management. The *Fisheries Management Act 1991* requires management in accordance with the long-term sustainability of Australia's fisheries resources for the benefit of all users and interest groups both now and in the future. In turn, this entails actively cooperating and consulting with fisheries managers, scientists, industry, government agencies and other interested groups in the process of developing and implementing fisheries management arrangements. This consultative process raises awareness of fisheries management issues while also providing opportunities for direct input and (critically) a sense of ownership in the fisheries management decision-making process. This level of consultation is possible because managers within the Australian Fisheries Management Authority (AFMA) are advised by management advisory committees (MACs) and resource assessment groups (RAGs), which have been established for each major federal fishery. MACs offer a broader perspective on management options, providing a forum to discuss fisheries issues and possible solutions. MAC membership is quite diverse and includes an independent chairperson, an AFMA manager, a research scientist, up to four industry representatives and an environment or conservation representative (e.g. someone from the Department of Environment or a non-government organisation (NGO)). Increasingly, MACs also have members representing the interests of state governments, recreational fishers and charter boat operators. RAGs also have broad membership, comprising fishery scientists, industry members, fishery economists, management and other interest groups. The intentional breadth of this membership ensures that scientific information (on the status of stocks and marine environment more generally), industry knowledge, compliance factors and economic data (market prices and the costs of harvesting) are all taken into account when discussing management strategies. Ultimately, RAGs provide advice to the MACs and AFMA explicitly stating uncertainties and risks associated with alternative management options. A particularly important point about RAG meetings is that they are open to anyone who is interested. While this degree of openness may sound like a recipe for chaos, in practice it is quite functional and the individual level of understanding of the issues has become quite high (e.g. fisherman have an understanding of what stock assessments contain and how to interrogate them to check their veracity and degree of uncertainty). This kind of collaborative participation in resource management is known as a form of co-management [58], and while it does not guarantee consensus, it does allow for effective utilisation of different forms of knowledge.

In Australia, a hierarchical means of delivering information to decision-makers is not unique to fisheries. Advisory councils presiding over matters of the environment, agriculture, fisheries, forestry and regional planning have a long history (e.g. the Australian Agricultural Council was founded in 1934. In 2000, the various councils were amalgamated to form two bodies, the Natural Resources Management Ministerial Council and the Primary Industries Ministerial Council). This means that precedents on the means of delivering the output of living scenarios already exist. It is only the scope that needs to be expanded.

A review of co-management initiatives from around the world [60] has identified some key conditions for success (summarised in Table 3). Chief among these is that representation must be appropriate given the environmental, population and management scales of the resource to be managed, while remaining small enough to be workable. At first glance this sounds impossible at a national scale, but Pomeroy et al [60] highlight that to meet the conditions for success inherently requires planning and implementation at several mutually supportive levels: local, community, cross sectoral and overall. As prototypes already exist for governance and sectoral participation, the most significant remaining gap pertains to the selection of representative delegates at lower scales who can take the outcome of the interactions and discussions and communicate them to a broader audience still (ideally the entire community). It may be possible to use well-established social and psychology tools (e.g. egoNets [61]) to identify delegates who can be the community contacts. For maximum effectiveness, these delegates should include representative individuals for different groups in the system and key communicators or people who connect many parts of the system together. A broad representation will be fundamental to the inclusiveness of the process, with the models acting as an honest broker, facilitating conversations among groups that may have conflicting viewpoints or objectives. Beyond the engagement with delegates, communication with the broader community will likely require ingenuity and effort, exploiting old and new technologies alike (e.g. from collaboration with television programs or documentary makers, to immersive gallery exhibitions, online games or more formal methods from social science and psychology, such as psychometrics, which have been used to increase awareness of sustainable water policies [62]).

Scale	Conditions affecting success
Supracommunity	Enabling policies and legislation Facilitators (help objectively define the problem, supply expertise).
Community	Appropriate scale and boundaries (representative, but not too large). Group connections (e.g. kinship, ethnicity)—not an absolute requirement (many examples where diversity was not inhibitory). Participation of those affected. Local leadership (or champion). Empowerment and capacity building. Community organisations (to legitimise participation of delegates). Cooperation of government and the powerful. Adequate financial resources. Active participation and sense of ownership. Accountability. Conflict resolution mechanism. Clear objectives. Enforcement & compliance.
Individual and household	Individual incentives (economic, social and political) to participate.

Table 3: List of conditions associated with successful co-management (from information in [58]).

7 What if we had tried this 40 years ago?

In thinking about the utility of the living scenarios approach, it is instructive to wonder how well it would have performed if we'd had the knowledge and technology to apply it in the past. There are two aspects to this. The first regards how well the models could have forecast the trajectory the world actually took. The second is whether an adaptive, participatory approach based on holistic models would have seen us follow a different path.

The first question is easier to address. Many of the models discussed in this chapter can be used to create a range of potential futures. If we had applied them in the past, it is possible that within the spread of projections was a trajectory fairly similar to what actually occurred. The reason it is possible to say this is that, in terms of the dynamics of the biophysical world, the models are reasonably robust. It is harder to capture social and economic dynamics, but even if these had been loosely specified by contextual scenarios then it is likely that the resulting trajectories for climate and natural resources like water or fisheries would have been sufficiently similar in form to what actually occurred to have usefully informed decision-makers. The evidence for this is that one of the ways climate models are used is to show that the observed trajectory of temperature is only possible if human emissions are included as inputs to the system. If the models didn't work, this test wouldn't work either. Moreover, we have the benefit of looking back and seeing how well simpler models applied in the past performed. The Club of Rome attempted to explore limits to growth over 30 years ago. At the time, the study was dismissed by mainstream economists, but recent retrospective analyses [63] have shown that what has actually happened over the last 30 years sits well within the envelope of possible outcomes forecast under the range of scenarios they considered (e.g. Figure 8).

More finely resolved details about specific aspects of the system sitting within such large-scale trends are harder to forecast. Technology is represented in the models, as are economic drivers and demographic structure. This means that in some trajectories something akin to shrinking family sizes and greater female participation in the workforce may have been forecast. By implication, this would necessitate the development of a childcare industry. However, if the model made no allowance for such a development ahead of time then it would not necessarily identify that such a thing would happen. Model processes may combine in unexpected and novel ways leading to unforeseen outcomes, but they are not capable of predicting everything, and especially not in detail. Technological parameters inside the models used as the basis for the original Limits to Growth analysis may be matched to advances in computing and, by taking a global perspective, they effectively incorporated aspects of globalisation. It cannot be said, however, that the models captured the social transformations being wrought by the internet.

The second query about how things may have worked out differently is much more difficult because we cannot go back and replay history. Given the models recreate global dynamics as well as they do, we could explore how things may have gone differently by changing parameters or performing specific interventions. In some ways this is what the original scenarios already do, much as the low-emissions scenarios of the IPCC do for climate simulations, showing what may happen if mitigation measures are put in place. More concretely, however, we can look to how trajectories have changed in other instances where adaptive participatory management has been employed. For example, in 2004 the Southern and Eastern Scalefish and Shark Fishery was facing declining economic and ecological performance as a result of overfishing. Previous management interventions had been unsuccessful and there was general agreement that management directions needed a rethink. Drawing on suggestions from managers, industry, scientists and NGOs, a broad set of scenarios was drawn up and evaluated (qualitatively and quantitatively). The range of options included business as usual as well as more stringent regulations, large-scale spatial closures and a form of mixed (or integrated) management that was so different from the existing management arrangements that the scenario was actually called 'blue skies'. The unexpected outcome of the analyses was that the blue skies option actually met social, economic and ecological objectives best in the long term, though at the cost of severe short-term disruption to the fishery. These results were only one source of information used by managers to address the fishery's problems, but it is noteworthy that many of the significant changes to the management of the fishery that were enacted in 2005 are elements of the blue skies scenario. It is hard to measure the direct influence of the analysis on the subsequent decisions, but the study did seem to capture the imagination of a range of stakeholders and act as a catalyst for significant change that put the fishery in a more robust position for dealing with subsequent shocks such as the global financial crisis, fuel spikes and shifting climate patterns. Based on a comparison with the rate of regulatory change in other fisheries, such rapid change would have been unlikely without a well-developed, participatory fishery management system [25].

