Volume 2

Negotiating our future:
Living scenarios for Australia to 2050

Australian Academy of Science

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Preface

This volume is a companion to Volume 1 of *Negotiating our future: living scenarios for Australia to 2050*, a book arising from 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 project is *Australia 2050: toward more environmentally sustainable and socially equitable ways of living*.

The first phase of the project was structured around a four-day workshop in late July 2011 at Bowral, NSW, involving 35 participants and leading to the present two-volume book. The workshop was based on the Dahlem model, a formula that has proved to be effective in facilitating interdisciplinary communication and cooperation. As applied here, this model centred on four interdisciplinary working groups that intensively examined the challenges of environmental sustainability and social equity, using four different foci: i) system resilience; ii) social and cultural perspectives; iii) scenarios for Australian futures; and iv) quantitative models. Volume 1 includes chapters reporting the findings of these four working groups together with an overall synthesis.

The present volume contains 14 background papers prepared before the workshop to review current knowledge, assess knowledge gaps and provide initial opinions in a range of key areas. Early drafts of these papers were circulated to all participants in advance in lieu of formal presentations of prepared papers at the workshop. The papers form a significant body of resource material supporting the findings presented in Volume 1.

The 14 chapters in this volume cover a wide range of topics relevant to the overall theme of the workshop and the project. Chapters 1–7 describe aspects of Australia's present state and trajectory, including health, population, social dimensions, food security and biophysical sustainability. Chapters 8–11 deal with the challenges of modelling the Australian system. Chapters 12–14 deal with scenarios and narratives and the tussle between objective realities and subjective aspirations in navigating the future.

All contributions (as with Volume 1) have been peer-reviewed under the guidance of the Workshop Steering Committee. In addition to responding to review comments some authors took the opportunity for major rewriting of material after the workshop to take account of feedback at the workshop itself and to provide better support for the overviews in Volume 1.

Michael Raupach, Tony McMichael, John Finnigan, Lenore Manderson, Brian Walker (Project Steering Committee)

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 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

Australia's health: integrator and criterion of environmental and social conditions

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Australians have good health and life expectancy by international standards. Nevertheless, a variety of ongoing and emerging trends pose future risks such as the well-recognised rises in obesity, depression and stress, particularly in younger Australians. Socioeconomic differences in health persist, most starkly between Indigenous and non-Indigenous Australians. Meanwhile, on an ever-closer time horizon, various large-scale sociodemographic and environmental changes, including human-induced climate change, pose other risks to Australia's future health. Within the wider Asian region, some of these great changes contribute to risks of novel infectious disease emergence and their more distant, regional and global spread.

We have not yet, however, properly understood the main determinants of human wellbeing, health and longer-term survival—especially within the frame of environmental sustainability and social equity. Those sources reside mostly in the environmental and social conditions that maintain the essentials of life and vitality, the cohesion of communities and the opportunities for equitably-shared personal fulfilment. Instead, we persist with a predominantly individual-focused perspective in our thinking about health and responsibility for health in Australia. Much modern biomedical science is seeking to personalise health care. The lure of genetic bar-coding persists; as does misplaced reliance on personalised behaviour modification. Inappropriately, the prevailing currency refers to individual lifestyles, not the community's way of living. Yet it is shifts in human ecology, in ways of living and relating that are the main determinants of rates and trends in health and disease in populations.

The challenge is to optimise the population/community-level health determinants via coordinated social, economic and infrastructural policies. 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 and socially equitable fashion.

1 Introduction

Australia's overall level of health is high by international standards. The health profiles of populations change over time, however, in response to altered social and material conditions, food and water supplies, environmental exposures, hygiene levels, consumer behaviours and health-care resources. Indeed, population health indices serve as a bellwether of long-term environmental sustainability and of social fairness and as the measure of the vitality and vigour that are key contributors to social progress.

The recent gains in life expectancy enjoyed by Australians and other populations will not necessarily continue. Indeed, life expectancies may yet fall—at least in some countries—because of the large-scale and escalating environmental imposts of the growing global population, the health-impairing behaviours associated with rising consumerism and the social tensions of persistent material disadvantage [1]. Is 'peak health' pending? (See also CD Butler chapter [2].

Health indices typically averaged across the population mask internal health disparities, including the persistent gap between Indigenous and non-Indigenous health. As the wealth differential between Australia's rich and poor has widened over recent decades, differences in death rates and life expectancy have widened. The forward momentum from various current trends, such as rising obesity levels in young Australians, points to a likely future widening of health disparities.

The next several decades are a critical time for resetting Australia's compass to a course that can both sustain our natural environmental resource base and achieve greater social equity, cohesion and a sense of shared purpose. Note, too, that 'sustainability' refers to the long term (well beyond 2050), not merely the needs of immediate generations; and 'equity' refers to fairness and justice, not merely descriptive measures of inequality. Those two goals are prerequisite to creating a more resilient Australia that can respond flexibly to this century's great environmental and social-demographic challenges and are supportive of improved and more equally shared health.

2 Population health: significance and function

As a society we rarely discuss the fundamental significance of population health in relation to broader sustainability issues. Australia has a high-quality health-care system by world standards, and our taxation-based social insurance for healthcare, Medicare, is an important national asset. Nevertheless, the popular understanding about health and disease is essentially myopic, individual-oriented and largely

oblivious to the fundamental determinants of population health.
We rely primarily on remedial (reactive) responses to individuals' health problems, rather than on community-wide longer-term strategies to facilitate health. Yet many such strategies would be integral to changes (e.g. energy generation and urban planning) that are sought in other sectors of infrastructure and practice.

The recent prominence of neoliberal values has reinforced the assigning of responsibility for health to individuals, while discounting (often as nanny statism) the potential community-wide and enduring health gains from well-chosen intersectoral changes to physical, social and cultural conditions. While public discussion in Australia about the sort of future society we wish to live in gathers momentum, the role and significance of population health continues to receive little attention [3].

Why this blind spot? Health can be viewed as both a means and an end. Many economists prefer the former perspective and therefore view poor health as a drain on economic productivity and social stability. Indeed, this utilitarian view of health, prominent in 19th century industrialising Western countries helped stimulate early investments in sanitation, sewerage, housing standards, factory emissions, food safety etc. These investments were made largely to enhance people's health, constrain welfare-support costs, increase work capacity and thus maximise economic growth. A modernised utilitarian view of gains in population health as prerequisite to economic growth in low-income countries was emphasised by the World Health Organization's Commission on Macroeconomics and Health [4]).

Health, at the population level, can be viewed in different ways. For example:

- as economic burden: rates of diseases, injuries and premature deaths are a major determinant of society's running costs
- as economic asset: population health underpins economic productivity and wealth creation and shores up the morale, vigour and resilience of society
- as an index of inequity: since both good health and access to healthcare are deemed basic rights, disparities in either index provide a measure of inequity
- as a criterion of a successful and sustainable way of life: persisting good health in a population provides one key measure of the environmental sustainability of the population's way of life and of its social-structural conditions.

That fourth view— as a criterion of a successful and sustainable way of life— invokes a more ecological and integrative understanding of the sources of good health and of the causes of disparities [5]. Members of any single community a bandwidth of level of health that reflects their shared physical, biological and social ecology while accommodating interindividual variations. This broader and less biomedically bounded perspective of health as a property of the population also comfortably encompasses mental health and indices of social engagement and self-fulfilment.

Much of Australia's health promotion discourse in recent decades has continued doggedly to focus on modifying individual behaviours, including via public education campaigns— as reflected in the *Report of the National Preventative Health Taskforce* [6]. A wider vision seeking intersectoral engagement in building health-supporting environments and commercial practices that are ecologically sustainable over time is lacking. For example, multiple wins would flow from modernised ready-access urban transport systems that cater for both physical and automated modes of travel, including benefits to environment, climate, population health and patterns of social interaction.

Good population health will be an essential feature, as a positive input and as a manifestation of a future environmentally sustainable and socially equitable Australia. We may not often think of our society in these terms but the building and progression of society is ultimately about maximising human wellbeing, health and survival, and (in today's circumstances especially) doing this in an environmentally sustainable and socially just and fair way. Fortunately, many of the major and often transformative changes needed to achieve sustainability will confer health gains, both physical and mental. Changes in ways that we settle and live in cities and towns; produce, process and distribute food; generate and use energy; move ourselves around our habitats; structure communities and relate to one another all hold promise of widely-shared 'collateral' health benefits.

Finally, we can also view the significance of and prospects for long-term shared gains in human population health as an analogue for what we seek for other species and ecosystems—those that we depend on and many others that may not be in a direct relation with us. Their vitality and resilience too provide ongoing feedback about our sustainability-related choices

3 Australia's current health profile

The population's average level of health can be measured via indices of health outcomes such as life expectancy, and of risk profiles, such as smoking prevalence. The former indicates past performance. The latter points to likely future health impacts.

Life expectancy

Around 1900, average life expectancy in Australia was 55 years for males and 59 years for females. Since then, males and females have each gained more than 25 years. Now Australia is in the world's top bracket of longevity with Iceland, Japan, France and Sweden [7]. Note, though, that life expectancy is a tip of the iceberg measure telling little about ongoing health status and experience of the survivors. Trends in Australian life expectancy at age 50 years projected to 2051 are shown in Figure 1.

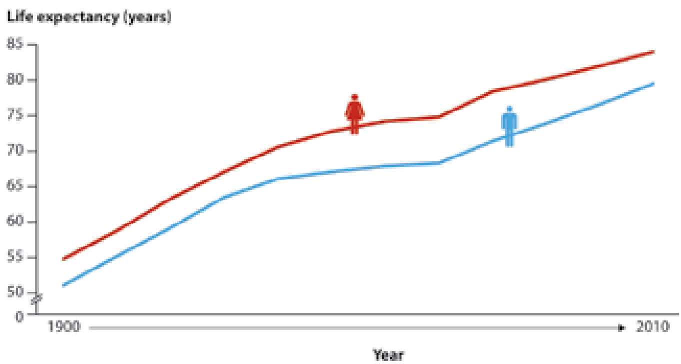

Figure 1: Australia's life expectancy at age 50 years: data to 2002–04, projections to 2051

We can reasonably expect further gains in Australia. However, while a longer life sounds enticing, life expectancy gains will impose extra burdens on society [8]. A 'longer stay' not only means a larger cumulative (lifetime) personal environmental footprint; foreseeably it also means a longer average period of personal waning health and increasing dependence and extra burdens and costs to family and society. An ageing society may diminish opportunities for younger people and (if more extended and creative use of experience and wisdom of 'elders' is not made) the resilience of society overall.

Overall national health profile

The overview of major health indices in Australia [7] lists the following:

Major diseases

- Cancer is Australia's leading broad cause of disease burden (19% of total) followed by cardiovascular disease (16%) and mental disorders (13%).
- Heart attack rates continue to fall and survival from them continues to improve.
- One in five Australians aged 16–85 years has a mental disorder (mainly anxiety or depression) in any 12-month period, including one in four 16–24 year-olds.
- The Type 2 diabetes burden is rising and likely to be the 'leader' by 2023.
- The incidence of end-stage kidney disease is increasing, with diabetes as main cause.

Health risks (circa 2007–08)

- Smoking prevalence (~16% in adults) continues to fall.
- Three in five adults and one in four children aged 5–17 years were overweight or obese.
- Rates of sexually transmissible infections continue to rise, particularly in young people.
- Illicit drug use has generally declined.

The recent rise of overweight and obesity in Australia and many other parts of the world is a strong signal—still widely misunderstood—that our modern way of living as a society is out of kilter with the biological needs, capacities and behavioural reflexes that have been honed by evolution. We have not yet learnt to live healthily with modern comfort, convenience and consumer choices.

Between 1995 and 2007–08, the prevalence of overweight (body mass index BMI >25) and obesity (BMI >30) in Australian adults increased by 20 to 25% across all age groups, in both men and women [7]. Lower-income Australians have higher rates (44%) than do upper-income Australians (38%). The figure in Indigenous Australians had reached a damaging 60% by 2004–05, accompanying a rise in sedentariness over the past one to two decades [7] and, for many, the consumption of a nutrient-poor and energy-dense diet.

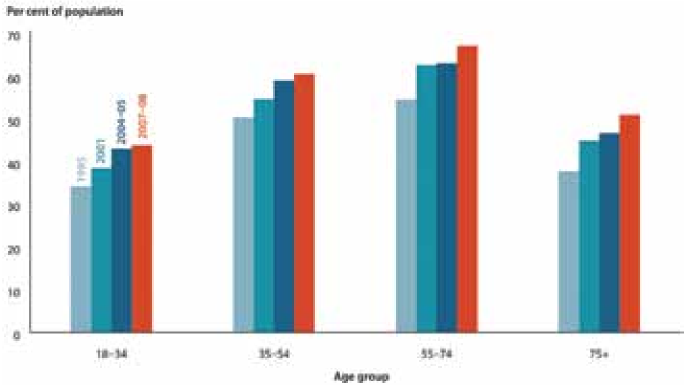

Figure 2: Time trends in overweight and obesity in Australia, 1995–2008 (AIHW 2010)

The central problem is that on average our personal daily energy budgets are increasingly in surplus. The combination of excess dietary energy and reduced expenditure of physical energy reflects fundamental shifts in the ways we produce, process, consume, move, work and enjoy recreation. The imbalance in personal energy budget varies between individuals, as do genetic factors that affect the efficiency of biological energy-handling. However, the *average* risk of obesity is elevated for all, reflecting our shared way of living.

Genes and disease: a cautionary note

The role of genes in health disorders is widely overstated. Individuals naturally vary in their genetically based metabolic profile, and this intrapopulation genetic variation yields the phenotypic variation that is substrate for selective Darwinian winnowing within the population's genetic spectrum as environments change over time. Gene discoveries provide easy headlines: media reports abound of laboratory science discoveries of genes for overweight and obesity, for example. However, the recent rise of obesity has nothing to do with a shift in the population genetic profile, which has remained essentially unchanged over that brief time, while the physical, social and cultural environments have changed greatly.

Improved population health in Australia does not lie in some DNA-based nirvana wherein personalised genetic bar coding determines permissible behaviours and the treatment of that person's health disorders. Rather, it lies in the collective and farsighted shaping and management of our natural and social environments, in recognition of their role as distal, underlying determinants of human biological and psychological wellbeing and health.

Obesity: health consequences

The ongoing rise in overweight and obesity presages a continuing rise in serious, life-threatening disease processes, especially Type 2 diabetes. Diabetes is now three times more common in Australia than it was 20 years ago and may become the leading cause of disease burden in Australia by 2023 [7] (Box 1). Although Type 2 diabetes has typically appeared in mid-adulthood, its incidence at younger ages is rising, reflecting the rise of early-life overweight and obesity. Research in the United States suggests that the emergence of near lifelong obesity and its health consequences could erode life expectancy [9].

Box 1: Excerpt from: National Preventative Health Taskforce Report (2009):

If the current trends continue unabated over the next 20 years, it is estimated that nearly three-quarters of the Australian population will be overweight or obese in 2025… Almost a quarter of Australian children are overweight or obese, an increase from an estimated 5% in the 1960s. … Type 2 diabetes is projected to become the leading cause of disease burden for males and the second leading cause for females by 2023, mainly due to the expected growth in the prevalence of obesity. If this occurs, annual healthcare costs for type 2 diabetes will increase from $1.3 billion to $8 billion by 2023.

Health disparities (especially non-communicable diseases)

Health disparities occur on many axes: age, gender, socioeconomic position, ethnicity and geography. Disparities attributable to socioeconomic position are of particular concern, and while less extreme in Australia than in many other OECD countries, they are significant. For example, the decline in death rates from coronary heart disease and stroke since the late 1960s, and the more recent downtrends in lung, colorectal and breast cancer deaths, have been unequally shared among Australian subpopulations. (This may reflect disparities in incidence, disease fatality or both.) At ages 25–64, the ratio of death rates in the lowest versus highest socioeconomic quintiles increased for all causes of death in men, especially cancer and cardiovascular disease deaths; similarly in women. Australians living in remote areas with poor access to medical services have a life expectancy approximately four years below the national average [10].

There is no simple solution to these health inequities. They reflect underlying deficiencies in social structures and relations, in built infrastructure, and in the differential health impacts of various aspects of modern consumer culture [11]. Further, many adverse health outcomes reflect the priming effects of lifelong biological conditioning (or programming) dating from foetal and early postnatal life—also, typically, unequally distributed within the population. The policy implication is clear though demanding. In addition to the usual vote-garnering strategies of government, such as providing counselling services and public education, we should plan long-term for future ways of living that both improve Australia's collective health and reduce inequalities in health.

Mental health and wellbeing

Mental health problems are the perennial Cinderella of public health and hence of prevention strategies. Lacking the tangibility of metabolic disorders or surgically tractable anomalies, they are less easily defined, measured and explained. Yet they are a major and apparently growing source of poor health in the Australian population.

Recent national survey data show that one-fifth of Australians aged 16–85 years had been affected by the more common mental health disorders during the previous 12 months. This included one-quarter of young adults aged 16–24 [7]. Depression is moderately higher in persons of lower socioeconomic status relative to the higher socioeconomic bracket.

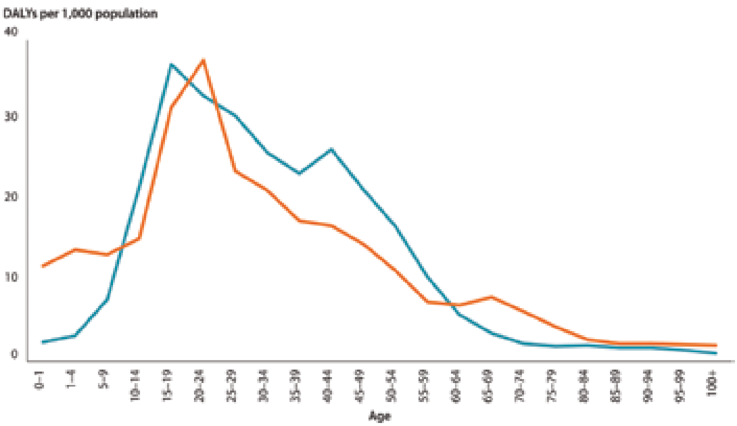

Figure 3: Burden of mental health disorders measured in disability-adjusted life-years (DALYs) in Australia in 2010: by age and gender [7].

The uptrend in anxiety, depression and related disorders raises the question: is our society heading in a direction poorly suited to the psychological and emotional needs of most people? Empirical research can elucidate what might impair mental health in Australia's way of life.

The extent of social contact is an important determinant. Research that began several decades ago [12] has established a clear theoretical and empirical basis for understanding how social relationships affect health. Prospective studies consistently show an increased risk of early death in persons with limited social contacts. Supportive research shows that neurohormonal activity is affected by social isolation and by other sources of stress—as in the major study of healthy middle-aged men and women in the London-based Whitehall II Cohort, which found that social isolation was associated in men with a higher blood cholesterol response to stress and both men and women with higher blood levels of the 'stress' hormone cortisol throughout the day [13].

A largely overlooked influence on wellbeing and health, both mental and physical, is time scarcity and its usual companion, time pressure—the chronic and typically stressful feeling of having insufficient time to do obligatory tasks, let alone activities that would enrich life and promote personal health (recreation, exercise and time to cook good meals). Related measures made over past decades indicate that lack of time has become increasingly prevalent in modern Australia, while contemporary research indicates that two-thirds of full-time employed mothers in two-parent Australian households experience recurrent time pressure, as do just under half of husbands/fathers and 80% of single-parent mothers [14]. These figures vary across socioeconomic strata, with higher-income families better able to buy in extra help. Time scarcity and pressure, often maximal in poorer families, can erode health both directly, and especially because of what it prevents people doing.

Macroscopically, comparisons of trends in national demographic, economic and social indices in relation to trends in disorders, diseases and death rates can provide important pointers to likely larger-scale, population-level influences. For example, the analysis of time-trend data, spanning four decades in 56 countries, indicated that 'processes of economic growth, market integration, foreign direct investment, and urbanization were significant determinants of long-term changes in mortality rates of heart disease and chronic non-communicable disease, and the observed relationships with these social and economic factors were roughly three times stronger than the relationships with the population's aging'[15].

Access to green space in the living environment improves both physical and mental health [16]. Small-scale psychological research shows that exposure to green space reduces stress and restores attention [17], while larger epidemiological studies have shown that green space is correlated with self-perceived health [18]. Here then lies a potential synergy between wiser management of natural environmental resources and facilitation of social contact—that is, convergent agendas of environmental sustainability, social cohesion and equity.

More than four in five young Australians surveyed say they are healthy, happy and satisfied with life. However, other health indicators suggest that many are faring poorly [19]. Adverse health trends include physical problems such as obesity and inactivity, psychological problems such as chronic tiredness, depression, drug abuse and, rarely, suicide (see also Fig 3). While some of this may originate in circumstances of homelessness, parental unemployment, poverty, hunger and insecurity—other dominant aspects of the current Australian way of life—may neither appeal to nor connect with many younger people [20]. Is this due to a sense of emptiness or meaninglessness, the flip side of a consumer culture that promotes owning and consuming as the path to happiness and fulfilment—or is it more to do with a complex of more pervasive influences associated with modernisation and its emphasis on materialism and individualism?

To give an adequate contemporary account of young people's health in general, Eckersley proposes that more attention should be paid to the pervasive social and cultural circumstances and values that dominate their changing world [19]. This, he argues, will carry us beyond a narrow focus on 'ill-health' to recognising the health-affecting deficits in the cultural mainstream of society where prevailing values and practices typically impair rather than improve life experiences, happiness, good mental health and social cohesion.

Health of Indigenous Australians

A glaring health gap persists between Indigenous and other Australians [21]. The dispossession and the destruction of culture that has been the experience of Australian Aboriginals and Torres Strait Islander peoples during the past 220 years have largely eliminated the cultural and spiritual foundations of good physical and psychological health. Enduring solutions remain elusive in the absence of educational equality and the restoration of rights, ownership and cultural identity.

Improved Indigenous health, states the National Strategic Framework for Indigenous Health [22] 'requires support for healthy interdependent relationships between families, communities, land, sea and spirit. The focus must be on spiritual, cultural, emotional and social well-being as well as physical health'.

Currently the gap in life expectancy between Indigenous and non-Indigenous Australians is around 12 years for males and 10 years for females. Child death rates are more than double the national average figure. The overall burden of disease is two-and-a-half times higher in Indigenous Australians than in their non-Indigenous counterparts and much of that burden is due to chronic non-communicable diseases such as diabetes, cardiovascular disease, chronic respiratory disease, chronic kidney disease and cancer. The proportion of adult Indigenous Australians who experience high levels of recurrent or chronic distress is double that seen in other Australians [7].

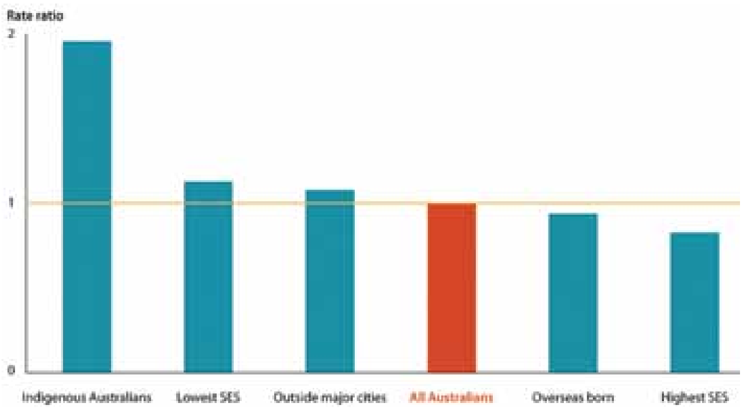

Figure 4: Relative rates of death (age-adjusted) in five major subgroups in Australia (All Australians = 1.0) [7]

4 Future health in Australia

Trends

Various health-related trends that are currently visible in Australia foreshadow impediments to improving, even maintaining, good health within the Australian population. As discussed above, these include:

- the rise in overweight and obesity in both adults and children
- increasing disaffection, disengagement and stress in many younger Australians
- the work–life imbalance (high by international standards) experienced by many within the Australian workforce and its consequences for family and personal life and health

- the rising speed with which infectious diseases emerge and spread internationally, and particularly in the East and South-east Asian region
- the decrease in local influence and control over food and consumer choices as the world economy globalises and the focus of daily life shifts from citizenship to 'consumership'.

Other influences on Australia's future health include population growth, patterns of settlement and daily living, population ageing (with its overhanging shadow of dementia), interactions with the Asia and Pacific region (including increased intercountry migration and multicultural living in the region) and the health risks from human-induced global environmental and climatic changes and from other environmental 'losses' within Australia.

Medical technologies and healthcare facilities continue to evolve. Meanwhile some public health strategies (e.g. the discourse on our urban futures) are at last being framed more broadly (and thus sustainably). These will help promote and restore good health.

Ageing

The continuing rise in national life expectancy along with the declining fertility will result in Australia's population-age structures becoming increasingly top-heavy. Major social changes will result—culturally, socially, economically and in health-care needs and facilities.

An ideal social goal is for citizens to live longer while incurring lower rates of chronic diseases at older ages—originally referred to as the 'compression of morbidity' [23]. Morbidity comprises two basic categories: organ/system disease processes and physical ailments and disabilities. Recent trends in these two categories in high-income countries have differed. The prevalence of many non-communicable diseases in older people has increased—presumably partly reflecting better detection and improved treatment. A more realistic goal might therefore be a longer period of living with disease (e.g. diabetes, high blood pressure and some cancers) but with lessened discomfort and impairment.

In many OECD countries older persons are physically fitter than their predecessors. Japanese over 65 years of age have experienced gains in mobility [24], while the proportion of US adults over 65 living without substantial disability has increased [25]. Meanwhile, population ageing will almost certainly herald an increased prevalence of age-related dementia. Currently around 200 000 Australians have dementia (twice as many women as men). This figure may more than double by 2031 [7].

Emerging infectious diseases

The death rate from infectious diseases in Australia plummeted during the 20th century. In the 1960s and 1970s, various eminent Australian and overseas scientists forecast a future world in which infectious diseases were only a minor problem. That world was taken by surprise in the last quarter of the century as the emergence of apparently new infectious diseases in humans accelerated. Since the mid-1970s around 35–40 new and seemingly human-adapted infectious diseases have been identified in humans. New infectious agents emerge particularly from animal sources (rodents, bats, primates, other mammals and birds), often in the ecologically dense settings of tropical forests and woodlands and frequently around urban-industrial conglomerations [26], which presumably reflects both socioeconomic factors (e.g. population density, antibiotic use and farming practices) and disturbance of local ecological systems [27].

In north-east Australia, a succession of novel and lethal viral infections in humans (e.g., Lyssavirus, Hendra virus) has emerged recently from bats, via primary infections of horses and dogs. The H1N1 swine flu pandemic of 2009 gained entry to Australia, and caused a number of deaths in Victoria. Meanwhile, several other 'old' infectious diseases (e.g. cholera, dengue fever and tuberculosis) have also increased around the world. The consequences for Australia of living in an increasingly interconnected world and region are illustrated by tuberculosis, which ominously has recently increased worldwide in the multidrug-resistant form. Currently, tuberculosis affects around 430 per 100 000 people in Papua New Guinea vs. 6 per 100 000 in Australia. An estimated one-fifth of tuberculosis cases in south-west Papua New Guinea (closest to Australia) are multidrug resistant and there has been increasing cross-border movement between that region and the nearby Australian Torres Strait islands.

Environmental deficits, exposures

Since settled agrarian living emerged, human societies have striven to make life more secure and comfortable. In recent times we have succeeded in material terms beyond the wildest possible dreams of those early struggling farmers and herders—success that has depended largely on our ability to harness high-density, portable energy from fossil fuels. Today some of that success has soured as aspects of this economic intensification adversely affect the natural environment and human health. Indeed, in the view of some, the world community may be approaching 'peak health', as life expectancy trends begin to flatten out and diverge between regions and income-defined groupings of countries [1].

Earth's environmental systems underpin life support for all species. Many of these systems are under increasing pressure from the growing global human population and its intensified economic activities, and some are showing serious strain and disruption, especially the world's climate system, the global nitrogen cycle and biodiversity stocks [28] Those environmental changes will all impinge on Australia. Climate change is already beginning to affect some health risks [29]. So too are other large-scale environmental changes in Australia that are part of worldwide mosaics, including land degradation, water shortage, urbanisation (with loss of fertile land) and overexploited fisheries.

Alongside these worldwide environmental changes are many demographic, social, cultural and economic changes. As populations grow and economic globalisation proceeds, human connectivity is increasing. Levels of average wealth (and of consumption and waste generation) are rising. These changes have far-reaching consequences for human health.

5 Climate change and Australia's health

Impacts of climate change on health

Australia, as poet Dorothea Mackellar famously remarked, is a sunburnt land of droughts and flooding rains. As those extremes multiply or intensify in response to climate change they will injure, kill and demoralise more people. Other health impacts will occur via less dramatic paths. These include the effects of climate-induced changes in levels of various air pollutants (inorganic, organic and biotic), enervating heat episodes in workplaces, altered patterns of infectious diseases, chronic stress in parts of rural Australia, and others.

Climate change will almost certainly increase levels of social and geopolitical instability in parts of the Asia and Pacific region, due to declining food yields, tensions over river flows and groundwater, weather disasters and coastal displacement. This will influence flows of people and the resultant health risks, including greater mobility of infectious agents. In parts of Asia the combination of population pressures, land-clearing, river diversions, agricultural activities and increased people movements makes more likely the emergence of novel infectious agents, some of which, assisted by warmth, water and winds, will find entry points into Australia.

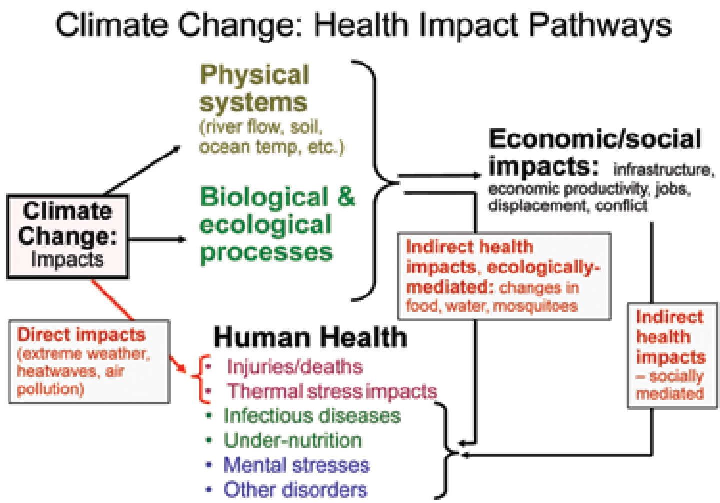

Figure 5: Schematic diagram of the main paths, direct and indirect, by which climate change influences human health risks and outcomes.

The several general categories of direct and indirect threats to human health are shown diagrammatically in Figure 5. Specific examples of these in the Australian context are shown in Table 1. Both the figure and table make clear the diversity of health risks to communities and populations posed by changes in climatic and (hence) environmental conditions.

Since the 1960s the annual frequency of very hot days and extended hot periods in Australia has increased. Severe heatwaves cause surges in both morbidity (often with hospitalisation) and mortality. The extreme heatwave in Victoria in early February 2009 caused an estimated 370 heat-related deaths in Melbourne over a one-week period. Future heatwaves in Australia are projected to be more intense and longer lasting. Climate modelling by CSIRO, which assumes continuation of the current warming trend, projects that by 2100 the annual number of days with temperature exceeding 35°C in Melbourne will rise from nine to 27 [30]. Extremes of heat endanger various occupational groups, and the annual number of dangerously hot days in Australia when outdoor work would be precluded is projected to increase substantially by 2070 [31]).

Urban air quality will also be affected by climate change, posing increased risk to those with chronic respiratory and cardiovascular diseases. Warmer temperatures will enhance the production of ozone, a known respiratory irritant, in urban air. Increases in airborne allergens—pollens and fungal spores—are also likely as plants respond to an environment that is warmer and richer in CO_2.

Already apparent prior risks apparently being amplified by climate change

Uptrend in average annual number of heat-days → deaths, hospitalisations

Increase in number and/or severity of bushfires → injury/death, respiratory hazard, mental health disorders

Probable current health impacts but not yet clearly identified/identifiable

Rise in foodborne diarrhoeal disease

Altered air quality: ozone formation, aeroallergens (pollens and spores)

Mental health impacts, particularly in some (drying) rural regions

Thermal stress in some groups of outdoor workers: physiological compromise, injuries, eventual organ-system damage

Predicted future health impacts

Extreme weather events: injuries, deaths, infectious disease, depression

Water shortages: impacts on hygiene, recreation, regional food yields

Mosquito-borne infections, including:

dengue, Ross River virus, Barmah Forest virus, Japanese encephalitis

Physical and behaviour-based health impacts in affected rural communities

Table 1: Climate change risks to health in Australia: present and future.

Vector-borne infectious diseases are sensitive to changes in climate and associated environmental changes affecting the habitat, reproduction and survival of vector species such as mosquitoes. Mosquito species that transmit Ross River and dengue viruses may spread beyond their current range in Australia, while also amplifying infection rates in endemic areas. Modelling for the 2008 Garnaut review projected that, under moderate global emissions reduction (mitigation) scenarios, the geographic region suitable for dengue transmission could spread southwards, putting 5–8 million people at risk by 2100 [32]. In contrast, for strong mitigation scenarios the estimated future population at risk would contract to less than one million people.

Foodborne and waterborne diarrhoeal infections are likely to increase under climate change conditions. Bacterial gastroenteritis, especially salmonella infection, is sensitive to temperature and hence to warming [33, 34]. In contrast, some viral causes of diarrhoea that are typically more common in winter may recede with warming [35, 36] Under medium-range climate change scenarios approximately a quarter of a million additional cases of bacterial gastroenteritis would be expected in Australia annually by 2050 [32].

Cyclones and floods, likely to be more severe under climate change, often damage water supplies, sewerage and electricity and may impede access to medical care. Impaired food hygiene, water quality and sanitation practices often cause gastroenteritis outbreaks. In the wake of such events there are adverse social and mental health impacts from property loss, bereavement and population displacement.

Australia has historically been a major food exporter. However, climate change, together with extreme weather events and other accruing environmental deficits, jeopardises food yields in parts of Australia. This, plus incoming ripples from climatic-environmental setbacks for major overseas food exporters (e.g. the United States in 2012), foreshadows rising food costs that may make healthy foods unaffordable for low-income families.

Many impacts of climate change will result in mental health disorders. Rural, remote and indigenous communities in many regions of the world are bearing the brunt of early human-induced climate change. Many such communities live closer to the vicissitudes of the natural world than do urban populations. More generally, children are vulnerable to emotional and mental health disorders due to fears and misunderstandings about climate change and due to their dependence on caregivers who may be adversely affected by climate change [14].

Adaptation to (unavoidable) climate-related risks

Since the world's climate is already changing, and with additional warming already 'locked into' the system, public health ('adaptive') strategies are needed to minimise the otherwise unavoidable health risks.

Making choices among the range of possible adaptation strategies requires consideration of relative vulnerability of different population subgroups. Vulnerable groups include the elderly, frail and chronically ill (e.g. heatwave risks), children (extremes of weather), remote Indigenous communities (reduced native species food yields, water shortage), occupational groups exposed to heat, and low-income families with uninsulated housing.

Over coming decades adaptation strategies will evolve, reflecting new knowledge, experience, and shifts in priorities. Currently proposed examples [37] include:

- reducing emission of local air pollutants
- enhancing microbiological safety of food and drinking water
- improving housing designs, especially insulation, ventilation and mosquito-proofing

- extending and improving control of disease-vector species, including insects and rodents
- ensuring diversity and resilience of agriculture; improving food availability and equity
- securing fresh water supplies to avert shortages and resultant health risks.

Health co-benefits from climate change mitigation actions

The compelling primary reason for taking early mitigation action is to avert the worldwide health risks from climate change. Meanwhile, there is a second, *positive*, health-related incentive for action. Populations taking mainstream mitigation actions will benefit from various near-term, localised, health gains (in addition to the primary global health protection being sought) [38]. Examples are:

- reducing fossil fuel combustion: cleaner air reduces rates of cardiovascular and respiratory disease, lung cancer and neurologic disorders
- improving energy efficiency of homes and buildings: reduces impact of heatwaves and cold weather; also asthma and allergies
- shifting from fossil fuel-powered transport (especially private cars) to more active transport (walking, cycling, mass transit): reductions in respiratory and heart diseases, breast cancer, obesity, diabetes, depression
- reducing animal food intake, especially red meat from methane-emitting ruminants (cattle, sheep, goats etc.): reduces cardiovascular disease and diet-related cancers.

6 Patterns of urban settlement and health in Australia

The human species has become a predominantly urban species. Australia has long been at the forefront of this urbanisation process. Cities are multiplying and growing rapidly, especially in developing countries. The UN Population Fund projects that 69% of people will live in cities by 2050. By then, Australia's population may comprise 30–40 million people from diverse backgrounds, with an older profile, living mostly in cities.

Urban form and function exert enduring influence on daily living conditions and behaviour patterns—and hence on health. Worldwide urbanisation thus represents a huge shift in human ecology, profoundly shaping health-related behaviours and outcomes. These include:

- patterns of spread of various infectious diseases within and between cities (e.g. SARS, influenza and antibiotic-resistant pathogens)
- the impacts of the car culture, including trauma, air pollution and physical activity levels
- changes in food supplies and consumer food preferences
- levels of social contact, wellbeing and mental health.

In the 19th century, the cities of industrialising countries were beset by infectious diseases. The latter 20th century cities, while nurturing material prosperity, promoted sedentary lifestyles, excess consumption and consequent lifestyle diseases. Cities now face the convergent pressures of larger and older populations, increasing environmental constraints and stresses, likely increases in risks of epidemic outbreaks, and threats to community cohesion and mental health. Mood and anxiety disorders are more prevalent in city dwellers. Further, dynamic MRI brainscans reveal how particular regions of the brain display different responses to stress, according to the life-stage in which urban living was first experienced [39].

Without insight and innovative forward urban planning many health risks will increase. Therefore, the planning and renovation of settlements in Australia should seek to accommodate ongoing shifts in demographics, environment, technology and culture in ways that maximise the prospects for human wellbeing and health while also achieving environmentally sustainable ways of living (in relation to both local and global footprint indices). Cities are more than engines of wealth creation, education and artistic creativity. They are where people live, eat, interact, relax, exercise and seek emotional fulfilment – all of which influence population health. The ‘urban futures’ challenge is therefore a great challenge for interdisciplinary thinking, intersectoral planning and implementation and community engagement in the process.

7 Prospects for prevention

Learning from the past

In Europe and colonial Australia the public health revolutions of the latter half of the 19th century led the way in initiating major changes and gains in population health. Much of that early focus was on sanitation, food safety, factory safety, control of black smoke, and quarantine laws. Infectious disease epidemics duly receded long before antibiotics and most vaccinations were discovered.

In the early 20th century, much effort went into further methods of controlling infectious diseases and into improving maternal and child health. Prevention was becoming more focused on families and individuals. That individual focus strengthened later in the 20th century as infectious diseases receded and non-communicable diseases such as heart disease and lung cancer began to rise. In the 1980s, following an upturn in the emergence of apparently new infectious diseases (e.g. Legionnaire's disease, swine flu, hepatitis C), the (initially) puzzling disease AIDS arrived. Identified as a viral disease, HIV/AIDS dominated public concerns and public health programs during the latter 1980s. Australia was a leader in its open approach to educating and changing behaviour.

Today's prevention tasks remain as great and protean as ever. Australia has seen recent major gains in tobacco control, drink driving, skin cancer prevention, immunisation coverage and HIV/AIDS control. Even so, we now also face larger scale changes on the economic, environmental, demographic and social fronts. Strategies in both research and practice for improving and maintaining population health are therefore of a scale and complexity that require new understanding, concepts, strategies and collaborations. Contemporary research is embracing systems theory and recruiting widened interdisciplinary collaborations to elucidate the complex dynamics of these pervasive influences on health.

Building a resilient Australia

> Population health may be an important factor in determining whether societies respond effectively to adversity ... In particular, mental health and morale could have a critical bearing on how societies cope with climate change and other 21st century global threats. [3]

Over the coming half century the Australian population must anticipate some major environmental surprises and 'shocks'. Climate change projections indicate that droughts, bushfires, floods and heatwaves will occur more often and more severely. There will almost certainly be increased migration of displaced people from the Asia–Pacific, creating other stresses. Collaboration across diverse research disciplines, policy sectors, private interests, and communities will help build the profile of physical, social and psychological preparedness needed for a resilient society able to cope and thrive in the coming century.

Public health systems will face new demands. Reliance on reactive healthcare strategies (doctors and hospitals) will not be sufficient. The Australian population at large faces the health consequences of major changes in environmental and sociodemographic circumstances.

Conclusion

In an environmentally sustainable and socially equitable future Australian population health should serve as a central criterion in planning and monitoring. We need neither an economy nor an intact natural environment primarily merely for their own sakes. Rather, they are population-level assets for comfortable, sustainable and healthy living. Great change is therefore needed in how we understand the underlying determinants of health and disease, optimise those determinants via social, economic and infrastructural policies, and modify the community's expectations of healthcare systems (and what society can afford).

Human civilisation is entering another great transformation. The Agricultural Revolution evolved gradually over several millennia, and the Industrial Revolution (not yet universal) has occurred over two centuries. The transformation to national and global environmental and social sustainability must be achieved within the next half century if we are to avert the worst, perhaps irreversible, consequences of the unprecedented environmental, climatic and demographic pressures we now face at that macroscale. The achievement of good and equitable population health is both a key objective of any enlightened society and, assessed over time, a key criterion of whether that society is living in environmentally sustainable, health-supporting fashion.

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Chapter 2

Health, population and climate change: Australia 2050

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An increasing number of environmental and social (eco-social) forces acting at the global, regional and national scale are influencing Australia's population health, size and carrying capacity. Mainstream forecasts of population health in Australia and other high-income countries predict further improvements in life expectancy and quality due to new technologies, new medications and better application of the growing understanding of life-course epidemiology. However, global eco-social determinants of population health are deteriorating far more quickly than appreciated by most health analysts. Without a greatly accelerated sustainability transition, including a move to a postcarbon economy, the interaction of rising energy costs, climate change and conflict may result in peak health following peak oil.

Apprehension of eco-social factors has motivated a growing popular opposition to further expansion of Australia's population. However, government will persistently favour business and strategic concerns, meaning the country's population is likely to undergo a substantial increase, perhaps to 40 million or more by 2050. This will also be driven by sustained demand to migrate to Australia.

Climate change in Australia will intensify, yet its local adverse health effects are likely to be minor in comparison to the wider threats from regional and global climate change, allied with other manifestations of nearing limits to growth. Even so, there are several policies and technologies that could not contribute to climate change adaptation and mitigation and also improve Australia's carrying capacity, simultaneously lowering the regional threats to our wellbeing. These changes focus on acceleration of the sustainability transition such as decarbonisation and effective foreign aid. Most fundamentally, effective Australian eco-social adaptation requires it to contribute to regional and global sustainability policies.

1 Introduction

It is commonly claimed that the future cannot be predicted, yet our capacity to use science to peer forward in time is improving. Analysis of the recent past is salutary. Some may say that the lens selected here is idiosyncratic, but few will find it sentimental. It is not reassuring. The tone of this chapter may be found unusual, even unsettling, because I take this opportunity to write as frankly as possible, risking being viewed as opinionated and polemic.

2 Wishful thinking

The year 2050 is barely 38 years distant. Figure 1 illustrates some of the key events in this period relevant to the themes of this chapter. Forty years ago, *The limits to growth* was published, having an enormous impact. Yet only 12 years later US President Reagan declared that global population was not a problem (including in low-income countries), further legitimising and establishing the 'cornucopian enchantment'[1]. During this period (approximately 1980 to 2005) mainstream scientific and elite political opinion considered that technology and ingenuity would be sufficient to solve major global problems. For example, during the 1990s, *The Economist* felt entitled to repeatedly ridicule environmental concerns in prominent articles. The long-standing editor of *Nature*, John Maddox, also considered that the risks of the environmental case were overstated.[2]

Policy makers, scientists and the public were not literally enchanted, but seduction, suppression, censorship, self-censorship and publication bias, including in the scientific literature, prevailed. Many data ostensibly supported the optimistic case. For example, during this period the global energy price remained comparatively stable and low, following the Organisation of Petroleum Exporting Countries (OPEC)-led oil shocks of the 1970s. These shocks occurred decades before the more fundamental demand–supply mismatch that will increasingly be experienced. Dr Fatah Birol of the International Energy Association identified the year of peak oil production as having occurred in about 2006 [3]. During this time of enchantment (which could instead have been used to prepare for the present), warnings of impending oil scarcity were marginalised, including in the scientific literature. This credulity occurred despite the implausible stepped increase to declared oil supplies reported by six OPEC countries in the late 1980s following an alteration to the rules, which provided an irresistible incentive for exaggeration [4]. Credulity also occurred, despite the fact that peak oil discovery (as distinct from extraction) occurred well before 1970 [5].

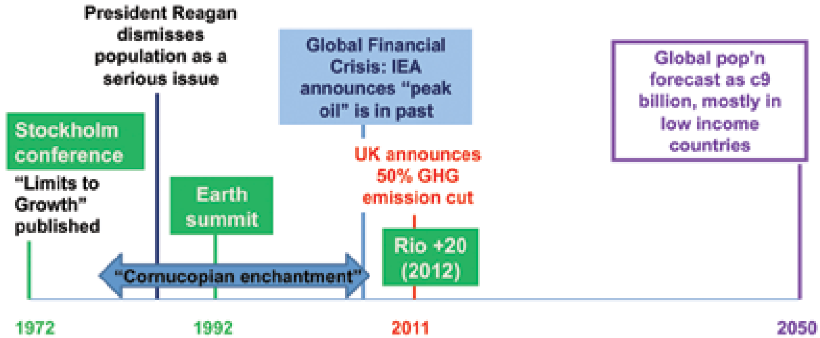

Figure 1: 2050 is less than 38 years away. It is more than 38 years since *The limits to growth* was published, at the time enjoying enormous popularity. Yet, only 12 years later, US President Reagan declared that population (including in low income countries) was not a problem, further legitimising the cornucopian enchantment, a period of about 25 years during which mainstream scientific and political opinion considered that technology would solve major global problems. This period of enchantment should end soon, yet popular understanding of its demise is immensely painful and disturbing. However, a principle motivation of the antipopulation growth movement in Australia, evident in the hostility expressed towards asylum seekers arriving by boat, shows partial public recognition of the difficulties ahead. All hope is not lost: in May 2011, the UK government announced an ambitious plan to halve greenhouse gases by 2025, heralding a new Industrial Revolution. The UK, of course, is where the original Industrial Revolution occurred, in the 18th century.

Further underpinning global complacency, the proportion of the global population classed as hungry by the Food and Agricultural Organization of the United Nations (FAO) fell sharply between 1970 and 1996 (see Figure 2). This fall was mainly because of the success of the Green Revolution, the name given to a cluster of agricultural innovations. These enabled a much higher production of food for a given area, though with a correspondingly high dependency on resources, including fertilisers and pesticides, some of which are derived from oil and other fossil fuels. The Green Revolution was named to contrast with the Red Revolution, reflecting widespread fear, and perhaps understanding, that global inequality, including of food, would hasten the collapse of capitalism. This spectre could be averted by more food production.

However, optimists who interpreted the phenomenal success of the Green Revolution as evidence that even larger scale triumphs of technology and knowledge would follow ignored, forgot or denied the warnings of Norman Borlaug and others (see below). Also, during most of this period, climate change was considered as remote or even benign [6].

As conventionally measured, the global economy has grown substantially since 1970. But such measures ignore the depletion in natural capital, especially of fossil fuels. Technological innovations also contributed to confidence, including

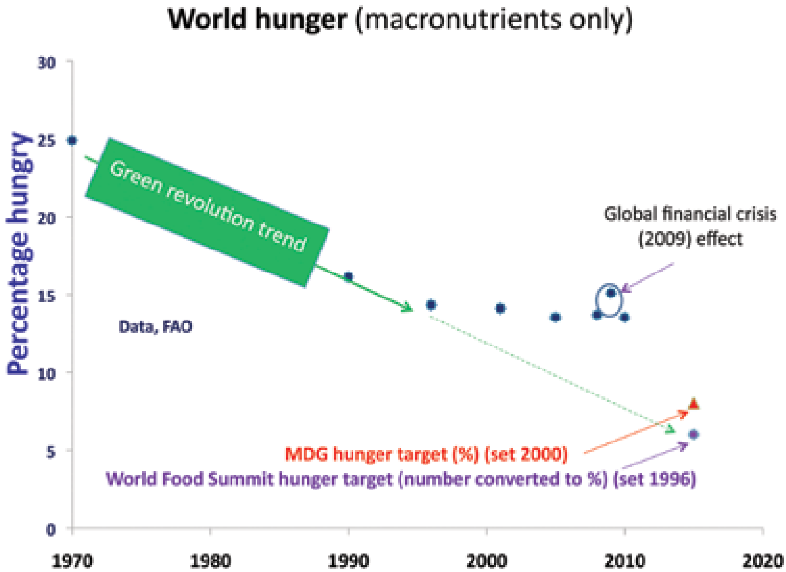

Figure 2: Wishful thinking–world hunger: the dream and the reality. Wishful thinking and poor science are clear with regard to world hunger reduction promises and goals. The World Food Summit target (diamond), set in 1996, appeared plausible to the politicians, academics and bureaucrats who developed and announced it in Rome in 1996, by extrapolating the trend between 1970 to 1996. However, even then, elite scientific opinion, as expressed by the *World scientists' warning to humanity* (1992), suggested the target set for 2015 would be unreachable. One consequence of the Cornucopian enchantment (see Figure 1) was to undermine attempts to lower global population growth (except in China), thus intensifying the failure of the World Food Summit target. Four years after the World Food Summit, the Millennium Development Goals were announced, including one for hunger (triangle). It was slightly less ambitious, but it, too, is far beyond reach.

the explosion of computing power, the scale of the internet and the decoding of the genome. Despite the dotcom bubble and the Asian financial crisis in the late 1990s, most economists during this period considered a repeat of the global depression unthinkable. Overconfidence in the capacity of capitalism was also boosted by the collapse of the Soviet Union and the marketisation of the Chinese economy. Even though the September 2001 attack exposed a dangerous gash in global society, high-income countries responded with a 'War on Terror' rather than global policy reform.

On the other hand, during the cornucopian enchantment a minority of elite scientists remained deeply concerned about the gathering pace and scope of global eco-social problems. Perceived risks encompassed not only climate change, long-term food security, loss of biodiversity and ecosystem services but also other elements of what the epidemiologist Tony McMichael called in 1994 'planetary overload' and the atmospheric scientist Paul Crutzen in 2002 called the ‘Anthropocene’. Less well understood were concerns about the relationship between environmental scarcity and the increasingly unequal distribution of opportunity, influence and wealth leading to social instability, violent conflict, rebellion and terrorism[7]. Preceding McMichael and Crutzen’s terms, the *World scientists' warning to humanity* [8][8] (which brought together over 1600 eminent senior scientists, including over 100 Nobel laureates in science) had repeated the central idea in *The limits to growth*. One signatory, Norman Borlaug, had made a similar statement in 1970 predicting that the Green Revolution would run out of steam in perhaps a generation (see Figure 2). In short, peak oil, peak phosphorus and peak carbon may be followed by peak food and peak health. I will return to this.

3 Denial

Today, while some policy makers and scientists apprehend the peril that global society is facing, popular understanding remains sparse. Awakening entails a fresh global understanding not only of humans as a geological force responsible for our collective fate but also as breakfasting in a world where, only the previous night, we and our predecessors destroyed much of the natural wealth that we once assumed would build our future. Awakening seems especially painful in Australia, the ‘Lucky Country’, and its principal ally, the United States—both nations with high current and historical per capita dependency on fossil fuels and with recent historical memories of the frontier. In both countries amplifiers of denial and antiscience have been especially powerful (see Figure 3). Population health globally has also been very slow to integrate the likely consequences of impending limits to growth [9].

The cornucopian enchantment arose because of a complex interplay between science, decision-makers, opinion-leaders and public opinion. The latter is especially fickle—readily amplified or tempered by the multiplier of group psychology—that is, by the opinion of the wider group (see Figure 3). The end of this enchanted era should surely be apparent, as evidenced in global financial crisis-stimulated attempts to reform the global economy and the gathering momentum to slow the rate of climate change. Full awakening should also be prompted by growing concern over the price and availability of future energy and food. However, numerous vestiges of denial remain. In Australia, key vested interests that have operated to delay preparation for the sustainability transition include the mining companies and electricity producers, employing proxies such as the Lavoisier group.

History shows that the true views of national elites are rarely revealed, but they can be deduced. At present, elite Australian opinion (awaking to oil scarcity but still largely in denial about the magnitude of future climate change) appears to foresee that Australia's relatively large coal and other mineral reserves will be the principal means to ensure affordable future Australian energy while simultaneously generating sufficient income to maintain an adequate defence force. Our democratic system may also be partly responsible for our collective lack of preparation: there is a perception that both main political parties risk extinction by electorates if told unpalatable news, even if truthful [10].

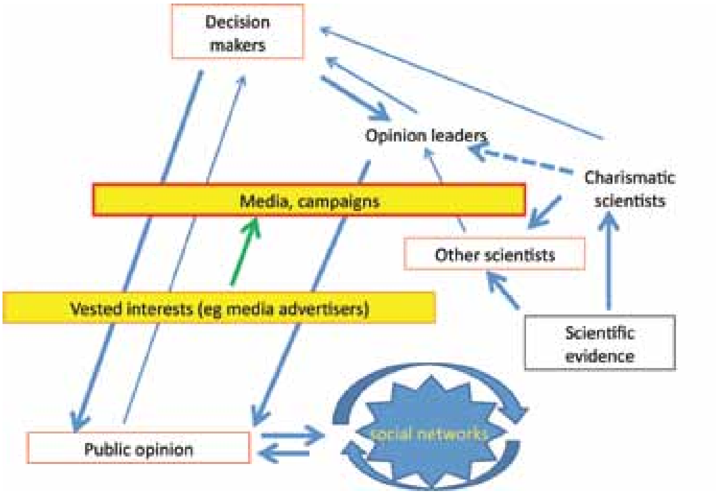

Figure 3: Denial, science and public opinion. A complex interplay exists between science, decision-makers, opinion leaders and public opinion. Denial is an important element of this, but applies at different levels within society (as indicated here by the presence of a box and its thickness). The scientific evidence of approaching limits to growth, including of severe climate change, is very strong. However, even within the scientific community, denial inhibits discussion of many plausible scenarios, resulting in a bias to optimism. A few charismatic scientists (e.g. James Hansen, James Lovelock) exhibit little self-censorship, but risk scientific credibility and reputation by speaking out. Vested interests, which profit from 'business as usual' employ and promote a suite of business and scientific leaders to present opinions that they favour. Importantly, few, if any, of these spokespeople (e.g. Fred Singer, Bjorn Lomborg) appear insincere or in strong denial. Arguably, however, many people who profit from the promotion of these views are in denial, similar to the tobacco industry in high-income countries in recent decades and in many low-income countries today (who were and are aware of the evidence). Mainstream public opinion pays little attention to science, or to evidence of impending limits to growth, even if surveys claim otherwise. Moreover, public opinion is fickle; quickly amplified or diminished through the multiplier of social networks. The role of denial as a component of public opinion concerning limits to growth role should not be overstated; perhaps more important factors are limited education, more pressing concerns, and 'cultural resistance' to science.

4 Hope

Denial is a psychological mechanism employed unconsciously to minimise anxiety, doubt, regret and guilt. It is, perhaps, essential for fortitude, if not happiness. But we do not know the future with certainty. Many previous prophecies of famine, the collapse of civilisations and other catastrophes have proven false or premature. It is yet possible that technological developments—as miraculous as electricity, the telegraph and space travel once seemed—could be around the corner. Indeed, in the energy field declining photovoltaic costs, large-scale solar thermal energy generation and the capture of excess renewable energy and its storage in car batteries may provide means to minimise the impact of rising liquid fuel costs and, at the same time, slow greenhouse gas emissions [11]. The recent UK Government decision to halve greenhouse gas emissions by 2025 is cause for genuine hope as are increasing discussions of alternatives to economic growth [12].

Other energy strategies—such as increased use of gas, coal seam gas, coal to liquids, biofuels, energy conservation, urban densification, greater electronic communication and increased public and active transport—will also supplement diminishing supplies of oil and could meaningfully bridge the gap between the present and a future supply of sustainable, comparatively clean energy provided by sun, wind and waves. A suite of nascent energy technologies exists such as advanced nuclear power, nuclear fusion, third-generation biofuels, large-scale carbon sequestration and the use of solar energy to generate biofuels from algae (or compressed hydrogen as an alternative energy carrier) and even to export portable energy from sunny desert areas across the ocean.

Desalination of seawater and poor quality groundwater may also increase human carrying capacity, especially if powered by renewable energy. Such developing technologies keep hope alive, but it would be an imprudent government that counted on miracles. Collectively, however, in recent years, most countries, including our own, have indeed relied far too much on hope. Captured by vested and timid interests, public opinion holds too much support for yesterday's technologies (such as the burning of coal and even of wood) and insufficient support for sunrise industries such as wind, solar and smart grids. This is especially so in Australia, a land flooded with sunlight.

5 Australian population health

The definition of health is much broader than the absence of physical illness and the extension of life, and it merges with wellbeing. Health has physical, psychological and spiritual dimensions. It is a precious asset often taken for granted until illness or disease strikes. Health cannot be sold, though poverty and health are rare companions. Human wellbeing also has intangible elements such as security, friendship and freedom. These elements also influence personal health and (at a population level) perception of Australia's desirable future population size and composition.

There is a longstanding debate as to whether health is determined more by individual factors (access to technological and surgical wizardry such as new organs, new procedures and the mirage of pharmaceuticals tailored to individual genetic profiles) or by collective determinants such as nutrition, equity, governance and sufficient exposure to nature and leisure. The debate is largely settled within population health in favour of collective factors, (see McMichael Chapter 1) but it thrives in the public and government sectors, and among many medical workers. For example, eating a healthy breakfast can be viewed as either a completely individual decision independent of advertising, or a choice influenced by advertising, which is especially effective among populations who are most vulnerable. The perspective on this is also fuelled by ideology—for example, people with a neoliberal world view are not only more likely to see diet as an individual choice but also support the right of the food industry to sell whatever it likes, even if it contributes to diseases such as diabetes. This ahistorical viewpoint also helps blind the wider health community to the risks we now face.

The first half of this chapter focused on the deterioration of the environmental and, to a lesser extent, the social determinants of global population health. Although life expectancy has continued to rise in both low- and high-income countries, it is plausible that this increase will not long continue. We may be very close to peak health as measured by average global life expectancy. In both high- and low-income countries, health gains are undermined by rising obesity and reduced nutritional variety as food prices rise. There is also an ongoing fall in social connectedness, though this may be partly offset by increased electronic connectivity.

To a considerable extent, these risks also reflect the recent rise in the faith of market forces to generate health for all, an approach that has created material abundance for some but led to a dangerous erosion in the determinants that lack a market price. However, all hope is not lost. Though perfection is impossible, a ‘muddle through’ world may still be achievable in which global life expectancy in 2100 roughly equals that of today but in which global population size is larger. Pathways to this are sketched in the conclusion. In such a world the current Australian population size and life expectancy would increase. Our per capita quality of life would fall, but not catastrophically.

6 Australian population size

Both the public and the government consider that Australia’s population, now about 22.5 million, will follow a variant of one of three potential trajectories in the coming decades. Each assumes an increase. Conventionally, these projections are described as ranging from very low to very high, yet when we reflect that Australian history started at least 50 000 years before 1788, even the lowest plausible modern population growth trajectory is extraordinarily high in historic terms. A rising population is clearly undesirable from an ecocentric perspective because even the most eco-friendly expansion of Australian population will reduce habitat. However, ecological protection is not and cannot (ethically, from an anthropocentric viewpoint) be the principal determinant of the future size of Australian human population. In any case, the relationship between biodiversity and human population size in Australia is highly nonlinear. For example, enormous harm occurred to Australia’s biodiversity through the introduction of species such as rabbits and foxes in the 19th century.

Many of the adverse regional trends described above (e.g. energy, climate change, food production, inequality and the fragility of the global economy) contribute to the recent growth of anxiety concerning Australia’s future population [14]. Hostility is particularly targeted at the tiny number of asylum seekers arriving by boat, vilified as ‘queue jumpers’—today’s version of the ‘Yellow Peril’. Minimal concern, by contrast, is directed at the far larger group who arrive by plane and overstay their visas.

Proponents of slowing Australia’s population size point with validity to the deterioration in urban infrastructure, to rising urban congestion and to unaffordable urban house prices as adverse consequences of high immigration, the main reason for the recent, high growth (even on a global scale) in Australian population size. Proponents also sometimes claim that rising population may lead to net food imports even though, on average Australia currently grows sufficient food for 60 million people per annum. This buffer of food for 40 million will be lowered by climate change and population growth, but probably not to zero.

On the other side, advocates for high immigration claim it will provide employees necessitated by the mining boom and assert (falsely) that it will help support an increasingly aged population. Though less readily admitted, a steady increase in skilled population will maintain a high demand for housing, underpinning house prices and disproportionately benefiting some economic sectors.

Military interests are probably powerful supporters of substantial population growth. Hugh White, Professor of Strategic Studies at the Australian National University, argues that a low-growth Australian population trajectory will create vulnerability in the context of declining US power balanced by a rise in Asian power [14]. Consideration must also be given to the possibility that a low-population Australian trajectory in a region of increased tension will lead to an intensification of 'fortress Australia', which will be increasingly costly to sustain both financially and physically. Such tensions seem likely to increase irrespective of Australian population size but will likely be intensified by a slowing of Australian population growth, which may enhance domestic xenophobia and offshore envy and resentment.

7 Conclusion

Australia faces a looming, multifaceted crisis. Global economic, social and environmental forces eliminate the chance of a stable or declining near-term Australian population trajectory irrespective of what activists and isolationists may wish. Even a low population growth rate in comparison to that of recent decades is high historically and will increase the total Australian environmental footprint [9]. It seems inevitable, even with the best planning, that population growth will further harm Australia's per capita quality of life, particularly in terms of urban space and environmental amenity. But such a decline need not be catastrophic or permanent. Our quality of life is currently very high and includes a cushion that can be reduced without tragedy.

Furthermore, a global revolution in green technologies is underway [15]. If sufficiently supported, promoted and successful, this revolution will go far to lessen the regional and global tensions that otherwise threaten to overwhelm the world both through climate change and rising energy costs. In that more relaxed world, Australia could also better cope with a sustained rate of moderate or even high population growth based mostly on migration. This would be plausible, for example, by developing new cities fuelled and watered by solar energy and desalination of seawater and groundwater. Memories of the relaxed, comparatively uncrowded nature of many suburbs and cities will fade, but the vastness of the Australian rural landscape will not.

But glib assurances that moderate or high population trajectories are sustainable simply by intensifying business-as-usual are misleading and even dangerous. Massive intensification of effort is urgently needed to convert sustainability rhetoric into reality. New energy, transport and water systems are not enough: Australia also needs to project a vision and demonstrate a genuine attempt to maintain a high quality of life with a lower environmental footprint, nationally, regionally and globally.

Recognition of these dilemmas is evident in sporadic, high-level calls to divert part of Australia's defence budget (circa $27 billion annually) to increased foreign aid (circa $4 billion). However, a higher quantity and quality of aid is insufficient to guarantee long-term wellbeing for Australia's population. To maximise that, policymakers and the global public need price signals and other incentives to drive sustainable practices.

Technologies and theories are developing to promote global sustainability, such as the new Industrial Revolution and steady-state economics. It is still possible to slow the global population trajectory by using rights-based family planning, thus enhancing the world's chance of meeting the next incarnation of the Millennium Development Goals. With enough effort, Australian society can assist in finding a pathway in which a higher population (domestic and global) is consistent with a muddle-through sustainability. This is achievable by lowering our per capita footprint and increasing the quality and quantity of our foreign aid. Time is short, the road is steep.

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Chapter 3

Australian population futures

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Australia stands at a turning point in its demographic development. It is crucial at this time that a vision of our future population is developed that takes full account of the best scientific knowledge and policy thinking and includes the wishes and opinions of all Australians. Public debate about population and immigration in Australia has too often been dominated by interest groups and has focused on extreme positions. On the one hand are those who believe Australia should increase its population as rapidly as possible and strive to double the current population. On the other hand are some extreme environmentalists who argue for an immediate cessation of population growth. It is my argument in this chapter that both of these extreme positions would have negative consequences for Australia and most Australians. Both positions oversimplify the population issue and see population policy as a silver bullet to deliver either economic prosperity, in the case of the 'growth at all costs' lobby or environmental sustainability by the 'zero growth' lobby. However, the relationships between population and economic growth, environmental sustainability, equity and liveability are much more complex than these simplistic positions suggest. Population policies must take full account of these complexities.

1 The contemporary population

The growth rate of Australia's population has been an issue of considerable recent public discussion. The rate of 2.2 % in 2008–09 was almost twice as fast as that of the global population as a whole as well as being almost 20% higher than growth in less-developed nations and more than five times higher than that of high-income countries. This represents the fastest annual rate of population increase since 1960. Although most recent data (for the year ended 30 September 2010[1] show that the rate has fallen to 1.6%, Australia still has the fastest growing population of any contemporary high-income nation.

To understand this growth requires that the overall rate is disaggregated into the demographic processes that contribute to population change—natural increase (births minus deaths) and net migration (the excess of incoming migrants over outgoing migrants).

Firstly, with respect to the mortality component of natural increase there has been an increase of 13.1 years in life expectancy at birth for males and 13.3 years for females since World War II. Even more striking, however, has been the change that has occurred in the life expectancy of older Australians. For men aged 50, 8.7 years of extra life have been added since 1971 and for women 7.0 years. More and more Australians are reaching retirement age and when they get there they are surviving much longer than earlier generations. (The main exception to this outcome has been the experience of Indigenous Australians, and there is much to be done to close that gap.)

These increases in life expectancy represent a major achievement but they also present a challenge. This challenge is not only because there are many more Australians surviving to old age than in previous generations, but also because it may well be that on average they are sicker than earlier generations. While there is some disagreement regarding this, it would seem that many of the Australians who are surviving through to old age do not do so as fully healthy individuals. In earlier times they would have died, but have been 'rescued from death' by such developments as intensive care units and open heart surgery. In short, Australia's mortality trends while a resounding achievement deliver a double whammy to the health system—there will be more older Australians than was anticipated and, on average, each will make greater demands on the health system. To this picture must be added consideration of obesity. The obesity epidemic in Australia (and elsewhere) has been well documented and represents one of the nation's major challenges. The national discourse on obesity has understandably focused on

1 The national population stood at 22.407 million at that time [6]

children and young people, but in fact it is Australian baby boomers who have the highest incidence of obesity.

The trajectory of *fertility* has a much greater impact on Australia's future population size and age composition than international migration [1] does, but it is accorded too little attention in discussions on Australia's future population. Elsewhere very low fertility rates are posing substantial challenges such as precipitous declines in working-age population and unfavourable ratios between working and non-working population for several European nations and a number of East and South-east Asian countries such as Japan, Singapore and, in the future, China: maintaining fertility at or near replacement can bring significant economic dividends for a nation.

Changes in Australian fertility over the past century can be summarised as follows:

- a steep decline in fertility from around 6 babies per woman in the 1870s to 2.1 in the 1930s Great Depression
- a steep increase in fertility following World War II which saw the total fertility rate (TFR) increase to almost 4 and which continued for around 20 years
- a precipitous fall in fertility in the early 1960s which bottoms out at around 1.9 in the late 1970s
- stability in fertility for a period of around 20 years from the mid-1970s to the early 2000s followed by a small recent increase.

If Australia is able to maintain a TFR of around 2 it will facilitate the eventual transition toward a demographically stable population in which each couple will replace itself, there will be a balance between those entering the workforce ages and those leaving them and there will be low levels of overall growth.

International migration has a larger influence on Australia's population than on any other medium-sized or large country in the world: around a half of Australia's population at any one time are migrants or the Australia-born children of migrants. Australia's international migration has undergone a major paradigm shift since the mid-1990s. The major changes that have occurred are as follows:

- Prior to the mid-1990s Australia largely eschewed temporary migration and the focus of immigration policy was entirely on permanent settlement. However, since the mid-1990s there has been a substantial increase in temporary immigration of people with the right to work in Australia, including students, temporary skilled migrant workers (457 visa) and working holiday-makers.

- There is an increasing focus on skilled migration and, in recent years, on employer nomination so that migration is increasingly being driven by employment demand.
- There has been a substantial increase in the diversity of the migrant intake adding to Australia's increasing multicultural diversity.
- Since the mid-1990s the State Specific and Regional Migration Scheme has channelled an increasing number of immigrants to settle outside of the major gateways of the mainland capitals (except Adelaide).
- Although Australia is emphatically a nation of immigrants, it also records substantial emigration. It is estimated that the Australian diaspora numbers around 1 million and is selective of young, skilled, well-educated Australians.
- Asylum seekers arriving by boat have increased in number but are still relatively few compared with the flows moving into Europe.
- New Zealanders are the largest single birthplace group among migrants to Australia and have ready access to Australia through the Trans-Tasman Agreement.

Ageing is widely acknowledged as not only the most significant demographic challenge facing high-income nations but also their major economic challenge. The series of Intergenerational Reports produced by the Department of Treasury underline the fact that this also applies to Australia [2]. Figure 1 shows the current Australian age structure, and the significance of the baby boom generation is apparent. Baby boomers make up 27.5% of the Australian population and 41.8% of the labour force. They began to pass the 65-year threshold in 2011 and already are beginning to leave the workforce in significant numbers. At the same time, it is interesting to observe in Figure 1 that there is a hollowing in the age pyramid between the ages 5 and 18. Hence the numbers entering the workforce ages will decline over the next decade or so before the recent increase in fertility will see the numbers begin to increase again.

Australia's population distribution is distinctive, being one of the most mobile and spatially concentrated of any country. Currently, 87% of the national population live in urban centres (clusters of more than 1000 people), 63.7% live in the capital cities and more than four out of five live within 50 km of the coastline. Australians move house more than any other national population, with 16.8% moving each year and 41.4% at least once every five years. Paradoxically, given this mobility, the structure of the national population distribution has changed very little over the last 150 years. While the basic structure of Australia's population distribution has been fixed for a long period, there has been a great deal of dynamism within that structure. Some have argued, for example [3], that there is an increasing dichotomy within non-metropolitan Australia between growing coastal populations and declining inland populations.

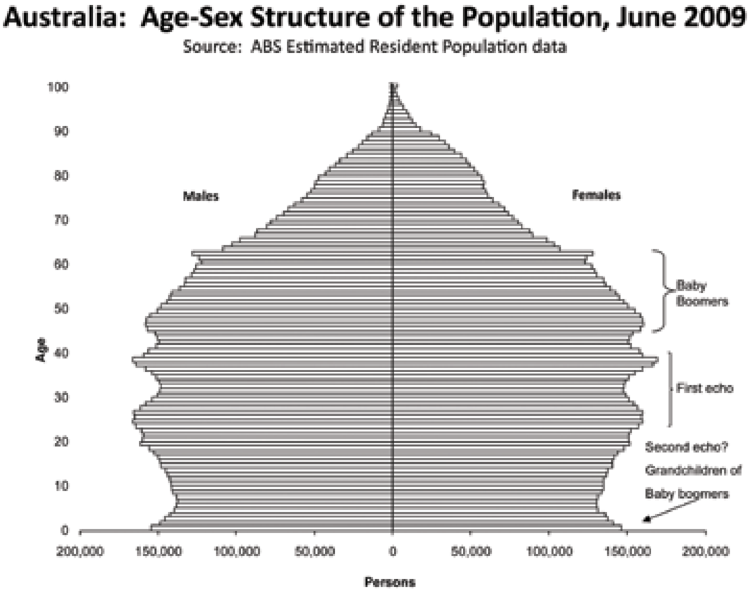

Figure 1: Australia: Age-sex structure of the population, June 2009 (Source: ABS estimated resident population data).

2 Population projections

Anticipating changes in Australia's population is an important element in planning. The Australian Bureau of Statistics (ABS) [4] projections of national population provide a useful basis for considering the range of potential population scenarios that face Australia. It is important to stress that these are projections, not predictions. They reflect a set of assumptions about future fertility, mortality and net migration. The sensitivity of these projections to changes in assumptions is well illustrated in Table 1, which shows the median projections made by the ABS in the 2005 and 2008 rounds of projections. The 2008 projections employed higher fertility and migration assumptions than the 2005 series because of an upswing in those in the second half of the decade. It will be noted that it results in a difference of more than 6 million people by 2051.

	Australia ABS 2005 Series B	ABS 2008
2006 actual	20.7	20.7
2007 actual	21.0	21.0
2021 projected	23.9	25.6
2031 projected	25.8	28.8
2051 projected	28.0	34.2

Table 1: ABS projections of the population of Australia, 2005 and 2008
Source: ABS estimated resident population data and projections 2005 and 2008.

The substantial differences in numbers in each age cohort and the age-specific impacts of fertility, mortality and migration mean that different age groups in the population grow at different rates. Table 2 shows how the median 2008-based projections see the growth patterns of the 0–4, 15–64 and 65+ age groups over the next four decades, and striking differences are in evidence. Even under these relatively high assumptions of fertility and mortality, the growth rate of the 65+ group is three times that of the workforce-age population in the period up to 2031 and twice as fast in the next 20 years.

Year	0–14		15–64		65+	
	Number	% growth p.a.	Number	% growth p.a.	Number	% growth p.a.
2006	4 050 445		13 954 776		2 692 659	
2021	4 693 727	0.99	16 527 365	1.13	4 395 453	3.32
2031	5 050 849	0.74	18 003 557	0.86	5 732 080	2.69
2041	5 335 328	0.55	19 514 934	0.81	6 759 002	1.66
2051	5 697 740	0.66	20 886 759	0.68	7 628 748	1.22

Table 2: Australia: projected growth of the population by age, 2006–51
Source: ABS 2008 Projections, Series B

It is important to stress the robust projections for the growth of Australia's older population up to 2051. Almost all of the older Australians over this period are already in Australia but most are still of working age. This provides a substantial opportunity to put in place policies to better prepare those groups yet to move into the older age groups. The United Nations [5], in summarising evidence and experience in coping with ageing populations, has made three observations of particular relevance to Australia: no single action by government can adequately address this issue. There are no silver bullets. Instead, policy adjustments should be carried out by effecting relatively small changes in many different policy domains. Making the necessary adjustments early is easier than delaying things until there is a crisis.

The Australian Government's Intergenerational Report has argued that counteracting the effects of the shift in age structure will require interventions in the three 'Ps'—population, participation and productivity. The report's authors particularly stress the significance of enhancing productivity per person as having the greatest potential to counterbalance the deteriorating balance between working age and older populations. Enhancing the growth of the working-age population through maintaining fertility close to replacement level and migration has a smaller role. Since migration is selective of young workers it can have a small ameliorating effect on the spread of ageing in the short-to-medium term, but this amelioration cannot be sustained indefinitely since migrants themselves also age.

There is a significant opportunity to increase workforce participation. Increases in the age at retirement are already in evidence. Policies regarding increasing the retirement age need to be carefully implemented to ensure equity, as physical workers are less able to continue working than sedentary workers. The policies must also be accompanied by sustained effects to facilitate changes in career, retraining, phasing from full-time to part-time work and reduction in discrimination against older workers. Increasing participation within the traditional working ages also has considerable potential and offers an opportunity to progress the government's social inclusion goals. A tighter labour market can provide the opportunity to engage groups in the paid workforce who have thus-far been excluded—Indigenous groups, culturally and linguistically diverse (CALD) groups, people with disabilities and those who live in areas of low accessibility and low socioeconomic status.

As important as the three Ps are in developing policy to facilitate Australia's coping with an ageing population, there are some additional considerations. There is a key fourth 'P'—preparation. Preparation for ageing is critical at all levels—for individuals and their families, the community and all three levels of government. Successful ageing at individual and societal levels requires preparation. Part of the preparation involves putting in place policies relating to the three Ps now rather than in the 2020s when the tsunami of baby boomer retirement reaches full force. It means analysing the baby boom generation to not only prepare them, but the society, so that baby boomers have productive and fulfilling retirements. It means not only considering policies to cope with the ageing population but identifying and enhancing the development opportunities which it can offer.

In discussions of Australia's future population the emphasis has strongly been on its economic consequences [2]. However, it is important to also briefly consider some of the social consequences. Australian families will continue to become more diverse and smaller on average as a result of ageing. There will be greater ethnic diversity as net migration becomes a larger proportion of national population increase. There are concerns for income distribution, social inclusion and poverty. With ageing there are real dangers that groups who have been unable to accumulate significant resources and assets during their working lives to support them in old age will fall into poverty. On the other hand, anticipated labour shortages may result in groups that have previously been excluded from the workforce—the disabled, the Aboriginal population, CALD communities, women etc.—becoming more engaged. The Indigenous population currently numbers 563 101 [6], making up around 2.5 % of the national population, and this proportion will increase somewhat over the next couple of decades. Projections of the Aboriginal population show that the number of Indigenous population will reach 1 million by 2040 [7]. The extent to which they are able to move out of their current disadvantaged position remains a key national issue.

3 Looking to the future

People are important. Australia's greatest resource is its population, and population growth, composition and distribution will play a major role in the extent to which the nation can achieve the goals of greater prosperity, sustainability, security and inclusion that it has set for the next two decades.

Australia will face a population dilemma over the next two decades. On the one hand there is a need for more workers, which will involve some population growth. Access Economics [8] has projected that over this period economic growth will result in a net growth in the number of jobs of between 0.9 and 2.5% per annum. The 2011–12 budget anticipated that there would be a net increase in jobs in Australia of over 200 000. McDonald [9] has shown that over the decade from 2000 to 2010 the Australian workforce increased by 2.1% per annum (compared with 1.5% for the population) and of this more than half was contributed by migration. If, as seems likely, a continuation of a net gain of jobs of around 200 000 per annum is continued over the next decade, how will they be filled?