Conclusions

The social norms, financial systems, institutional structures and so on that define society today are a result of past decisions taken in response to short- to medium-term pressures. The evolution of society has, by and large, been without regard for the strategic future. As a result, we have no guarantee that these norms and institutional structures are appropriate for the future. The challenge for science is to produce holistic representations of the world and its possible futures so as to identify community (private and public) policy options that are inconsistent with community and environmental resilience in the longer term. This means that the current state of society may not be appropriate if conditions change. When shaping policy pertaining to national issues and challenges associated with our collective future, it is important in a healthy democracy for the community to have the means to contribute to the development of alternative policies. People of all walks of life must understand the implications of proposed policies, what those policies require of them and what effect their implementation will have on their world. Without such understanding it can be easy to assume people and the system will behave as expected but for reality to play out very differently.

Models of all forms are already an everyday part of living. Quantitative models are being used to give insights into what the future may hold and are deeply embedded in government decision-making (e.g. treasury forecasts). The development of strategic integrated models that look forward decades at a national scale can support discussions of shared visions of potential futures that are consistent with society's values and the biophysical reality of the planet. In turn, this allows for planned formation of policies that include a sense of the long-term objectives. The models will need to provide sufficiently clear guidance that is regularly updated as both the modelling and what constitutes a preferred space evolves. This aspect of the living scenarios concept will not be easy at a national scale, but if it proves as effective as it has on smaller regional scales then it has enormous potential.

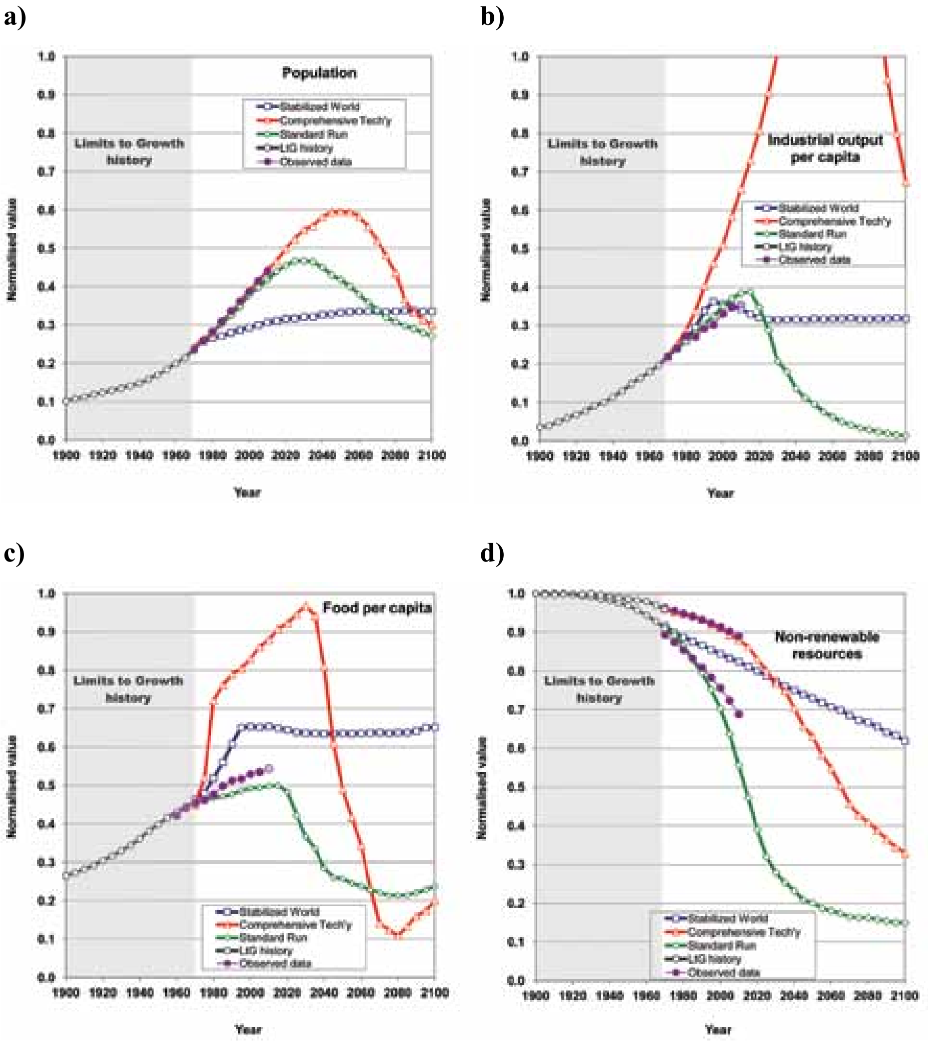


Figure 8: Comparison of Limits to Growth model projections and observed data for **a)** population, **b)** food per capita, **c)** industrial output per capita and **d)** non-renewable resources remaining (as of [62]).

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Chapter 6

A survey of projections of futures for Australia

Fulton, EA, Finnigan JJ, Pearman GI, Raupach MR

This chapter surveys quantitative projections for future trajectories of some major components of the Australian system over the next few decades: i) population, society and economy; ii) resources and industries; iii) climate and the physical environment; and iv) terrestrial and marine ecosystems. The projections are obtained from a variety of component or sectoral models rather than from a fully integrated assessment that does not yet exist. The component models show that Australia's population will increase and shift to an older median age. Economic growth is forecast to continue over 2011–50 at around 2.5% per year (a little slower than over past decades) and to shift towards service and away from primary and secondary industries. Recoverable reserves of some major fossil fuels (black coal, natural gas) and minerals (iron ore, bauxite, copper) are forecast to be exhausted in 60–80 years at current rates of extraction and much sooner for other resources (gold, lead, zinc, crude oil). Accordingly, Australia's physical trade balance (including mining, manufacturing and agricultural sectors) is forecast to show continued growth in exports to the mid-21st century, but then to collapse rapidly to around neutral. Trajectories for greenhouse gas emissions are strongly dependent on mitigation policies, including carbon pricing. Climate change will have significant effects that depend strongly on region, but broadly there will be adverse consequences for heat stress on agriculture and urban systems, water availability in southern Australia, incidence of drought and fire, and likely rises in species extinction rates and shifts in ecosystem structure.

1 Introduction

Quantitative projections of Australia's future to 2050—and in some cases beyond—already exist for many of the areas discussed in this book. These estimates have been produced using a variety of existing models for components within the overall Australian system, such as trends in population, the economy, resources, climate and physical environments, and ecosystems.

Component models such as these are not the same as the integrated assessment models (IAMs) discussed in Chapter 5 of this volume [section 6] because individual component models cannot accommodate interactions between components that are built into comprehensive assessment models spanning many components. For example, economic models usually assume specified trajectories for population and associated demand, while population models make assumptions about fertility and mortality rates that depend on many aspects of societal wellbeing, including the economy. IAMs attempt to describe such interactions.

Despite these difficulties, a substantial base of information is provided by existing models of components of the overall Australian system. These represent the best currently available estimates of trends in components given existing tools and knowledge of the processes that shape the system. Well-known examples include the *Garnaut climate change review* [1], other projections of climate and environmental variables [2], the Intergenerational Reports of the Australian Government [3], population projections from the Australian Bureau of Statistics (ABS) [4] and Treasury projections of future economic growth and sectoral activity.