In this context it is relevant to look at the numbers in individual age groups entering the retirement years and to match them with the cohort entering the workforce ages at the same time. Table 3 attempts this using 2008-based population projections and shows that in 2010 the number of people aged 20–24 significantly outnumber those aged 60–64. However, it must be remembered that these included over 200 000 overseas students on temporary visas (the total foreign tertiary student population in 2010 was 469 619, half of whom were aged 20–24). Since many of these students will leave Australia upon completion of their studies, the excess of entrants to the workforce relative to likely exits is not as great as appears in Table 3. The important point, however, is that with the next five-year age group the difference between older and equivalent younger groups decreases and in the following ages, in fact, the numbers in the older cohorts are greater. The message is clear then that it will not be possible to meet the likely net increase in the demand for workers without some migration. The key question is how much migration?

Age group	Persons	Age group	Persons	Difference
60–64	1 211 785	20–24	1 648 245	436 460
55–59	1 325 024	15–19	1 500 354	175 330
50–54	1 469 314	10–14	1 403 729	65 585
45–49	1 574 540	5–9	1 365 719	208 821
40–44	1 551 437	0–4	1 460 757	90 680

Table 3: Australia: differences between age groups at 30 June 2010 Source: ABS [6]

In this respect, recent modelling by the Department of Immigration and Citizenship [10] is shown in Table 4. The modelling indicates that growth in GDP of around 3.25% requires an annual net growth in employment of around 0.8% per annum. However, the growth of the labour force without migration would only be 0.5%. The differences would need to be made up by net overseas migration which would be around 188 700 per annum over the next decade.

Employment growth to meet GDP target	0.8% p.a.
Employment growth with zero net migration	0.5% p.a.
Average annual net migration to meet GDP target	188 700 p.a.
Assumptions GDP target growth	3.25% p.a.
Labour productivity growth	1.6%
Average working hours	Constant

Table 4: Labour demand over the 2010–20 period Source: Hoffmann [10]

It is likely then that labour demand will continue to grow in Australia, at least over the next decade and a half. However, currently 42% of the Australian labour force are baby boomers and most of them will leave the workforce over the next two decades. On the other hand, it is increasingly apparent that there are substantial environmental constraints on population growth, especially relating to water.

The introduction of water restrictions in Australia's major cities during the last few years has vividly brought home two things. The water resources of the continent are limited and our use of them has been profligate. The pressures that rapid population growth have placed on infrastructure and environment and resources in hot spot areas such as South-east Queensland, coastal New South Wales, Sydney and Melbourne are well known. Moreover, climate change will exacerbate these pressures. CSIRO and the Australian Bureau of Meteorology [11] have recently demonstrated conclusively that there is a long-term trend of rainfall decline in south-eastern Australia which currently is home to more than 80% of Australia's population. There is a substantial mismatch between the distribution of run-off and that of population, with less than 15% of Australians living in areas experiencing an increase in rainfall.

Too often the solution to environmental challenges such as water shortages in the Murray–Darling Basin is seen to be stopping population growth. In fact, population numbers are only one of the elements creating pressure on the environment. Levels of consumption per capita and the way in which the resources are exploited are also very important elements in creating environmental degradation. Australia suffered massive environmental degradation in the 19th century when its population was only a fraction of the present size. Clearly there is a need for us to change the way in which we harness, store and use our water resources. Certainly population growth places pressure on such resources but there is a need for us to capture, store and use our water more effectively. Stopping population growth alone is unlikely to be sufficient.

Indeed some would argue that the economic impact of such a policy would have undesirable environmental outcomes because it would reduce the resources that would be available to move toward more sustainable processes.

It is not only issues of population size that are important, but also those of population distribution. Australia's population growth is likely to remain mainly in capital cities. However, in considering the development of Australia's population policy, issues of potential change in Australia's settlement system need to be fully considered. This doesn't mean major shifts of existing population but it could have significant implications for where future investment is directed. There are a number of issues which need to be considered:

- several of the fastest developing sectors in the Australian economy have a strong non-metropolitan orientation—e.g. mining and tourism
- already there is net outmigration of the Australia-born from some of our largest cities, such as Sydney
- the retirement of baby boomers is likely to lead to an increase in the numbers of retirees living outside of cities, creating demand for services
- the escalating costs of continued growth of major metropolitan areas
- environmental constraints and the effect of climate change in south-east Australia.

It may be that there is some scope for encouragement of growth outside of capital cities but this must be the subject of detailed study. It is not enough to say that such efforts failed in the 1950s and 1970s. The world is very different in the 2010s, especially in relation to the structure of the economy and networks of transport and communication. The bottom line in regional development is that it only should be encouraged in regions with the resources for sustainable economic growth.

So what is needed? On the one hand we have the manifest need articulated in the Intergenerational Report of Treasury [2] to grow the population. On the other are environmental constraints that are likely to be exacerbated by climate change. Too often the policy alternatives that have been discussed emphasise one or the other of these issues to the detriment of the other. What Australia needs is a population (and immigration) policy that takes full account of both of these elements. It will require trade-offs and compromises but should be informed by the best science and not the lobbying of interest groups. It requires a coming together of physical and social sciences to chart out a range of potential population futures. No single academic discipline has hegemony here. This should be the task of the new Ministry of Population.

Population policy should not be seen as a stand-alone policy. Good population policy should support and facilitate beneficial outcomes in the key areas of national interest—economic development and growth, environmental sustainability, social inclusion and being a responsible global and regional citizen. Population policy does need to consider the best science and research available across all relevant disciplines. However, it also should take into account the views of all Australians about the vision for our future. Migration and population growth will continue to be significant in Australia over the next few decades in all of the realistic scenarios of the future. However, that growth must be environmentally sustainable. Population growth and distribution must be informed not only by labour force demand but also by environmental considerations. Growth with sustainability needs to be the objective, at least over the next two decades.

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Chapter 4

Settlement and the social dimensions of change

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Global warming, an increase in extreme weather events, population growth and greater longevity, expanding urbanisation and considerable economic, political and demographic instability all appear to be occurring rather more quickly than most of us would have predicted. In order to anticipate consequences, in this chapter we delineate how different processes, conditions and structures interact in response to the pressures of population growth and climate change. To respond to these pressures, we argue the need for broad interdisciplinary involvement in policy and practical action.

1 Introduction

Managing adverse events related to climate change and human settlement patterns requires resilience through appropriate governance, policies, social structure and social capital. The term 'resilience' has evolved from origins in materials science and is now used broadly and loosely in psychology and health sciences and across community and business. Resilience implies an ability to bounce back from adverse events; in policy contexts, the nature of change and our exposure to events for which we have little or no precedent makes the capacity for resilience especially important. These adverse events include natural disasters such as sudden storms, and rapid economic and political destabilisation as exemplified by the global financial crisis, rebellion or terrorist events, which create sudden disruption and slower economic, social and environmental changes. Communities need to have strategies to deal with different types of change, and to be able to manage when various checks fail to withstand assault.

The concept of resilience needs to include an understanding of 'robustness', the ability to withstand such events, to survive and to adapt to new circumstances. Furthermore, the rate of technological, social and environmental change is now so fast that bouncing back no longer aids adequate recovery. Building community resilience needs to be developed so that people bounce forward to enable better adaption or even transformational change. The capacity of refugees to escape, undergo extraordinary personal hardship and danger, and re-establish household and community life on resettlement is tribute to the resilience that most people possess. The capacity for resilience at an institutional and governmental level is perhaps less clear and there is a clear challenge to anticipate risks and disasters, and to develop policies, programs, infrastructure and structural support to avoid their greatest negative effects.

Resilience is shaped by the physical, procedural and social aspects of the community [1]. To respond to the effects of a changing climate these might include at a physical level storm drainage systems or access to air conditioning during heat waves (although a long-term approach would need to find ways to avoid using equipment and systems that add to rather than remediate the problem); procedural responses could include early-warning systems and emergency planning policies. Equally important are social responses: as simple as building inclusive social networks to ensure that people who are marginalised, in addition to those who are well connected, are protected during extreme weather events.

2 Urbanisation

The challenge of urbanisation is to support an expanding population while avoiding accrued environmental pressures. This is made difficult in Australia because of conventional patterns of settlement, the structure of the economy and other policies that drive these patterns. Settlement is concentrated in the east–south-east coastal corner of the country, specifically within and around three megacities—Brisbane (including the Gold Coast, Ipswich and Sunshine Coast areas), Sydney (with an expanded urban area extended to Wollongong, Campbelltown and Newcastle) and Melbourne (including the rapidly expanding area south-east to West Gippsland and west to and including Geelong). The outer rings of these cities are consistently areas of entrenched and compounded disadvantage. The implications of this development pattern have received limited attention. Cuthill [2] has emphasised the policy and planning needs for hard infrastructure and natural resource management, but less attention has been paid to the social dimensions of sustainable development and the implications in this for social capital, social infrastructure, social justice, equity and engaged governance. Yet these areas are all critical to ensuring social resilience.

The residential spread that is characteristic of south-east Australia has occurred with the increased acquisition of, encroachment into, and absorption of industrial, public and farm land. In consequence, housing has taken over land previously dedicated for work, recreation and market gardening. Insofar as new housing is built commercially, there has been limited attention in development planning to ensure houses of varying sizes and types are built or that a mix of housing, education, employment and services is achieved in relation to land use. Conventionally, there is little development of infrastructure or services prior to, or concurrent with, housing and settlement and little protection of local industries that might offer employment to new settlers and provide ways of redressing the costs of densification. Howland's work in Maryland (US) [5] suggests the need to ensure that industrial areas rezoned for alternative uses do not cause either major employment or tax losses, and that this rezoning allows for integrated use of land for industry, residential, commercial, service and office purposes. But also we need to ensure that housing policy does not reinforce the geographic and social disparities of contemporary urbanisation, and exacerbate these as the young children of pioneer residents become the marginalised youth of coming decades [6–8].

Migration to cities and the demands for housing in expanding urban areas are only part of a more complex picture of population change and displacement. That picture includes outmigration and its impact on those communities that people leave, the development and demolition of public housing, the impact of gentrification on housing affordability and community structure, and problems of home ownership and home foreclosure. Kirk and Laub [10] argue that residential turnover undermines informal social control and leads to increased crime; in this context, they emphasise the need for longitudinal data on neighbourhood change.

3 Regionalism and rural economies

The competing pressures of climate change and increasing urbanisation will affect the nature of rural and regional areas in Australia. Much of the work on climate change has been concerned with the structural changes that follow ecological damage and lack of economic viability—changes in land capacity, productivity, crop quality and quantity, water, and animal health. These are often compounded by globalisation and the import of cheap products and goods.

Population diversity with growth and resettlement raises questions of the future role of rural areas, including questions about social expectations of living and quality of life, access to services and natural resources, communications systems and their complexity, and food security [12]. In Australia as elsewhere, the intensity and distribution of migrant settlement in metropolitan areas and regional cities have varied due to social networks, community and local government initiatives and federal and state government policy. In the United States, Katz and colleagues [13] describe the emergence of distinctive residential patterns—'new metropolitan geographies'—with globalisation, and of settlement patterns shaped by economic opportunities and social connections. The settlement along the Murray River of Maori and other Pacific Islanders and of Iraqi immigrants in the Goulburn Valley (Vic.) are local instances of this [14–16]. In Dandenong (Vic.) [17], the everyday negotiation of cultural difference has the potential to blur fixed ethnic boundaries and to strengthen social and cultural inclusion, although not without considerable public investment in these processes. Other examples in Australian rural communities illustrate the dynamics of social cohesion and intercultural relations.

The built environment, migration and heritage, belonging and social cohesion all contribute to create a local sense of place. The history of Italian settlement in Griffith (NSW) and the interplay of economics and cultural capital offers an interesting example here [18]. In general, diverse settlement strategies have the potential to consolidate and extend human capital, tourism and industry, including, Lee [19] argues for the United Kingdom, providing the environment for ethnic minority entrepreneurship. Yet there are also differential impacts on social capital in the short term, highlighting the importance of appropriate human services programs and inclusive governance in such areas.

Future settlement planning needs to incorporate the different economic and historical roles of distinct places. Australia lacks the tradition of diverse ‘amenity migration’ and recreational home development characterising the United States [20], but significant numbers of people have opted for shifts in residence on retirement, sea- and tree-change migration and, among people with limited incomes and at times from marginalised backgrounds, a growing caravan park population is developing [21]. Rethinking settlement for a larger Australia needs to take account of these trends, and to consider how such shifts in residence change the local sociodemographic make-up, local governance arrangements, and the relationships of people and place.

One example of intentional regional growth is the rural ‘smart cities’, typically centres of higher education such as Albury–Wodonga (NSW/Vic. border), Ballarat (Vic.), Armidale (NSW) and Toowoomba (Qld) where there is considerable temporary in-migration (of students, for instance) but also the sustained migration of industry employees (i.e. academic staff) and services. While the growth of smart cities has little effect on population growth overall, even between states, the patterns and incentives of mobility need to be followed through in policy terms, including in terms of an extended model that encourages rural growth in different areas.

Access to urban employment has at the same time been key to ensuring the growth and population retention of such areas, and to preventing their decline. As Partridge and colleagues argue [23], the continued viability of semirural areas also requires support for links between rural and urban areas through the provision of ‘reasonable’ transportation infrastructure and other ‘built’ infrastructure. The Central Coast development of New South Wales—between Sydney and Newcastle—illustrates the problems created when rural centres are expanded to meet housing needs without comprehensive investment in other services and infrastructure or attention to the problems bred by isolation, unemployment and poor access to amenities. Continued but less concentrated population growth and settlement requires parallel strategies for sustainable and innovative businesses, educational and other facilities, and strong relationships with other social institutions, including those of governments and local communities [24]. Policies and community development programs are also needed to head off tensions and disharmony within these communities.

There is an ongoing need to ensure viable rural and remote communities that are not dependent on an urban ‘feed’. As indicated above, the expansion of smart cities is one approach. In addition, there is a need to continue to support community production of food and goods. The ratio of food producers to food consumers is declining globally and there are questions of both equity and energy use regarding the provision of food and other agricultural products for purposes such as growing urban populations, ensuring agricultural prosperity, reducing rural and urban poverty [25], and avoiding dependence on other, poorer economies. In Australia, we need to address geographic nationwide disparities, and in doing so rethink the nature of settlement in places such as in northern Australia [26, 27]. This is less a matter for architecture or town planning than for social research and politics.

4 Mobility and access

Mobility and access to infrastructure will be critical to accommodating population growth in an environmentally sustainable and socially equitable way. The nature of the workforce is changing rapidly for many reasons, including workforce ageing, global markets and technological change. We seem to be slow to adapt to change, with a general assumption that an ageing demographic means a greater number of retirees rather than an extended working life. Access to employment opportunities within reasonable distances of residential areas is particularly important to maintain employment and so to sustain productivity. Communities are more likely to thrive when people have access to work that matches their skills and is within reasonable commute times, with access to high-speed broadband and flexible conditions of employment. Urbanisation and the development of suburbs at further distance from the main commercial centres mean that access to amenities puts pressure on other factors within households. Residential populations at the fringe of cities and in regional and rural areas have fewer choices of public or private schooling or tertiary study.

The rate of market and technological change also means that time out of the workforce can be debilitating as it is difficult to obtain new, requisite skills. At present, we do not have policies and programs for responding to regular, rapid technological changes that would allow the continued reskilling of workers in order to help them stay in work. Although people in long-term unemployment are most likely to require reinvestment in education and skills, the need to gain new skills affects all workers.

Access to health care for populations who live away from central services will also be problematic in terms of their need to access emergency hospital care and specialist health professionals and for restructured comprehensive community-based services to deliver appropriate services. Where barriers limit access then health services will be sought only for acute situations and preventative health measures will not be prioritised. This harms population health, and the cost (and efficiency) of state services. The introduction of state- and federally funded ‘superclinics’ to service growing communities suggests there is a need for governments to engage in forward thinking to address anticipated future as well as present needs.

Another aspect of life that is affected by mobility and access to resources is the ability to source affordable and healthy food. The concept of ‘food deserts’ was investigated in a study in Adelaide [28]. The most significant fact influencing access to food for people in such communities is the availability of independent transport to shops. The research suggests that food access problems in Adelaide are not so much the product of geographic distance between home and shop as the social or welfare networks that allow people to access private transport. Social networks that provide avenues to private transport for accessing health, education and employment may be similar enablers.

Another aspect of mobility is the extent to which reliance on private transport may affect wellbeing. Lack of options for walking, cycling or walking to public transport can affect how active an individual is and limit incidental exercise. Long commutes to employment or for leisure also place pressures on household budgets, time and family relationships. The relative distances between home and essential services, schools and work, and the manageability of these arrangements all affect quality of life, sense of place and community and resilience, especially in terms of the social response.

5 Health and vulnerability

Chronic conditions, both physical and mental, are likely to remain prevalent, but many problems associated with poor health can be addressed with shifts in policy and investment. We can also identify the program demands to reduce the number of people in these vulnerable groups and the continued challenges in providing them with appropriate, adequate and quality care. They include Indigenous Australians, refugee and humanitarian settlers, illegal immigrants and visa overstayers, people without private health cover, with physical and/or intellectual impairments, those from sexual minorities, and individuals who have been incarcerated, are drug or alcohol dependent, homeless, aged, isolated, frail or extremely poor. This is a long list, likely to grow as climate change and economic marginalisation drive further social exclusion.

The responses to these challenges are important and must go beyond improving opportunities to work, since the structure of work and the kinds of industries generating employment opportunities are likely to change in the coming decades. While there is a common assumption that participation in employment and work life will improve wellbeing and facilitate social inclusion, poor educational status, location, access to work and poor health status all present barriers to employment supporting positive health outcomes. A recent study in Canberra (ACT) and Queanbeyan (NSW) illustrated that people who were unemployed or in poor quality jobs (i.e. without security, physically demanding, low status) had few options for mobility to better jobs, and people in poor quality jobs experienced poorer physical and mental health than people who were unemployed [29].

Pressures on housing, unpreparedness for disaster resulting in loss of property and in some cases loss of life, and long commuting time all result in increased stress. This leads to a greater incidence of anxiety and depression and co-morbidities such as increased drug and alcohol misuse, interpersonal (particularly gender-based, but also racial) violence, and homelessness. We have limited approaches to these concurrent problems, and we urgently need research on how to address these problems directly and to find ways to better link services and their delivery.

There has been considerable discussion of epidemiological transitions and shifts in patterns of disease, with a growing understanding of the continued risk of both old and new infectious disease with a growing burden of chronic conditions. But Hanlon and colleagues [30] have argued a fifth wave in public health, reflecting the complex challenges of obesity, inequality and loss of wellbeing, and broader problems of exponential population growth, money creation and energy usage. Their observation of the co-occurrence of obesity, inequality and loss of wellbeing reinforces growing evidence of the underlying causes and social preconditions of Type 2 diabetes and cardiovascular disease, and coincident depression. A recent study in Melton (Vic.), a commuter township with high unemployment out of Melbourne, highlighted housing and everyday living costs, health, transport and intrapersonal factors, and lack of the availability of preferred food, which all inhibited people from accessing nutritious food of their choice [31]. For older people, this was compounded by inability to shop for, prepare and eat affordable and nutritious food. Research on food deserts, mentioned above, make the same point—many people lack access to quality food for contextual and financial reasons [28].

In countries such as Australia, poorer people are most likely to be overweight or obese and at risk of various chronic diseases. This pattern will continue while interventions are directed towards individuals (e.g. to lose weight) rather than the economic and social conditions that influence exercise, and food availability and choice. Again, creative planning is required for new housing developments and suburban renewal that include footpaths, parks, and public transport, and encourage local food production.

6 Governance and participation

In imagining Australia 2050 we face particular problems regarding governance, including to ensure representation and inclusion [32]. An emerging evidence base of alternative forms of governance ensures community engagement and participation as illustrated by the partnerships and other cooperative forms of governance already operating for environmental management. Taylor [33] illustrates the need to include diverse actors in governance—in his example, governments, farmer groups and others—to coordinate and maintain inclusive, legitimate and viable forms of governing.

Playford (SA) provides a contemporary example of innovative governance and urban renewal to address population growth and social disadvantage. The Playford Alive program operates as a joint venture with the Land and Management Corporation, the state Department of Families and Communities, and the community through a dedicated reference group. This project combines redevelopment of an area known for social disadvantage, the 'peachy belt' along Peachy Road, and greenfields development to the north. There are three observations relevant to this discussion.

The first is its physical infrastructure. Several hundred houses in the existing residential areas have been demolished to make way for new stock to blend with greenfields stock. The new development hangs on a 'transit-orientated development') at Munno Para train station. Three schools have been closed and replaced by two new 'superschools'. The development also includes the regeneration of wetlands and provision of parks, green spaces, walking tracks and playgrounds. In addition, there are two new 'super GP clinics' funded by the state and federal governments.

The second feature is in the policy and procedural approaches. The City of Playford mandated minimum local employment numbers for development contractors and matched this with skills training to provide employment opportunities for local residents, and to encourage a sense of ownership of the shared facilities being constructed, such as a BMX track. The medium–high density development allows for affordable housing and home ownership. The planning code has guidelines for features such as verandas, transparent front fencing, and windows overlooking public space to enable passive security. The code also instructs on the provision of solar hot water, water tanks and natural light for energy efficiency.

The third is the social approach. The community is a partner in the project through a Community Reference Group, which also runs information stations at local shopping centres. The schools are setting new expectations for students and their families and there are plans to renovate and extend the community centre.

The approach to urban development reflected in Playford operationalises the themes we have discussed in this paper. While it is too early to determine where the renewal in the City of Playford is successful on a commercial or social scale, its basic principles of sustainability and inclusion provide an example of the types of interventions and solutions that could be extended elsewhere if we are to meet aspirations for a prosperous, environmentally sustainable and socially equitable Australia.

The social dimensions of understanding how communities adapt to economic, social and environmental change are complex and interconnected. These include responses to climate change and sustainability, urbanisation, where populations are located and why, mobility and access to infrastructure and services, and how people are able to find a sense of purpose and wellbeing through work, skills development, health, and community participation. We can infer from other work that these kinds of disruptions will have far-reaching social, interpersonal and psychological problems. Our next task is to document this literature and to identify how the worst fallout might be avoided.

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Chapter 5

Physical realities and the sustainability transition

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In responding to the global impact of local and regional activities, sustainability science has become captured by economic assertions about what constitutes progress. Although the policy high ground of continued marginal change is entrancing, by compromising essential scientific truths we risk forestalling the transition to a more sustainable society until global and regional systems are near collapse. To contain this compromise, six science realities must be incorporated into any sustainability science. These are: i) existence and growth is physical; ii) energy is the key; iii) lifestyle has impacts on most physical dimensions; iv) globalisation allows the outsourcing of impacts; v) sustainability policy is deceitful; and vi) personal consumption in aggregate must substantially decline. Since the relationship between human development and progress can be defined in adequacy terms by per-capita energy use, this defines a physical space that sustainability transitions must move toward. By acknowledging this reality, Australia's views on what is national progress must change and development trajectories must improve population health and lower the impact of our activities on land, water, biodiversity and atmosphere.

1 The problem

Human influence now extends to the planet's boundary and science ponders what might constitute a 'safe operating space for humanity'[1]. In these global boundary issues, Australia has high impacts. For example, we are one of the highest per capita greenhouse emitters in the world, releasing 28.3 tonnes of CO_2-equivalent per year. Our economy uses 900 000 litres of fresh water each year on a per capita basis, much of which is drawn from stressed and overused river basins in southern and western Australia. In global terms, Australia is seen as relatively water rich, despite many rivers having poor health. One detailed assessment of 26 000 kilometres of Victoria's rivers and streams showed that only 21% were in good or excellent condition. Only one of the Murray–Darling's 22 river basins was found to be in good condition. Australia's large continental landmass—much of it arid and relatively unused—means that much land is relatively intact in cover terms and satisfies clearance thresholds. About 8% is intensively used but trends in biodiversity loss suggest cautionary future land use. Among animal species, 426 are classed as threatened (55 extinct) and of flora species, 1324 are threatened (48 extinct) with growing threats due to habitat fragmentation and invasive plans and animals. At an ecological community level, 46 communities are classed as threatened. Climate change will be a significant driver of threatening processes in future, highlighting the connections between within-country activities and pressures that accumulate at a global scale.

All of this means that preparing Australia's transition to global and national obligations for equitable impacts on atmosphere, water, land and biodiversity begins from some difficult starting points. The tensions displayed daily in political, media and business arenas between the requirements for economic growth, population health, regional conservation and global atmospheric care bear witness to many contested beliefs and possible solutions. This chapter will propose that physical issues should dominate both the theory and practice of the sustainability transition. Specifically, energy use per capita is both the essence of human development and the core of planetary boundary problems. The realistic directions for a sustainability transition are both stark and austere, and possibly beyond the capabilities of human decision-making today.

2 Contested elements of the sustainability transition

Existence and growth are essentially physical. Given the significant environmental impacts that Australians have brought about in the 220 years of European settlement and globalised commerce, it seems trite to note that what makes an economy function is mostly physical and thus has effects on the physical world. National debate deliberately decouples the daily churn of interest rates, household electricity prices and federal budget deficits from the underpinning physical transactions that foster lifestyle and drive economic value adding. Thus the nation's water accounts are organised under accounting frameworks different than the linked sector-by-sector arrangement of the system of economic national accounts. This means that water use is seen—through low-flow shower heads and efficient appliances—to be an urban requirement of 100 000 litres per person per year rather than the full lifecycle cost of 900 000 litres per year embodied in the goods and services used by affluent Australians. Farmers are seen to use water, rather than householders being ultimately responsible for the water used to produce the goods and services they demand. State of the Environment reports carefully avoid the unpalatable reality that economic growth and population growth are central drivers of impact while better technology and revamped institutions do little to reduce those impacts in a whole-of-system sense.

Energy transactions are central

Energy use is the central motor of economic function and, therefore, human wellbeing and notions of equity, be they national, global or intergenerational. Modern economics mostly ignores the centrality of energy, creating a fantasyland where the human spirit drives productivity and horizons for the human-spirit enterprise are virtually limitless.

Three recent nodes of scientific analysis focus on the centrality of energy. Robert Ayres [2] and colleagues have used physical analysis to dissect century-long gross domestic product (GDP) time series for the United States and other developed economies. Explaining an era that began with horse-drawn ploughs and ended with gas turbines and nuclear energy, they show that the physical parameter 'work' (horsepower or kilowatts of energy applied to the driveshaft of a vehicle) explains most economic productivity, sector-by-sector and in aggregate.
The analytical treatise that won the economist Robert Solow the Nobel Prize explained only 20–30% of economic productivity with the factors capital and labour, and allocated the remainder to innovation (the 'Solow residual')—an erroneous conclusion now enshrined in public policy as multifactor productivity.

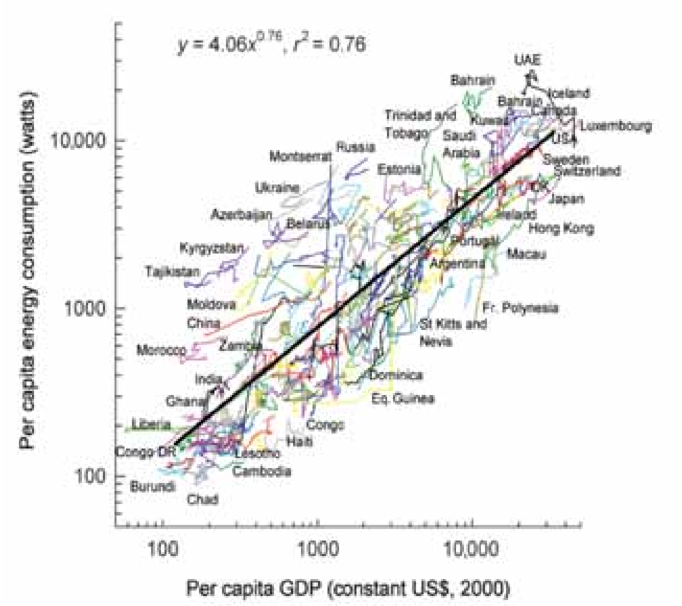


Figure 1: Per capita energy consumption graphed against per capita economic product for 220 nations for 24 years (1980–2003) on a log scale. Individual coloured lines trace each country's trajectory in that period while the heavy black line is the regression line of each country's mean values. The line slope of 0.76 approximates the metabolic rate of animals compared to body mass, suggesting the metaphor of a metabolism of nations—the more affluent the economy the bigger the energy requirement. (Figure 1 from reference 5).

It is true that innovation drives changes in the efficiency of energy transformation and the end use of that energy in homes and factories. However, it is transformed and delivered energy, not innovation that drives each sector's value adding, which accumulates to the national performance measure of GDP.

Reiner Kummel [3] and colleagues use related physical analyses to attack an assumption at the core of modern economics—the factor cost theorem. Simply put, the factor cost theorem asserts that the most important inputs to production will be priced according to their productive or catalytic effect. The conundrum is this: energy is responsible for 50–60% of economic productivity (assessed on long-run analyses of the United States, German and Japanese economies) yet its 'factor cost' is only 5%, suggesting that it is underpriced theoretically by a factor of 10. Kummel interpolates this physical reality to the employment and competitive challenges now faced by developed economies in a globalised marketplace. Given this reality, energy taxes should replace income taxes. Then the factor cost theorem could operate in practice as it does in theory, and labour in developed countries need not be uncompetitive in price terms for many value-adding activities that sum to the GDP measure.

The chicken-and-egg question of whether energy use drives GDP or GDP drives energy use has been explored through many iterations and reviews by David Stern [4], now of the Australian National University's Crawford School of Public Policy. This intricate analysis requires that a clear philosophy guide the method of causative proof, and underpinning that, the assembly of the data series under examination. His 2010 review shies clear of absolute proof that energy use drives GDP, but has three central findings. Firstly, energy is central to GDP and, most importantly, cannot be substituted. Secondly, in the more complex analyses energy and GDP are seen to be so closely intertwined that they cannot be separated. Thirdly, the issue of decoupling society from physical impacts cannot be resolved by simply moving to a service economy since this requires complex energy-dependent infrastructure fuelled by continuous, high-quality energy supply, mostly electricity.

These central but somewhat theoretical insights of Ayres, Kummel and Stern can be viewed more practically in the 220-nation view of energy use and economic productivity shown in Figure 1. Developing countries cannot scale the ladder of opportunity and success without orders-of-magnitude increases in energy use. Why these insights—now well tested through time, iteration and example—are not more central to the sustainability narrative is puzzling. Obviously mainstream economics remains unconversant with the physical reality that most of its production quotient derives from a factor generally held outside of its theoretical base. The cited authors here are not published in the mainstream economics journals and two of them are frequently rebuffed in their pursuit of this academic audience.

The physical fact of energy centrality offers three lessons for Australia's sustainability transition. Firstly, since energy causes or drives economic productivity, reducing energy use through efficiency policies and consumer behaviours could reduce economic productivity. This effect is currently masked by outsourcing many energy intensive activities, to China for example. Secondly, since the productivity jumps in the past have been in a physical sense due to improvements in energy transformation processes, the move to renewable energy generators, whether for electricity or transport fuel, must move current productivity measure backwards because renewable infrastructure is less efficient in a per unit-of-capital productivity sense. Thirdly, this energy centrality lies at the heart of Garnaut's diabolical policy challenge for the mitigation of climate change—perhaps even the man himself does not fully understand it. Since the Industrial Revolution began, humankind's estimates of its own worth have been based on fanciful theory and a core production factor, the essentiality of which continues to be ignored by the key actors.

Lifestyle has impacts over most physical dimensions

Rockström's planetary boundary concept lays out the dimensions where humankind will exceed the globe's resource base or its ability to process wastes. The sustainability transition needs to acknowledge that most of those factors are directly embodied in each citizen's lifestyle, and in aggregate for the population at large. Depicting the physical lifestyle of each shire and suburb in Australia against its yearly income shows that income/spending drives environmental impacts, whether at home or abroad, across three key planetary boundary indicators—greenhouse gas emissions, water use and land use (Figure 2). While this is tacitly acknowledged in the politics of carbon taxation, the fact that all planetary boundary areas are linked through consumption and economy remains tacitly ignored in public policy.

Polluters, farmers and pastoralists are easy political targets for policies on emissions, water use and land clearance, but the average citizen—the demander of goods and services through the market—is the real driver of impact. Introducing physical carbon taxes at low levels will do little to change society's physical pecking order shown in these graphs. Unless pricing levels are stringent enough to bring aspiration under control, shopping will be the avenue to economic self-determination and societal position. These graphs show that while the lowest-income suburbs are the least impacting on a full life cycle basis, the levels there for emissions and footprint at least are still three times the levels we need to transition towards in order to ensure global equity in impacts.

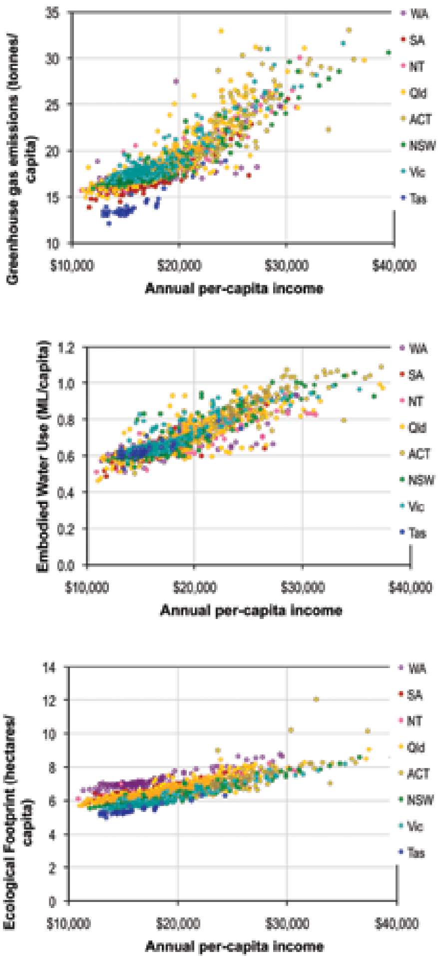


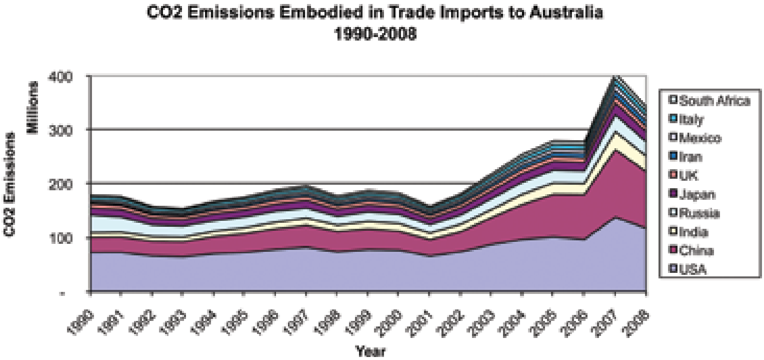
Figure 2: Environmental dimensions of the full life cycle (direct + indirect effects) impacts of per capita consumption for each shire and suburb of Australia. Graph shows greenhouse emissions (top: tonnes per capita), managed water use (middle: megalitres per capita) and ecological footprint (bottom: hectares per capita) graphed against per capita income (figures from [6]).

Globalisation spreads impacts offshore

The recent announcement by the UK's Minister for Energy and Climate Change, Chris Huhne's [7], that a 50% emissions reduction by 2027 would be enshrined in law resulted in poll-enhancing headlines but is based on deceitful accounting principles. Institutionally, the United Kingdom at least has energy and climate change under one roof, but a report from its Department for Environment, Food and Rural Affairs [8] has shown that the UK's consumer emissions have risen 18% while its official accounts have reported reductions of 5%. Most emissions are outsourced to other economies, with 70% of imported emissions due to China, 20% to other European countries and 10% from the rest of the world.

Much of this apparent subterfuge is due to a Rio Earth Summit decision that emission accounting should be production-based or territorially based rather than consumption-based. This mixes advantages and disadvantages all round, but robust global accounts are now routinely available for emissions but less so for water and biodiversity impacts. The reality that developed countries import the majority of emissions embodied in international trade but avoid accounting for them is the anomaly undercutting climate negotiations, made more difficult to unravel as shopping by developed countries helps developing countries develop.

Globalisation's environmental complexity is illustrated in Figure 3, which shows Australia's imports and exports of embodied carbon dioxide emissions over the last 19 years. For two-thirds of the time series Australia maintained a positive balance in emissions, exporting more than it imported. Since 2004, however, consumption and development have driven rapid increases in imported emissions so that the economy now occupies two less advantaged positions in climate negations terms, being both a high per capita producer and consumer. The pattern of imports shows the United States maintaining a steady contribution (70% merchandise and 30% services) over the period but also reveals a rapid rise in China's recent contribution (90% merchandise and 10% services), as manufacturing and employment were outsourced to China because of their scale and wage advantages. How to reconcile these complexities is difficult, especially if the global boundary issues of land use, water and biodiversity are added to emissions. Globally scaled and finely detailed trade analysis is now commonplace, making integrated production chains more transparent to policy and thus open to regulation, border tax adjustments and moral suasion.



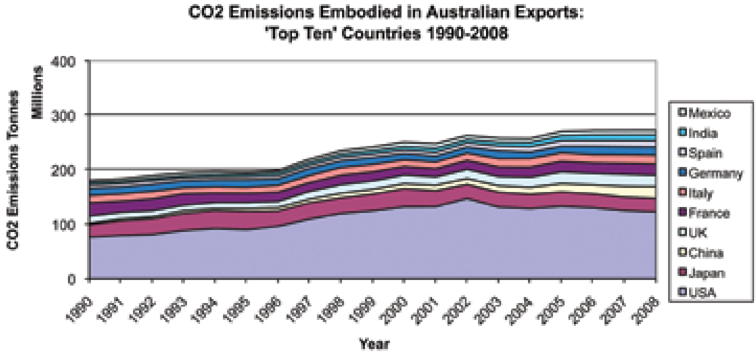


Figure 3: Carbon dioxide emissions embodied in trade imports to Australia (top graph) and trade exports from Australia (bottom graph) for the 10 most important countries in each category for the period 1990 to 2008. (Source: Eora Global Model, ISA Group, University of Sydney [9]).

Sustainability policy—mostly talking the talk

The dominant economic beliefs treat many environmental resources as free goods, ensuring that sustainability policy is misguided and based on narrow accounting protocols. Thus mainstream environmental advocates must adhere to dominant beliefs that might change the system only marginally. Current proposals for carbon pricing that won't alter the slope of the relationships in Figure 2 are a good example of marginality. The recent Sustainable Australia—Sustainable Communities [10] population policy is another non-policy resting on no integrated analysis and reporting scant sustainability data. Comprehensive and integrated physical datasets are not kept across all jurisdictions and thus there is by definition no possibility of charting environmental improvement or decline.

Yet the sustainability long game relies on maintaining strong links to the status quo along with comprehensive data and rule-of-thumb policy principles. This requires consummate political skills, the ability to avoid compromise and to resist entrapment by the status quo. Dispassionately maintaining core science disciplines while they are dismembered by political and industry attacks requires a principled and resolute perfection, qualities not often found in a single sustainability practitioner. Going 'feral' even in one moment of weakness makes the retrieval of former influence very difficult.