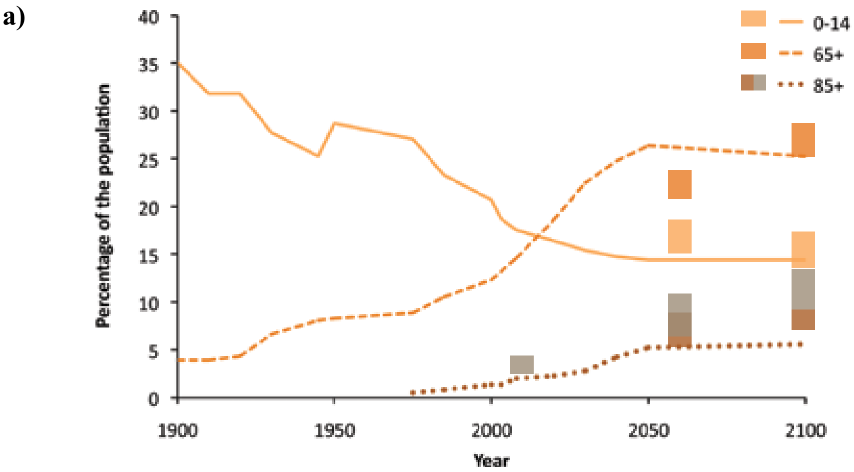
In this chapter we survey existing projections of futures for Australia as a system under four headings to collect components that are logically considered together: i) population, society and economy ii) resources and industries; iii) climate and the physical environment; and iv) terrestrial and marine ecosystems. These categories cover similar ground as the survey of past trends and the present state of the Australian system, in Chapter 1 of this volume [Section 3]. However, components are grouped in a slightly different way here for convenience.

All projections are uncertain [this volume, Chapter 1, Section 4] but the uncertainties are not often quantified other than by consideration of alternative plausible scenarios. Climate change projections are among the few classes of projection where uncertainties are stated explicitly. All projections surveyed in this must be interpreted as uncertain and henceforth uncertainties will be mentioned and discussed only where they are explicitly available.

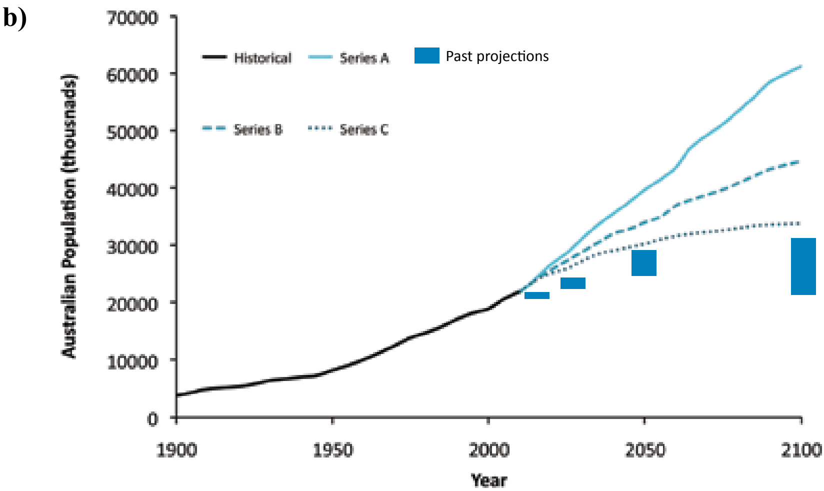
2 Demographic, social and economic futures

Three major components of the human part of the Australian system are demographics, economics and social interactions. All of these deal with human society, how it is interconnected and how it functions. Demographics addresses the balance between fertility and mortality and the things that influence them. Economics deals with the production, consumption and transfer of wealth, while social aspects deal with more intangible (but often more deeply felt) concepts such as equity [this volume, Chapter 3 and Volume 2, Chapter 3]. It is quite difficult to find projections of social aspects of Australian society. In contrast, two comprehensive examples of long-term modelling of Australia's future population and economy (its size, productivity and make-up) are contained in *The Garnaut climate change review* [1] and the series of Intergenerational Reports [3]. The Garnaut review concentrated on the economic implications of alternative future policy and climate pathways, while the Intergenerational Reports considered broader community aspects such as population structure and government spending. A range of economic models contributed to these reports, but chief among them is the Monash Multi-Regional Forecasting (MMRF) modelling framework, a vertically integrated macroeconomic computable general equilibrium model [this volume, Chapter 5, Section 3].

The first step in any economic projection is determining the future population base. Hugo [Volume 2, Chapter 2] details current population projections for Australia based on analyses by the ABS. In summary, the standout features of Australia's future population will be an increase in numbers and a transition to a much older median age (Figure 1a), rising from 36.8 years in 2007 to between 41.9 and 45.2 years in the 2050s. In absolute terms, the size of the population will also be significantly larger than today, reaching between 30 million and 43 million by the 2050s, with the difference in the final numbers dependent on future immigration patterns (Figure 1b). These changes in population are not evenly distributed across Australia (Figure 2a): Queensland, Western Australia and the Northern Territory are projected to have rising shares of the national population due to differential fertility rates and patterns of migration between states, while the relative shares in South Australia, Tasmania and the Australian Capital Territory will decline. The greatest projected increase in the percentage of the population over 65 is for Tasmania, which will see an increase of 1.5 times the national average. In contrast, ageing in the Northern Territory will not be as marked, with a projected rise of less than half the national average.



Lines are projections from [3], solid bars are projected ranges from [5]; with the second (paler) set of bars for the 85+ age group from [4].



Series A: fertility = 2.0, longevity = 96.1, net migration = 220,000

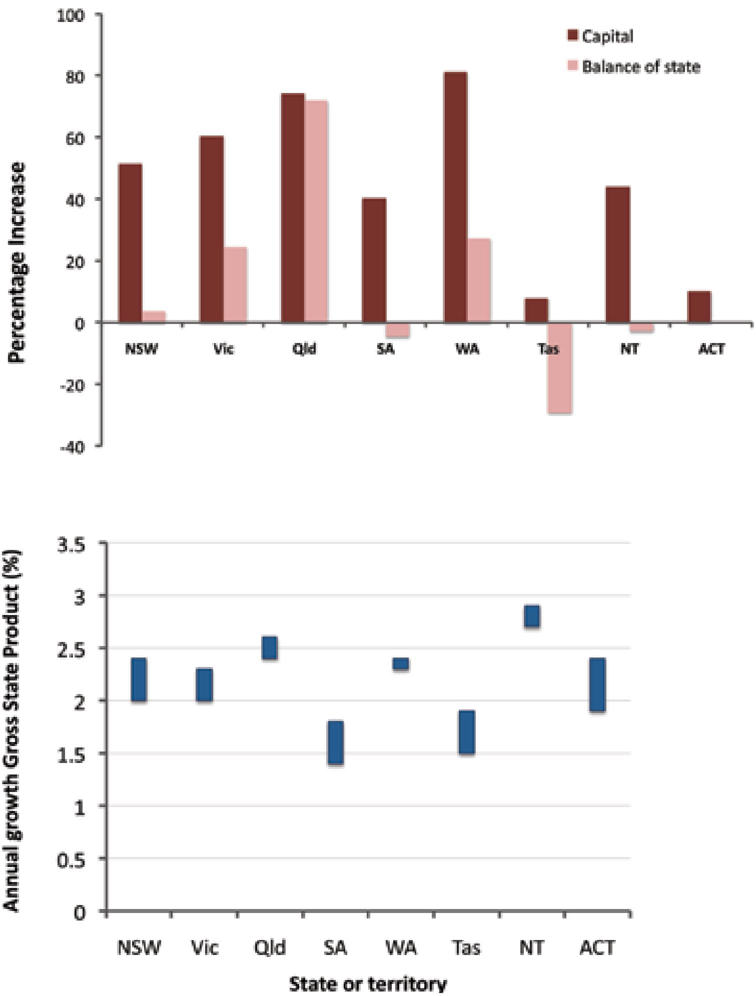
Series B: fertility = 1.8, longevity = 88.0, net migration = 180,000

Series C: fertility = 1.6, longevity = 88.0, net migration = 140,000

Past projections (ABS 2000) provided for reference: fertility = 1.6-1.75, net migration = 70,000-110,000.

Figure 1: Projected trajectories for **a)** Australia's total population (under differing assumptions regarding migration and growth rates as specified under the plot) and **b)** the percentage contributions of different age groups. Data from [4, 5, 6].

a)



b)

Figure 2: Projected percentage changes in population and annual gross state product growth rates for each Australian state: **a)** projected increase in population size for Australian in 2056 [5] and **b)** projected range of the annual growth rate of gross state product for each state in 2040 (Treasury MMRF projections from Commonwealth of Australia [7, 8]).

One of the most commonly used economic indicators is gross domestic product (GDP). Projections of real (constant price) GDP show an increase of 200–250% from 2010 to 2050, with a projected rate of growth of around 2.5% per annum, lower than the historic average of 3.3% over the past 40 years from 1970 to 2010 [1, 3]. The constraints on projected economic growth are assumed to be placed primarily by population and productivity growth as well as labour force participation. The degree of participation in the workforce will be a critical determinant of Australia's productivity and thus GDP as Australia's population ages. Current projections assume that labour productivity will continue to grow at the current historical average of 1.6% and that labour supply will grow by 0.8% per year. This growth will come largely from improved means of supporting participation such as education and health programs as well as removal of barriers that prevent participation by people aged over 65, without which there would be a significant drop in labour force participation rates (Figure 3). Australia's current participation rates are 65.2% (September 2012 [4]), as compared to 82.3% for Iceland [9], so an expanding participation is possible.

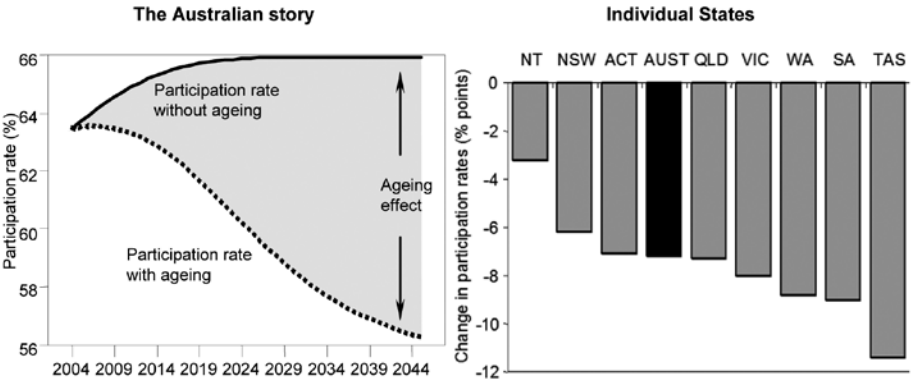


Figure 3: Example of aggregate Australian participation rates in employment with and without ageing effects [6]. The increasing rate of participation if there was no shift in Australian age structure is due to increasing female participation rates. The greatest ageing effects are in those states that are projected to see the greatest amount of aging (e.g. Tasmania).

As with population, there will be significant differences in productivity between regions (Figure 2b). The capital cities along the east coast currently dominate economic activity, with New South Wales and Victoria accounting for 55% of economic activity, but this is projected by Deloitte Access Economics [10] to decline in relative terms by 2040, when areas of northern Australia such as the Pilbara and the Kimberley in Western Australia will contribute approximately 42%, up from 35%. Much of this northern activity is directly related to exports.

Rising per capita incomes in developing nations are expected to lead to increasing demand for Australian exports, a 13% increase above 2005 terms of trade, and a restructuring of Australia's trade partnerships; for instance the proportion of Australia's total exports going to China, India and Indonesia is projected to rise from 14% to 40% by 2100 [1].

Projected trends in the productivity of individual economic sectors (e.g. manufacturing, agriculture, mining etc.) are based on relative productivity, demand, available resources and labour. Demand is the factor most likely to shift between sectors into the future. Shifts in both international and domestic demand will combine with differential productivity across sectors to induce shifts in the relative contribution of industries to the overall economy. For example, projections to 2040 of the share of employment per sector [10] indicate that while the gross form of the distribution is relatively stable there are some important shifts in individual sectors (Figure 4) such as the halving of the agricultural contribution, the 15% drop in manufacturing's share of employment and relative increases for health, public administration, construction, real estate and mining. In general, demand by both households and government bodies is expected to shift toward services in response to the needs of an ageing population.

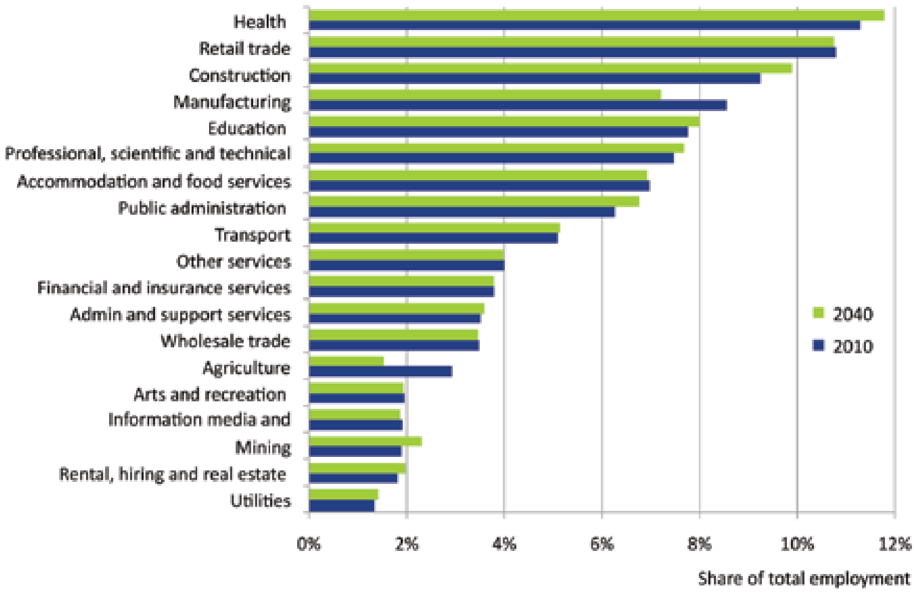


Figure 4: Share of total employment across Australian industries in 2010 and 2040 [10].

Despite the projections of rising GDP, the ageing population brings with it a fiscal burden, as can be seen in a comparison of the projected relative government expenditure by category (Figure 5). This burden is also projected to fall on a smaller tax base—today there are five people working for every person over 65; by 2050 this is projected to have declined to 2.7 [3]. Overall this would lead to an accumulating and growing fiscal gap (where spending exceeds revenue) of up to 2.75% of GDP annually, which would see the projected budget drop into deficit by the 2040s and that deficit reach 20% of GDP by 2050 [3].