Personal consumption in aggregate is the key

Because personal consumption drives economic growth and advancement any theory that suggests limiting consumption is not politically appealing. Theory suggests that each individual, community and nation in the developed world must at least halve or even quarter the physical implications of their yearly lifestyle. Descriptions of a future weightless economy are fanciful from a physical perspective when they describe service workers in densified cities transiting by light rail to a dwelling where the inmates consume an ever-growing take-home pay with declining impact. Physically, it is true that affluent spending has marginally lower impact per dollar of spend but the much larger volume of spending makes efficiency quotients irrelevant in absolute terms. Public policymakers still quote a hypothetical inverted U-shaped relationship where impacts are lowest for lowest and highest spenders, and largest for those caught in a medium lifestyle/technology netherworld [11]. Fully trade-corrected consumption analyses show no evidence for an environmental Kuznets relationship. Science unpicked this fanciful Kuznets' curve hypothesis three decades ago by finding that overall impact rises incrementally with volumetric spending over all categories (construction, shelter, food, clothing manufactured products, mobility services and trade). However, public policy retains its immunity to these unpleasant facts.

3 Science background to this position

Whole-economy science and the evidence base

The evidence base for the proposals here were developed throughout a series of future-orientated, whole-of-economy studies focused on human population policy (*Future dilemmas* [12]), life cycle analyses of all economic sectors (*Balancing act* [13]), marine fisheries (*Fish futures* [14]), agricultural production, land and water resource (*Decision points* [15]) and the low carbon transition (*Powerful choices* [16]).

The simulation systems and models used here were science-based, effectively implementing the physical laws of thermodynamics and mass balance within and around the function of Australian economic system. The Australian Stocks and Flows Framework [17] used for *Future dilemmas*, *Fish futures* and *Decision points* was the most comprehensive and expensive of these. *Balancing act* was based on environmentally and extended input-output analysis and could or should become the standard for sector-based environmental and social accounting within the system of national accounts. *Powerful choices* simulated economic function from an embodied energy perspective (the chain of energy transactions required to bring a good or service to the point of purchase) and allowed simultaneous accounting of economic, physical and pollution issues.

Almost uniformly, the initial policy reaction has been to bury or ignore these reports, which in some ways gave them an attractive notoriety and thus helped their spread, but their effectiveness in policy terms remains low. The rot continues with the burying of the *Physical implications* report [18], an expanded update on the original human population study. Both tactical and strategic issues are important here. The immediate tactics of client and political engagement in most of the studies could have been improved, but not in paid contracted time given the always marginal nature of the funding contracts. Strategically, the bigger issue is that economic and political thought does not really accept in their day-to-day deliberations the concepts of limits and physical laws that might restrain optimism and growth.

Six rules for sustainability

The tens of thousands of simulation runs underpinning these reports fostered a distillation into principles of sustainability to entrain a common understanding of dynamics, structure, knock-on effects and unintended consequences that regularly fell out of the modelling procedures.

The six principles derived so far, are as follows:

1. Stabilise physical consumption and the human population that drives it.
2. Constrain the flows of the grand elements (carbon, nitrogen, phosphorus and sulphur) and managed water.
3. Base society on cycling and reuse (flows) rather than virgin materials (stocks).
4. Shorten supply chains.
5. Engineer society for durability and resilience.
6. Have taxes tell the truth.

The ‘consumption and population’ principle rests firstly on the need to stabilise human population with an adequate age structure to balance workers and nonworkers. The ‘grand element’ principle is now enshrined in the planetary limits work with core importance for climate change (C) and the long-term health of agricultural soil and water bodies (N, P, H_2O). The ‘cycling and reuse’ principle should guide design for suburbs, waste treatment, water management and food systems. ‘Shortening supply chains’ aims to localise employment, provide human waste for agricultural soils and regionalise the closing-the-loop concept in the previous principle. The ‘durability and resilience’ principle aims to ‘do it right the first time’ in the design of appliances, houses, suburbs and cities and to slow down the churn central to the throwaway society, the waste stream and economic growth. Having ‘taxes tell the truth’ suggests an integrated physical taxation scheme based on the embodied carbon, water and land in the consumption activities of every household. A draft documentation of the ‘taxes’ principle [19] proposes that its implementation at the cash register through the GST system could raise $20 billion per year, penalise the purchase of high-impact items, do away with payroll tax (the double dividend return promised by environmental taxation) and leave $5 billion per year for environmental refurbishment. Given the political pain today of a $20–$30 per tonne carbon tax, this principle may seem the most foolhardy of all.

A low-carbon transition example

The incompatibility of the business-as-usual trajectory for key sustainability elements is shown briefly in explorations of Australia’s transition to a low-carbon economy by 2051. The studies compared a renewable-energy transition with a best conventional–fossil plus nuclear transition. Both transitions competently reduced the stock of greenhouse emissions over the 45-year period by 60% and maintained economic growth rates in line with Australian Treasury expectations.

However, on a per capita basis neither the renewable nor best-fossil scenarios could lower net emissions below 12–15 tonnes per year, well in excess of the 3–5 tonnes required for the globe to achieve atmospheric stabilisation under a ‘contraction and convergence’ scheme that provides per capita equity for developed and developing worlds. It is only with economic growth rates of less than 1%, effectively stabilising volumetric GDP in constant dollar terms at today’s level, that territorial emissions can trend down towards the ideal level of 4 tonnes per capita by 2051 (Figure 3).

These results are problematical from four perspectives. Firstly, they are not acceptable in today’s political economy terms and will be dismissed by core players in national decision-making. Secondly, they disagree with the dominant narratives from both the Nicholas Stern and Ross Garnaut reviews which assert that, while humanity's situation is perilous, growth can continue unchecked providing carbon is priced and innovation given free rein. Thirdly, the models may be incorrect wholly or partially, and certainly some of the assumptions are open to close questioning. Fourthly, the successful scenarios dictate that personal consumption in physical terms be halved compared to the business-as-usual option and that our households embrace a physical lifestyle (energy, emissions, materials etc.) similar to that experienced in the early 1980s. In science terms, using proper accounting protocols that obey physical laws, these results are somewhat unsurprising and report somewhat repetitively, core learnings from The Limits-to-Growth era and legions of analysts last century such as Lotka, Soddy, Georgescu-Roegen, Tainter and many others.

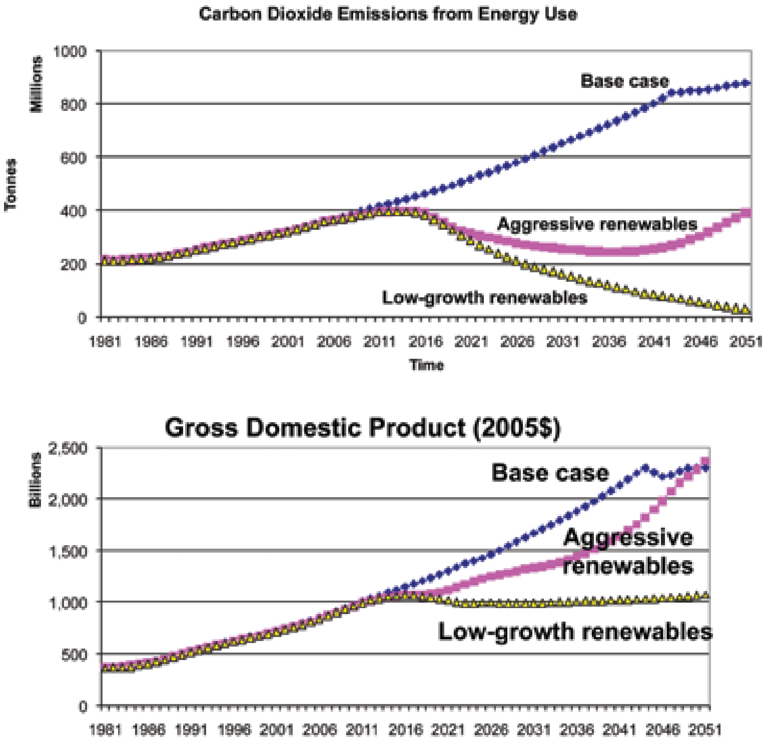


Figure 4: Carbon dioxide emissions (top graph) and gross domestic product (bottom graph) for the Australian economy for two low-carbon transitions (aggressive renewables, low-growth renewables) compared to the base case scenario [20].

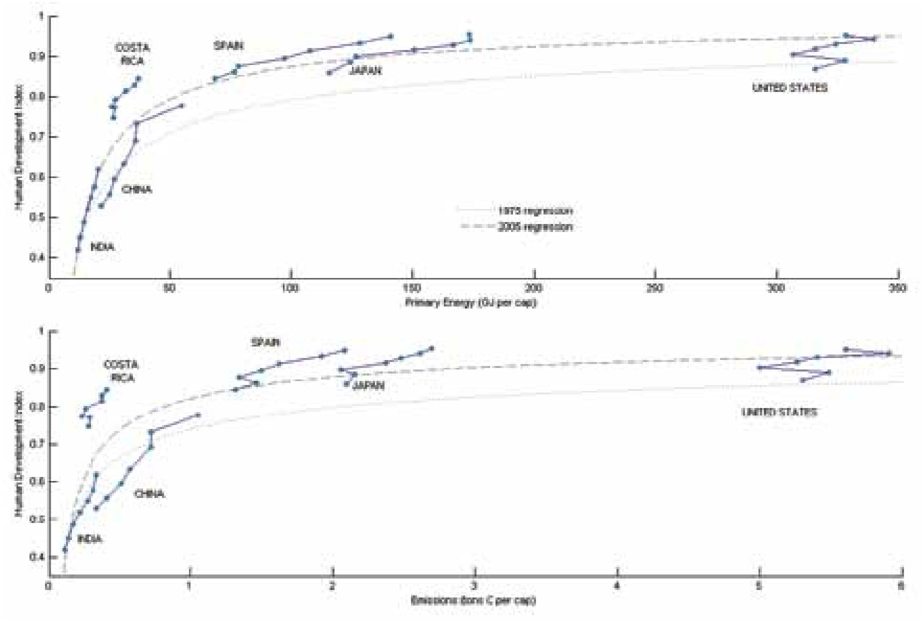


Figure 5: Development trajectories for six selected countries showing the HDI (y axis) against primary energy use (x axis GJ per capita) and carbon emissions (x axis-tonnes C per capita). (Source: Figure 4 [21].

4 Focus on the core pathway: energy is the key

The United Nation's Human Development Index (HDI) (components: life expectancy, education, income) shows that adequate levels of development can be attained at energy-use levels less than one-quarter that of high energy users such as the United States and Australia [21] (Figure 5). High per capita energy use is often correlated to a range of poor population health outcomes such as a looming epidemic of obesity and diabetes. This is true for the United States and Australia currently with 35% and 30% obese individuals respectively. The relationship is not universal. However, as higher energy-user Japan (5% obese) is distinct from Spain (20% obese) and Costa Rica (30% obese).

Nevertheless these graphs show unequivocally that core human development objectives can be met at a per capita energy use between 30 and 60 GJ yearly. Currently, Australian lifestyles drive an energy use of 315 GJ per capita suggesting that human needs can be met at 20% of current energy use and fossil carbon emissions less than one tonne of carbon (3.7 tonnes CO_2) per capita yearly. The study from which Figure 5 is drawn projects the increasing efficiency with which HDI levels are attained and suggests that by 2030 adequate HDI is possible with much lower energy use and carbon emissions, even allowing for expected population growth.

The obvious caveat is that high energy-use countries will not retrace their development pathways along the energy-use gradient without considerable acrimony and a fundamentally different economic structure. The case for developing countries to further develop while expanding energy use and carbon emissions is graphically obvious given the orders of magnitude difference of the high energy users and their impact on atmospheric carbon loadings.

Australia's prospects for change seem bleak when seen in the context of the world order depicted here. Its current second-place ranking in HDI terms comes with high-energy use, leading-edge carbon dioxide emission and related crises in biodiversity, land and water. It is possible that the decarbonised economic and physical structures described previously can reduce energy use, maintain human development and reduce national impacts on regional and planetary boundaries. In fact the low-growth, low-carbon economy does just that, giving per capita energy use similar to that of the early 1980s. Thus dejouling the economy while lessening impacts on planetary boundaries should be the essential goal in designing Australia's sustainability transition.

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Chapter 6

Feeding Australia in 2050

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Australia can currently feed its population three times over, and the country's impressive record of innovation and adoption of technology suggests that yields of major crops will continue to increase. Although land degradation has been severe, the widespread uptake of conservation farming practices has slowed and in some cases reversed the trajectory of degradation. The threat to Australia's food security as we approach 2050 resides in the global unrest that will quickly follow any large perturbation of an already precarious world food supply. Although the gap between average farm yields and potential yields is wide in most parts of the world, the signs are that the Green Revolution ushered in during the 1960s is slowing, and we are unable to contain the associated environmental fallout. It could be argued that the spectacular advances in food production over the past 50 years stem from our ability to manipulate 'simpler' systems and our currently dominant scientific modus operandi is inadequate for tackling the complex socio-ecological problem of global food security. Over a period when investment into agricultural research has been declining, the United Nations Millennium Development Goal of halving the proportion of people who suffer from hunger between 1990 and 2015 may well be slipping through our fingers.

Introduction

About one in every 180 Australians is a full-time farmer. Our farmers grow enough food for 22 million Australians and about 40 million more inhabitants overseas. Much of this production comes from the 3% of Australia's land surface that is used for dryland cropping and the 0.4% under irrigation [1]. If we need to feed an extra 10 to 20 million Australians by 2050 the task should be well within our capabilities.

The Australian agricultural sector has a history of innovation that has led to enormous change both in the technology used for farming and the social fabric of the countryside. Each decade the prices received for farm goods fall 10% relative to the costs of production. Innovation is the only way to survive. Every generation sees about half the farms go out of business, snapped up by neighbours and others who can produce more efficiently on larger parcels of land, lending truth to the saying 'the greatest threat to an Australian family farm is another family farmer' [2]. Consumers have reaped the benefits. Over the past 25 years expenditure on food has dropped from 14% to 11% of the household budget [3].

Although individual farmers suffered enormously through the millennium drought between 1997 and 2009, and industries such as rice and cotton shrunk to almost nothing, the total value of farm and fisheries production through the decade of drought barely dipped below the $30 billion mark maintained through the 1990s [4]. The long run of poor seasons knocked only half a ton per hectare off the average national wheat harvest (Figure 1). Yields dropped precipitously in certain years but the productivity was not decimated to the extent seen during similar droughts 100 years earlier. Similarly, the huge drop in water available for irrigation during the drought did not have a proportional impact on the bottom line, as farmers switched to more water-efficient options and traded water from low-value to high-value crops.

This picture of a productive, innovative and adaptable farming sector is not, however, the full story. There are significant threats and challenges both internal to Australia and externally that the scientific community is yet to fully grasp.

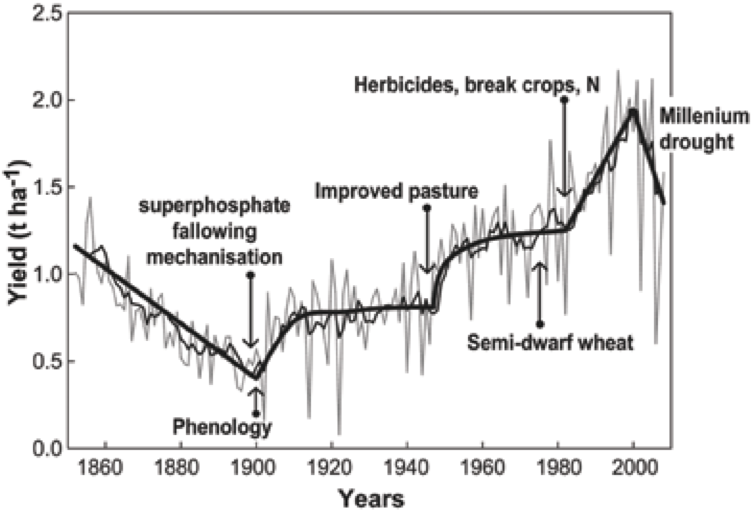

Figure 1: Trends in national Australian wheat yields (from 5)

2 Internal threats

Land degradation

Land degradation as a consequence of food production is the most obvious threat to sustained food production over the long term. The very act of 'clearing the bush' during colonisation set in train the processes of erosion and dryland salinity and ccontributed, together with the introduction of annual crops and pastures, to the process of acidification. If we consider that prime agricultural land in Australia covers 100 million hectares, then half of this currently has a surface pH less than 5.5, the value at which the yield of many crops starts to decline. More worrying is the one-quarter of agricultural land affected by subsoil acidity, which is much harder to remedy [6].

Of these varied aspects of land degradation, dryland salinity has traditionally received the most national attention, although it disappeared quite suddenly off the national agenda during a run of abnormally dry years. Although its figures were subsequently contested, an audit in 2000 predicted that 5.7 million hectares had a high risk of developing dryland salinity, rising to 17 million by 2050 [6]. Combating erosion is one area where genuine progress has been made through the widespread adoption of conservation tillage. Nevertheless, in regions that are intensively farmed, sediment loads in rivers are 10 to 50 times greater than they were in pre-European times.

The challenge of combating land degradation is that processes often unfold slowly, without stimulating sufficient remedial action, before reaching a sharp threshold past which the problem kicks in. For example, crop yields are not affected by saline watertables 5 metres below the soil surface, rising at 0.1 m per year. But when watertables reach 2 m from the surface the problem can become intractable. Similarly, the crop response to falling pH is highly nonlinear. Although pH is fairly easy to correct with liming, it is usually uneconomic to do so and by the time economic losses start to appear it can be too expensive to rectify the problem.

Over the past 100 years average national wheat yields have risen four-fold, from 0.5 to 2 t/ha, illustrating how innovation has been able to mask the slow underlying degradation (Figure 1). In fact yields have increased most sharply over the past 30 years when land degradation has been most evident. Conservation agriculture, widely adopted by Australian grain growers, embodies many management activities that will halt and can even reverse degradation [5]. Yet land and water degradation still cost the country billions of dollars each year [7].

Climate change

Although we have a reasonable idea of the increase in temperature and some idea of the change in rainfall we can anticipate as global climate changes over coming decades, we do not know what the genetic and agronomic package will look like in 30 years time. Based on current agronomy, one major study shows a slight increase in wheat yields by 2050 across the Murray–Darling Basin except for the driest sites. This occurs because the increase in yield due to rising CO_2 outweighs the negative effects of rising temperature and declining rainfall. However, this slight trend starts to reverse stubbornly after 2050 at all but the coolest and wettest sites [8].

Water supplies for irrigation will be reduced. Projections for the Murray–Darling Basin suggest about 10% less water in the river by 2030, with about half the impact flowing through to irrigators [9]. Dry years are predicted to occur more frequently but not with the severity that regions have experienced over the last decade. A 5% reduction of water to the irrigation sector by 2030 may seem small, but this will be on top of a minimum buyback of 30% of existing allocations now under negotiation, which will be required to give some hope of stabilising the health of the river system. Due to the highly nonlinear relationship between rainfall and run-off, median conditions in 2070 are likely to resemble dry extremes of 2030.

Capacity to innovate and change

In the past 10 years the productivity of Australian farms increased at 1.3% per annum, while over the previous two decades productivity grew by an average of 1.8% each year [10]. This slowing has been attributed to the continuously falling investment into research and development (R&D) [11]. Studying agriculture has gone out of fashion, with only 510 agricultural graduates from all Australian universities in 2001, freefalling to 370 in 2006 [12]. Agriculture is the sector with the highest median-age workforce in Australia, with 36% of workers aged over 55. Some estimates are that half of currently working agricultural scientists will retire in the next few years [13]. The capacity to innovate is withering.

Part of the reason for the above is that an increasingly urbanised population has lost touch with the real issues facing rural Australia. It is taken for granted that there will always be enough food. Meanwhile, as a nation we are putting on weight quickly. In the past 15 years the proportion of overweight or obese in the 45–54 age bracket climbed from 42% of the population to 68% [14]. One in four children aged 5–17 now slot into the overweight/obese class [15]. Type 2 diabetes, which is linked to obesity, is projected to become the leading disease burden by 2023, exceeding cancer. Viewed from this angle, we could say the modern food system is not very healthy.

3 External threats

Past successes

Much progress has been made in the battle against world hunger, with the percentage of undernourished citizens of the developing world falling from 33% in 1970 to 16% in 2005 (Figure 2). What is even more remarkable is that this was achieved during a period when the world's population more than doubled. Much of the success has its roots in the Green Revolution package of improved crop varieties combined with wider use of fertiliser and the expansion of irrigation, although the results are not evenly spread. Food production per capita in China doubled over this period, while in subSaharan Africa production has struggled to keep pace with population growth.

The last four data points on Figure 2 suggest all is not well. Food prices had been relatively stable for decades but started to creep up at the turn of the century and then spiked in 2008. The cause of the price spike was put down to a run of poor seasons across several major grain-producing countries, low global food reserves, high oil and input prices and diversion of corn to biofuels, combined with the increased consumption of meat and dairy products associated with rising incomes across much of Asia. As expected, the world food system was able to adjust to the price signal and the situation started to stabilise in 2010.

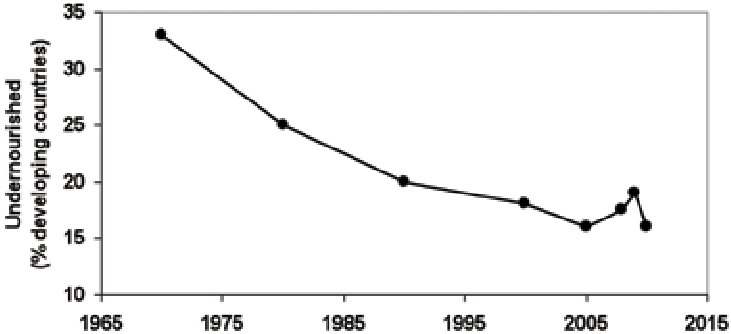

Figure 2: Proportion of undernourished people in developing countries (FAO (last two numbers are estimates from [16]).

When we look at the absolute number of undernourished in the world the picture looks grim (Figure 3). Little progress was made over the 30 years prior to 2005 and the 2008 price spike has had an immediate flow-on effect to world hunger. Tens of millions have no capacity to absorb any price increase and must join the ranks of the undernourished. Moreover, the events leading up to the 2008 price spike were at first thought to be an unlucky meeting of unrelated factors. But prices are soaring again in 2011 and may well exceed the highs of 2008, suggesting that the confluence of events may be the new norm.

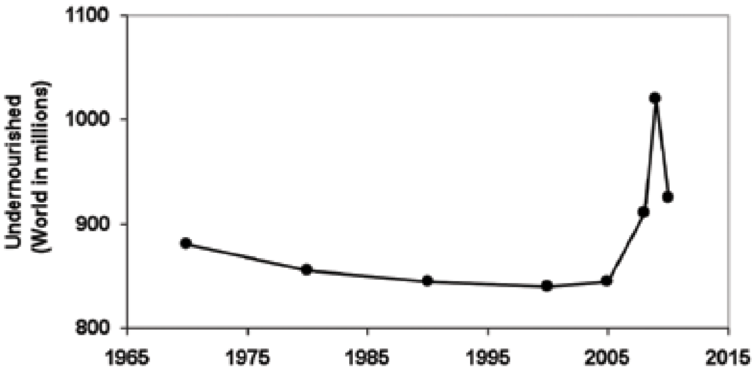

Figure 3: Number of undernourished people in the world (last two numbers are estimates from [16]).

Problems ahead

The remarkable achievement embodied in Fig 2 has for the most part come from an increase in yields per hectare rather than from an expansion in the land area under agriculture. This is largely by necessity—suitable land for growing crops is running out. About 1.3 billion hectares of global arable land spread among 7 billion people only gives one-fifth of a hectare each. Popular notions of low input farming and peri-urban agriculture are not going to feed the world.

While the efficiency of production on an area basis has increased, the efficiency on an input basis has not. Global use of nitrogen fertiliser has increased more than seven-fold over the period that food production doubled. Only half of this nitrogen is recovered in harvested crops, with the remainder entering aquatic and atmospheric systems [17, 18, 19]. Moreover, the cost of nitrogen fertiliser rises with the cost of energy, and current usage is already a major component of greenhouse emissions from agriculture. Known reserves of phosphate are found in countries with high local demand (China), and parts of the world plagued by political turmoil (North Africa).

Global warming potentially opens up northern latitudes for crop production but the impact on some developing countries is alarming. India and China rely heavily on the snowmelt from the Himalayas for irrigated crops and the reliability of this supply is threatened by shifting rainfall patterns. Already these two countries are over-exploiting their groundwater reserves for food production. India produces 15% of its grain crop on essentially non-renewable groundwater [20]. Perhaps the biggest threats to global food security will take us by surprise, such as the rust fungus, Ug99, which originated in Uganda, with the potential to decimate the 85% of the world's wheat crop susceptible to this new strain.

Existing technology still has much to offer, as illustrated by the large yield gap between average farm yields and those obtained from experimental stations or by the best farmers. Yet the signs are that the Green Revolution ushered in during the 1960s is slowing, and we are unable to contain the associated environmental fallout. The next hoped-for revolution, based on novel crop genotypes, has started to have some impact. Yet the early successes that have seen the development of crops expressing insect toxins (Bt) and others with herbicide tolerance may not represent the vanguard of a new wave of crops that will be adapted to salt, drought, waterlogging, heat and cold. The former successes only involved relatively small alterations to the genetic code to produce or detoxify a certain chemical. Adaptations to biotic stressors involve multiple mechanisms and structures interacting at various organisational scales with mindboggling complexity [21] and are likely to be much more elusive to capture than the more ardent proponents of the biotechnology industry suggest.

The UN Millennium Development Target 1.C: 'Halve, between 1990 and 2015, the proportion of people who suffer from hunger' now looks to be slipping through our fingers. Shocks to the world food supply through shifting climates, disease outbreaks and unaffordable or unavailable inputs would quickly lead to hunger. Although Australia could feed its population three times over, we only produce 1% of the world's food supply and our ability to adapt will be overwhelmed by the international political unrest that will quickly follow any large perturbation to an already precarious world food supply.

4 A new social contract for science

The global population of the obese now rivals that of the undernourished, while the task of feeding the hungry is undermined by a host of social problems and declining investment into agricultural research. Global public spending on R&D for improving food security now stands at one-fiftieth of spending on military armaments, while by 2003 the average yield-improvement of wheat, rice and maize had dropped to half of the 3% per annum level it had been running at in the 1970s [22]. Yet reversing the funding trend in itself will not be enough. Our problem may run deeper than that.

It could be argued that the spectacular advances seen in figures 1 and 2 stem from our ability to manipulate simpler systems. This is not to say that the breakthroughs were not remarkable but that our current dominant scientific methodologies are inadequate for tackling complex socioecological systems [23, 24]. We are struggling to heed a call from within our own community about the need to think differently about contemporary issues facing society [18, 25]. We have failed to grasp Holling's warning—that success in managing one target variable in isolation leads to 'less resilient and more vulnerable ecosystems, more rigid and unresponsive management agencies, and more dependent societies' [26].

As a community we are yet to take up the challenge of negotiating 'a new social contract for science' [27] to address the intimate connections between food production, natural resource management, human health, social justice and national security.

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Chapter 7

Towards a resilience assessment for Australia

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The challenge of responding wisely to global change may be usefully addressed from the perspective of resilience. Approaches that focus on resilience place an emphasis on dynamics in response to disturbance and are concerned with the capacity of a system either to absorb disturbance and maintain the same function or to transform significantly in the face of change. Resilience assessments have been made for particular regions in Australia and there is an established set of methods for making such assessments. In this paper we draw on such assessments to highlight aspects of resilience that are relevant at a national scale and suggest approaches to making a resilience assessment for Australia. We offer a preliminary framework for such an assessment and identify potential benefits. By recognising the coupled relationship between human society and the planetary environment, a resilience assessment responds to the need for intelligent integration across scales and across knowledge from all sectors of society. We suggest that a resilience assessment, if used as part of a process of engagement across many sectors of society, would help build social capital that itself would contribute to resilience and the capacity for transformation.

1 Introduction

Background

The concept of ‘a safe operating space for humanity’, proposed recently by Johan Rockström and colleagues has proved to be a useful integrating concept when considering global change—‘the biophysical and the socioeconomic changes that are altering the structure and the functioning of the Earth System’ [1].

Global change has occurred to such an extent, it is argued that we are in a new geological era or epoch: the Anthropocene [2]. Rockström and colleagues put forward the ‘safe operating space’ concept to frame our understanding and response to global change [3]. They recognised that the biophysical conditions of the past 10 000 years, known to geologists as the Holocene, have been the only conditions under which humanity has thrived, and that human activities are changing these conditions. They sought to characterise biophysical conditions that are necessary for humanity, drawing particular attention to the conditions that are being perturbed significantly by human activities. The authors identified nine ‘planetary boundaries’ that define the safe operating space associated with Holocene conditions [also see Volume 1, Chapter 1, Section 2].

The authors’ focus on boundaries reflected their understanding of resilience and critical thresholds in the Earth System. Resilience is the capacity of a system to absorb a disturbance and reorganise so as to maintain its function, structure and feedbacks—and therefore identity [14]. Analyses of resilience place a strong emphasis on understanding feedbacks between different parts of the system and across scales (e.g. market outcomes are the accumulation of individual choices in a range of sectors, and in turn affect such choices on short- and long-term time scales—the dynamics of such feedback interactions inform resilience analyses). This awareness of nonlinear dynamics distinguishes resilience approaches from more conventional risk management that does not usually take discontinuous changes into account. Approaches to understanding systems that take a resilience perspective also emphasise the need to consider the whole system at multiple scales so as to avoid the problem of partial solutions with unintended secondary consequences. We contend that it is this partial solutions approach that is bringing the world to the brink of planetary boundaries. In circumstances where certainty (predictability) is high and the risks from making a mistake are small, it may be appropriate to adopt a ‘maximum sustainable yield’ approach to resource use and management. But where the reverse is true, an appropriate response is to build resilience.

Responding to some of these issues at the national scale, a recent report by the Prime Minister’s Science, Engineering and Innovation Council (PMSEIC) investigated the interconnections between carbon, energy and water in Australia [4]. The report presented the challenge as follows:

> The fundamental energy-water-carbon challenge for Australia is to find pathways which combine a low-carbon economy, the ability to thrive under water limitation, social wellbeing and economic sufficiency—all in the presence of global uncertainties and shocks. Some of the necessary changes may occur incrementally (relatively slowly and in small steps), while others will call for transformations (rapid changes in large jumps).

The authors concluded that a focus on resilience is useful for navigating this challenge:

> A core concept that can guide the necessary integrative perspective is that of resilience. A resilient system can [1] recover from shocks and disturbances, [2] adapt through learning, and [3] undergo transformation when necessary.

The report outlined the difference between resilient and non-resilient futures:

> At energy-water-carbon intersections, adaptation towards resilience takes advantage of potential synergies and uses tensions as opportunities for change. Pathways consistent with such adaptation will reduce GHG emissions, lower overall water demand, maintain overall environmental quality and maintain or increase social and economic wellbeing. In contrast, there are many other pathways which have the potential to satisfy only some essential goals while worsening the outcomes for others, and may also lead to undesirable states from which recovery is difficult—for example, lock-in to high-emissions pathways.

Key recommendations from the PMSEIC report included enhancing the resilience and sustainability of landscapes and built environments, and tackling these issues through an ‘enhanced knowledge and learning system’ that is characterised by an unprecedented level of cross-sectoral and cross-disciplinary integration.

The need for a resilience assessment

‘Resilience’ has proved to be a useful integrating concept in both the planetary boundaries work (a global focus) and the PMSEIC recommendations (an Australian focus). We suggest that an important aspect of ascertaining a safe operating space for Australia would be to characterise the resilience of the Australian social-ecological system. Such a resilience assessment would include biophysical, social and economic dimensions and pay particular attention to the interconnections between them. We emphasise that resilience does not imply an unchanging system, and can involve significant transformation.

Walker and colleagues wrote of the need for global institutions that are capable of responding to looming global-scale failures [5]. We currently lack global institutions that can foster cooperation capable of resolving social dilemmas such as the 'tragedy of the commons' [6]. Nor are existing institutions well equipped to address integrated problems, tending instead to focus on single issues—the World Health Organization addresses human health problems, the Food and Agriculture Organization addresses agriculture, the United Nations Environment Program deals with environmental issues and so on. Examples of truly integrated approaches at the global scale are rare. The same is true at national scales. Australian research institutions, government agencies, businesses and legislation in particular are oriented towards single issues or tightly defined fields of endeavour. As a matter of urgency we need more effective ways of bringing out the collective knowledge of all sectors of society. The issues we are considering involve high uncertainties, high decision stakes and are conceptualised very differently according to the experience and world views of different stakeholders. Such issues cannot be addressed solely by specialist scientific knowledge and require genuine collaboration with all sectors of society [7–9].

The Academy of Science project, Towards an Environmentally Sustainable and Socially Equitable Way of Living, asks the following question: What is our realistic vision for an ecologically, economically and socially sustainable Australia in 2050 and beyond? The purpose of a resilience assessment would be to integrate existing knowledge and engage more broadly outside the academic community to address this and related questions. There is a body of existing work on resilience in Australia that can be built upon in this endeavour [10–15], and the Resilience Alliance has published workbooks on conducting regional resilience assessments [16, 17]. Here we consider what it would look like to apply such a framework in a nation-scale assessment.

2 A framework for resilience assessment in Australia

Useful attributes of a resilience assessment

In outlining a possible framework for assessing resilience at a national scale we first review the characteristics that would be desirable for such an assessment to be useful. We seek a resilience assessment with the following attributes:

1. *Timescale* The timescale is relevant to 2050 at least.
2. *Context* The assessment is informed by a range of alternative global scenarios and a set of projections for feasible Australian futures (e.g. population trajectories).

3. *Specified resilience* The assessment characterises 'specified resilience': the resilience of particular aspects of Australian society to defined shocks.
4. *General resilience* The assessment characterises 'general resilience': our ability to cope with all kinds of shocks, known and unknown, so as to continue functioning in a desired way.
5. *Transformation* The assessment explicitly explores options for transformational changes in the system, both at fine scales and, if needed, at the scale of the whole system.
6. *Dynamics* The assessment draws on complex systems insights and methods to characterise the dynamics of the connected social-technical-biophysical system.
7. *Participatory, adaptive processes* The assessment is conducted in a participatory manner and as part of an adaptive learning process so that it contributes usefully to effective and ongoing engagement with individuals, communities, businesses and governments.

Context: projections for Australian and global futures to 2050

A resilience assessment will need to be informed by forward projections of population (both global and national) and characterisations of possible global and national futures [see Volume 1, Chapters 1, 4 and 6]. Existing significant modelling and scenario exercises such as the Intergovernmental Panel on Climate Change (IPCC) assessments and the Millennium Ecosystem Assessment play a significant role in characterising the global biophysical context.

Specified resilience

As the term suggests, specified resilience is the resilience of particular aspects of a system to specific shocks. At local and regional scales within Australia, resilience assessments ask questions about the resilience of valued system goods and services—such things as agricultural production; soils and landscapes; the supply of clean water; valued ecosystems such as wetlands and particular forests; biodiversity (sometimes including iconic species); community wellbeing; the 'health' of towns; and so on. At the scale of Australia, what are the attributes whose resilience is of most concern? And what kinds of shocks do they need to be resilient to? Where do we see the greatest threats, and who are most vulnerable?

A report by Australia 21 conducted an assessment of this kind [10], identifying specific external and internal shocks to which Australia may need to be resilient (Table 5). A resilience assessment would provide an opportunity to identify such shocks, but more importantly seek to learn from past events (e.g. financial crises,

Internal/ External	Title	Nature and Effect	Comment
Internal	Oil depletion	The current oil issue is really just an emotion-led price spike. However, around 2015 we expect oil production to be physically constrained and Australia's domestic stocks to be very low. The price Australia can adapt to and our trade balance will look simply dreadful. The most important issue is that supply will become erratic and cause breaks in important chains and therefore widespread disruption.	Possible that Australia could make a reasonably quick adaptation to compressed natural gas.
Internal	Population ageing	Around 2030 we expect that approximately 25% of Australia will be over the age of 65 giving increased health and pension costs, but more importantly, a stable or slightly declining workforce that does not increase government coffers through continual growth and expansion of consumption. Tied into lack of investment in all-round skills.	Several good analyses point to this being a bit of a beat-up to frighten the punters, provided Australia gets expected productivity growth and progressively increases social spending by 5%.
Internal	Land and water toxicity	By the mid-2020s many land and water 'sleepers' will be coming home to roost, potentially giving saline and acidic rivers that in turn make irrigation agriculture extremely problematical. Once these go past the buffering thresholds it may be difficult to entice rivers and land to return to reasonable ecological function.	A really bad fright in the 2010s may scare us enough to invest heavily enough to repair sufficiently.
Internal	Semi-permanent El Nino	The main topics of discussions about global change in Australia are higher temperatures and more cyclones. More worrying would be if rainfall patterns move permanently off-land and most of the country's production areas remain in semipermanent drought.	A real possibility with reasonable support for hypothesis that this has happened to the south-west of Western Australia
External	Infrastructure fragility	Lack of substantial investment since the 1970s in widespread 'dull' infrastructure essentials, such as water, electricity and transport, leads to the widespread co-occurrence of system failures in the 2020s.	This is real now but a few megafailures in the next two decades might wake us from our slumber.

Internal/ External	Title	Nature and Effect	Comment
Internal	US-led economic meltdown	The 'shopping mall' economy of the US requires large inflows of capital (mainly from Asia) to underpin and sustain growth in most of the world. The US now has large trade deficits, very large debt and a large underclass of deprived peoples. If the US economy cracks it will take most of the developed world with it. Because China had nowhere to send manufactures, our commodities exports would dry up overnight.	Recognising this, perhaps the rest of the world would simply not let it happen. However, the co-occurrence of a New Orleans and a 9/11 attack would probably do it.
External	Large depreciation of Australian dollar	A large downturn in several commodity exports (e.g. Brazil and Argentina blow us out of the water on iron ore, grains and meats) could rapidly increase our trade deficit (especially when oil is biting hard), cause a flight of capital and make our external private debt (circa $500 billion now) difficult to pay interest on. Most importantly, our superannuation funds will give very little retirement cash flow and cause much social 'grey' anger.	Unlikely that Australia could sink as low as Zimbabwe, but Argentina is a reasonable model.
External	Human pandemic	The current bird flu issue is the most likely. The key issue is not just the number of people it kills or makes very sick but the degree to which it could clog up social and economic transactions, such as that the economy would stall and normal things become unworkable.	
Internal	Animal plant pandemic	Possible that a superbug or plant weed from a GE escape or mistake (perhaps with human implications) could emasculate production but, more importantly, completely stop agricultural exports.	Continual wind down of practically skilled field operatives would allow the issue to intensify while the 'suits' risk managed.
BOTH	Co-occurrence	Take your pick of the above, but any two or three in combination could synergise the unwieldy outcomes of each individual one into untold and unforseen myriads of truculence.	Perhaps too apocalyptic, but requires research and role-playing to determine most-thoughtful responses.