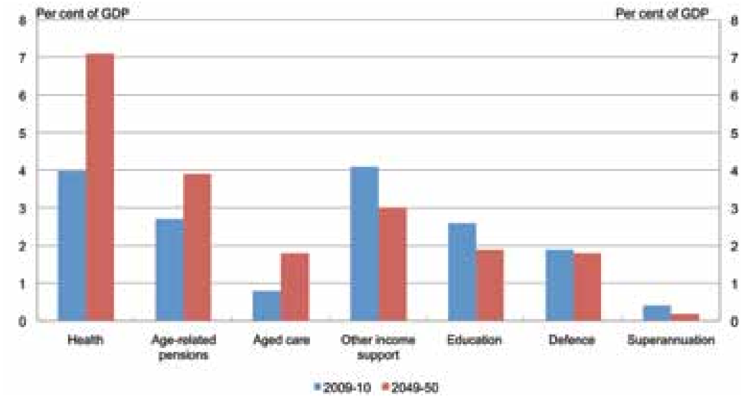


Figure 5: Projections of Australian Government spending by category in 2049–50 (redrawn from [3]).

3 Resource and industrial futures

Australia's resource sector has been one of the defining shapers of economic growth through the late 20th and early 21st century. Looking to the future, estimating the remaining state of Australia's mineral and other extractable resources is a contentious task. Making such estimates depends on many factors:

- the capacity to find and access resources relative to the rate of demand. This is not a constant because prices rise when a resource becomes scarce or when there is a growing demand (e.g. if a mineral becomes the basis of a new technology or as population grows and there are more consumers). This means that once-unprofitable methods may become viable, changing the estimates of available extractable resources.
- the existence of trade or regulatory barriers that affect security of access to the resource or limit uptake of certain technologies or impact on costs associated with extraction, processing or transport of the resource

- the position of threshold points that can shift behavioural practices (e.g. making an item a 'must have' or alternatively seeing a once common technology become obsolete), which in turn affect demand
- the environmental implications of usage, emission and extraction trajectories and whether these are deemed acceptable or not by the broader communities, both nationally and in nations with which we trade (as expressed through international conventions, trade agreements or embargos).

Nevertheless, under current rates of exploitation it is possible that at least some of Australia's economically demonstrated resources could be exhausted by 2050 (Figure 6).

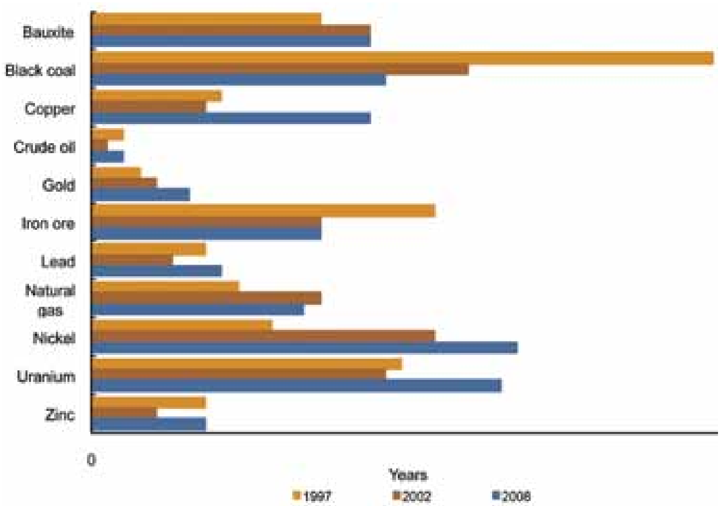


Figure 6: The indicative life of a non-renewable resources (the ratio of economic demonstrated resource to annual production) from resource and production data in 1997, 2002 and 2008 [3]. Brown coal is not included here; its indicative resource life in 2008 was 490 years.

The Australian Stocks and Flows Framework (ASFF) has been used to look at possible future pathways for the level of resource extraction in Australia [11]. ASFF is a simulation framework for tracking all the physically significant stocks (e.g. population, livestock, infrastructure, capital and durable goods) and flows in the Australian socioeconomic system [12]. The model covers processes such as demography, consumption, transport, construction, manufacturing, energy, mining, agriculture, forestry and trade. Schandl et al [11] used this model to focus on scenarios of mineral availability and agricultural productivity. The three scenarios considered by them all project growth in extraction until around 2035 when the trajectories diverge, depending on assumptions about the technological feasibility of extraction of different resource pools. Notably, per capita resource extraction begins dropping in all cases by 2050, but remains above today's level at least until the end of the 21st century (Figure 7). Domestic material consumption follows very similar trajectories in general form, although the actual values in tonnes per capita are 25–30% lower.

A key indicator used by economists to consider the state of industry and trade is the *physical trade balance*, which is that part of the nation's balance-of-trade accounting dealing with goods from agriculture, mining and manufacturing (with exports of these products providing hard currency to pay for imports). Figure 8 shows Schandl et al's projections of tonnes per capital imported (so a negative value means exports). It is clear from this that exports continue to increase steadily (the curve becomes more negative) until local resources are insufficient to meet demand and then imports rise (the curve turns and begins to rise) as the resource shortfall is met with imports.

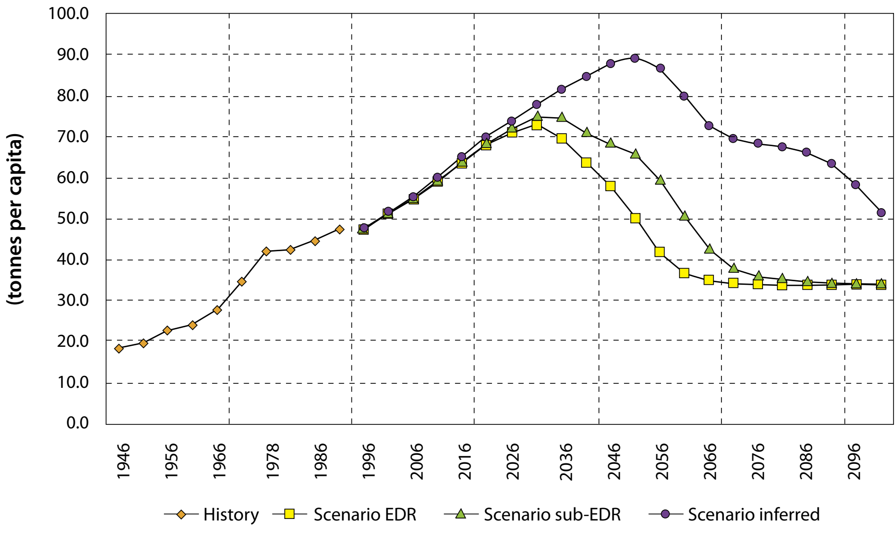


Figure 7: Projected domestic extraction of natural and mineral resources in Australia [11]. The three scenarios are based on total accessible resource pools matching 2008 economically demonstrated reserves, reserves proving to be subeconomic (due to technological constraints or resource prices) and larger reserves (defined based on currently inferred resources).

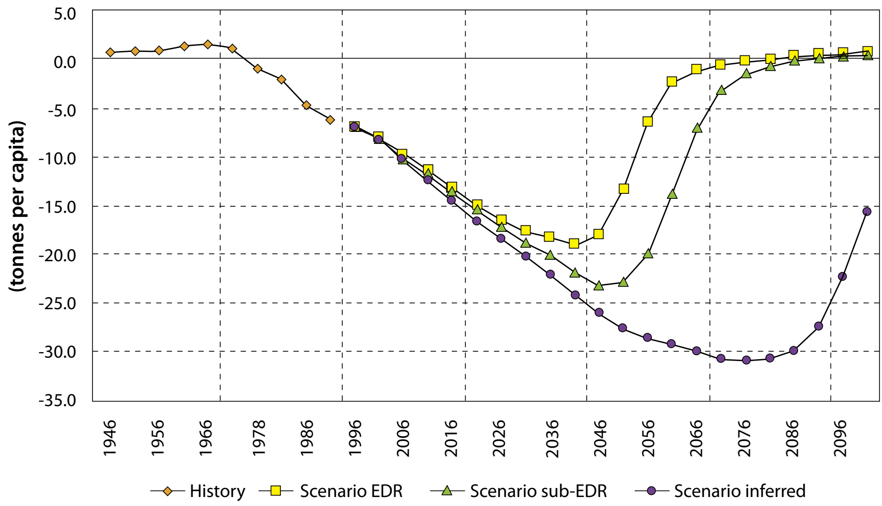


Figure 8: Projected Australian physical trade balance [11]. The three scenarios are as in Figure 7.

Beyond these broadscale models there are three aspects of Australian industry that have been modelled intensively: i) agriculture; ii) energy; and iii) emissions. Despite Australia being food secure [Stirzaker, Chapter 6 in Volume 2], agriculture is expected to suffer severe impacts of climate change. Garnaut [1] projected a drop in agricultural trade volumes of 10% by 2050 and almost 50% by 2100, although domestic demand was untouched. The drop in exports is due to substantial reductions in agricultural output. This is supported by the findings of Gunasekera et al [13], who projected a 15–79% reduction in the export of key Australian agricultural commodities in the absence of any climate change adaptation in agricultural practices or mitigation. This drop in trade is driven in part by a predicted slowing of the global economy, but also by a drop in potential production —by 2050 Australian wheat production is projected to drop by roughly 14%, beef and dairy by around 18–19%, and sheepmeat and sugar by 14%. Regionally, declines in production are predicted across the board, with the beef industries in Queensland and the Northern Territory the hardest hit, dropping by more than 30% by 2050.

The energy sector is also likely to see large changes by 2050. Projections in Syed et al [14] see energy consumption growing by nearly 35% by 2030. While coal and oil are likely to continue supplying the bulk of this, the contribution by gas and renewable energy sources are projected to increase substantially by 3.4–3.5% per year. Growth in consumption is projected to be highest in Queensland and

Western Australia (by almost double), but the distribution across sectors is likely to remain largely unchanged. Electricity generation and transport sectors will remain the two main users of primary energy (using 39% and 24% of projected 2030 total energy consumption respectively—roughly what they make up today), with mining the only industry showing significant consumption growth. Forms of energy consumption by transport could shift substantially if alternative transport fuels come to dominate petrol and diesel, although this may only occur if infrastructure constraints are rapidly addressed [15]. Gross electricity production is projected to increase by nearly 50% by 2030, reaching 366 terawatt hours, mostly due to an expansion in gas-fired and wind energy (scenario projections produced for the examination of the Carbon Pollution Reduction Scheme see similar increases in energy generation, though with much larger contributions by renewables, gas and carbon capture technologies [7]). Coal and LNG exports are projected to remain strong due to Asian market demand, with LNG exports potentially reaching 73 million tonnes per year, which would require the development of a number of current greenfield projects. In contrast, limited refinery expansion options and declining oil production are projected to continue, leading to a weakening in the trade of these products by 2030, with net imports increasing by 3.3% per year on average.

The trajectory of Australian greenhouse gas emissions is obviously heavily dependent on specific policy and technology scenarios as well as adaptation behaviour. Without further policy change, Australia's emissions are projected to continue rising, reaching 44% above 2000 levels by 2050 [16], with electricity generation the greatest source (Figure 9). Emissions are significantly lower (dropping to 200 Mt CO_2 equivalent by 2050) under alternative emission pathways (Figure 10), potentially with relatively little economic penalty (less than 6–7% drop in GNP per capita by 2050) [1, 8]. The greatest reduction in emissions is projected to be in the energy generation sector (seeing a close to 300 Mt CO_2 equivalent reduction by 2050), though all sectors would see some level of reduction driven in part by increased energy efficiency and effective demand management. There is also a variation in costs of mitigation between sectors, which would drive a structural shift in the Australian economy, with growth slowing for emission-intensive sectors (e.g. coal, and aluminium smelting), but increasing growth for low and negative-emission sectors (e.g. forestry and renewable energy).

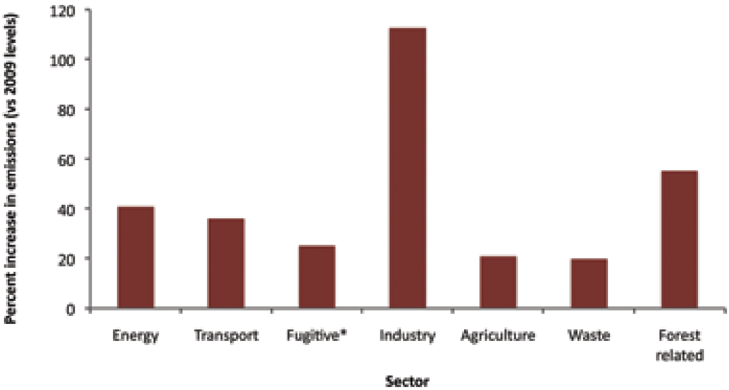


Figure 9: Growth in greenhouse gas emissions by sector 2009–30 without policy intervention (data from [15]). Note that fugitive emissions are from coalmines and gas projects.

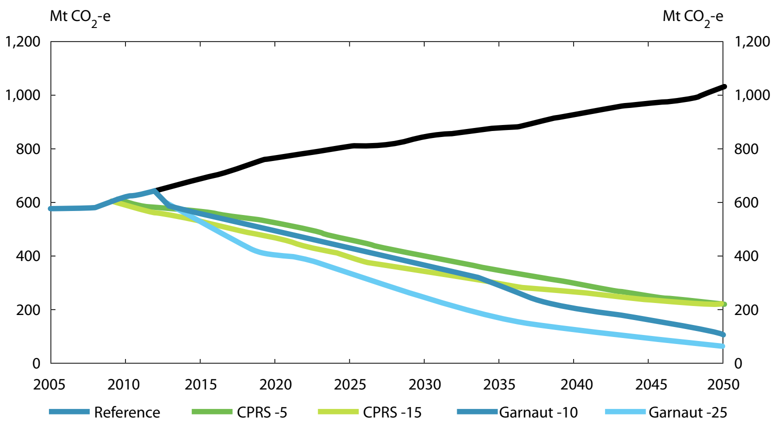


Figure 10: Projected future emissions under alternative emissions pathways. Trajectories of emissions with carbon pricing lie between those produced for the examination of the Carbon Pollution Reduction Scheme and a long-term emissions level of a little over 600 Mt CO2-e depending on initial starting prices [7, 8].

4 Futures for Australia's climate and physical environment

Comprehensive reports exist on global and national projections for specific aspects of the climate. Unless specified otherwise, all projections discussed in this section are drawn from the 2007 CSIRO report on climate change in Australia [2].

Of all the physical features of the Earth System, air temperature has probably received the most attention, with many global [17] and regional projections made. Temperature projections broadly indicate warming, to an extent depending on scenarios for global greenhouse gas emissions. In turn, these depend on trajectories for industrial and agricultural development and on the level of future emissions mitigation. Projections of future climates, including temperature, are also subject to significant model-based uncertainty because of because of poor regional resolution and lack of knowledge of critical parameters and processes [17], reflected in a spread of projections from available models.

To reflect these two different kinds of uncertainty, it is informative to give projections for particular emissions scenarios (for example, low and high) and to show results in probability bands, for instance from 10th to 90th percentiles of the distribution of projections from available models. This is done for temperature in Figure 11. This figure shows that air temperatures over Australia will probably rise by less than 4°C by 2050, with the greatest warming in the north-west and away from the coasts. Along with this warming, the annual number of hot days over 35 °C is expected to increase substantially—for example, Canberra is projected to see a rise in the number of hot days from 5 per year to between 8 and 26 days annually by 2070. For Darwin the projected increase is from 11 to between 49 and 308 days each year. There is also up to a 59% median reduction in the frequency of frosts—the reduction is not as large as the maximum daytime temperatures would suggest, due to an increase in diurnal variation.