Table 5: Table of shocks from an assessment by Australia 21 [10].

terrorist attacks, floods, droughts, cyclones, SARS and swine flu outbreaks, tsunamis, bushfires, price spikes, and so on). It is not enough simply to identify vulnerabilities, but rather identify those system attributes that confer resilience when these shocks occur.

While anticipating shocks and assessing the resilience of particular aspects of Australia to those shocks is useful and a necessary component of a resilience assessment, we can never be sure of what shocks might prevail, and we will never know enough about Australian social-ecological systems to rely on our knowledge of such specified resilience. An equally important aspect of resilience, therefore, is to investigate general resilience.

General resilience

Where an assessment of specified resilience addresses questions of 'resilience of what' and 'resilience to what', assessing general resilience involves identifying system properties that are known to confer resilience to a variety of unspecified disturbances. Such an endeavour is useful in that it offers a way of integrating insights learned from many kinds of perturbations across a range of systems and lends itself to fostering a generic adaptive capacity rather than prescriptions for responding to defined shocks.

Some of the characteristics of a resilient system include [14]:

1. *Diversity.* A resilient system embraces and works with diversity and variability, recognising their value in building flexibility and keeping options open. Resilience is maintained by probing boundaries (e.g. by allowing rather than controlling variability) and cultivating some system redundancy (e.g. by fostering diversity, which can come at the expense of short-term efficiency).

2. *Modularity.* Over-connected systems are susceptible to shocks that propagate rapidly throughout the whole system. Modularity is one means to avoid this situation. In such a system components are strongly linked internally but only loosely connected to each other.

3. *Understanding the controlling variables.* Ecological systems are known to respond nonlinearly to slowly changing control variables (e.g. nutrient concentrations in a lake ecosystem, proportion of woody shrubs in a rangeland ecosystem, groundwater levels in a catchment). As the controlling variable changes, it precipitates a change in the feedback structures, which in turn triggers rapid shifts in other variables. In social systems the controlling variables need not be slowly changing, but can be rapidly fluctuating quantities such as market signals. The important point is that system attributes that we care about are usually best understood and managed by knowledge about underlying processes and feedback structures.

4. *Tightness of feedbacks.* Here we are referring primarily to the tightness of the human learning response: how quickly do we detect and respond to important signals? Adaptive management and management strategy evaluation approaches explicitly foster tight learning loops [18, 19].

5. *Social capital.* The capacity of people to respond together effectively depends critically on well-developed social networks, trust and leadership.

6. *Innovation.* An environment where learning, experimentation and novelty are rewarded and encouraged is better able to foster an ability to change and adapt than an environment preoccupied with enforcing compliance to a uniform set of processes.

7. *Overlapping governance.* Polycentric adaptive governance enables adaptive capacity more so than top-down, linear chains of command that favour one-size-fits-all decision-making.

8. *Ecosystem services.* The success of the human endeavour rests on the quality of the ecosystem processes supporting humanity. A resilient system is one that cherishes these processes and ensures the value of 'ecosystem services' is explicit in the economy.

Many of these system characteristics reveal an implicit trade-off between efficiency and resilience. Innovation, diversity and variability imply redundancy and 'suboptimal' solutions for those whose chief pursuit is resource or time efficiency. A common response to many of the problems we face, particularly around resource and energy issues, is to reward greater efficiency. However such responses can be counterproductive through rebound effects [20, 21]. This represents a form of undesirable system resilience, and we note that resilience is not always 'good': 'business as usual' can be a very resilient outcome. In some cases what is really needed is a capacity to transform.

Transformation

Transformability is the capacity to become a different kind of system when the existing system has either shifted into an irreversible undesirable state, or when such a shift is inevitable. Maintaining resilience at one scale of a system can require transformational changes at other scales—keeping Australia, as a nation, resilient may require transformational changes in some areas or sectors of the country.

Transformability is basically determined by three attributes: i) an acceptance of the need to change and a preparedness to do so; ii) options (opportunities) for change, which flow from encouraging novelty, innovation and experimentation at all scales; and iii) mechanisms for facilitating change (as opposed to subsidies and strictures not to change). A very important question facing Australia is: In which parts, regions or sectors of Australia do we need to build the resilience of existing system states, and in which parts do we need to promote transformational change? An assessment of the potential to dematerialise the Australian economy, for example, found that transition rather than incremental efficiency improvement is needed [22].

3 Where to start: system definition and assessment methodology

System definition

Addressing questions of specified and general resilience and transformation will require tangible system definitions of 'the linked social and biophysical system that is Australia'. We suggest in the next section that system definition be the outcome of a participatory process. However, we can anticipate that the most useful system definitions will involve a characterisation of the dynamics of natural, physical, human and social capital.

Robert Costanza defines capital as 'a stock that yields a flow of valuable goods or services into the future' [23]. Elinor Ostrom described four types of capital as follows [24]:

- *Natural capital* 'encompasses the rich array of biophysical resource systems that are the ultimate source and storehouse of all human productivity'
- *Physical capital* is 'the stock of human-made, material resources that can be used to produce a flow of future income'
- *Human capital* is 'the acquired knowledge and skills that an individual brings to an activity'
- *Social capital* is 'shared knowledge, understandings, norms, rules, and expectations about patterns of interactions that groups of individuals bring to a recurrent activity' (see, for example, the work of authors such as Putnam [25], Portes [26] and Bourdieu [27], as well as Manderson and Woolcock [28, 29] for Australian perspectives).

In discussing the relationships between them, Ostrom wrote [24]:

> Physical capital cannot operate over time without human capital in the form of the knowledge and skills needed to use and maintain physical assets to produce new products and generate income. If physical capital is to be used productively by more than one individual, social capital is also needed.

Characterising these forms of capital and the relationships between them is not trivial, especially if they are to be included in a quantitative modelling framework. Challenges include the need to identify specific observables for each of those forms of capital, and to characterise the nature of the interactions between them. Interpreting what any assessment of these forms of capital *means* is also problematic. It is not the case that 'more = better'. Ostrom pointed out that each of these forms of capital has a 'dark side', where they can be put to damaging and destructive uses rather than beneficial (e.g. someone skilled in computer programming has a form of human capital that can be put to use to solve the problems of the world, but that same human capital can also be invested in unleashing a destructive computer virus upon the world).

Ecosystem modellers build models that capture the relationships between key stocks and the dynamics of the system. Of particular relevance here are 'end-to-end' or 'whole-of-system' models that attempt to represent all relevant processes in the system: abiotic and ecological (including human) processes and the dynamic coupling between processes. These models are capable of alerting us to seemingly innocuous changes that precipitate nonlinear responses due to changed feedback loop structures and other system properties. In a comprehensive review of end-to-end ecosystem models, Fulton pointed to many of the benefits and weaknesses of such models [30]. One of the most important recommendations was to avoid pursuing a single, 'best' model. Multiple models, including simple models, qualitative models, statistical models and comprehensive process models are an essential part of an end-to-end modelling capability [See Volume 1, Chapter 5].

Participatory engagement and adaptive management

Synthesising interdisciplinary knowledge into large-scale assessments is a relatively recent endeavour, perhaps best exemplified on the global scale by the IPCC assessments and The Millennium Ecosystem Assessment (MA). As a participant-observer in the MA process, Richard Norgaard reflected on the challenges inherent in such undertakings, and the benefits that flow from them [31]. Unlike an assessment that is based purely on quantifying physical stocks and flows in a particular region, an assessment that seeks to offer an intelligent synthesis of ecosystem and social interactions on a variety of scales (and consider future trajectories that result from these interactions) invariably encounters significant obstacles. Norgaard named eight such obstacles [31]:

1. The fragmented, disciplinary nature of science.
2. The existence of multiple formal frameworks, interpretive approaches and metaphors across different fields of knowledge that are not united in an overarching meta-model.
3. The lack of an 'inherent' scale of study: spatial and temporal scales and grain of individual studies are always conditional on the exact problem, analysis framework and context constraints such as time and budget. Added to this is the need to understand interactions across scales.
4. The unavoidable importance of historical contingency and local context in making sense of knowledge.
5. A pervasive difficulty in reliably distinguishing between ecosystem services that are derived from a sustainable flow from nature versus those that flow from degrading the ecosystem.
6. Extreme difficulties in finding common and agreed ways to make valuations that readily allow comparison and prioritisation (e.g. via converting all valuations to a common monetary currency).
7. The existence of too many direct and indirect drivers of ecosystem change to be able to determine clear, unambiguous policy directives.
8. The rarity of 'universal' insights—published work on case studies often speculate on more general lessons that would be universally applicable in other cases, but in the MA evidence for such universal insights was hard to find.

While the MA was an interdisciplinary assessment, it was primarily among natural scientists. The resilience assessment we are proposing would involve participation from both science and other fields of knowledge. The issues identified by Norgaard were not 'solved' in the MA. Rather, some resolution and progress were made possible only when participants were prepared to 'shift': 'to a large extent, the shift entailed becoming more humble and more comfortable with irresolvable ambiguity' [31]. Norgaard pointed to the importance of deliberative processes that enable the above difficulties to be explored in a constructive dialogue: a very human endeavour that accepts the partiality, plurality and provisionality of knowledge. These findings are consistent with those found by others working in similarly complex settings [7–9, 32]. It is very important to stress that a more humble, accepting stance does not entail taking an 'anything goes' attitude. Rather, such dialogue as part of a participatory process can be a key means for tackling uncertainty and quality control [33]. Ecosystem modellers have found that participatory involvement in the design and use of the model is beneficial [30]. When characterising human social dynamics it becomes particularly important to adopt participatory methods. There are many approaches, and we suggest there is much to be learned from the art of 'companion modelling'. Companion modelling has been described as a form of participatory modelling that 'requires a permanent and iterative confrontation between theories and field circumstances' [34]. It is a valuable method for eliciting knowledge from a broad spectrum of stakeholders. Furthermore, having stakeholders actively engaged in model development increases the likelihood that insights from the model will be understood, accepted and acted upon. These benefits have been particularly apparent when such models form the basis for role-playing and similar games used by communities to solve complex problems in social-ecological systems [34, 35].

Central to our proposed framework, then, is the use of participatory processes that both inform and are informed by the system representation, which in turn requires an end-to-end modelling capability. The dialogue would be informed by a range of global scenarios and Australian population trajectories, and would in turn generate rich, well-informed and plausible narratives about our future.

Framework evaluation

A central aspect of evaluating any framework is to seek criticisms, improvements and alternatives from others. In particular, we consider the following questions to be important in such an evaluation:

> *What aspects of the framework are useful?* Does it foster improved mutual understanding and communication of the key issues? Does it inform constructive action?
>
> *What are the alternatives?* The overarching question we are considering is: What is our realistic vision for an ecologically, economically and socially sustainable Australia in 2050 and beyond? We have framed a response to this question according to resilience principles and we have proposed an approach to assessing resilience Australia. What are the alternatives and what might change significantly as a result of a different framework? Such questions are important if we wish to be open and inclusive.
>
> *Is a quantitative assessment possible?* Can the conceptual framework be turned into a quantitative assessment and is it useful to do so (e.g. for detecting and monitoring change over time)?
>
> *What are the relationships to other facets of the Academy of Science 'Australia 2050' project?* In recognition of the parallel 'Australia 2050' workshop sessions on quantitative modelling, scenarios and social dimensions of change, we ask how a resilience perspective relates to these other perspectives, and what can a resilience framework contribute to these lines of inquiry and vice versa?

4 Conclusions

A system that is resilient is not an *unchanging* system. In fact, resilience has been described by the Stockholm Resilience Centre as ‘the ability of a system to change in order not to change’. Preventing change, keeping a system stable over time, causes it to lose resilience. To live together in a resilient world is to anticipate change and respond wisely, sometimes taking active steps to prevent change, and sometimes acknowledging inevitable change and either absorbing its impacts or transforming accordingly. Such decisions rely on collective knowledge about the system dynamics, and in particular the system feedbacks.

Formal assessments such as the IPCC assessments on climate change and the Millennium Ecosystem Assessment have been and will continue to be extremely important. They contribute to a shared global awareness of important issues and provide vital supporting material to guide action. Within Australia we have assessments such as the State of the Environment reporting (http://www.environment.gov.au/soe/index.html), the Sustainable Yield assessments for major water systems (http://www.csiro.au/partnerships/SYP.html), and the National Land and Water Resources Audit from 1997 to 2008 (http://www.environment.gov.au/land/nlwra/index.html). We suggest that a goal of *resilience* would similarly require some kind of assessment process. The word ‘assessment’ might suggest a quantitative snapshot, yet this is an overly narrow interpretation. We envisage a resilience assessment would mediate dialogue between all disciplines and sectors and would in itself contribute to building human and social capital necessary for resilience. The dialogue would be complemented and informed by a modelling capability that provides self-consistent, quantitative scenarios for our future. From such an endeavour we would develop a richer set of integrated narratives about the world, Australia and our future in the Anthropocene. Ultimately, our choices and actions reflect the stories we tell [Raupach, this volume, Chapter 14].

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Chapter 8

What is a model, why people don't trust them, and why they should

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It is easier to make one's way in the world if one has some sort of expectation of the world's future behaviour. Even when facing a very complex problem, we are rarely in a state of full ignorance: some expectations of system behaviour and the level of risk arising from uncertainty are usually available and it is on the basis of these expectations that most decisions are taken. Humans use models, which are mental or formal representations of reality, to generate these expectations, employing an ability that is shared more or less by all forms of life. Whether it is a tree responding to shortening day length by dropping its leaves and preparing its metabolism for the winter ahead or a naked Pleistocene ape storing food in advance of winter for the same reasons, both are using models. This view leads to two outcomes. The first is that predictions, seen as an expectation of ranges of future behaviours, are not just desirable, but necessary for decision-making. The often-asked question 'do models provide reliable predictions?' then shifts to 'given a certain problem, what type of models provide the most useful and reliable prediction?' The second outcome is that modelling is no longer a scientist's activity but is instead a social process. Different types of models can be employed to ensure that all available information is included in model building and that model results are understood, trusted and acted upon.

1 Introduction

For a discussion of models we begin from what may seem an unusual point: a definition of life. Rosen [1] introduced the concept of anticipatory systems, suggesting that a defining distinction between living and non-living systems lies in the need for the living to anticipate the future behaviour of their environment and the likely outcome of their interaction with it. Loosely speaking, a ball rolling towards a wall is bound to hit the wall, while a living being provided with perception can detect the presence of the wall, anticipate the impact and, if convenient, plan for its avoidance.

This idea is at the core of much work in artificial intelligence as well as in complex system science, as formalised in the computational mechanics literature [2–5]: agents store information from the past and from it extract regularities. These regularities are a 'model' of the environment, which is used to anticipate (predict) its future behaviour. The number and sophistication of the regularities the agent is able to store and process are measures of a model's complexity. Forms of life at different levels of the evolutionary tree are able to use models of higher and higher complexity. At one extreme, bacteria hardwire simple models in their biological structure, while at the other extreme humans employ conscious mental processes and store formal mathematical tools in books and computers. Nonetheless, they both 'model' and 'predict'.

From this perspective, a computational Earth System model running on a supercomputer is 'just' a sophisticated solution humans have evolved to address their need to interact with their environment. More important for our discussion, according to this approach modelling (including computational modelling) is not only a natural but also an essential activity.

This view of the role and purpose of models may not match our intuition, according to which highly complex processes are extremely hard to understand. Also our experience tells us that complex dynamics often appear to be controlled by surprises rather than regularities. This has led many authors to claim that the use of computer modelling to study and predict complex processes is unwarranted. This criticism takes many forms, which for the sake of conciseness we summarise in three points: a) computational models have a very poor prediction track record [6, 7]; b) most model predictions are not testable because of their conditional nature [8–11]; and c) behind an appearance of objectivity, model outcomes reflect the subjective beliefs and assumptions of model users [12, 13]. According to this criticism, the benefit of modelling is limited to one or more of these activities: explanation of past events, understanding of natural processes, learning [14] or simply providing an avenue for communications [14, 15].

This criticism is very important. However, it is based on a crucial assumption and a misunderstanding. The assumption is that a prediction is *desirable* but not *necessary*; that is, a prediction is an ideal or discretionary input to, not a requirement for, decision-making. Our discussion above suggests the opposite: if we accept that a prediction is *essential* to *any* decision-making, then the question would shift from ‘can model predictions be trusted?’ to ‘how do models compare to other approaches to prediction?’ We thus need to address this crucial question: is prediction desirable or necessary for planning and decision-making?

The misunderstanding has to do with the habit scientists have of using whatever is available—in this case, models—to do science. While prediction as we are describing it requires models, models can be used for more than prediction—they can be used for exploration and understanding and even control [16]. Prediction need not necessarily be scientific—although we argue that, at its best, it is.

2 About prediction

Three concepts are fundamental to our discussion. First, for prediction we do not intend the anticipation of an exact behaviour or event, rather an estimation of its likely limits. In other words, a prediction should not be understood as a prophecy [11]. For example, while it is widely known that weather forecasts are not reliable past 5–6 days, no one would believe that the temperature in Darwin in summer could be 40°C or –40°C with equal probability; as a result no one would travel to Darwin in January with a ski jumper. The limited predictability past 5–6 days still has allowed a certain level of effective planning by avoiding carrying unnecessary clothing. Second, predictions are conditional: any prediction is carried out within a context and is valid only within that context. In the above example the conditioning is given by our understanding of tropical climate; should this change, the prediction would no longer hold and would require updating [16]. Finally, the effectiveness of a prediction is scale-dependent [17]. For example, while the geophysical community is today sceptical about its ability to provide accurate prediction on where and when large earthquakes can occur, it is nevertheless able to predict the broad geographical areas in which large earthquakes can be expected. While this kind of predictability seems to offer little to planning [18], it still has considerable practical impact in deciding, for example, in which geographical areas expensive antiseismic constructions methods are necessary and where they are not. Once understood in these terms prediction becomes an integral part of any decision-making process: formulating a plan implies choosing among potential alternatives and envisaging (= predicting) which one is more likely to deliver desired outcomes [19].

If we accept that prediction is necessary for planning and decision-making, then it is important to next ask what tools provide the most reliable prediction given the problem at hand. Notice that this question is problem-dependent, not only because different problems may require different approaches, but also because the most accurate prediction is not necessarily the most reliable. Together with using numerical models or other computational tools predictions can be provided by experts, local knowledge or participatory settings. It is thus important to compare the predictive performance of computational models against alternative approaches on the core items of criticisms discussed above: a) prediction track record; b) lack of testability due to their conditional nature; and c) inherent subjectivity.

We are not aware of any large-scale comparisons of the predictive accuracy of models and alternative methods. However, the available literature on the logical and attitudinal fallacies that even experts display for simple dynamical problems should warn us that it is probably unwarranted to expect humans to mentally predict the behaviour of highly complex systems in a consistent and reliable manner [20-28]. Predictions provided by experts, local knowledge and participatory settings will also be dependent on both explicit and implicit conditioning, including tacit information and hidden assumptions. A discussion of different forms of conditioning and its impact on modelling can be found in [29]. As nicely argued in [30], modelling offers an avenue for making such conditioning and assumptions explicit by coding and documenting the model, which may be sidestepped or not considered necessary in alternative approaches. Naturally, the same reasoning applies to the subjective nature of predictions.

So we arrive at a more expansive view of prediction for humans than just ‘expectation of the future’. We need to include the human knowledge of the past (culture), the human need to explore and understand (science) and the human bias to act (policy and intervention). Together these colour our approach to prediction and the sorts of models we tend to use.

3 Types of models

Accepting that models are a necessary component of a decision-making process does not imply believing that a) modelling reduces to running a single sophisticated computational model; b) that modelling is something only scientists do; and c) that the outcome of a model should be trusted uncritically. In fact, much of our work has been based on preaching and practising the opposite: a) models need to be built by teams including scientists and model recipients because much of the information needed to implement a model is implicit or tacitly held; b) model results need to be carefully explained and understood in order to be trusted and acted upon by decision makers; and c) information about uncertainty in the model outcome is crucial to formulate an effective plan.

As a result, our approach to modelling focuses on treating ‘building a model’ as the catalyst rather than the final aim of the process. In other words, extensive interactions between scientist, decision-makers and model recipients to introduce, showcase, discuss and tune the model used for final decision-making become both a requirement and an opportunity to ensure model relevance and acceptance and increase the broader understanding of the system’s function. To fulfil these roles we develop five broad classes of models: conceptual, toy, single-system, shuttle, and full-system [also see Volume 1, Chapter 5].

In *conceptual models* the main drivers of a system are highlighted for subsequent representation as components of the model. This first kind of model is usually expressed as a conceptual diagram summarising our understanding of system function. In *toy models* a problem is simplified in such a way that only a handful of components are included. Their purpose is mostly educational: we want to understand how each component affects the problem and in order to achieve this we temporarily renounce a satisfactory understanding of the overall problem. In *single-system models* we include a fairly detailed representation of a single component of the system. These can be used to introduce stakeholders to modelling, provide results from the study of a single activity (addressing sector-specific issues) and feed into the development of a final full-system (multisector) model. In *shuttle models* [31] (or minimum realistic models), we include the minimum number of processes we believe are crucial for a basic understanding of the overall problem. We know these models are simpler than they need to be for full-system description, but they provide a sufficient understanding to enable us to contemplate many questions with existing (often incomplete) datasets. These models can also be a useful stepping stone to building, using and correctly interpreting the more complex models needed to check for unexpected outcomes resulting for feedbacks buried in a full-problem description. The term ‘shuttle’ refers to taking us from a minimum to a full description of the problem, a journey that is necessary both to developers in model definition and parameterisation, and to stakeholders in the interpretation of the final full-system model results. Finally, the *full-system model* includes all information collected for a region and addresses all scenarios of stakeholders concern, whose definition has been greatly eased by using the ‘simpler’ models.

As an example, a conceptual model may identify population growth and industrialisation as two of the main drivers for climate change; a toy model may describe how emissions affect peak temperature; a single-system model may include the effect of regulations on national emissions; a shuttle-model may include a simplified representation of the interaction between economic growth, population dynamics and warming. This will gradually 'take' us to comprehend the 'full' model, which may include trade, financial market dynamics, sequestration, geo-engineering etc. Figure 1 summarises the stages at which different model types are employed, the role they play and how they can support the development and use of a full-system model.

All of the model types have their own value and the full set need not always be employed—in some cases enough is learnt from conceptual models to improve predictions, in other cases the feedbacks captured in shuttle models are an effective means of refining predictions, while in others the system of interacting pressures and actors is sufficiently complex that only a full-system exposition can guide decision-makers through the complex network of feedbacks and unexpected outcomes of interactions.

For complex issues, 'full models' may represent the crucial component of the 'anticipatory system' according to Rosen's definition: it is the tool that the decision-making team, as a unified agent, employs in order to explore and evaluate options for actions. The other model types allow for engagement of different parties involved in the decision-making team, including researchers, formal decision-makers and stakeholders at large. In other words, they help the decision-making team work as a team. In particular, they can: a) allow a less-biased interpretation of available information; b) allow for learning of specific skills and attitudes needed when facing complex problems; and c) provide an avenue for communication and collaboration.

Allowing a less biased interpretation of available information is important because people with different world views may interpret and draw very different conclusions from the same information [32–40]. Research on attitudes to climate change, nanotechnology and vaccination, among other issues, shows how world views affect policy support more than available information does because these views filter how such information is processed. Accounting for such biases in a model (by parameterising the model according to different worldviews, [41]) may be a way to highlight the issue and the potential inconsistencies that may arise from it and move the discussion from perspectives to mechanisms in the hope that this may reduce the influence of biased information interpretation.

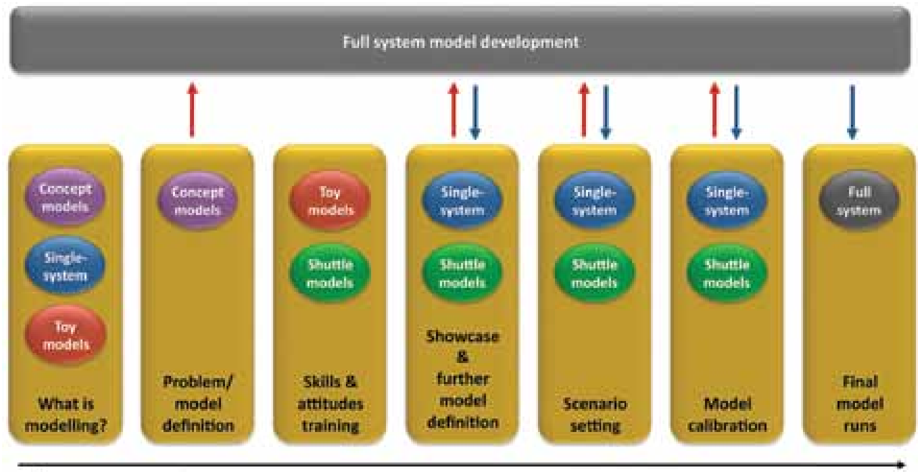

Figure 1: Relation between a) a modelling project (top dark rectangle); b) different types of models (coloured ovals); and **c)** stakeholders engagement phases (yellow rectangles). The arrow at the bottom suggests an approximate chronological order.

Conclusion

We think that prediction is what living things do and that they do it through models. But we also think that the relationships between models and predictions are varied, and—importantly in the case of humans—dependent on the context. We also think that rather than diminishing or muddying the matter of prediction, this enriches it and places it in a very human context. Models could be better used and their results more trusted if this was better understood.

Thus we argue that training on specific skills and attitudes is needed to help us face complex problems. This is important because scientific insights risk being lost unless they are understood by those making and supporting decisions: recent studies have shown that human cognition and psychology affect decision-making at least as much as the complexity of the problem at hand [21, 23, 25, 26, 42]. Computer models resembling flight simulators can be designed to train individuals to better understand the basic processes of real-world significance for decision-making, including management of limited resources and unexpected feedbacks. The belief underneath this approach is that managing and predicting complex behaviours can be learned and that models can represent systems in a manner appropriate for learning and training.

Not only cognitive skills but also cognitive attitudes are crucial to effective decision-making about complex problems [24, 43, 44]—the behavioural attributes and habits we bring into a problem, the way we formulate goals, interpret outcomes against expectations and balance emotional responses like humility, curiosity, frustration and blame-shifting have a significant influence on how effectively we deal with complex situations [43]. Tangible, constructive means to improving problem solving in complex settings can be identified and trained via computer models [43, 45]. Interestingly, some of the most effective cognitive approaches (including tolerating high levels of uncertainty, acknowledging mistakes, searching for counterevidence, self-reflection etc.) can be in direct opposition to behaviours rewarded in political and management roles. More widespread awareness of what makes an effective decision-maker, possibly leading to improvements in training programs, may have an immense impact on a wide variety of real-world issues.

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Chapter 9

Quantitative modelling of the human–Earth System a new kind of science?

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The five grand challenges set out for Earth System Science by the International Council for Science in 2010 require a true fusion of social science, economics and natural science—a fusion that has not yet been achieved. In this paper we propose that constructing quantitative models of the dynamics of the human–Earth system can serve as a catalyst for this fusion. We confront well-known objections to modelling societal dynamics by drawing lessons from the development of natural science over the last four centuries and applying them to social and economic science. First, we pose three questions that require real integration of the three fields of science. They concern the coupling of physical planetary boundaries via social processes; the extension of the concept of planetary boundaries to the human–Earth System; and the possibly self-defeating nature of the United Nation's Millennium Development Goals. Second, we ask whether there are regularities or 'attractors' in the human–Earth System analogous to those that prompted the search for laws of nature. We nominate some candidates and discuss why we should observe them given that human actors with foresight and intentionality play a fundamental role in the human–Earth System. We conclude that, at sufficiently large time and space scales, social processes are predictable in some sense. Third, we canvass some essential mathematical techniques that this research fusion must incorporate, and we ask what kind of data would be needed to validate or falsify our models. Finally, we briefly review the state of the art in quantitative modelling of the human–Earth System today and highlight a gap between so-called integrated assessment models applied at regional and global scale, which could be filled by a new scale of model.

1 Introduction

The International Council for Science (ICSU) visioning process has led to the definition of five grand challenges for Earth System science [1]. At the heart of these challenges is an assumption that we can understand and possibly model the dynamics of the coupled human–Earth System—the intersection of the natural Earth System and human society. A signal benefit of this would be the ability to construct a compelling quantitative narrative of global change. The Australian Research Council's (ARC) Learned Academies Special Projects Australia 2050 project wrestles with the consequences of global change for Australia. We need to know, therefore, just how far quantitative modelling can take us in understanding the possible or likely trajectories that the social-ecological system that is Australia will take through the 21st century. In this paper we will try to make the case that quantitative modelling can profitably take us further than is conventionally assumed.

In the Anthropocene [2], Earth System Science (ESS) must be approached as a true fusion of the social, economic and natural sciences. However, ESS must then confront the problem that these three disciplines are at quite different stages, both practically and epistemologically, when it comes to quantitative modelling. The history of natural science is well known and libraries are devoted to it. It has at its heart the possibility of testing hypotheses against observations rather than by appeal to pure reason, an idea often traced back to Roger Bacon in the 13th century but which flowered in the Enlightenment and is now understood as the 'Scientific Method' [3]. This primacy of empirical falsification has been the means by which science has made the modern world, although it is also true that in practice the ideals of the scientific method sometimes take time (even generations) to have effect [4]. Despite this, natural science now has a robust set of fundamental laws of nature which serve as the scaffolding for quantitative modelling.

The social sciences cover a very broad field and most of the disciplines involved do not subscribe to the scientific method as a guiding principle (at least as it is defined above). Those that do are sometimes termed the positivist[1] social sciences and their origins can be traced back to the 'social physics' of August Comte and the developments of sociology as a science of society by Weber, Durkheim and Marx in the early 20th century [5]. Pinker (2002) [6] has argued strongly that areas of the social sciences consciously ignored empirical falsification in the last few decades of the 20th century, eschewing especially ideas and evidence coming

1 Wikipedia defines Positivism as a set of epistemological perspectives and philosophies of science which hold that the scientific method is the best approach to uncovering the processes by which both physical and human events occur.

from evolutionary psychology. While, over the past 15 years there has been a good deal of constructive engagement between social scientists and modellers using complex systems science approaches, it remains true that much of even positivist social science seems averse to the kind of generalisations that lead to the laws of nature that natural science relies upon. Instead, it is often claimed that human foresight, intentionality and reaction to the results of any forecast are insurmountable barriers to modelling social dynamics. We will confront this objection in §3 and §6 below.

The most quantitative branch of social science is economics, a discipline sufficiently rich that it is best regarded as a separate field. Economics also has two broad manifestations: normative economics, which is concerned with philosophical principles for organising the economy (and in recent times other aspects of society too), and positive economics which seeks to explain the dynamics of economic processes. Positive economics is the branch which covers economic modelling and is the area with which we wish to engage. Economic modelling can be further split into microeconomics which searches for 'bottom up' descriptions of phenomena, while macroeconomics addresses the economy as a whole by 'top down' reasoning. Microeconomic principles that are widely used in macroeconomic modelling, such as rational agents and perfect markets, have attracted wide criticism because, taken individually, they are contradicted by experiment and experience [7, 8, 9, 10]. Nevertheless, the philosophy of this approach, which seeks general principles to explain wide ranges of phenomena, sits more comfortably with modelling in natural science than much of social science.

We will argue here that social and economic natural laws remain to be discovered. These are likely to be statistical rather than deterministic, but this is no novelty in science as we know from disciplines such as statistical mechanics or quantum mechanics. In fact, we argue more strongly that the extension of natural sciences into the previously unexplored areas of complex systems and nonlinear dynamics, which modern computing power has made possible, provides signposts for similar developments in social and economic science. Quantitative modelling of the human–Earth System can be a catalyst for such development. This is an unashamedly positivist agenda which is intended to complement, or at least parallel, more traditional constructivist[2] approaches of social science.

2 Constructivism is a theory of knowledge that argues that humans generate knowledge and meaning from an interaction between their experiences and their ideas. Perhaps its most extreme modern manifestation is in the postmodernism expounded by philosophers like Foucault and Derrida, which can be paraphrased (crudely) as the view that all knowledge is socially constructed and hence subjective.

Many unconnected lines of current investigation are relevant to this goal. To bring them together we will organise them around some of the most important characteristics of the development of natural science over the last 400 years. These include:

- integrative questions of sufficient practical importance or intellectual curiosity that they focus the attention of the best thinkers
- observed regularities that speak of underlying laws
- the co-opting or inspiring of mathematical techniques
- data collection
- testing of hypotheses against data.

We will spend most time on the first two of these points, concentrating on the type and range of models that it is possible to construct. We will pass more quickly over the technical approaches they will require; this is a topic for a companion paper. We will then sketch out the current state of the art as we see it and, finally, the most important gaps that need to be filled as we set out to address the fundamental question addressed by the Australia 2050 Program.

It seems apposite to end this introduction by asking why the second word in our title was 'modelling' rather than 'prediction' or 'understanding'. Joshua Epstein, in his illuminating essay 'Why model'[11], gives 16 reasons for modelling other than prediction, which many people assume is the only goal of modelling. Among the most important of those other reasons are:explaining, illuminating core dynamics, guiding data collection, discovering new questions and placing bounds on plausible outcomes. More fundamentally, Epstein points out that modelling is universal; it is just that most people's models are implicit and unconscious. Boschetti et al. [12, 13], in this volume, develop this view to a more radical conclusion. They argue that modelling is what living things do. In other words, all living things continually construct predictions (models) of the consequences of their interaction with the physical world and then respond to these predictions. These 'models' may be wired by evolution into the nervous systems of lower animals, or in the case of humans, may be heuristics honed by evolution and encoded in our genomes. The kind of models that we are discussing here are vastly different in degree but not in kind from such simple instinctual models and they serve the same purpose. They allow us to form a view of where we are going as a group, a population or a species, and to take avoiding action if it is a place we don't wish to end up. A critical difference is that we are now a species with strong global connections, so that evolved heuristics are no useful guide to sensible behaviour. We are taking the view in this paper that the scientific method is the best means we have for constructing predictions of the likely consequences of our actions as a connected species in the 21st century.

2 Integrative questions

The history of science and mathematics since The Enlightenment is replete with major questions and challenges that were embraced by the research community. Some of these were commercial. Before Galileo trained his improved telescope on the heavens, it was providing early warning of ships approaching Venice and giving an edge to his sponsors in the Venetian market. Indeed, the age of exploration and the need for precise navigation was a spur to astronomy through the 16th, 17th and 18th centuries. Some questions were primarily intellectual: the interpretation of the fossil record spurred the invention of geology; classification of the natural world led to Darwin and Wallace's Theory of Evolution. And some were primarily humanitarian, as when confronting the scourge of infectious disease led to the development of microbiology. Understanding radioactivity and nuclear physics engaged much of the scientific world in the early 20th century, while the second half of the same century saw the flowering of genetics and cell biology. Most recently, the problems and challenges of climate change have catalysed a huge growth in our understanding of Earth System dynamics, so that it is probable that the decades around the turn of the 20th century will eventually be seen as the era of Earth System science.

These problems and questions were global in nature and engaged the best scientific minds of their age. On a more modest scale, what questions can we pose to galvanise the growth of a quantitative science of human–Earth System dynamics? Here we propose three—two of them broad and one more specific.

Question 1: How do we dynamically couple the physical planetary boundaries of Rockström et al.[14] by including the influence of human actions on planetary systems?

The planetary boundaries concept [14] has proved to be a powerful framing of the physical consequences of global change. This approach takes the dynamical state of the planet through the late Holocene, the period in which all human civilisation developed as a desirable state and which we do not wish to leave inadvertently. It then defines nine threshold levels for physical attributes of the Earth System that we should not transgress if we want to avoid crossing 'tipping points' from which recovery would be painful or impossible[3]. The logic of the planetary boundaries approach assumes that we have a reasonable understanding of the dynamics governing the crucial biogeochemical processes for which thresholds can be clearly identified[4].

3 The boundaries are specified values of: climate change, ocean acidification, stratospheric ozone depletion, N and P cycles, freshwater use, land use change, biodiversity loss, atmospheric aerosol load, chemical pollution.

4 Subject to assumed future refinement and modification of course.

It is immediately obvious that several of the nine 'state variables'—specified values of which form the boundaries—are strongly coupled by the underlying dynamics of the natural Earth System (Figure 1a).

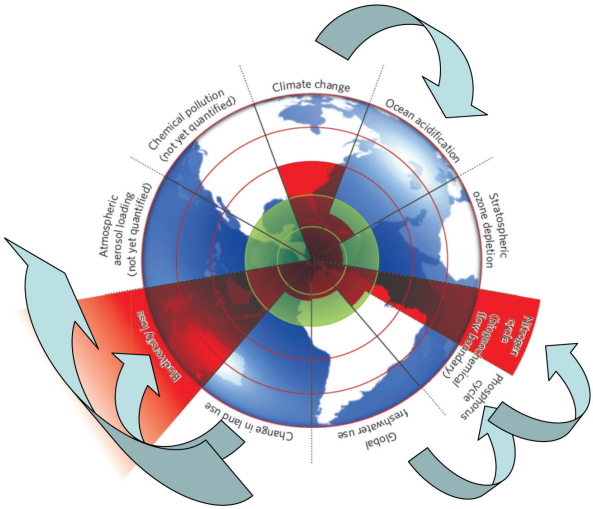

Figure 1a: The natural dynamics of the planet couple groups of boundaries.

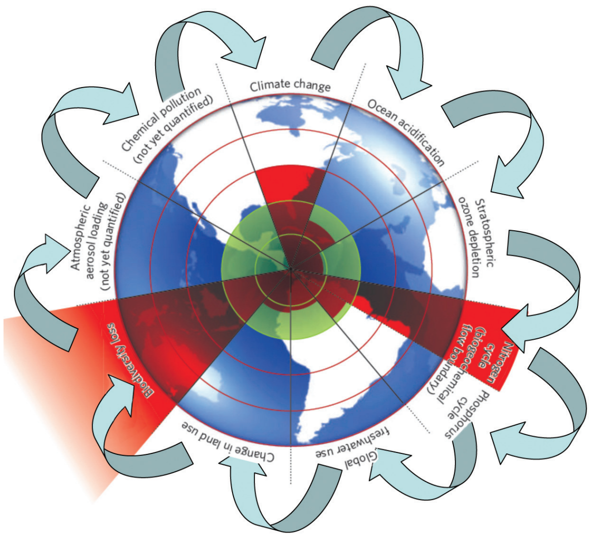

Figure 1b: Food production, urbanisation and economic growth driven by population growth ´and human aspiration dynamically couple all the boundaries. Figures 1a and 1b are adapted from Rockström et al. (2009) [14].

For example, the nitrogen and phosphorus cycles are coupled to the hydrological cycle (freshwater use) and also to the carbon cycle (climate change). However, all of the nine indicators are coupled if we extend planetary dynamics from the natural Earth System to the human–Earth System. Climate change and ocean acidification are consequences of human interference with the carbon cycle, one driver of which is land-use change, but land-use change has also led to rapid loss of biodiversity and is accompanied by increased diversion of fresh water to human use (Figure 1b).

Ultimately, these changes are driven by population growth and the increase in economic activity that has led a significant fraction of the world out of the Malthusian trap [15, 16]. This economic activity depends on fossil energy use, which in turn is causing ocean acidification and climate change.

A first step in answering Question 1 would be to include the physical flows of energy and materials that are mediated by human actions in the same framework as the natural biogeochemical cycles. This is the province of economics and, in particular, of macroeconomic modelling, in which physical quantities are tracked. In effect, such models are calculating the social and industrial stoichiometry of the planet.

Current macroeconomic models make simple assumptions about the microeconomic factors that drive the flows of material and energy that accompany economic activity. These drivers implicitly include the aspirations, choices and mental models of producers and consumers and those government actions that affect markets. Generally, these models also assume some critical factors affecting productivity and economic growth such as the rate and causes of innovation. Improving the realism of these elements of economic models takes us into the realm of social science, as we must now consider the interplay between individual actions and societal constraints as it affects demographics, aspirations at population level, the role of information, the contagion of ideas and other factors. Although this question is posed at a global level, it applies with equal force to the question of defining a 'safe operating space' for Australia in the 21st century.

Our first integrating question was posed from the standpoint of physical processes. Addressing it at successively deeper levels has brought us into the realm of social science and social dynamics, and this prompts a second integrating question that is both more ambitious and more difficult than the first:

Question 2: Can we expand the concept of planetary boundaries to the human–Earth System so that we identify threshold values of coupled biophysical–societal parameters that must not be transgressed if we wish to avoid disastrous tipping points?

Question 2 implies that there are social analogues of the Holocene that we do not wish to leave inadvertently. We can make this concrete by positing that this desirable state is defined by minimal conditions of access to life's necessities, together with universal human rights such as social equity, gender equality, education, and self-determination define [17]. In a recent Oxfam discussion paper, Raworth (2012) [18] juxtaposed these social desiderata with the biophysical parameters of Rockström et al. [14] to define the biophysical–social safe operating space as a doughnut, or torus bounded on the outside by the biophysical parameters and on the inside by the social–ecological ones. It is clear that the boundaries are coupled. For instance, access to potable water depends on the total freshwater available, while freedom from hunger requires that sufficient food be produced. Nevertheless, the kind of dynamics that we need to understand when we consider how the thresholds that bound this torus are coupled, are more complicated than simple arithmetic. We can illustrate this by an example: that of the links between inescapable volatility in food availability and price, inequality in wealth and social unrest.

Roughly one-seventh of the world's people suffer food insecurity. The primary cause of this is the 'distribution gap'—although enough food is being produced in the world today to feed everyone, the calories fail to reach roughly 1 billion hungry mouths because of inadequacies in food trade and distribution and the insufficient purchasing power of the poorest [19]. While most food is still produced close to where it is consumed, a significant and growing fraction of the world's food is traded internationally. Production of food in modern agricultural systems is very dependent on energy for fertiliser production, farm operations, transport and processing. Oil and gas, which supply much of this energy, are also internationally traded between a few producers and many importing countries. World trade in food and energy, and the monetary system that enables it through markets and credit, form extremely complicated networks. Analysis of these networks [20, 21, 22] reveals that they have forms that are conducive to both dynamic [23] and topological instability. Dynamic instability means that even small shocks to food and energy availability can propagate through the network, growing in amplitude as they do. Topological instability means that flows are vulnerable to the failure of critical links or nodes. Together, these features mean that the supply of food and energy is intrinsically volatile even without the major shocks caused by events such as subprime mortgage failures.

For example, the Food and Agriculture Organization food price index rose by over 50% in 2008 following growth in oil prices, then fell in 2009–10 before hitting new heights in 2011–12 [24]. After almost two decades of steady prices to 2007 we are now seeing unprecedented price volatility superimposed on a trend of price increases. It remains to be seen whether this will continue, but the structure of the underlying trade and supply networks suggest that this kind of behaviour should not be surprising.

Wealth is unevenly distributed within and between countries in the world. This is illustrated in two ways in Figure 2.

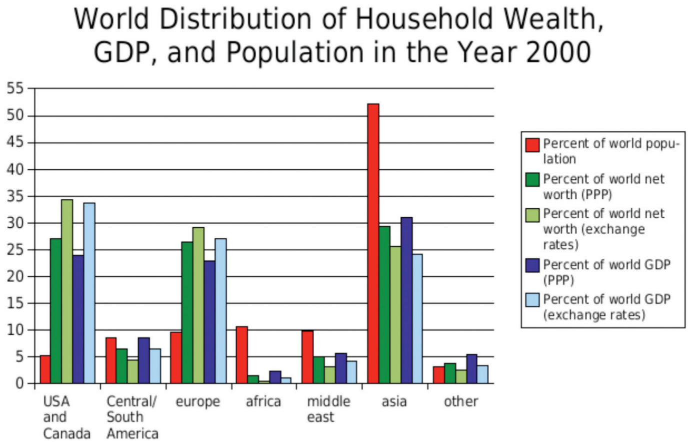

Figure 2a: Variation of share of global population and wealth for major geopolitical groupings. From, Davies et al.

Figure 2a shows the relationship between world population share and share of global wealth for major geopolitical groupings. It is very clear that the world today is divided roughly into 15% of the population who are 'haves' and the 85% who are 'have nots' A different way of displaying this global between-country inequality is Figure 2b, which plots cumulative population against cumulative wealth as a Lorenz curve [25]. Perfect equality is denoted by the 1:1 reference line. It is widely assumed that we are observing a trend towards global convergence of income and wealth led by major developing or emerging economies like China's or Brazil's [26]. However, both evidence and opinion on this is mixed [27, 28, 29]. Even assuming convergence, it will take many decades before the lead of Western nations, which were the first to industrialise, is lost. It is obvious that the poorest countries will be those least able to cope with rapid increases in food and fuel prices without significant hardship.

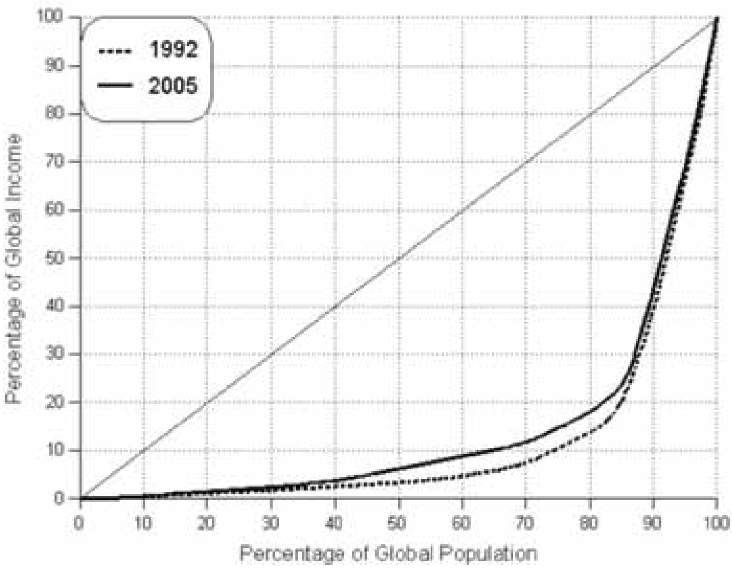

Figure 2b: Lorenz curve illustrating wealth (GNP/capita) inequality between N countries. Data source: United Nations Development Program (2007) [30]. From Marshall and Goldstone (2007) [25].

Gross national wealth or income is, however, only part of the story. Income inequality within countries can mean that even polities whose national GDP is not too small may see a rapid increase in the number of their citizens who are food or energy insecure as prices rise. We can construct Lorenz curves for individual countries, but it is more convenient to summarise the inequality in a single number, the Gini coefficient [30]. A low Gini coefficient indicates more equal income or wealth distribution, while a high Gini coefficient denotes more inequality. Worldwide, Gini coefficients range from approximately 0.23 in Denmark to 0.71 in Namibia. National Gini coefficients are widely scattered, with no strong correlation with GDP. Some rich developed countries have relatively high Gini coefficients, while some poorer countries are quite egalitarian. Nevertheless as Figure 2c shows, Gini coefficients greater than 0.5 are only found in countries with GDP per capita below U$10 000 (2001 equivalent). When rapid rises in food prices impact countries with both high Gini coefficients and low national GDP the food distribution gap can widen alarmingly quickly, so that a significant fraction of the populace cannot access or buy food in adequate quantities. For example, in Sierra Leone, a poor country with a high Gini coefficient of 0.62, the price of food in 2008 rose 300% in 6 months [31].

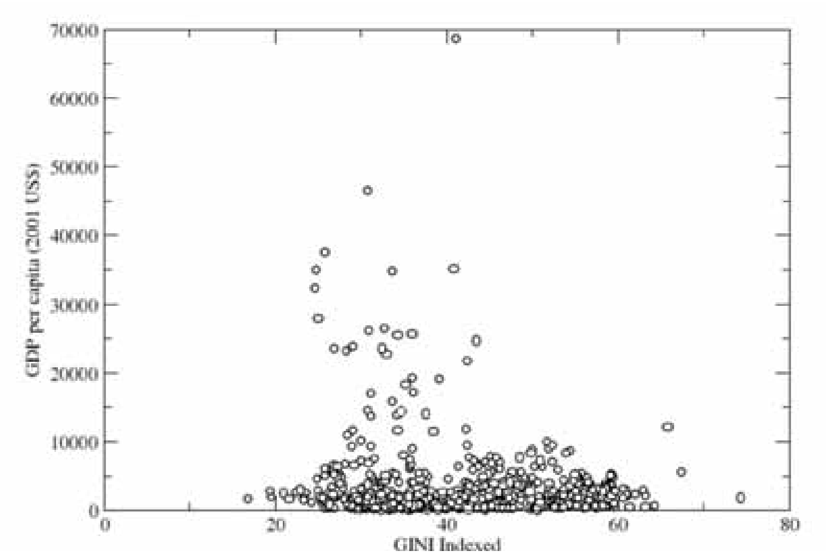

Figure 2c: Gini coefficient expressed as a percentage vs. GDP/capita for N counties. Source: World Bank. Data is from 2004, the latest year for which GDP and Gini coefficient values are available for a representative range of countries.

There has been a good deal of recent analysis of the relationship between food (and energy) insecurity and social unrest, rebellion, conflict and war [32–35]. A comprehensive Index of State Fragility was constructed by Marshall and Goldstone (2007) [25] and tracked since then [36]. This index integrates many of the factors that lead to state failure and move a society out of a social safe operating space. State failure is evidently a human-biophysical tipping point. Its dynamics involve the intrinsic volatility of intersecting food, energy and financial markets, the poverty, inequality and consequent vulnerability to food and energy insecurity of a society and the social and institutional settings that modulate the reaction of the people to these circumstances.

A clear difference between this kind of tipping point and the purely biophysical ones of Rockström et al. (2009) [14] is that the social safe operating space is itself a normative concept with considerable geographic, ethnic, historical and, most contentiously, ethical variability. Hence answering Question 2 has two major components. The first involves defining desirable or acceptable social states, and the second requires the coupling of social processes and the relevant human–Earth System dynamics that determine whether societies can remain in these states over the long term.

A version of this question, downscaled to Australia, is implicit in the concept of a safe operating space for the human–Earth or 'social–ecological' system that is Australia in the 21st century. One possible focus of such a national version would be the conflict that could arise when we plan to increase urban density to improve transport and energy efficiency and minimise costs in reticulating water and waste, but ignore changes in social interaction, social stratification and societal cohesion that result from the rapid decreases in personal living space, especially for poorer groups, that these strategies imply

Question 3. Are the United Nations Development Programme's Millennium Development Goals[5] simultaneously achievable without transgressing the physical planetary boundaries?

Our first two motivating questions are broad in scope. The third is more focused, specific and topical: are the United Nations Millennium Development Goals (MDGs) fundamentally self-defeating? It has been persuasively argued that the poorest countries in the world are still operating in a Malthusian economy [15]. The first characteristic of such an economy is that any innovation that increases per capita wealth leads to increased fertility and decreased mortality, and so to a population increase (and vice versa). Second, the growth in national wealth is much slower than population growth, so that the increased population reduces per capita wealth and the 'subsistence level', where births equal deaths, is inexorably driven towards greater poverty. If we accept that many of the countries targeted by the MDGs are operating in the Malthusian mode, then three of the MDGs—reducing child mortality, improving maternal health and combating HIV/AIDS, malaria and other diseases—which, taken together, all act to increase population, have the potential to confound the first goal of eradicating extreme poverty and hunger. Unless richer nations take action to ensure wealth grows faster than population and is equitably spread in such countries, these four MDGs are in opposition. A full integrated analysis of this possibly self-defeating enterprise would provide a high-profile integrating question for human–Earth System dynamics to address. The answers have obvious relevance for Australia as a developed and rich nation in close proximity to major foci of poverty and population growth in the Asia–Pacific region.

5 The UNDP's Millennium Development Goals are to:

- Eradicate extreme poverty and hunger
- Achieve universal primary education
- Reduce child mortality
- Improve maternal health
- Combat HIV/AIDS, malaria and other diseases
- Ensure environmental sustainability
- Promote gender equality and empower women
- A global development partnership.

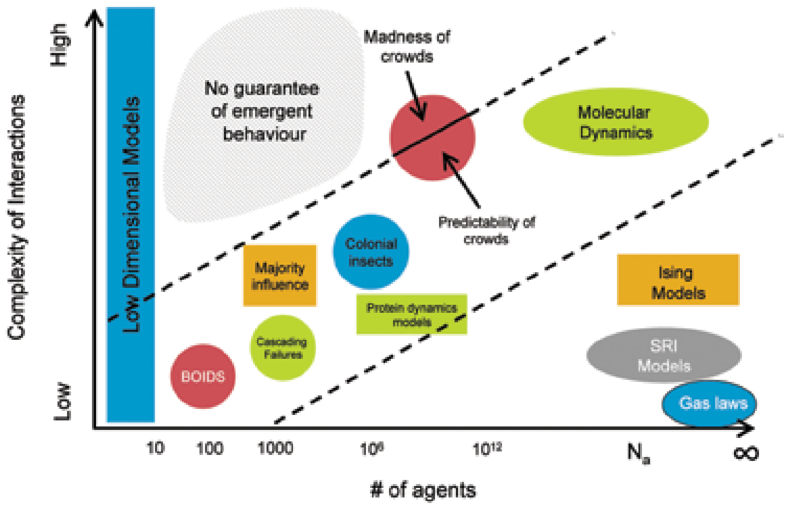

Figure 3: This diagram illustrates schematically the concept that there is a trade-off between the number of agents interacting in a system and the complexity of their interactions so that 'stable' emergent behaviour requires more agents if their interactions are more complex. The region between the diagonal lines is the domain explored by complex systems science.

3 Observing regularities that speak of underlying laws

An objection that is often raised to the idea of integrating social dynamics with natural dynamics is that the unavoidable dependence on contingency in a system where humans are actors places such limits on the capacity for quantitative description that prediction, even in a probabilistic sense, is doomed to failure. A related objection is that the act of prediction in itself will influence the future trajectory of human affairs, rendering any predictions false. And a third objection is that we possess no quantitative theory governing the social dynamics that lie at the heart of human–Earth System dynamics. Indeed, at this point we usually encounter epistemological disagreements with the main body of social scientists [6, 8, 37].

Against this third objection we set recent developments in complex systems science, especially as translated into models of the physical economy, but also including social network theory, evolutionary game theory and similar fields (§4 below).

In reply to the first two objections, we hypothesise that, at sufficiently large scale, modelling, the human–Earth System is no different in kind from modelling other complex systems such as the climate. Even though the climate's sensitivity to initial conditions ensures that just one of an infinite number of world lines will be followed and that this chosen trajectory will be path-dependent, we nevertheless believe that we can model climate change successfully. The paradox is resolved by the existence of an attractor for climate that evolves much more slowly than the chaotic secular motions we call weather or climate variability. If we expect the human–Earth System to behave in an analogous way, it must also contain attractors at appropriate scales. Their existence would imply that the strong influence of human foresight and intentionality, which allows contingency to dominate, applies primarily to small subgroups of society. In contrast, on population or global scale there are societal attractors that evolve slowly relative to the space and time scales over which societal characteristics such as received opinions, norms and public choices change. Individual worldlines on these attractors are sensitive to perturbations by individual or small group behaviour, but general societal behaviour is confined to the surface of the attractor.

So is there clear evidence of regular repeated patterns of behaviour that suggest underlying and universal principles of societal organisation that modelling can capture?

Attractors in the human–Earth System

Let us extend the climate metaphor by defining the concepts of societal weather and societal climate. Societal weather refers to those social dynamics that are so dominated by the contingency of individual or small-group actions that they are effectively unpredictable. Societal climate comprises repeated or enduring (but not necessarily periodic) patterns of behaviour. Intuitively, we can think of such regularities as having dominant time scales that are significant relative to a human lifetime, (e.g. a generation or longer) or that involve so many people that individual behaviours are insignificant compared to the emergent actions of the masses. A tentative and incomplete list of examples of societal climate, starting from the largest scales of space and time and moving to smaller might be:

- the Neolithic Revolution—the transformation from hunting and gathering to agriculture and pastoralism
- the Industrial Revolution
- the demographic transition
- large-scale changes in social attitudes such as
    - the Axial Age
    - the Enlightenment

    - the welfare state (extension of altruism to non-family members)
    - female emancipation
    - the outlawing of slavery in the West
    - political movements

- rise and collapse of hegemonies

- transitions in social organisation (e.g. chiefdoms, heroic societies, feudalism, city-states, nation-states)

- urbanisation growth and decay of cities

- overexploitation of finite resources.

The first three examples above might be thought of as societal 'ice ages', given their transformative nature. Each led to massive increases in both social complexity and population [38, 15. The increased complexity could not be unravelled without population collapse. In contrast, the continual rise and collapse of empires or hegemonies [39, 40] might be viewed as examples of 'societal ENSOs', in reference to the El Nino–Southern Oscillation climate pattern.

The ubiquity of these processes is a strong indication that they are fundamental features of human society interacting with its environment. Agriculture was invented independently on at least six sites widely separated in space and time, while urbanisation and the cycling of hegemonies appears to have followed parallel patterns in the Old World and the Americas, despite the separation of their human populations in the Palaeolithic [41, 41]

If we accept that societal climate and the underlying societal attractors exist in the sense set out above, it is reasonable to ask why this should be so. We suggest three reasons:

- First, that the constraints imposed by physical planetary boundaries (at any stage of technological development) are sufficiently strong to keep important features of the human–Earth System within predictable bounds.

- Second, that consistency between interacting sets of societal choices imposes further strong constraints on societal developments: path dependency means that prior choices can exclude many later opportunities.

- And third, that fundamental features of human behaviour result from evolved human nature and lead to repeatable patterns of societal dynamics, with the implied assumption that such dynamics are amenable to modelling by appropriate methods.

These patterns of social dynamics will be manifest in different societal properties such as population, resource use, physical infrastructure or social complexity. Not all of the list of possible societal climate attractors suggested above will be seen in all of these variables. For example, the procession of hegemonies seen in history prior to the Industrial Revolution involved growth and decay in social complexity, urbanisation and social organisation, but occurred against a background of imperceptible change in innovation, resource use, general standard of living and population [15].

We propose finally that these fundamental features of societal dynamics are amenable to quantitative modelling, especially material, energy and information flows, broad measures of social complexity and technological innovation rates, if we use the appropriate mathematical tools.

4 Mathematical techniques for modelling the human–Earth System

Natural science grew in step with applied mathematics. Science variously stimulated the development of mathematics, as in Newton's calculus, applied contemporary developments in pure maths, as in Einstein's use of Riemannian geometry, or was itself guided along its development path by the mathematical tools available, as in the simultaneous emergence of linear operator theory and quantum mechanics in the early 20th century. So what are the appropriate mathematical techniques for modelling the human–Earth System? In this section we want to briefly discuss three broad approaches we think are essential partners in the modelling enterprise we are proposing.

System dynamics and dynamical systems theory

Most of the current descriptions of human behaviour contained in large-scale models of the human–Earth System employ algebraic, differential or difference equations to model average properties of society. Modern developments in system dynamics offer fundamental understanding of the kind of behaviours we should expect from the human–Earth System. These would include the nature and existence of simple, strange and stochastic attractors, hysteresis and tipping points or catastrophes [43, 44]. Perhaps most fundamentally, these developments warn us that expectations of system behaviour based on experience with quasi-linear, deterministic systems is likely to be actively misleading when we come to the human–Earth System.

Agent-based modelling

The difficulty of representing social dynamics at population scale has been one of the incentives for the development of models of human behaviour at the individual level—so-called agent-based models (ABMs) or multi-agent systems [45, 46, 47]. There are many examples of the successful application of such models at a range of scales. These include models of markets where ABMs yield realistic behaviour in contrast to the efficient markets assumed in most economic models [48], or the description of crowd behaviour [10], or of disease spread [49, 50], where ABMs capture critical features which continuum models usually ignore [51]. More fundamentally, it has been argued that ABMs are the natural framework within which to approach the modelling of complex systems comprising many interacting agents [52].

Network theory

Social interactions take place on a network of human–human contacts. Economic systems comprise interactions between individuals, companies, conglomerates, countries and trading blocs. Network analysis has shown that many of the properties of such systems are determined to a greater or lesser degree by the topology of the contact network, regardless of what actually constitutes the interaction between the elements (or nodes) of the system [53]. When we consider social or economic networks, we find that it is usually much easier to describe the network structure than to catalogue all the possible types of interaction that can take place across the links. If there are some types of important societal or economic behaviour that are then largely determined by the network topology, we can gain important qualitative insight and even quantitative predictive power by analysing the topology. Network theory, especially in combination with evolutionary game theory, has delivered important insights into fundamental features of human behaviour such as altruism, cooperation, the spread of ideas and rapid shifts in social attitudes or norms [54–62], and references therein.

In practice, we will need to rely on all of these approaches in judicious combinations to construct appropriate models, a point we return to in Section 6.

5 Data collection and the testing of hypotheses against data

We began by saying that testing hypotheses against evidence is at the core of the revolution in thinking which led to modern science and built the modern world. It must clearly be an essential part of the program we are proposing. Moreover, as pointed out by Epstein ([11]; §1 above), one purpose of model building is to guide data collection. Our expectation that the human–Earth System will usually exhibit the behaviour of a complex adaptive system warns us that some attempts to understand, validate or calibrate our models may be misguided. For example, since the global financial crisis of 2008, the financial community has spent much effort trying to find deterministic cause-and-effect relationships to explain individual peaks and troughs in financial indicators. This is probably futile. Recent research in complex systems science has demonstrated that in complex networks of dependency, conventional notions of cause and effect are essentially meaningless. Instead, what 'causes' do is perturb systems that have their own endogenous, nonlinear dynamics [63, 64]. A more appropriate goal for the financial community would be to understand the intrinsic instability of world financial markets and the role of that instability in generating volatility [65].

In §3 we identified many dynamic patterns from the history of society. Assembling data from recent history, let alone the distant past, to test quantitative models is a difficult and specialised task. The IHOPE Project of the International Geosphere–Biosphere Programme has taken on precisely this challenge and will be a key partner in this research agenda. Costanza et al. (2007a) [66] discuss the data requirements and the goals of IHOPE in detail as well as touching on the question of how much we can learn about the future by studying the past. Here we must confront the question posed by Haldane in 1932: 'Is the history of the last 6000 years in the process of being replaced by a new historical process which will not obey any 'laws' we can detect in the old history'? [5]. Certainly global society is now connected in terms of material and information flows to a degree that it never has been before [21, 67]. It is indeed possible that the social dynamics of humanity have now reached a no-analogue state, so that complete models of the modern human–Earth System can only be compared with history submodel by submodel.

However, this proposition in itself is amenable to investigation. We propose that modelling using the tools we have already discussed is the best way of attempting an answer. Even if some key aspects of the dynamics of the modern world cannot be observed in the past record, there are other historical events that are clearly directly relevant to our immediate future and for which we currently have no convincing or uncontested explanations—for example, the Industrial Revolution, the demographic transition or the great post-1950 acceleration of global development [15, 68].

6 The state of the art in modelling the human–Earth System and the gaps to be filled.

Modelling at two scales—the global and the regional—currently captures most of the effort devoted to quantitatively linking social, economic and natural processes. Global integrated assessment models IAMs) play a key role in Intergovernmental Panel on Climate Change assessments of climate change [69, 70]. (These models are used to calculate emissions of greenhouse gases caused by human activity as an input to physical climate models and also to compute the impact of the resulting climate change on economy and society. Typically they contain economic and demographic modules as well as descriptions of physical processes such as agricultural production, energy generation and climate (see [71] for a general description of models of this class).

The economic modules of IAMs parameterise human behaviour implicitly through the assumptions of neoclassical economics, including efficient markets and representative human agents who operate to maximise their profit and consumption. Experimental economics and psychological studies tell us unequivocally that humans individually do not behave in this way, while the question of whether markets are actually efficient in the long run remains contested in economics [7, 9, 10]. The models also explicitly assume simple parameterisations of other social factors (or fix them exogenously). An example of this is the rate of technological innovation, a process whose drivers and constraints are poorly understood and for which there exists little or no consensus on mechanisms, or even on evidence. Most fundamentally, their simple equilibrium economic formulations essentially forbid the appearance of strongly nonlinear dynamics, making these models incapable of endogenously generating the kind of nonlinear tipping point behaviours we observe in the real world.

The failure of classical economics to predict or offer remedies for the global financial crisis of 2008 lends weight to the views of those within the profession who insist that economic modelling needs paradigm shifts to attain the predictive status of natural science. A comprehensive review of the problems of models based on neoclassical economics, together with some suggestions for the research that is needed, can be found in Helbing and Balietti 2011 [10] or in a host of web-based discussions, e.g. http://www.unifr.ch/econophysics/editorial/show/id/52.

Regional IAMs often contain much-more sophisticated models of human behaviour, usually via the route of agent-based modelling (see §4 above). The most effective models represent dynamics operating at many scales, choosing the appropriate scale and parameterisation for a particular process through a judicious mix of ABM and dynamical systems approaches (see §4 above). Such models represent the state of the art for regional IAMs. A fundamental difference between global and regional IAMs is that the former are usually used to generate scenarios by running the models forward with some set of parameter choices. Regional models, in contrast, are often used in participative mode, where the model is primarily used as a tool for engagement with communities or managers. The model is then used to demonstrate the physical or economic consequences of human choices [Boschetti et al. 2011, this volume, Chapter 8].

The use of these models in this participative mode is also a practical recognition of the fact that our ability to model many aspects of human behaviour a priori is severely limited. Instead of supposing that the model can capture contingent social behaviour, human 'liveware' is cooped in both developing the model structure and eliciting the human responses and patterns of interaction that the model requires. This can be a positive feature. Used in this way, the model reproduces the biophysical processes that would result from the choices and actions of the participants in the model development. The participative approach is now widely applied and has reached a high level of sophistication [72].

A key message we take from this supports the hypotheses in §3. At small group size in any single realisation, contingency can rule. At this scale, processes that confound predictability dominate, such as the response of the human agents in the model to the model's predictions. Contrasting the dominant role of contingency at regional or small-group scale (say up to a few hundred people interacting in a social setting) with the observed regularities of the human–Earth System at large scale, which we noted in §3, raises the question we flagged earlier: at what scale (if ever) does strong dependence on contingency weaken or even disappear? This is a critical question that determines the scope of possibilities for modelling the human–Earth System at global scale.

In Figure 3 we schematically plot observed regularities or emergent behaviours of systems [73] against two variables: the number of agents and the complexity of the interactions between them. The obvious deduction is that in many circumstances, if enough agents are interacting, then 'predictable' properties of the system will emerge. What we do not have at the moment are robust theories of whether and where agent numbers cancel out complex agent–agent interaction and switch contingent and effectively random behaviour into behaviour with some useful degree of predictability.

What is clear is that there is a significant gap in scale and approach between global IAMs, whose size, complexity and recourse to equilibrium formulations makes them ill-suited to investigating strongly nonlinear dynamics, and regional IAMs whose social dynamics tend to be ruled by contingency. This suggests the need for another level of quantitative modelling, which we could call IAM's of intermediate complexity, or IAMICs. These would allow us to explore the consequences of parameterisations of social dynamics coupled with the biophysical world, in which the full range of system behaviour could be explored. There are some examples of very simple precursors to such IAMICs, such as Grigg et al. (2010) [74] and Brede and deVries (2010) [57], but the development of IAMICs that truly represent nonlinear world dynamics would be, we believe, a powerful organising focus for the program we propose.

7 Concluding remarks

Is quantitative modelling of the human–Earth System a new science? Modelling societal dynamics is certainly not a new idea. Historians and sociologists have been proposing qualitative models of societal change for a century. In his far reaching book, *Deep futures*, Cocks (2003) [5] devotes a chapter to this subject, comprehensively surveying the contributions of social scientists and historians, starting with the seminal works of Marx, Weber, Durkheim and Spengler. Cocks contrasts these views with attempts to understand the mechanics of societal change derived from analogies with ecology and biological evolution. While all these theories can be falsified in principle by new information, they are overwhelmingly subjective and have rarely been subjected to the test of translation into quantitative mathematical models.

Here we have made the strong claim that developments in complex systems science have opened new windows into the description of societal dynamics and new ways to fuse this with the dynamics of the natural world. The inexorable rise of computational power continues to widen the space within which these new developments can play. In our view, these developments have changed the rules of the game, so that the time is now ripe for real advances in integrative modelling of the human–Earth System.

It is tempting to close with another meteorological analogy. The idea of modelling the weather numerically was proposed and attempted by LF Richardson in 1910, long before digital computers existed. In the 1950s, John von Neumann saw weather modelling as one of the strongest motivations for building digital computers, and indeed this was one of the first tasks they were given. Despite this, it is only in the past two decades that weather models consistently outperform ‘persistence’—that is, the prediction that tomorrow’s weather will be roughly the same as today’s. We may have finally reached this point in modelling social dynamics.

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Chapter 10

Science to inform and models to engage

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Scientific evidence and evidence-based reasoning are likely to face epistemological challenges when brought into societal debate if their foundational assumptions generate cognitive dissonance among key elements of the community. The risk of dissonance is even greater when scientific demonstrations and models are concerned with the decisions and behaviours of people interacting with an environment of interest. In this case, scientific information is often perceived as distorted or biased due to the inherent uncertainties attached to human ecosystems

Human ecosystems are complex and adaptive, largely due to our individual cognitive capacities and communication skills. Complex systems science aims to track uncertainties attached to these systems by exploring metaphoric models of reality.

1 An old debate after all

Four centuries ago the English philosopher Francis Bacon classified the intellectual fallacies of his time under four headings, which he called idols. An idol was defined as an image held in the mind that received veneration despite its lack of a defining substance. Bacon did not regard idols as symbols but rather as fixations. In this respect he laid the foundations of modern psychology. For Bacon, knowledge was intimately mixed with the idols, hence prefiguring our present concepts of beliefs and mental models [1]. More importantly, Bacon drew visionary consequences from the existence of the idols for the communication of innovative ideas (*Nova organum* 1620: 346:35) [2]:

> Enter quietly into the minds that are fit and capable of receiving it; for confutations cannot be employed, when the difference is upon first principles and very notions and even upon forms of demonstration.

Individuals and groups exhibit varied responses when faced with new information. If such information is consistent with existing behaviours and beliefs, it can be readily accepted and integrated. However, if the new information conflicts with current behaviour and belief, the resulting state is described as cognitive dissonance [3]. According to the theory, one can reduce the inconsistency and psychological discomfort of cognitive dissonance by changing one's beliefs, values or behaviour. Another way to avoid dissonance is to reject or avoid information that challenges belief systems or to interpret dissonant information in a biased way. Elaborating on the conflicting views upon 'uncertainty' between scientists and policymakers to explain the science–policy gap, Bradshaw and Borchers (2000: 30) [4] outlined the complexity of cognitive dissonance:

> Dissonance between existing beliefs and new information may be shaped by a host of factors, all of which inhibit the rate at which scientific findings are assimilated into policy. In what we have called the 'volition' phase of the science-policy gap, public debate around an emerging scientific consensus may derive from a combination of cultural, psychological, and economic interests threatened by the policy inferences of dissonant scientific findings.

Unlike scientific inquiries that use verification (modus ponens) and refutability (modus tollens) in an iterative and constructive way, folk-reasoning seems to use one or the other in ad hoc mental settings that try to minimise dissonance with socially and historically contingent beliefs. At the end of the 19th century Charles Sanders Pierce, a founder of modern semiotics, also suggested that we lacked direct access to reality and had to use 'signs' so as to mediate between our mind and the world [5]. Pierce hypothesised that as signs were socially shared, it was society that established their meaning. Therefore, any truth was provisional and the truth of any proposition could not be certain but only probable. It follows from this preamble that scientific evidence and evidence-based reasoning are likely to face epistemological challenges when brought into societal debate if their foundational assumptions generate cognitive dissonance among key elements of the community. The risk of dissonance is even greater when scientific demonstrations and models are concerned with the decisions and behaviours of people interacting with an environment of interest. In this case, scientific information is often perceived as distorted or biased due to the inherent uncertainties attached to human ecosystems.

2 Human ecosystems are uncertain

Human ecosystems are characterised by very strong and long-term interactions between human communities and their environment; as such they constitute an expansion of the ecological concept of ecosystem. According to Stepp et al. (2003) [6] human ecosystems not only process matter and energy flows, but also—and more specifically—information flows. Therefore, they display very specific characteristics due to our ability to communicate and learn from others, creating the conditions for co-evolutionary processes in which chance gives a hand to necessity. Bradbury (2006) [7] argues that until recently human beings had been able to adapt to changes and to cope with co-evolution through rather simple heuristics. But human activities have gradually strengthened the links between loosely connected environments and societies—let's call it globalisation. More information, more interactions, and shorter communication paths tend to create intractable dependencies between events and to generate deeper uncertainties overall.

Batten (2000) [8] relates the uncertainty of human ecosystems to the idiosyncratic nature of human decision-making processes. As a matter of fact, we as cognitive beings constantly shift from deductive to inductive reasoning in order to solve daily problems or to assess complex, collective situations. Deduction is reasoning from the general to the particular. A perfectly logical deduction yields a conclusion that must be true provided that its premises are true. Inductive reasoning involves pattern formation and pattern recognition, aided by intuition and creativity. Clearly some people are more intuitive or creative than others. But we all share this capacity to adapt to complex situations through alternate inductive and deductive reasoning [9].

By admitting that most human ecosystems are highly complicated, we acknowledge their inherent uncertainty. Thus we also accept the fact that it may not be possible to understand the intimate processes leading to well-established facts supported by social observations. For example, Durkheim (trad. 1979: 58) [10] in his famous study of suicide concluded that no matter how much a researcher knows about a collection of individuals 'it is impossible to predict which of them are likely to kill themselves. Yet the number of Parisians who commit suicide each year is even more stable than the general mortality rate'. A process that seems to be governed by chance when viewed at the level of individuals turns out to be strikingly predictable at the level of society as a whole. Hypothesising that most human ecosystems are complex and adaptive in nature, we need to accept the fact that they display these unexpected emergent properties, challenging our hopes of understanding the workings of causation [11].

3 Using metaphoric models to track uncertainty

During the late 1980s, research on complex and adaptive systems in biology or physics progressively permeated the social sciences. Concepts like emergence, path dependency, dynamic equilibrium or adaptation were directly transposed into studies on human ecosystems [12]. Here we need to stress that these concepts are only theoretical predicates imposed by complex systems science in its attempt to better describe reality: observed systems are complicated, only their theoretical representations ought to be complex and adaptive. As a consequence, scientists have developed computer-based metaphors called social simulations in order to identify and better understand emergent processes within real systems [13]. Most of these models rely on an atomistic vision of human ecosystems; these atoms—being called agents or nodes—are metaphoric representations of social entities and aim at reproducing plausible, if not realistic, behaviours [14]. Boundless attempts to simulate reality with these computer metaphors have sometimes resulted in erasing limits between simulated and observed systems. Lissack and Richardson (2001: 101 [15]) criticise some complex systems modellers for not recognising this duality:

> The act of interpreting differs from the act of observing, and both may differ significantly from the underlying phenomenon being observed. In their failure to respect this distinction, [these scientists] are implicitly suggesting that the interpretation is reality. However, while a good model of complex systems can be extremely useful, it does not allow us to escape the moment of interpretation and decision.

But a large majority of complex systems scientists safely use computer simulations as virtual laboratories where they can test, replicate and compare social theories in order to better understand reality. The types of uncertainties they have to face can be separated into two classes: i) ill-defined predicates, and ii) nonlinear interactions. The first class includes cases where observed social patterns rely on unknown or largely implicit rules. Hence the modeller faces the challenge of inferring atomistic rules without calibrating observations in order to validate macrolevel patterns. For example, Dray and colleagues (2008 [16]) designed an atomistic model of illicit drug use and street markets in Australia. Despite the support of a transdisciplinary team of experts, the authors admit that, because of the illicit nature of the industry, several simulated processes are highly hypothetical, although macropatterns match epidemiological observations. Similarly, any attempt to simulate Durkheim's findings on suicide would have to rely on a series of speculative predicates. Often these are temporary limitations lifted by new inductive evidence or innovative deductive theories. Hence, from this perspective, one might see the uncertainty attached to simulated emerging phenomena as being an indicator of our incomplete understanding of social reality.

Unlike ill-defined predicates, uncertainty linked to nonlinear interactions stems from purely deterministic rules. Complexity is generated from a large number of iterative and conditional interactions between social entities (atoms). These outcomes become rapidly intractable, leading to unexpected emerging phenomena. This second class of uncertainty has attracted a vast amount of literature since the 1990s [17, 18, 11]. Within this literature the most striking evidence of the analytical value of atomistic simulations was given by Arthur (1994) [19] with his famous El Farol metaphor. One intriguing result of the simulation is that deterministic individual decisions, while totally unpredictable for an external observer, drive the entire system towards a stable state due to its self-referential conditions. Though fascinating, this emerging simplicity shouldn't be taken for granted. Indeed most of the time nonlinear interactions drive social simulations towards highly unstable grounds and emerging complexity. Nowadays the conditions under which simplicity emerges from complex atomistic interactions are at the core of research on complex systems [20].

4 A constructivist viewpoint upon uncertainty

So far we have asserted that human ecosystems are complex and adaptive, largely due to our individual cognitive capacities and communication skills. Complex systems science aims to track uncertainties attached to these systems by exploring metaphoric models of reality. One can feel the potential tension between grounded reality and artificial metaphors, social sciences and computer engineering, and constructivism and positivism. As a matter of fact, mainstream research on artificial human ecosystems stems from distributed artificial intelligence, which has developed a very normative approach to human behaviour [21, 22]. The advantage of a normative approach is that it establishes a consistent analytical framework in order to create and validate scientific knowledge. Its main limitation is to acknowledge the fact that science is inherently objective and that scrutinised reality is unique. While suiting perfectly computer development principles, these assumptions become questionable when addressing issues related to human cognition or social interactions.

Is there an objective way to describe decision-making processes? Maturana and Varela (1980) [23] denounced the circular paradox that arises when scientists seek to address and explain human cognitive abilities by using those same cognitive abilities. They argued that the primary response to this paradox had been to ignore it and to proceed with respect to a fixed and objective reality external to our acts of cognition. The authors disputed the very concept of objective reality by considering: i) people operating in multiple 'worlds', particularly sociocultural one and ii) a 'world' being moulded by contextual factors intertwined with the very act of engaging it. Their autopoieitic (self-creating) theory considered living beings as living systems embedded into larger systems constituted by themselves and the environment they interact with. Unlike other more positivist approaches to human ecosystems [24], their constructivist theory included the observer himself into the analytical framework.