The changes in temperature are associated with shifts in precipitation, humidity and winds. Results for precipitation are highly variable and depend on the scenario. The best estimates (50th percentiles) across all scenarios are that by 2050 there will be some increase in precipitation in the north, grading to declines of 5–20% further south and inland. Given the water supply concerns already present in Australian cities, it is instructive that a risk assessment based on the projections indicates a >60% risk of a drop in mean annual precipitation across the bulk of the continent by 2050 regardless of scenario [2].

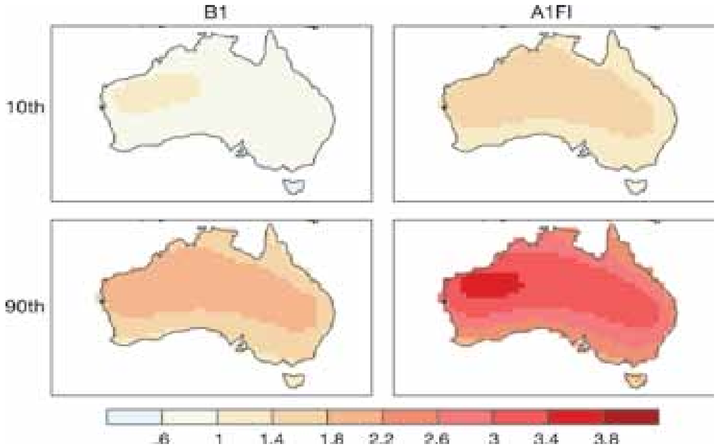


Figure 11: Projected range of annual warmings (°C) for 2050 showing the 10th and 90th percentiles for representative low (B1) and high (A1FI) emissions scenarios. From [2].

Relative humidity is also projected to decrease (by1–4%) over much of Australia, particularly in the west and south. In contrast, there are projected increases (4–8%) in evapotranspiration across northern and eastern Australia, with smaller (<4%) changes across the rest of the continent, the greatest changes being seen in the cooler months. Results for wind are variable and dependent on the scenario as for precipitation, but increases in wind speed are likely through the mid-latitudes of Australia and down the east coast [2].

Taken together, all of these shifts in climate are likely to significantly increase drought and fire in some parts of Australia, particularly in southern regions. The number of months of drought is projected to increase up to 40% by 2070 in eastern Australia and up to 80% in south-western Australia [18]. Likewise, the number of very high and extreme fire days is likely to rise—for example, from 23 per year in Canberra currently to as many as 38 by 2050. In addition, landscape fire models project an increase in the area burned annually [19].

Other physical changes projected for Australian terrestrial landscapes are increases in the extent of saline soils (which may grow to cover as much as 17 million hectares by 2050 [20]) and a decline in stream flow in southern Australia [21]. Changed river flow combined with salt already in the system is likely to see a decline in water quality. A 2006 analysis of climate change impacts on salinity and water yields in the Murray–Darling Basin [20] found that water yields in the Murrumbidgee, Goulburn and Border river catchments are projected to drop by up to 43–54% by 2070, with end-of-valley stream salinity concentrations projected predicted to increase by 8–11%.

Climate change will also affect the ocean. Similar gross spatial patterns of sea surface change are projected under most scenarios (shown for example in Figure 12), with most warming in the tropics and down the east coast. Rising levels of CO_2 dissolved in the ocean cause acidity to increase, in some places to the point where the physiology and skeletal formation of ocean microfauna and microflora could be severely impacted. Many other aspects of marine systems are also projected to change, although the exact form of those projections are currently much less certain. Some examples include:

- the level and distribution of sea-level rise, which may more than double the size of 100-year return level storm tides around Australia, leading to a doubling or more of the areal extent of any associated flooding
- changes in ocean circulation, such as the extension of the East Australian Current, shifting species distributions and altering larval dispersal patterns
- increased stratification of the ocean, which would slow mixing of nutrient-rich waters up into the sunlit production zones, which in turn would alter ocean productivity
- the spread of hypoxic zones, also known as 'dead zones', marked by low levels of oxygen[1]
- changes to the intensity and frequency of storm events.

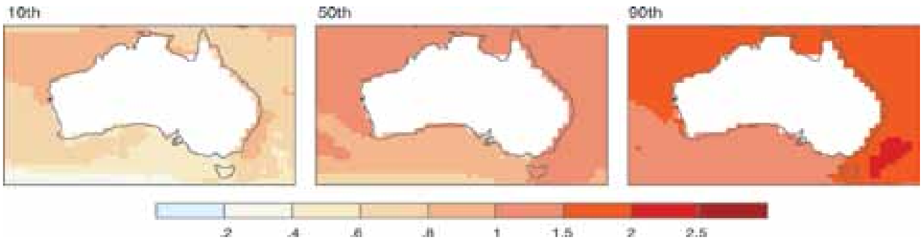


Figure 12: Projected range of annual warmings (°C) in sea surface temperature for 2050 for an emission scenario with A balanced emphasis on all energy sources (A1B), showing the 10th, 50th and 90th percentiles. From [2].

1 Most hypoxic events in Australia have occurred in highly modified or polluted estuaries. However, small dead zones have previously been reported off south-western Australia and there is the potential to expand dependent upon the amount of nutrient pollution, ocean stratification and warming and plankton production levels (bacteria acting on material from these can starve water of oxygen).

5 Futures for Australia's ecosystems

Many studies have been done (or are underway) to combine all of these changes in biophysical conditions and projected shifts in distribution of individual species (see Figure 13 for two examples). While these studies are useful, there is potentially more interest in how cumulative change (via physical factors that influence the environment, changing levels of species populations, their interactions and human use) will shape Australia's ecosystems into the future. While no national integrated model exists, early versions have been applied regionally.

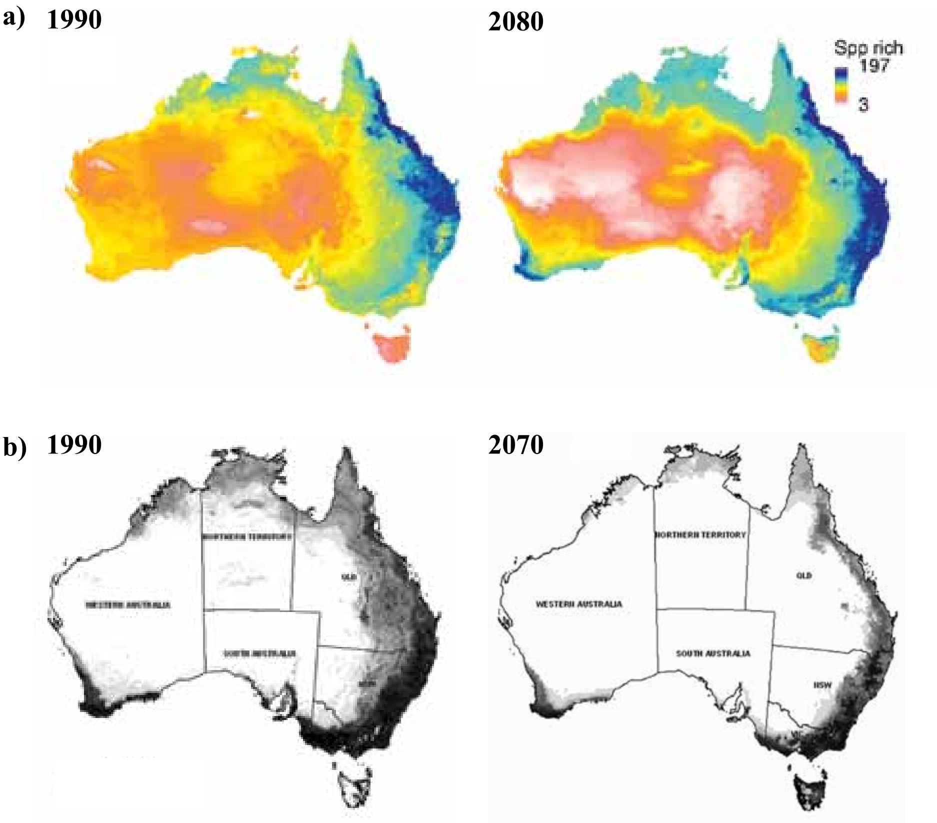


Figure 13: Examples of projected in species distributions driven by changing climate: **a)** savanna birds [22] and **b)** koalas [23].