Despite its robust foundations, the autopoieitic theory has failed so far to translate into a pragmatic analytical framework. The main reason for this failure is that denouncing circularities is not sufficient for designing concrete methodologies that would overcome the paradox. Hence validating atomistic models of human ecosystems might face three types of uncertainties born from ignorance (ill-defined predicates), complexity (nonlinear interactions) and subjectivity (observer-dependent design). A way out was probably inferred by Reynolds (1987) [25], pioneer of atomistic computer metaphors, when asked about the validation of his Boids simulating flocks of flying birds:

> Success and validity of these simulations is difficult to measure objectively. They do seem to agree well with certain criteria and some statistical proportions of natural flocks and schools. Perhaps, more significantly, many people who view these animated flocks immediately recognize them as a representation of a natural flock.

Reynold's proposal is nothing less than accepting social validation as a major component of a scientific evaluation, through a collective and consensual construction of truth.

5 Towards postnormal analytical frameworks

Funtowicz and Ravetz (1993) [26], studying the relationship between applied research and environmental policy, proposed a new scientific posture they called 'postnormal science' From a postnormal scientific perspective, the inclusion of an adequate set of stakeholders in research development legitimates scientific inputs to the debate. Thus these participants perform a function analogous to that of peer reviewers in traditional science. Furthermore, Funtowicz and Ravetz (1993: 745 [26]) challenge the commonly admitted rationality of decision and action:

> Until now, with the dominance of applied science, the rationality of reductionist natural scientific research has been taken as a model for the rationality of intellectual and social activity in general. However... this ideal of rationality is no longer universally appropriate. The activity of science now encompasses the management of irreducible uncertainties in knowledge and in ethics, and the recognition of different legitimate perspectives and ways of knowing.

We also have to accept the fact that social simulations, even the more sophisticated ones, will always be pale copies of the original, subjective and partial representations of a dynamic and uncertain reality. But recognising this very peculiar fact doesn't mean that these models are useless. Even Lissack and Richardson (2001: 105) in their criticism of computer-based atomistic models admit that:

> There is no need for the models in question to have predictive power, despite the strong desire of both consultants and their clients those models 'work'. The pedagogical value of exploring the interactions of complex relations through the manipulation of models is more than enough to justify the efforts that go into model development and proliferation. Clearly, it is easier to manipulate a computer model than a fully-fledged 'in reality' laboratory experiment, but the limitations of such models must be remembered.

Nowadays a growing community of scientists tend to accept a postnormal scientific posture and engage in collective design of their atomistic models with experts and stakeholders. This co-construction process doesn't intend to provide normative models of reality. Instead, it is meant to enhance discussion and collective decision around and about the mediating object [27]. In these models social entities (atoms) are designed according to the consensual information provided by the participants. Decisional rules and behaviours implemented in the simulations are the expression of participants' perceptions [28, 29]. Hence this constructivist and postnormal process deals with uncertainties in different ways:

- Ignorance (ill-defined predicates) is dealt with through individual contributions of experts on plausible atomistic features and processes (populating process).

- Complexity (nonlinear interactions) is dealt with through social consensus among participants on existing and plausible realities of the system under study (framing process).
- Subjectivity (observer dependency) is dealt with by fully acknowledging the inherent limitations of the designed model (embodiment process).

D'Aquino and colleagues (2003) [30] propose a formal approach of co-construction of social simulations aiming to support collective learning and decision-making. Acknowledging the complex and adaptive nature of human ecosystems, their c*ompanion modelling* (ComMod) approach requires a permanent and iterative confrontation between theories and field circumstances. ComMod deals with the dialectic confrontation between researchers, models and observed realities. The subjectivity and contextual nature of the models is fully acknowledged, as the observer is considered as part of the experiment. Furthermore, ComMod emphasises the modelling process itself rather than concentrating only on the model, embedding information gathering, model design and use of simulations into a collective process [9]. Incomplete knowledge, contrasted viewpoints and limited capacities of prediction are inherent and explicit weaknesses of this approach. But the legitimacy of the outcomes, through social validation of the whole process, supports a more effective use of such models by decision-makers [31]). Finally, ComMod might help to reduce the epistemological gap between science and policy described by Bradshaw and Borchers (2000) [4]: far from reducing uncertainties (policy standpoint) or relentlessly exploring them (scientific standpoint), co-constructed social simulations tend to 'domesticate' uncertainty through the populating, framing and embodiment processes described above. But it must be clear that decision-makers have to satisfy themselves with 'what if' scenarios, which are inherently limited and uncertain. Hence decision-making has to become again what it would have never ceased to be: a risky business for professional and responsible gamblers. Under this condition only, a new kind of complex systems science can bring in reality-connected and fast-evolving support systems.

Global issues need large scale models

While participatory approaches to social modelling have demonstrated their effectiveness to deliver at local and mesolevel scales, global issues like responses to climate change or a global financial crisis need large-scale simulations to be meaningful. It is fair to recognise that constructivist and postnormal approaches to modelling aren't naturally suited to inform large-scale models. Direct upscaling of locally validated social models holds the risk of i) incorrect generalisation of empirically validated decision-making processes or behavioural patterns, and ii) missing essential explanatory factors that wouldn't have been revealed in the local context being studied. Consequently, statistical demographic models developed by quantitative sociologists or general equilibrium models developed by macroeconomists tend to dominate the world of large-scale social simulations. Shortcomings attached to both approaches have long been documented: the latter relying on unrealistic state equilibrium and economic rationality conditions, while statistical demographics provide a succession of causal snapshots without knowledge of the social dynamics at work. These models have proven to be reliable as long as local actors display expected behaviours. Simulated outcomes will prove to be utterly wrong whenever unexpected behaviour occurs.

In the field of population health research Galea and colleagues (2009) [32] have proposed to overcome the current shortcomings of epidemiological models by integrating ethnographic information into their analytical and modelling framework. Their approach, called social epidemiology, uses complex system dynamic models to integrate local and global levels of information. In Australia, Moore and colleagues (2009) [33] provide a case-based illustration of such an integrative process whereby epidemiology, ethnography and modelling engage in an iterative and recursive dialogue in order to develop a generative sociological framework [34].

Population synthesis techniques have been widely used in conjunction with activity-based models applied to health, transport or housing research [35]. Based on large-scale statistical demographics (often drawn from census data), these microsimulations tend to generate mechanistic and repetitive local behavioural patterns. An obvious way forward would be to bring together population synthesis and social epidemiology paradigms to create richer more dynamic pictures of the social fabric under study. Though intuitively attractive, this proposal imposes significant constraints on the research framework: i) creation of long-term transdisciplinary research teams; ii) maintenance and regular updating of statistical demographics and ethnographic information; as well as iii), a need to socially validate the content of the model and its outputs. Under such a framework, large-scale simulation models would mediate between scientists, local actors, domain experts, practitioners and policymakers. While conceptually attractive, this approach would probably face overwhelming challenges if these core models were to be used as interactive media for targeted audiences. As a matter of fact, computational requirements, development timelines and relevant skills associated with large-scale models are often incompatible with agile, intuitive and interactive uses. Instead, we suggest the creation of 'shuttle models' that would encapsulate simplified or limited versions of the core model in order to engage with specific stakeholders on a given set of issues. For these shuttle models to be useful and consistent with the core model they would need to respect the integrity of a common ontological architecture. Each interactive model could use a subset of ontological components, or simplified versions of some of them, as long as their space of local solutions doesn't violate the boundaries of the overall space of solutions generated by the core model. The development of these highly interactive and visually intuitive instances of the core model could be used as 'flight simulators' with specific targeted audiences, taking the pioneering work of Meadows (2001) [36] to the next level.

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Chapter 11

An economic approach to modelling

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The economic system is large and complex. It cannot be known with certainty and it is subject to uncertain external forces both economic, such as technological innovation, and non-economic, such as climate change. Modelling this system is therefore fraught with difficulty. But modelling is necessary because economics is a key dimension in government and private decision-making processes.

The current climate change debate highlights the importance of economics. Scientists measure and try to understand the nature of climate changes that are taking place, while society keenly looks for answers to the big questions:

- *is climate change happening?*
- *if so, then what are the implications for the physical world?*
- *is there a human-induced component?*
- *if so, then can we do anything to reduce its impact?*

But equally (and perhaps more) so, society demands answers to the associated economic questions:

- *what are the economic costs and benefits of climate change without action?*
- *what policy instruments can be used to reduce the human-induced component?*
- *what are the economic impacts of taking action?*

1 Introduction

For many years at the Centre of Policy Studies (CoPS) we have been constructing and using economic models to answer questions like those posed above in the context of climate change. CoPS's models are classified as computable general equilibrium (CGE) models. Their key distinguishing characteristic is an applied orientation to providing inputs to policy debate. This reflects, in part, the history of the funding of the group, which was originally established in 1975 by the Australian Government under an interagency arrangement—the IMPACT Project—administered by the then Industry Commission, now named the Productivity Commission. Since then, Australian government agencies, principally the Productivity Commission, the Australian Bureau of Agricultural and Resource Economics and Science (ABARES) and the CSIRO have continued to support CGE research at CoPS and have themselves maintained substantial in-house modelling capabilities.

The aims of this paper are threefold: i) to outline the structure of a standard CoPS model; ii) to explain the keys to successful modelling as practised at CoPS; and iii) to explain the main challenge in modelling long-term scenarios—credible handling of technological change. Section 2 contains a brief overview of the main CGE model currently in use at CoPS for examining long-term, mainly greenhouse issues: the Monash Multi-Regional Forecasting model. Keys to successful modelling the CoPS way are discussed in Section 3. Modelling long-term technological change is discussed in Section 4. Section 5 has some final remarks.

2 The Monash Multi-Regional Forecasting model

Overview

The Monash Multi-Regional Forecasting model (MMRF) is a dynamic, multisectoral, multiregional model of Australia [1]. The current version of the model distinguishes 58 industries, 63 products produced by the 58 industries, 8 states/territories and 56 substate regions. At the state/territory level it is a fully specified bottom-up system of interacting regional economies. To allow estimates of the effects of policy at the substate level, a top-down approach is added.

General equilibrium core

MMRF determines regional supplies and demands of commodities through the optimising behaviour of agents in competitive markets. Optimising behaviour also determines industry demands for labour and capital. Labour supply at the national level is determined by demographic factors, while national capital supply responds to changes in industry profitability. Labour and capital can cross regional borders in response to relative regional employment opportunities and relative rates of profitability.

The assumption of competitive markets implies equality between the price of output and the marginal cost of production in each regional sector. Demand is assumed to equal supply in all markets other than the labour market where short-run unemployment can occur. The government intervenes in markets by imposing sales taxes (e.g. the GST) on commodities. This places wedges between the prices paid by purchasers and prices received by producers. The model recognises margin commodities (e.g. retail trade and road transport freight) that are required for each market transaction (the movement of a commodity from the producer to the purchaser). The costs of the margins are included in purchasers' prices but not in the prices received by producers.

MMRF recognises two broad categories of inputs: intermediate inputs and primary factors. Firms in each regional sector are assumed to choose the mix of inputs that minimises the costs of production for their levels of output. They are constrained in their input choices by a three-level nested production technology. At the first level, intermediate input bundles, primary factor bundles and *other costs* are used in fixed proportions to output. These bundles are formed at the second level. Intermediate input bundles are combinations of goods imported from overseas and domestic goods. The primary factor bundle is a combination of labour, capital and land. At the third level, inputs of domestic goods are formed as combinations of goods sourced from each of the eight domestic regions and the input of labour is formed as a combination of inputs of labour from nine different occupational categories.

In each region a representative household buys bundles of goods to maximise a utility function subject to a household expenditure constraint. The bundles are combinations of imported and domestic goods, with domestic goods being combinations of goods from each domestic region. A simple function is usually used to determine aggregate household expenditure as a function of household disposable income via a fixed coefficient, typically referred to as the average propensity to consume. Government final demand is exogenous or assumed to be a fixed proportion of private consumption. Foreign export demand is determined commodity by commodity via downward-sloping foreign demand curves: a shock that reduces the unit costs of an export sector will result in increased export volume but a lower foreign currency price.

Physical capital accumulation

A key dynamic mechanism in the model relates to capital accumulation. Investment undertaken in year t is assumed to become operational at the start of year t + 1. Under this assumption, capital accumulates accordingly:

$$(1) \qquad K(t+1) = (1-DEP) \times K(t) + Y(t)$$

where:
K(t) is the quantity of capital available in industry at the start of year t
Y(t) is the quantity of new capital created during year t, and
DEP is the rate of depreciation, which is treated as a fixed parameter.
Given a starting point value for capital in t = 0, and with a mechanism for explaining investment through time, equation (1) can be used to trace out the time paths of industry capital stocks.

Investment in year t is explained via a mechanism of the form

where: (2) $$\frac{K(t+1)}{K(t+1)} - 1 = F^{t}\left[\frac{EROR(t)}{RROR(t)}\right]$$

EROR(t) is the expected rate of return in year t
RROR(t) is the required rate of return on investment, and $F^{t}[\ ]$ is an increasing function of the ratio of expected to required rate of return with a finite slope.

In the implemented version of MMRF it is assumed that investors take account only of current rentals and asset prices when forming current expectations about rates of return (static expectations). An alternative treatment available allows investors to equate the expected rate of return with the present value in year t of investing $1, taking account of both the rental earnings and depreciated asset value of this investment in year t + 1 as calculated in the model (rational expectations).

Projecting forward with MMRF

In projecting forward with MMRF a large amount of information from specialist forecasting agencies is first compiled and then incorporated directly into the model. The model is then used to trace out the implications of the exogenously imposed forecasts at a fine level of industrial and regional detail. In recent work for the Federal Treasury's study of the carbon pricing mechanism projections were required going out almost 100 years. For this work, information imposed on the model included:

- state/territory macroeconomic forecasts to 2020 based on information provided by the Treasury
- national-level assumptions for changes in industry production technologies and in household preferences developed from MMRF historical-decomposition modelling
- forecasts for the quantities of agricultural and mineral exports from a range of industry sources
- estimates of changes in generation mix, generation capacity, electricity fuel use, electricity emissions and wholesale electricity prices from specialised electricity modelling
- forecasts for state populations and state participation rates drawing in part on projections in the Treasury's Intergenerational Report
- forecasts for land-use change and for forestry sequestration from experts at ABARES
- forecasts for changes in Australia's economy-wide terms of trade and for the foreign export and import prices for Australia's key traded goods in agriculture, mining and manufacturing drawn from simulations of ABARES's Global Trade and Environment Model.

To accommodate this information in MMRF numerous naturally endogenous variables are made exogenous. To allow such naturally endogenous variables to be exogenous, an equal number of naturally exogenous variables are made endogenous. For example, to accommodate forecasts for the aggregate terms of trade, an all-commodity and all-region shift variable that imparts an equiproportionate change in the positions of foreign-demand schedules for Australian exports was made endogenous. To accommodate forecasts in the early years for real private consumption by state, the average propensity to consume in each state is made endogenous.

3 Keys to successful modelling at CoPS

The usefulness of CoPS's models, such as MMRF, for generating long-term scenarios stems from a number of factors [2]. The most important are the models':

1. capacity to carry credibility-enhancing detail
2. flexibility in application
3. transferability
4. interpretability.

Credibility-enhancing detail

Policymakers require detail from economic modelling. They want to be able to identify convincingly which industries, occupations regions and households would benefit or lose from policy changes and when the benefits or losses might be expected to flow. Economic theory alone, or stylised general equilibrium analysis, is not well-suited to meeting information demands at this level of detail. But combining the theory in a CGE framework with disaggregated industry-level data, labour force survey statistics, data on the sector composition of the regional economies, and household income and expenditure data, provides the tool that policymakers require.

Take for example the current emissions policy debate in which CGE modelling is playing a prominent role. As in earlier policy debates (about trade liberalisation, for example) detail has been a key issue and CGE modellers have had to deal with a series of challenging questions. These include:

- Stationary energy accounts for more than 50% of Australia's greenhouse gas emissions. At what level of detail must the stationary energy sector be modelled for the effects of policy on its emissions to be captured adequately?
- Concern about greenhouse gas emissions centres on a global externality problem. Does this mean that the consequences of emissions policy can only be investigated using a global model? In any case, the domestic effects of a particular country's policy will depend on what other countries opt to do. If we are using a single-country model to analyse domestic policy, how can the effects of foreign countries' policies be included?
- Emissions policy is policy for the long term, with the underlying global externality and many abatement options involving complex dynamics. It is now routine for CGE models to have dynamic or quasi-dynamic structures, but how many dynamic mechanisms are required to make a meaningful input

to decisions about emissions policy? For example, do we need agents with full intertemporal optimisation, or will recursive dynamics do?

- The possibility of international emissions leakage is a problem that proponents of unilateral emissions policy must face. What is an adequate representation of a country's emissions-intensive, trade-exposed industries?

'More detail' is generally the answer to questions like these, with the required additional detail provided by augmenting the representation of the sector inside the CGE model or by linking the CGE model with more specialised models.

For the modelling of the carbon pricing mechanism, much of the modelling of global aspects of the scheme was undertaken using the Global Trade and Environment Model. Information from this model was then used to inform simulations of MMRF. The role of MMRF was to supply estimates of the effects of the scheme on the Australian economy at the level of detail required by policymakers to support the policy debate. A key dimension was detail about the electricity system. To cover this, MMRF was linked to a specialised bottom-up model of the Australian electricity system. In the original work commissioned by the Treasury and the Garnaut review, the electricity modelling was conducted by the consulting firm McLennan Magasanik and Associates using their probabilistic simulation model of the electricity market. Subsequent studies were undertaken with the consulting firm Frontier Economics using a similar bottom-up model of the electricity supply system.

Flexibility in application

Carefully considered and empirically supported detail not only enhances credibility in policy circles, it also increases a model's flexibility in application by providing appropriate variables to be 'shocked'.

Closure choice[1] is another important aspect of flexibility inherent in CoPS models. At CoPS we routinely utilise four different closures of a CGE model.

1 By closure we mean the choice of variables to be determined by the model (endogenous) and the variables to be determined by the model user (exogenous). A typical CGE model has more equations than variables. Hence a specific number of variables must be made exogenous; the remainder are endogenous.

1. For modelling historical trends, an *historical* closure. Exogenous variables are chosen so that historical data on changes in consumption, investment, government consumption, exports, imports, industry output and so on can be introduced into the model exogenously. Computations from this closure produce detailed estimates of movements in 'unobservable' technology and preference variables and also generate up-to-date input/output tables that incorporate all statistics available since the latest published set of accounts.
2. For decomposing the key factors underlying past economic changes, a *decomposition* closure. Exogenous variables are the technology and preference variables endogenous in the historical closure that can be 'shocked' with the changes deduced from an historical simulation. Computations with this closure can be used to identify the roles in the growth of industry outputs and other naturally endogenous variables of changes in technology and preferences that are naturally exogenous.
3. For generating future scenarios, a *forecast* closure. The underlying idea is similar to the historical closure. In both cases variables for which information is available are made exogenous. This might include macro variables, exports by commodity and demographic variables for which forecasts are provided by official organisations. Technological and preference variables in forecast closures are largely exogenous and are given values that are informed by trends from an historical simulation.
4. For deviating away from forecast due to policy changes or other exogenous shocks, a *policy* closure. Similar to the decomposition closure, the policy closure is concerned with how exogenous changes cause changes in employment, industry output etc. In a policy closure naturally exogenous variables are exogenous and naturally endogenous variables are endogenous. In policy simulations all exogenous variables except those affected directly by the policy under consideration are given values from the forecast simulation.

A final aspect of flexibility relates to the model's underlying economic theory. In the MMRF model, for example, default assumptions are that production is at constant returns to scale, markets are perfectly competitive and there are zero pure profits.[2] These are conventional assumptions that are typically categorised as *neoclassical*. However, if empirical evidence suggests otherwise, then the model is sufficiently flexible to allow for alternative assumptions. For example, in the modelling of the carbon pricing mechanism allowance was made for increasing costs of resource extraction in mining as the underlying resource diminishes.

2 Constant returns to scale means that if all inputs are changed by x per cent, then production changes by x per cent. Perfectly competitive markets means, among other things, that no participants are influential enough to have the market power to set the price of a homogeneous product. Pure profit can be typically thought of as monopoly rent. Zero pure profits means that for each industry cost equals sales, where cost includes allowance for *normal* profit.

Also, in the CPM modelling allowance was made for pure profit accruing in the electricity sector. In other applications, deviations from perfect competition have been allowed, but in this area there remain considerable theoretical and practical problems (e.g. Hoffmann 2001 [3]).

Transferability

A key to good modelling is transferability, supported by documentation of the theory and database and of the computer code. Training is also important. At CoPS much work is done to document all modelling efforts covering the technical side of the work as well as the results. Without such work the modelling has little credibility. Credibility is also enhanced by training, to allow people to use the model for themselves. At present CoPS runs four training courses a year, two in Australia and two overseas. The courses, which are nearly always fully subscribed, are designed for economists from government agencies and universities who are not necessarily modellers.

Interpretability

Users of CoPS models are often faced with sceptical audiences of policy advisors (and scientists!) who may have some economic training but little knowledge of economic modelling. In this context, a key to CoPS' modelling success has been its emphasis on interpretation of results.

On the one hand, interpretation is about telling a story true to the modelling outcomes without referring to the technicalities of the modelling. This is difficult but essential for the general acceptance of the results. On the other hand, interpretation is about explaining results in quantitative detail. This aids credibility and acceptance of the modelling but it is also a check on whether the modelling has been done correctly.

To this end, CoPS modellers make extensive use of 'back-of-the-envelope' models. There are three roles for such calculations [4]. First, with a model as large as the MMRF 'the onus is on the model builders to provide convincing evidence that the computations have been performed correctly, i.e. that the results do in fact follow from the theoretical structure and database'. Second, back-of-the-envelope calculations are the only way 'to understand the model; to isolate those assumptions which cause particular results; and to assess the plausibility of particular results by seeing which real-world phenomena have been considered and which have been ignored'. Third, by extending the back-of-the-envelope calculations, 'the reader will be able to obtain a reasonably accurate idea of how some of the projections would respond to various changes in the underlying assumptions and data'.

4 Technological change

In making long-term projections for the economy a key challenge is the treatment of technological change. In general terms, technological change is the change in output possible with a given level of inputs arising from the processes of invention, innovation and diffusion of information. Induced technological change is a key avenue via which population growth indirectly affects the size of the economy measured by the value of real resources available for production (real GDP).

MMRF's structure abounds with technological change variables which, in a forecasting closure, are normally exogenous and set either to zero change or to values deduced by extrapolation from an historical simulation of recent history. In modelling the effects of climate change in MMRF this treatment is enlarged to accommodate, in the base case, the idea that over time the economy is becoming more energy efficient and so technological progress in each industry is biased towards energy efficient production.

However, there is a growing literature that technological change, rather than being autonomous, is a result of processes that can be understood mathematically and hence can be modelled. There seems to be three main processes:

1. direct-price induced
2. private and public investment in research and development (R&D) induced
3. learning-by-doing induced [5].

Detailed summaries of the literature on endogenous technical change in the context of modelling climate change can be found in four special journal issues: *Resource and Energy Economics* 2003 (25), *Energy Economics* 2004 (26), *Ecological Economics* 2005 (54), and *The Energy Journal* 2006.

Direct-price induced technological change is not dissimilar to relative-price induced substitution in demand. The only difference appears to be when it relates to substitution between different technologies for producing the same item. A good example is MMRF's treatment of electricity generation choice. MMRF recognises a variety of power-generating industries distinguished by the type of fuel used, with allowance for different forms of renewable generation. There is also an end-use supplier (*electricity supply*) which distributes electricity to final users. *Electricity supply* can substitute between the different generation technologies in response to changes in relative production costs.

R&D-induced technological change comes in a variety of formulations. Seminal work in this area includes Kamien and Schwartz (1968) [6]. The key element is that technological progress is the result of investment in R&D. Analogous to the formation of physical capital in equations (1) and (2), the typical R&D approach envisages a formation process for R&D capital (the stock of knowledge) driven by investment in R&D. Just as the yield from physical capital is a factor input to real GDP, so the yield from the stock of R&D becomes a GDP driver. The degree to which R&D drives growth depends on the extent of spillover (or crowding out) from R&D investment in one area into other areas of the economy.

The R&D type of technological change can be incorporated into the MMRF framework by the inclusion of knowledge capital in the production function of each sector. That stock could be further split into two [7]: *appropriable* knowledge (specific and captured by the industry) and *non-excludable* knowledge (spillover from R&D elsewhere). Investment in R&D is affected by many factors, including demographic, such as the intake of skilled migrants, and social, such as the average level of educational attainment.

Learning-by-doing technological change was first noted by engineers who observed that unit labour costs in manufacturing declined with accumulated experience. In economic modelling this is often handled by making average cost in an industry a declining function of cumulated output. Calibration of the relationship is often based on 'learning' or 'experience' curves which show how much unit cost declines as a function of experience or production.

A good example of a learning-by-doing mechanism is that incorporated into the MMRF model for infant renewable-generation industries. At present the volume of production in these industries is negligible and unit costs are high. Over time government policies designed to encourage the uptake of renewable generation increase their use. As use increases, cumulative production expands and unit costs decline through learning by doing.

5 Final remarks

The keys to CoPS's success in economic modelling generally are: credibility-enhancing detail; flexibility; transferability; and interpretability. These principles should be the basis for economic modelling of long-term future scenarios involving different rates of population growth, which is the focus of the Australia 2050 work. On detail, the modelling should be able to show growth trajectories for a range of variables both national (macro) and structural, including regions and industries. On flexibility, the modelling should be able to accommodate a wide range of exogenous inputs: demographic (e.g. population, age structure), economic (e.g. world growth) and political (e.g. greenhouse policies).

The modelling should be well-documented and, if necessary, reproducible by others. Finally, the modelling results need to be well-explained in a way that those not directly associated with the modelling can understand.

Technological change will be a key feature in any set of credible long-term projections. MMRF includes many technological variables but in most cases these are treated as exogenous and shocked with independently determined estimates. There are a number of approaches to making technological change endogenous, and these need to be explored and tested to see if they should have a role in future modelling.

Finally, one point not touched on so far is the necessity to account for supply-side constraints as the modelling proceeds further out from the future. One such constraint is on greenhouse emissions. This has been discussed in some detail in this chapter. But there are many others, including constraints on water availability (by industry of use and region), fossil fuel availability, arable land, and labour of certain skill types.

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Chapter 12

Applying scenarios to complex issues: Australia 2050

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The scoping question for Australia 2050—What is our realistic vision for an ecologically, economically and socially sustainable Australia in 2050 and beyond?—sets out a complex objective. This chapter identifies three types of scenario suitable for managing complex risks: exploratory or problem-based, normative or actor-based, and reflexive scenarios that combine various scenario types and are updated through action-based research. Generic risk assessment is defined as the effect of uncertainty on objectives where risks are events that have positive or negative outcomes. Complex risks are distinguished from tame risks: the former are 'wicked' problems that manifest complex system behaviour whereas the latter are linear, bounded problems. Three phases within the process of assessing complex risks are identified: the scoping, analytic and management phases. Three epistemically defined types of risk apply to these phases: idealised, calculated and perceived risk. Each phase within the assessment process requires a different application of scenarios. Risk scoping explores the problem and decision space, defining idealised risks and deciding on scenario types to be applied. The analytic stage uses deductive and inductive methods to calculate risks, applying mainly exploratory scenarios. In the management phase both calculated and perceived risks need to be managed, largely through normative scenarios. Reflexive scenarios use information from short-term actions to inform long-term strategy, applying learning by doing to inform complex objectives and pathways to those objectives. Hosted within an institution, regularly updated with new knowledge and used by a wide range of decision-makers, these could be termed living scenarios.

1 Introduction

Scenarios are useful tools for making decisions when outcomes are uncertain. Carter et al. [1] provide the following description for scenarios used in a research context:

> A scenario is a coherent, internally consistent, and plausible description of a possible future state of the world [2–4]. Scenarios are not predictions or forecasts (which indicate outcomes considered most likely), but are alternative images without ascribed likelihoods of how the future might unfold. They may be qualitative, quantitative, or both. An overarching logic often relates several components of a scenario, for example a storyline and/or projections of particular elements of a system. Exploratory (or descriptive) scenarios describe the future according to known processes of change, or as extrapolations of past trends [5]. Normative (or prescriptive) scenarios describe a pre-specified future, either optimistic, pessimistic, or neutral [6], and a set of actions that might be required to achieve (or avoid) it. Such scenarios are often developed using an inverse modelling approach, by defining constraints and then diagnosing plausible combinations of the underlying conditions that satisfy those constraints [7].

Scenarios are especially useful in complex settings with 'deep uncertainty' where there is limited scope for quantitative prediction. Scenarios have been used widely in corporate settings for strategic management, in national strategies such as the Mont Fleur scenarios used in South Africa to transform national policy after apartheid, and in planning global change at national to global scales [8]. This chapter concentrates mainly on the latter, but all examples are relevant to scenario practice.

How scenarios can be applied to the different stages of the decision-making process has not been well-described to date. The role of scenarios within the Australia 2050 project offers the opportunity to consider this issue in more detail. Several questions come to mind such as: What should scenarios look like? What content should they have? How can they contribute to decision-making? To answer the last question, possibilities range from using scenarios to raise public awareness of an issue through to exploring governance options for transformative change.

This chapter describes how scenarios can be applied within a broader framework of complex risk management. Risk is dealt with here at two levels. On the first level are informal risks, the uncertain decisions that people make as part of their normal lives. The second level involves the formal risk management process. Three phases within that process that are relevant to scenario use are scoping, analysis and management. Scenarios have different roles within each of these phases.

2 Scenario typologies

Scenarios are usually thought of as subjective, narrative-driven storylines that aim to explore a wider range of futures than would be obtained from straightforward projections of current trends. Their content ranges from storylines to highly detailed numerical projections [9]. Scenarios focusing on sustainability received prominence with the Club of Rome *Limits to growth* [10]. These were members of a larger family of scenarios foresighting global trends constructed during the 1970s [11, 12] and later followed by endeavours such as the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, Global Environmental Outlook and others.

Existing scenario typologies tend to reflect the state of play at the time they are assembled, become outdated as the field evolves, and often fail to capture the full range of contemporary scenario development [8, 13]. The scenarios seem to be regarded as products of research rather than as tools designed to function in particular sorts of inquiries [13]. Three typologies [8, 13, 14] are described here and adapted. Van Notten et al. [8] concentrate on content, Borjeson et al. [14] on philosophical underpinnings, and Wilkinson and Eidenow ([3] on solving 'wicked' problems.

Van Notten et al. [8] list three major characteristics, goals, design and content, and 10 minor characteristics of scenarios. These characteristics are very useful for constructing scenarios, so are recommended in that capacity. But because they cover the descriptive aspects of scenarios rather than their functional aspects, they do not greatly assist decision-making.

Borjeson et al. [14] review typologies with a variety of philosophical underpinnings, choosing predictive, exploratory and normative scenarios as their main scenario types. Predictive scenarios were selected based on practitioners' use of the term prediction in connection with scenarios [14].

However, predictive scenarios are problematic. Van Notten [8] states: 'there are thus varying definitions of 'scenario' but on one point there is consensus: it is not a prediction'. Predictions are often used in rational comprehensive planning models: highly detailed plans based on the analysis of a limited set of possible future states (or just one) and the objective responses required to achieve a desired set of outcomes given those states. Feedbacks, unexpected events and other system processes mean that complex systems rarely follow such pathways (see Finnegan et al. [15] for a discussion of prediction in complex systems). Because a major role for scenarios is to promote enquiry and choice rather than suppress it with expert predictions, predictive scenarios are counterproductive.

Such methods also limit the ability to represent users' values in problem-solving, instead containing a limited 'objective' set of values.

Similar problems can arise for those who build and use scientific models. Models produce scientific predictions that can be mistaken for predictions of the future. While a model's theoretical application may be sound, in a system rich with drivers and feedbacks the model itself may be incomplete, so there usually has to be some translation between 'model world' and the real world. Scenarios can be used to fill that gap. For example, Carter et al. [1] emphasise that climate scenarios are usually purpose-built for specific impact assessments and rarely use direct model output, but modify climate model output in a range of ways.

Representing hard-to-define goals is also problematic for prediction. For example, both sustainability and 'dangerous climate change' are hard to define with precision, due to differing social and cultural constructions of what they may mean. This uncertainty is reflected in the expert literature [16]. Uncertain predictions of uncertain goals invite controversy. Scenarios can be used to survey a range of plausible pathways and goals in such cases; therefore a participatory process is likely to achieve broader agreement than expert judgement can by itself.

Although likelihood cannot readily be ascribed to any single scenario, this can be overcome by using scenario ensembles. Storylines can be compared and contrasted and quantitative estimates, such as warming or population growth, can be produced according to their likelihood of exceeding given levels. For example, levels of climate change associated with low emissions are more likely to be exceeded than those associated with high emissions. Using scenario ensembles allows likelihood to be addressed in a Bayesian manner, where participants use a scenario process to update their prior assumptions For example, 'If I manage risk this way, am I likely to achieve my goal?' After addressing such questions a stakeholder's prior estimates may change; they may step away from focusing on the most likely outcome to survey the spectrum of potential consequences or completely reframe the way they see the issue. The ability to do this collectively also fosters social learning, potentially building a community of practice [17, 18].

Wilkinson and Eidinow's [13] typology centres on problem-based, actor-based and reflexive interventionist multi actor-based scenarios. It is designed to fit into Funtowicz and Ravetz' [19] postnormal science framework. The more commonly used exploratory and normative scenario types readily substitute for problem- and actor-based scenarios in this typology. Problem-based scenarios are developed using deductive and inductive methods, whereas actor-based scenarios are normative. Their third type of scenario is termed the reflexive interventionist or multi-agent based (RIMA) scenario, designed to work with wicked problems' [13]. Problems are described as wicked when they are not well-bounded, are framed differently by assorted actors and groups, harbour large uncertainties that range from scientific to existential, and have unclear solutions and pathways to those solutions. Here RIMA scenarios will be termed reflexive scenarios. Problem (exploratory) and actor-based (normative) scenarios are combined to assess problems and evaluate solutions. The reflexive component is acting to implement favoured solutions and apply ongoing learning in action-based research. Instead of a single conceptual framing, a variety of epistemologies can be applied within single scenarios or different scenario families.

Linking these typologies with research methods, the major determinants of scenarios can be described as problem–actor, exploratory–normative, top-down–bottom-up (in terms of scale) and forward-looking–backcasting (or prescriptive-diagnostic in terms of time). In methodological terms this sets up a process goal construct. While exploratory scenarios are prescriptive, normative scenarios can be run in both forecasting and backcasting modes. Forward-casting normative scenarios concentrate on the initial state and process; for example a set of specific policies, whereas backcasting defines a normative state in the future; for example sustainability, then diagnoses how to achieve that state over time given specific starting conditions and a set of key drivers. Reflexive scenarios will most likely contain one or more two-way processes from the above list.

Wilkinson and Eidinow [13] make two important points: modern practitioners often borrow widely from the different scenario traditions, so a fixed typology may be counterproductive, and rather than trying to forge a single world view through a scenario-building exercise the aim is to describe a range of epistemic views. This view is reinforced by Cocks [20] in his chapter.

3 Classifying risk

Sustainability is viewed here through the lens of risk management. As mentioned above, risk encompasses both formal and informal meanings. The definition of risk in the International Standard ISO:13000 refers to *the effect of uncertainty on objectives,* whether positive or negative [21], rather than being the classic idealised risk focusing on a specific hazard. This broader definition is also more suited to the 'risk society', where many future risks are created by modern society and its technologies [22–24]. The investigation of sustainability can be viewed as the assessment of risk in the face of modernism. The modern world is fixated on the future, but creates a great many of the risks it faces. Deep uncertainties produce the following paradox: because the future is fearful, displacement occurs and more familiar 'tame' risks receive the most attention while larger 'wicked' systemic risks are ignored.

'Tame' and 'wicked' risks

Risks can be classified as tame or wicked complex system risks. Tame risks are characterised by a widely agreed conceptual framing. Values are bounded, and there is an established process for calculating risk with the capacity to reconcile calculated and perceived risk. This is the classical view of formal risk management that focuses on the problem or risk.

Complex risks are wicked problems occurring in complex system settings. They are characterised by disagreement over how risks should be framed, including the metrics by which risk is measured and by disagreements as to whether a given risk or the set of solutions proposed to solve that risk will cause the greatest harm. Both climate change and population growth are notable examples. Complex risks are consistent with the range of characteristics associated with wicked systems [25]: their limits are difficult to constrain; they have multiple causes and many interdependencies; there may be unforseen consequences of addressing the problems; the issues are not stable and have no clear conclusions; they are socially complex and are not the responsibility of one organisation at single scale; they will involve changing behaviour; and they are beset by chronic policy failure [26] and market failure [27, 28].

Tame and wicked risks therefore contain fundamental differences that require scenarios to be applied in different ways. Tame risks with bounded values can be managed using a linear process of standard risk assessment, as illustrated by the generic framework outlined in the ISO standard for risk [21]:

1. Establish the context: what do we need to take account of and what are our objectives?
2. Identify the risks: what might happen—how, when and why?
3. Analyse the risks: what will this mean for our objectives?
4. Evaluate the risks: which risks need treating and which are the priority for our attention?
5. Treat the risks: how best should we deal with them?

Two overarching concepts are:

- Communicate and consult: who are our stakeholders, what are their objectives and how should they be involved?
- Monitor the risks: have the risks and controls changed?

For the linear application of tame risks, scenarios are useful but relatively straightforward: addressing gaps in knowledge in one or more of the five stages above, or facilitating communicating among collaborators (e.g. researchers and stakeholders).

Managing complex risks

For complex risks, the way people make decisions (process) is as important as the decisions that need to be made. As different modes of reasoning come into play the so-called rational model of decision-making does not dominate. The psychology of risk also changes throughout the assessment process and both formal and informal understandings of risk are relevant.

The conceptual, technical and believed aspects of risk are linked by three important aspects of, idealised risk, calculated risk and perceived risk. Taking the above structure idealised risk covers the scoping stage (1), calculated risk covers the identification and analytic stage (2, 3), and perceived risk interacts with calculated risk in the evaluation and management stages (4, 5).

Idealised risk is the conceptual model of risk as it is framed during the scoping phase. This includes the ideals that shape the socially constructed views of risk brought into an assessment by stakeholders and researchers. Examples include dangerous anthropogenic interference with the climate system, population growth, ecological carrying capacity, risk to economic growth and so on. Idealised risk therefore not only influences how risk is calculated but also how it is perceived.

Calculated risk aims to estimate idealised risk as accurately as possible using scientific and technical resources such as observations, theory, models and experiment. In complex systems, calculated risk is inherently uncertain because, even given high confidence, probabilities are likely to be conditional. Nonlinear outcomes, such as tipping points, may also be predicted qualitatively with high confidence but are even more difficult to quantify; for example melting of large ice sheets due to unchecked greenhouse gas emissions. *Perceived risk* is the rough estimate of risk by a member of the general public [29].