For native terrestrial ecosystems, projected adverse effects for certain types of species are expected to become progressively worse as temperature rises, as summarised in Dunlop and Brown [24]. If temperatures increase by <1°C by 2050 then terrestrial ecosystems, which are used to some level of variability anyway, may change very little. The worst-affected would be mountain and tropical ecosystems, with a projected 50% decrease in habitat for vertebrates in northern Australia tropics. In contrast, the projected loss of core habitat for Victorian and montane tropical vertebrate species and acacia species would be <5%, though as much as 28% of dryandra species' core habitat would be significantly reduced in south-western Australia and the habitat for three frogs and 15 threatened or endangered mammals in western Australia would be lost or restricted. If, however, temperatures rise by 3°C or more, then the projected loss of core habitat for Victoria and montane tropical vertebrate species is 30–70%, with 75% of all rainforest bird species becoming threatened and 30 tropical species projected to go extinct [25]. The core habitat of 92% of butterfly species would decrease. There would probably be an 80% loss of freshwater wetlands in Kakadu in the Northern Territory and more than 66% of the core habitat for dryandra species could be significantly reduced in south-western Australia, which could also lose all acacia species. As native species are lost, weeds such as prickly acacia or buffel grass and other invading species are projected to expand [24]. All of these changes also hide the considerable variation among species in the responses to climate change and the potentially extensive compositional change of surviving ecosystems, with extensive changes likely in the species mixes seen in woodlands, grasslands and wetlands [24].

There have also been modelling studies of the cumulative effects on marine ecosystems and along Australian coastlines. For example, Fulton et al. [26] found that for the Ningaloo–Exmouth region of the Gascoyne in Western Australia, by 2050 there would likely be a contraction in agriculture and some other aspects of the local economy (e.g. a contraction of the peak tourism season and a drop-off in tourism segments unwilling to pay for air conditioned accommodation), slower growth in the population (as a result of ageing), higher unemployment and a decline in available services. At the same time, a switch to a primarily resource-extraction economy based on large-scale oil and gas extraction and associated developments would bolster the regional economy and employment but strain available housing and local energy and water resources. The projected ecological impacts were also significant (regardless of whether the resource developments went ahead or not), with the habitats becoming more vulnerable due to the combined effects of storms and acidification. Turtle-nesting beaches would be heavily impacted by sea-level rise and storms. The projected state of fish stocks is less affected by climate drivers and more by what form of fisheries management was employed. Similar exercises performed for south-east, north-east and north-west Australia [27] found high variation across species in the outcomes of potential future climate change, development and marine resource exploitation. In general, however, bottom-dwelling invertebrates and fish tend to decline, while small fish and other upper ocean-dwelling species will be better off (Figure 14). This results in a potential regime shift (a large change in the structure of the ecosystem) off south-eastern Australia around mid-century. There are economic implications of these shifts, but these are highly variable and typically dependent on social, economic and regulatory barriers to adaptation. While vertically integrated commercial operators (who can shift target species as some species become unsustainable) could see an increase in relative value, smaller operators (including recreational fishers) could see a 30–51% decline in catch. There are also implications for what form of management would be effective, with the level of sustainable catch dropping by 10% by 2050. This has knock-on implications for spending and trade in recreation and tourism because increasingly affluent societies consume more fish, which would need to be imported if current patterns continue.

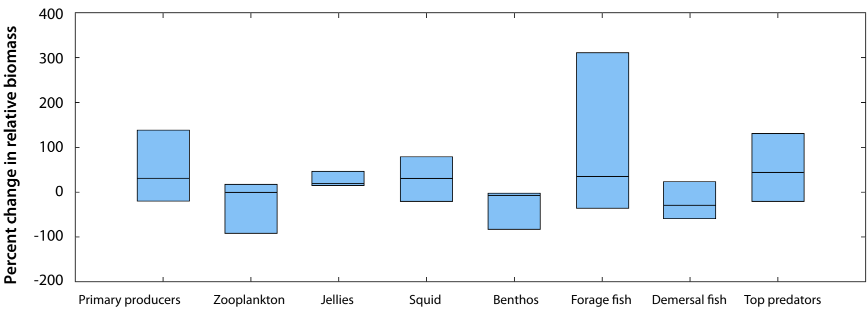


Figure 14: Range of results per marine ecological functional group for southeast Australia climate change simulations [27]. The uncertainty bands indicate the range of results observed across all modelled groups across all simulations using alternative parameterisations. The median of each range is marked.

6 Conclusions

We have surveyed existing quantitative projections of the development of major components of the Australian system over the next few decades. In most ways, the outcomes are consistent with the current expectations of most of the Australian policy, business and academic communities: population will increase and shift to an older median age; economic growth will continue at near its present rate; trajectories for greenhouse gas emissions are strongly dependent on mitigation policies, including carbon pricing; and climate change will have significant effects. All these views are consistent with the 'giant forces' or global megatrends for the next few decades, as briefly summarised in this volume, Chapter 1 [Section 4].

Some of the quantitative projections outlined here do not sit comfortably with current outlooks. In particular, there are tensions in a future with continued heavy economic reliance on exports of non-renewable resources with lifetimes of the order of 80 years or less (Figure 6). Economically, resource limitation will start to become significant well before this. Also, there are major environmental issues with a continued reliance on a global fossil fuel-based energy system, given the urgent need to reduce global CO_2 emissions to mitigate the dangers of climate change.

What reliance can be placed on quantitative projections of the kind summarised here? They represent the best available evidence at this time, but there are two broad reasons for caution.

First, these are projections for sectors or components of the Australian system, mostly without consideration of the coupling between components. There is a great need of IAMs that can handle the full system, with couplings and feedbacks between components, as called for in a recent report to the Prime Minister's Science, Engineering and Innovation Council [28]. The challenges of the science behind IAMs are also discussed in Finnigan [Volume 2, Chapter 9].

Second, it is likely that models have difficulty with surprises. Almost by definition, surprises from circumstances that fall at the edge of or beyond the envelope of 'expected' situations for which models are designed. This is true of sophisticated models of system components and also of sophisticated IAMs, just as it is true of simple quantitative models and the mental maps that constitute the models inside people's heads [Chapter 5]. There are many examples of recent events that have taken expert communities by surprise in this way, despite the reliance by those communities on sophisticated models. The 2008 global financial crisis was partly associated with a mispricing of risk and a lack of financial connectivity in sophisticated models, and those same models failed to see the crisis even as it was developing [29]. On a much smaller scale, models of the Australian electricity market have continued to predict growth in demand even in the face of observed downturns over the last few years associated in large part with unexpectedly large deployment of rooftop solar systems by households [30, 31].

These reservations are emphatically not an argument for discarding quantitative models from the toolkit for navigating the future. They are a call for interpreting models with due regard for their assumptions and for their disciplinary or sectoral restrictions.

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