Complex concepts such as sustainability and climate change can be idealised, calculated and perceived in different ways. Each idealisation will potentially lead to a different method of calculating risk. For example:

1. The precautionary principle has led the UN's Framework Convention on Climate Change Council of Parties to agree a limit of 2°C above pre-industrial temperatures for mean global warming due to anthropogenic greenhouse gas emissions.
2. The neoclassical economic view seeks to optimise the cost-benefit outcome by balancing the price of carbon with the cost of avoided damages due to the reduction that price affords.
3. The libertarian view that accepts climate change science rejects international climate policy frameworks like the Kyoto Protocol, preferring to leave the mitigation of climate change to market forces, leaving society to adapt to change as it occurs.

The first idealisation is calculated according to the likelihood of exceeding a carbon emission budget set according to precautionary estimates of impact; the second through dollars per tonne of carbon balanced against long-term economic damage; and the third is predicated according to precautionary limits on personal liberty.

Complex risks are also affected by the heuristics (rules of thumb) of decision-making. Two particularly important influences are the asymmetry between likelihood–value and between buying–selling and gain–loss. For the same expected economic value (likelihood times value), in high-likelihood, low-value settings, likelihood dominates decision-making whereas value dominates in low-likelihood, high value settings. In situations where 'you sell' a bet to me, compared to where 'I buy' a bet from you, on average people will sell the same value bet at a higher price, anchored on their own preference for selling high and buying low. A similar asymmetry is found in willingness to pay to avoid loss being much higher than the willingness to pay to make a future gain [30, 31]. Hyperbolic discounting also means that I may fear a small loss now rather than accept that loss for a large gain in the distant future.

Experimental psychology and surveys of social attitudes suggest that the perception of risk is affected by a variety of factors, including the heuristics of gain and loss, the diverse cultural mapping of attitudes to risk, different risk-averse and risk-seeking behaviours, rates of time preference, and sense of personal identity [30–34]. In complex systems with competing risks this is problematic, especially if the researchers calculating risk are framing risk according to a specific paradigm and are unaware of how competing frameworks affect the calculation and perception of those risks. Mike Hulme in his book

Why we disagree about climate change [35] points to this as a primary source of disagreement over what climate science means for policy.

Some of the largest biases affecting risk perception come from the psychological effects of uncertainty and dread. Psychometric studies suggest that perceived risk can be three orders of magnitude different to calculated risk [36] and that uncertainty and dread are two major drivers of this difference [37]. The difference between familiar and unfamiliar risks can also be interpreted in this light where familiar risks are often more tolerated than more likely but less familiar risks. Culturally driven perception of risk also means that perceived risk, including how different stakeholder groups perceive risks that have been calculated by experts, can vary widely [33, 38].

The word risk changes from a noun to a verb throughout the risk assessment process [39, 40]. This change occurs between the analytic and management stages and can be linked to the problem-based (exploratory) and actor-based (normative) scenarios described above. During the risk-calculation stage, the exposed place, community or process is 'at risk' because something of value is vulnerable to harm. At this point, risk is a noun and assessed as a potential loss—problem-based scenarios are used to explore these risks. In the risk management stage, the phrase 'to risk' refers to the opportunity of gaining an uncertain advantage. When a risk is calculated, the focus is on loss; when a risk is managed, the focus is on gain. Normative scenarios seek solutions that minimise harm and maximise benefit. In complex systems, both calculated losses and gains are uncertain. Therefore, how those risks are idealised and perceived becomes very important.

For tame risks, the step from what is calculated to be at risk to the calculated benefits of managing that risk is straightforward. Even though the chance of a net benefit over time is uncertain, taking a smaller risk to offset a larger risk is generally accepted. The gap between calculated and perceived risk is either negligible or can be managed through education and awareness-raising. Examples of this include various forms of insurance, flood mitigation and disaster mitigation.

Different idealised, calculated and perceived risks create wicked problems, requiring a greater focus on the use of scenarios to address those problems. Actions taken to manage one risk (climate change, population growth), may be seen as placing another valued activity (economic growth, sectoral income) at risk. Risks may also be systemic, being a product of complex interactions—for example, climate change, population growth, peak oil, food security. The task in such situations is to avoid the risk trap where risks become socially amplified [41] and opinions oscillate between extreme states of perception [42].

For complex risks, the expectation that 'better science' will lead to 'better' decision-making does not necessarily hold. Scenarios become useful not only for exploring what decisions need to be made but how those decisions may be made. As such, scenarios have a role in all three phases of risk nominated above: during the scoping, risk analysis and risk management phases. The pathways between informally idealised and perceived risk on the one hand and formally idealised and calculated risk on the other mean that these issues are relevant not only under formal risk assessments but any time that decisions relating to complex issues are being addressed.

4 The use of scenarios in risk assessment

Scenarios for scoping risk

Scenarios can help develop the conceptual models used in assessing risk. Both exploratory and normative scenarios can be applied to ask the questions 'what future do you think there will be?' given a specific set of underlying drivers and conditions, and 'what kind of future would you like to see?' given a specific set of values and goals [43]. The type of scenarios required for further assessment can also be identified. Decisions include whether to use three, four, or more scenarios and whether to integrate different types of scenarios or to proceed with a uniform approach.

In complex settings, a problem-based scenario may not start with a single issue such as population growth or climate change, but aim to identify all the relevant issues in identifying and managing potential risks. The act of scenario building opens up possibilities creatively by nominating potential future outcomes and assessing they are viewed as harmful or beneficial, serious or trivial. Having carried out this task, the risks that merit further analysis can be nominated [44].

Scenarios for risk analysis

The risk analysis stage assesses what is at risk, estimating likelihoods before the stage of ranking and evaluating risks. Metrics for analysis need to be identified. Existing institutionalised metrics will be widely accepted but many risks linked to issues such as sustainability are uncertain, having no clear thresholds that mark acceptable, unacceptable or disastrous outcomes. Other factors to be addressed include the interaction of multiple drivers, sustainable development pathways and human and environmental security.

Under conditions of high uncertainty scenarios can explore beyond the limits of scientific models. They can be used to analyse and evaluate risk where an event is deemed plausible but where that risk cannot be reliably quantified. They also have flexibility that most models lack. Both prescriptive and diagnostic assessments can be used (i.e. event and outcome-based approaches) to explore vulnerability to specific drivers and broader social vulnerability. They can also bridge scales. Many local processes will be somewhat independent of global trends, allowing freedom to generate local storylines and blend them with national and global scenarios. Scenarios can also reflect a range of values and accompanying metrics, allowing different frames of reference to be contrasted.

Understanding and communicating risk, or contributing to policymaking, does not demand the degree of precision required by science. The insights provided by scientific assessment can be provided through scenarios as long as the process is salient, credible and legitimate, but anecdotal evidence suggests that scenarios have a credibility problem with policymakers [13]—the main issue being that models are perceived as giving 'hard' evidence while scenarios are 'soft'. The role of scenarios as a credible source of evidence for policymaking therefore requires greater emphasis than it currently receives.

Scenarios for risk management

The heuristics of risk switch from those of loss to benefit through the transition from risk analysis to risk management. If vulnerabilities identified in the analysis phase are accepted then the starting position at the beginning of the management phase is one of net loss. The accepted role of normative or agent-based scenarios is to reduce harm and increase benefits from that position of loss.

Risk perception in complex systems is critically important. It governs whether calculated risk is accepted in the transition from loss to gain. For example, if a cure is perceived to be a greater risk than the disease, then the diagnosis in the form of calculated risk may be challenged. In such cases risk can be socially amplified (or attenuated), and losses attached to potential and perceived risk come into conflict. An example is where climate policy conflicts with the impacts of climate change—advocates using science are accused of hyping the science to accentuate dangerous impacts.

Management scenarios can provide a portfolio of potential options that can be contrasted in different value settings. In assessing these portfolios stakeholders become familiar with a range of potential solutions that may involve both process and goals, reducing the uncertainties associated with acting. Implementation, monitoring and review can initiate a strategy of learning by doing and, in doing so, reflexive scenarios come into play.

5 Reflexive scenarios

Reflexive scenarios are most useful in complex system settings where both the risks and solutions are uncertain, and where confounding processes and values are present [13]. Responses to 'surprises' can be rehearsed as is the case in military exercises. These scenarios involve a systems approach where agency, or learning by doing, is the main aim. Reflexivity applies where actors within a system observe that system and their response to it over time, monitoring anticipated and emerging risks and their own reaction to those ongoing changes. This is the most complex and least practised set of scenarios and marks the difference between periodic strategic planning where an 'optimal' plan is devised then rolled out until the next planning phase, and adaptive management that has the capacity for large changes in response to changing circumstances between planning phases. An example would be where a regulatory system managing an essential service such as energy or water contains triggers for substantial changes in response to events or new information written into it.

Such scenarios contain both exploratory and normative elements, and can accommodate prescriptive and diagnostic methods. They do not seek a single consensus view but aim to accommodate a range of world views. Different actors become more aware of their own attitudes and those of others to the specific risks in question and how they use formal and informal knowledge in decision-making. The largest drawback to their use is the lack of a community of practice and established institutional and governance role for scenarios in strategic policy development.

6 Conclusions

Scenarios used in social-ecological assessments are dominated by exploratory, top-down scenarios in forecasting mode. However, the research community is making a serious effort to develop participatory scenarios that cross the boundaries between knowledge and action and are salient, credible and legitimate (after [45]). A key aim of using participatory approaches to scenario building is to facilitate social learning. However, the theoretical basis for this is not well developed despite the fact that a great deal of empirical evidence shows that social learning can take place [17, 18]. A further aim may be to build ongoing collaborations where institutions and the community develop and maintain reflexive scenarios as tools for foresighting solutions, tracking progress and monitoring ongoing and emerging risk.

Tame risk assessments undergo a continuous process where risk management options flow on logically from the analytic phase. Scenarios are largely passive, assisting planning and communication. Roles include sharing different perspectives (e.g. as researcher, planner, operator, policymaker) incorporating different conceptual approaches, terminology and metrics (e.g. policymakers will be motivated by policy completion and uptake, operators by profit and livelihood).

In complex risk assessments, calculated and perceived risks compete with each other according to different world views. Disagreements can begin with idealised risks that have very different epistemic origins. Asymmetric heuristics used in decision-making affect loss and gain, likelihood and value and transactions involved in buying and selling. This asymmetry is exacerbated by the switch in what is at risk (prospect of loss), to take a risk (prospect of gain) that occurs between the analytic and management phases of the risk assessment process. This contributes to messy situations where scenarios are an important tool in working to accommodate these differing views.

The suggestion by Wilkinson and Eidinow [13] for more reflexive scenarios has been taken up here and strengthened through its application to the decision-making process in managing complex risks. Although space does not allow a full description, the case is made that tame risks can be distinguished from complex risks commonly associated with wicked systems. For complex risks the focus is not only assessing what is at risk and how to manage it (ontology) but is also on the process of decision-making (epistemology). The asymmetric nature of decision-making combined with 'deep uncertainties' associated with complex systems makes the linear process associated with the assessment of tame risks unsuitable.

The model of complex risk briefly described here recommends separating the scoping, analytic and management phases of dealing with risk. These phases are linked to idealised, calculated and perceived risk that each has different epistemic structures. The idealisation of risk in the scoping phase sets up the conceptual model(s) to be applied in an assessment, calculated risk is developed in the analytic phase of an assessment and perceived risk affects every aspect of the process, particularly the risk management phase.

How would the scenario typology described in this chapter inform Australia 2050? Cocks emphasises the need for evolutionary thinking, also saying 'scenarios, broadly defined, are our one and only "umbrella" tool for studying the future of complex anthropic systems' [20]. A reflexive scenario process would become a central organising feature of an assessment, with specific scenario types being more suited to specific stages of the assessment.

True reflexivity arises out of the stages of risk management and monitoring, where actors observe and learn from their actions over time. It is likely to involve so-called double-loop learning, with internal learning being achieved among individual actors and a second loop taking place at the institutional and governance level. Scenario storylines and data can be modified. Normative scenarios may redefine their goals or process. For example, at this stage, the shared view of what might be considered sustainable in 2050 will be very broad, with significant disagreement about details. A credible process will reach agreement that these goals can be redefined over time and identify a process for doing so. Scenarios can play an important role in this process.

A set of national scenarios that have credibility among major stakeholders and the public, and are living entities—so-called living scenarios—could fulfil this role. These would be hosted within an established institution and regularly updated with new learning. In the national context, exploratory and normative scenarios that address the various stages of the risk management process would be developed and updated as new learning becomes available. This is a very different process to the existing one of muddling through with little vision beyond the current election cycle.

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Chapter 13

Alternative normative scenarios for Australia 2050: economic growth, conservative development and postmaterialism

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This chapter outlines three strategies that address a common set of economic, social and environmental concerns in different ways and with different emphases. The strategies are presented as manifestos for three hypothetical political parties seeking to govern Australia over coming decades—the Conservative Development Party, the Economic Growth Party and the Post-Materialism Party. These manifestos then become the foundations on which I build three scenarios that speculate on what the longer term quality-of-life consequences might be if Australian society made a conscious choice to be guided for some decades by each of these sociopolitical philosophies. Starting with a well-defined sociopolitical philosophy permits one to plausibly infer something about a) society's subsequent choices of policies, priorities, plans and programs for seeking its goals, and b) society's reactions to various contingencies, including various global-change possibilities. I particularly want my scenarios to alert people to the need to avoid short-termism when choosing paths.

1 Introduction

The world keeps looking for convincing alternatives to the laissez faire and the communist models of social organisation, and also the pragmatic mix of policies and programs that seemed to work in mixed economies during the 1947–73 ‘golden age’ but which began failing soon after. This is despite the fact that the battle to have societies organised around the ideas of self-regulated market capitalism and small government has been temporarily won by the proponents of those ideas. The First World is likely to be made up of societies that are variants of the ‘capitalist democracy’ model for a good half century to come. One of these will be Australia. Within that boundary condition, what are the practicable choices we have for managing our society? If, as I will be assuming, we want a society with good long-term survival prospects and offering high quality of life to all (goals that I lump together as *quality survival*), can we articulate and evaluate defensible and distinctly different alternative ways of attempting to create such a society? Even if it takes 50 years to get there?

This chapter is based on the unadventurous assertion that it is not too difficult to abstract from our culture’s pool of ideas about societal organisation and several coherent, integrated, ideotypical strategies for managing Australian society. While there is evidence and argument to support the adoption of any of these strategies, evidence is not proof, and in the end these strategies have to be regarded as belief systems which, if implemented, may or may not produce the Australia we want.

What I have tried to do is formulate three strategies that address a common set of economic, social and environmental concerns in different ways and with different emphases. Inevitably, it is easy enough to identify similarities between these strategies and contemporary political positions. But I have bent over backwards to play down such links and compensate for my own biases, and I present the three strategies in as fair a way as I can. I would like readers, too, to resist going into partisan mode as soon as they think they know which strategy best reflects their political allegiances.

The three strategies are presented as manifestos for three hypothetical political parties seeking to govern Australia over coming decades—the Conservative Development Party, the Economic Growth Party and the Post-Materialism Party. These manifestos then become the foundations on which I build three scenarios that speculate on what the longer term quality-of-life consequences might be if Australian society made a conscious choice to be guided for some decades by each of these sociopolitical philosophies. Starting with a well-defined sociopolitical philosophy permits one to plausibly infer something about a) society’s subsequent choices of policies, priorities, plans and programs for seeking its goals, and b) society's reactions to various contingencies, including various global-change possibilities.

A scenario is a preview of future events or conditions. The proposition behind my 'narrative experiment' is not that scenarios can predict the achievement or otherwise of particular social goals by some mid-future date—they cannot. Rather, it is that by carefully detailing a small but diverse selection of the many paths Australian society could choose to follow, and by speculating in an informed and disinterested way about the differential consequences of following one or other of these paths over time, it might be possible to make a better choice about which, or which mix of, or which variation on these paths to start on now. Selecting a path to start down now does not commit the society to remaining on that path for 50 years, of course. Tomorrow (figuratively speaking), when circumstances change, the experiment can be repeated and another path perhaps chosen.

I particularly want my scenarios to alert people to the need to avoid short-termism when choosing paths. Despite the fact that many private and collective decisions made in the late 20th century will have marked consequences for our grandchildren's quality of life (i.e. the degree to which their needs are being satisfied; the things that contribute to the feeling that life is worth living) in the mid-future—around 2050—and beyond, these consequences are rarely taken into account more than minimally in choosing what to do today about education, infrastructure, environmental management, defence and so on. Further, there are many recurrent decisions that, while individually having little effect on quality survival now or in 2050 (e.g. land clearing, annual immigration levels, groundwater loadings), cumulatively stand to have enormous impact on indicators of quality survival by that time. Also, despite the fact that a number of exogenous threats to national sovereignty, to the basic structure of society and to individual wellbeing can be dimly foreseen occurring in coming decades (e.g. global warming, resource depletion), we do little to pre-empt them or deflect them. The same applies to opportunities—for example, how do we plan to capitalise on the ubiquity of high-speed access to the internet? Our society's inability to factor these sorts of longer term implications into its current decision-making is widely recognised as a blind spot and has been given a name—short-termism, or 'grasshopperism'.

For an extended development of the scenarios presented here, see Cocks [1].

2 The three scenarios

The three scenarios are built around three core beliefs about how a society seeking high quality of life for all should respond to four overarching hazards of our early 21st century society: an inappropriate rate of economic growth (too low? too high?), increasing environmental degradation, increasing social injustice and declining sociality (social health) paralleled by rising sociopathy (social decay).

The first of these core beliefs, underpinning an *economic growth strategy*, is as follows: while it is true that environmental degradation and social injustice are important impediments to achieving high quality of life, these hazards will be ameliorated without resorting to any serious collective intervention, if we move towards a more individualistic form of social organisation focused on the feasible objective of reaching and maintaining a high rate of economic growth. Sociopathy is not a priority problem.

The two-pronged strategy proposed for implementing this philosophy is to selectively remove significant barriers to profit-making by entrepreneurs (e.g. environmental regulations) while focusing a small (by today's standards) government sector on the task of providing business with cost-saving infrastructure, such as transport and communications, and productive human capital in the form of a technically educated workforce. Other priority components of this strategy are population growth, extended property rights, a flexible labour market, and free trade.

The second of these core beliefs, underpinning a *conservative development strategy*, is as follows: environmental degradation and social injustice are important impediments to high quality of life that will only be ameliorated if they are managed directly within the context of a more hierarchical, reconstructed form of social organisation. Nonetheless, it is desirable and should be possible to do this and simultaneously reach and maintain a high rate of economic growth. Sociopathy is a collateral problem rather than a priority problem.

The strategy proposed for implementing this philosophy centres on achieving full employment, this being the best way to address both social injustice and social decay. A jobs-and-incomes program will be funded by a major tax reform program. Environmental degradation will be addressed by an environment management program that will have a significant 'green jobs' component. Environmental damage is strongly related to energy consumption and the quantities of raw materials entering the economy as inputs and leaving the economy as pollutants. Regulatory, fiscal and market-based measures will be used to stabilise net materials use and energy use as rapidly as possible and to cap the rate at which land is converted from low-intensity to high-intensity uses. Other priority components of this strategy are industry-support programs, trade management programs and population stabilisation.

The third of these core beliefs, underpinning a *postmaterialism strategy*, is as follows: environmental degradation, social injustice and sociopathy are all important impediments to high quality of life that will only be ameliorated if managed within the context of a more mutualistic form of social organisation. Economic growth is also a priority problem requiring management, but in the sense that it is too high rather than too low, with social and environmental costs exceeding the benefits.

The strategy proposed for implementing this philosophy focuses on transforming the economy, redistributing power in society and radically reforming the socialisation system, these being the starting points for ameliorating environmental degradation, social injustice and pervasive social decay.

The socialisation system assisted by a formalisation of citizens' rights and responsibilities will concentrate on producing responsible, collaborative and useful community members. Power redistribution will be sought through the widespread development of participatory, non-adversarial institutions and the devolution of state and Commonwealth powers to strong regional governments. A range of tools (e.g. comprehensive recycling, population stabilisation, decentralisation, import replacement, a cap on personal consumption) will be used to diversify and localise and 'green' the economy and the cities so as to conserve energy, materials and natural systems. Stabilising consumption will facilitate investment in social, human and institutional capital at the expense of 'output-increasing' capital.

While it would be surprising to see the Australian electorate vote for and persist with any of these strategies strictly as described, it would be most surprising to see the postmaterialism strategy adopted. It implies a greater change from reigning values and ideas than the other two scenarios. Adopting an economic growth strategy or a conservative development strategy would be less surprising in the sense that these strategies simulate positions towards the ends of the range of conventional wisdom in First World countries.

3 Scenario outcomes

By role-playing each strategy's proponents in turn we can evoke some perceptions of possible successes and failures for each strategy in relation to the mid-future societal goal of quality survival, particularly its economic, environmental and social dimensions.

Thus the economic growth scenario, which lacks any direct incentive for income redistribution, could lead to a highly polarised society of 'haves' and 'have nots'. But it could also lead to a society where large economic surpluses and high middle-class incomes become available for enhancing non-market aspects of quality of life. Alternatively, attempts to achieve high economic growth with minimal intervention could fail for various plausible reasons and this, the worst of both worlds—no growth and no equity—could generate great social conflict. Given a) the correlation between economic growth and energy growth, and between energy growth and environmental degradation, and b) an absence of extramarket environmental controls, this strategy could also lead to poor environmental quality if highly successful in its main endeavour. A possibly higher rate of technological change under an economic growth scenario could work to either the advantage (e.g. cleaner fuels) or the disadvantage (e.g. toxic new chemicals) of the environment.

The conservative development scenario could lead to a society enjoying both a healthy environment and resource base and quite high consumption of market goods. Success in achieving full employment would stand to improve quality of life for all, not just the unemployed. Alternatively, stubborn resistance from the business community to having to pay the full social costs of using natural resources and having material and energy throughputs regulated and taxed might result in GDP decline or half-hearted environmental management or both. A gridlocked society gripped by pluralistic stagnation could be the fishhook lurking in a strategy that pins its hopes on strong government to solve problems in an age of globalisation when governments are becoming less able to change their societies.

In economic terms, the danger in the postmaterialism scenario is that if consumption is capped and the economy is pushed to be more diversified, democratised, localised and environmentally benign, activity might simply decline rather than move vigorously towards a new production-investment mix. For example, the economy's 'brain workers' might emigrate in search of higher salaries and poverty could be widespread. A banana republic economy is conceivable. However, if the postmaterialism economy flourished within its self-imposed constraints, and if plans to actively combat sociopathy succeeded, the result would be an increasingly equitable, supportive, collaborative and environmentally healthy society, with most living in modest comfort.

Finally, looking outwards, what are the threats and opportunities posed for these three strategies by the uncertainties of socioeconomic globalisation and environmental global change? For example, by war, uncontrolled mass migration, or natural disasters and rainfall shifts associated with climate change? Or by a booming or slumping world economy? Or by domestic contingencies such as sharply declining local oil and gas supplies, or the rapid loss of crop and pasture lands to degradation?

Perhaps economic growth is the best strategy for guaranteeing participation in the growth sectors of a booming world economy. But remembering that all competition creates losers, would the price of failure here be higher than under conservative development or postmaterialism? And a diversified, localised, more self-reliant postmaterialism economy might serve us better under global recession; a diverse economy can be a strength or a weakness. An economic growth economy generating high GDP would have the productive capacity, although perhaps not the necessary incentive, to tackle many of the foreseeable threats to Australian society. Outcomes would depend on whether the business sector decided to collectively support any politically chosen response to a shock, a somewhat unlikely eventuality except in the case of total war. Also, a growth-oriented society might lack the social cohesion, the social capital (e.g. trust between groups) to respond to contingencies requiring widespread mobilisation of the population.

Being relatively decentralised and relatively less developed economically, a postmaterialism society might find it difficult to respond in a coordinated productive way to various nation-threatening contingencies. Conversely, an actively managed society with strong central government and an experienced bureaucracy, as in the conservative development strategy, could be well-placed to respond to national emergencies and external shocks—for example, the imposition of strong global carbon dioxide emission controls.

4 Lessons and conclusions

Does the prospect of finding a place in the sun or going down the gurgler economically, socially or environmentally differ significantly between strategies? It has to be concluded that all three strategies contain both favourable and unfavourable portents for this society's quality survival, and that from the short analysis here it is difficult to claim a clear superiority for any one.

Accepting this inconclusiveness, several lessons follow: none of the debates we have visited is new. All three strategies reflect reasonable positions and supporters of one have no grounds for being intolerant of disinterested supporters of the others. Reasonable pluralism—that is, a pluralism of reasonable positions—is an indicator of a healthy society.

In reality, as distinct from scenario land, democracies never select a strategy like economic growth, conservative development or postmaterialism and stick with it single-mindedly. It is more accurate to think of society as trying to follow several strategies simultaneously and that what is being regularly readjusted is the balance of effort going into each of these. The question we can reasonably ask is, which strategy do we need a measured dose of at this time, assuming our three strategies span the possibilities reasonably well, as I have tried to ensure. I leave this question to the reader, just as I leave it to the politicians to recognise that the primary malfunction in our system of government is its incapacity to identify farsighted, comprehensive and explicit alternatives, and to give people a choice between these rather than a choice between marginal responses to topical issues.

A more general legacy of the present analysis is some conclusions about the value of scenario building, the primary one being that it sadly underused as a decision aid.

Scenario building is essentially a perception-heightening or awareness-heightening exercise. It sharpens one's view of current reality and one's view of what future reality could be like. It does not produce an explicit solution to a clear-cut problem such as choosing a national goal-seeking strategy. What it promises is to help people:

- develop a way to think about the future of Australian society
- clarify options for national mid-future goals
- clarify differences between target values (ends or goals) and instrumental values (means)
- foresee external and internal problems and opportunities that could emerge in coming decades—and perhaps to foreshadow responses to these

- think strategically about alternative ways in which society can still be feasibly managed, and the limits to such management
- speculate about some of the mid-future consequences of choosing and persisting with each of those alternatives
- realise that apparently diverse strategies for quality survival have much in common after allowing for differences in emphasis
- become aware of the range of factors to be taken into account when considering the longer term consequences of today's choices.

Building national scenarios will never be seen as useful by the minority who reject the idea of 'society', or reject as meaningless the idea of society adopting or being able to adopt a collective purpose in the form of social goals; nor by those who believe that the forces moulding the more-distant future are so wild and unpredictable that the costs of attempting to choose between options on the basis of their foreseeable consequences will always outweigh the benefits.

Many people fear what the future holds. By demonstrating that the future can be analysed, discussed and bounded, one might hope to improve public confidence and, as Kenneth Clark observed, 'it's lack of confidence, more than anything else, that kills a civilisation'. [2]. Having explicit social goals and strategies, a vision for the society can provide people with an energising sense of purpose.

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Chapter 14

The evolutionary nature of narratives about expansion and sustenance

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Both globally and in Australia the industrial era starting in the 19th century has been a time of rapid, nearly unbroken economic growth tightly linked with growth in material consumption. Exponential growth cannot continue forever on a finite planet, leading to an emerging collision between the presently irresistible force of growth in material consumption and the immovable reality of the finitude of Planet Earth. This collision takes many forms and will occur over many decades, but by several estimates some of its effects are already evident and many will be deeply entrenched by the second half of the 21st century. The colliding forces draw upon two broad narrative families, one about the paramount need for expansion of the human enterprise and the other about the paramount need for sustenance of an increasingly fragile natural world. Narratives (defined here as meme sequences that empower conviction) are governed by evolutionary dynamics, through diversification, selection and amplification of success. The evolution of more subtle and resilient narratives is essential to empower the transition to a society that lives within the means of a finite planet and improves wellbeing at the same time.

1 Introduction

The time since 1800 has been a period of almost continuous, near-exponential economic growth that continues apace both globally and in Australia (average real economic growth rates from 2000 to 2007 were 3.3% per year for Australia and 4.4% per year globally [1]). Broadly, consumption of energy and resources has grown at a comparable rate [2]. At the same time, Planet Earth is under pressure from cascading human impacts upon the natural world [3, 4, 5], most of them being consequences of increases in human population and affluence. Human-induced climate change is an important example, but far from the only one [5].

We therefore have a fundamental dilemma: the planet is finite, but growth in almost every facet of human activity is pushing at the boundaries of the 'operating space' within which the natural world can function effectively and maintain healthy biota [5]. Yet, as the signs of collision between growth and the finite Earth become ever more apparent, material consumption proceeds ever faster.

Analyses of the collision between growth and the finite planet are often focused on the magnitude and growth rates of economic and social drivers, or on observed or predicted responses in natural and human systems. However, in this paper I want to strive for a different perspective on the fundamental dilemma—and routes to its resolution—by examining the two great *narratives* that encapsulate the opposite sides of the dilemma. (Soon I'll define the idea of *narrative* properly). In doing this, I am focusing not only on biophysical or social dynamics in the external world but also on the models or concepts of the world that live inside our minds.

It is worth summarising the thread of this chapter at the outset. The central hypothesis is that narratives really matter and we need better ones. The argument involves eight propositions: i) from objective evidence, there is a looming collision between growth in material consumption and the finitude of Planet Earth. 2); this collision will create a whole new class of global vulnerabilities unknown in previous human experience; iii); human responses to these vulnerabilities are determined as much by subjective narratives about the world as they are by objective realities; iv) therefore, human–Earth interaction in the present epoch depends on the cultural and psychological dynamics that govern narratives, just as strongly as on natural and economic dynamics; v) the dynamics governing narratives are fundamentally evolutionary, being based on diversification, selection for success, and amplification of success; vi) two broad families of narratives, based around 'expansion' and 'sustenance' concerns, are now competing for cultural ascendancy through this evolutionary process; vii) to resolve the fundamental dilemma created by the collision between growth and the finite planet new, subtler and more-resilient narratives are required in addition to (and, in fact, to empower) essential technical, economic and institutional transformations; viii) the process of narrative evolution can to some extent be guided to facilitate the emergence of these essential new narratives.

Each of the above propositions is nontrivial in the sense that the contrary assertion is argued by some intelligent people. In this short paper it is not possible to provide complete arguments for all propositions, but I hope to at least indicate the flavour of these arguments.

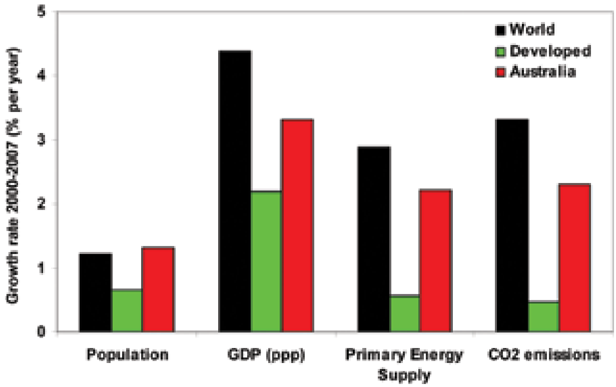

Figure 1: Growth rates over 2000–07 of population, real GDP (purchasing power parity), primary energy supply and CO_2 emissions, for the world, developed (Kyoto Annex 2) nations, and Australia. Data from IEA [1].

2 The collision

Human population, economic productivity, energy use and CO_2 emissions are growing almost everywhere. The growth rates of all four of these important indicators are lower in developed nations than for the world as a whole because of high growth in developing nations. However, Australia is exceptional among developed nations in having growth rates in all four indicators that are closer to the global average than to the averages for developed nations (Figure 1). Indeed, Australia's population growth rate is faster than the world average. Australia is therefore a developed nation with growth profile approaching that of the developing world.

Global growth is a phenomenon of the last two centuries and therefore historically exceptional. Incomes and living standards per person before 1800 varied across societies and epochs, but there was no upward trend because technological advances were lost through increases in population (the Malthusian trap) [6]. Only after the Industrial Revolution did innovation rates become high enough to break out of the Malthusian trap, due in large part to the enormous societal advantages conferred by the availability of large quantities of cheap energy from fossil fuel combustion [7]. In turn, this led to population increases as living and health standards improved (recognising the different effects of these improvements on fertility and mortality) and also to human modification of the global carbon cycle and human-induced climate change [7].

The indicators in Figure 1 (population, economy, energy and emissions) are deeply connected in ways that point to some of the processes and driving forces behind the growth of the last two centuries [2, 7]. These processes are complex and evolving, with globalisation now playing an important role. Rapid development in China (economic growth around 10% per year over 2001–10), India (around 8%/y) and other developing economies is both driving the global economy and also forcing developed nations to restructure their economies away from manufacturing and towards services—or in the case of Australia, towards the supply of iron, coal and gas. The result is a global growth engine of enormous power, complexity and interconnectivity.

Growth is occurring not only in the four indicators in Figure 1, but also in a vast range of other indicators of human activity and pressure on the natural environment [4]—for example, in extinction rates, measures of climate change, changes in nutrient cycles, ocean acidification and depletion of marine ecosystems (natural indicators), and in trade volumes, tourism, air travel and internet connectivity (as indicators of human activity).

There is a mountain of objective evidence that all of this growth cannot continue forever. It is axiomatic that exponential growth can only continue for a finite time in a finite system—sooner or later resources of water, nutrients, land or minerals become depleted or the system becomes imbalanced by the accumulation of by-products like carbon dioxide. As long ago as 1972 the Club of Rome report [3] pointed to limits to growth. Although criticised strongly by some, the main projections of the report have proved to be broadly accurate over 30 years [8]. More recently, the concept of a 'safe operating space for humanity' [5] has been used to explore boundaries for the healthy functioning of natural planetary support systems, with the conclusion that nine boundaries are under pressure and three (for biodiversity, climate and nutrient cycles) are already exceeded.

Focusing on climate change, it is now a scientific near-certainty that human-induced climate change is real, is happening and will accelerate as greenhouse gas emissions increase; the evidence has been accumulated in four successive

Intergovernmental Panel on Climate Change assessments [9] and summarised in numerous public documents [e.g. 10]. All of this evidence (and much more) supports the first proposition in the introduction: there is a looming collision between economic growth based on material consumption and the finitude of Planet Earth.

What vulnerabilities will arise through the collision? A partial list might include (in no special order): i) physical climate change impacts (heat stress, water stress, flooding, sea level rise, ocean acidification); ii) loss of biodiversity and function in terrestrial and marine ecosystems; iii) disturbances to nutrient (nitrogen and phosphorus) cycles; iv) build-up of environmental toxins (pesticides, radioactive materials etc.); v) loss of food security (both from extra demand and also from decreases in supply caused by other environmental pressures); vi) loss of water security (for similar reasons); vii) increased risk of global pandemics affecting humans and food supplies (through greater global connectivity); viii) increasing risk of catastrophic failures in systems now necessary for human life support (trade, finance, communication, information etc.); ix) social disruptions and collapses as societies are impacted by other vulnerabilities. This list could easily be extended.

From even a casual glance at such a list it is evident that these pressures and vulnerabilities have several important general characteristics. First, they are *interactive* and augment one another—for example, the combined effects of warming, acidification and resource overexploitation on marine ecosystems are much greater than the sum of each effect in isolation [Fulton 2011, pers comm]. Second, many of the vulnerabilities have a *tipping-point character*: many pressures have little apparent effect until some threshold is passed, at which point the consequences are sudden and unstoppable (examples include melting of ice caps, ecosystem transitions and economic collapses). Third, consequences are *cascading*: one vulnerability triggers others, leading to unmanageable cascades of cause, effect and feedback. Fourth, all vulnerabilities act at *multiple scales*: regional vulnerabilities are already being felt in many areas, and global vulnerabilities ensue through connectivities in a globalised world. Fifth, each of these vulnerabilities is at least somewhat *unpredictable* in timing, magnitude, severity, trajectory and interactivity with other vulnerabilities. This is a list of risks rather than certainties. However, many of the risks have been quantified on an individual basis as significant to high [5, 9, 11, 12]. Sixth, all vulnerabilities *increase with human population and affluence* through increased consumption and connectivity.

Together, the above characteristics support the second proposition in the introduction: the collision between growth in material consumption and the finite planet will create a whole new class of global vulnerabilities unknown in previous human experience because of their degree of interactivity and their global connectedness.

3 Narratives and their dynamics

The previous section is an assessment of objective realities in the external world. This section enters the realm of the subjective by exploring the third, fourth and fifth propositions in the introduction: that human responses to global vulnerabilities are determined as much by subjective *narratives* about the world as by objective realities; therefore the human–Earth interaction in the present epoch depends as strongly on cultural dynamics as it does on natural and economic dynamics, and that the dynamics governing narratives are fundamentally evolutionary.

First, it is critical to be clear about the meaning I am ascribing to the key word. *Narratives* are inner stories that express conviction. They encapsulate our experience, knowledge and values about the world and motivate our actions. They are usually shared among a group, and provide powerful sources of cultural and social cohesion. Narratives in this sense are strong medicine: they are much more than fictional tales or accounts of day-to-day experience. They set our hearts on fire, reconcile us to fates beyond our control and guide us as we try to shape our destinies. Although religious belief may provide a narrative for some people, narratives (as stories that express conviction) are part of everyone whether they adhere to a religion or not.

This idea of a narrative has commonalities with the ideas of a mental model, mental picture or mental map, but goes deeper. A sketch map and a masterpiece of Indigenous art both reflect mental pictures of landscapes, but one reflects a profound cultural narrative as well.

The idea of narrative advanced here has antecedents in the work of Roger Schank, a researcher in artificial intelligence (AI) who asked what AI is actually trying to emulate [13]. His answer was that intelligence, as humans characterise it in normal experience and identify it in other people, consists not of the ability to do complex calculations or solve logical puzzles, but rather to interact through stories. Intelligence, in his view, is about the depth and richness of stories and the extent of their connectedness through hooks to other stories. I have borrowed this idea of a story as the currency of cultural intelligence and adapted it to identify a narrative as the currency of cultural conviction.

A narrative in this sense also has important commonalities with Richard Dawkins's concept of a meme [14], a 'unit of cultural transmission' which acts as a cultural evolutionary replicator. Narratives are collections of memes or meme sequences. They are culturally transmitted and are subject to evolutionary dynamics [15] in 'culture space' through diversification, selection and amplification. However, not all memes or meme sequences are narratives: memes as defined by Dawkins also include cultural junk matter or viruses, such as advertising jingles, which have high replicating power but are regarded by their hosts as a waste of space at best and malign at worst, akin to biological or computer viruses.

Narratives (in the sense used here) reflect and embody norms and values and can be thought of as their memetic encoding. An illustration of the importance of this encoding is the way that norms and values are taught in families, schools and the community—through stories rather than through lists of rules or books of law. The law books matter, but they are not how most people describe their values to themselves or to each other.

The evolutionary perspective provides some insight into the ways that narratives work and spread. As meme sequences, narratives are evolving replicators. They *diversify* in a culture space (by variations in recall and transmission); they are subject to *selection* pressures (a good narrative being one carrying a strong conviction that empowers its host mind); and successfully selected narratives are *amplified* by spreading preferentially in culture space.

It is important to note that the selection criterion for a successful narrative is conviction, not objective truth. There is no requirement for a narrative to pass the standard scientific tests of logical consistency, falsifiability and consistency with empirical evidence. A narrative may pass these tests, but many highly successful narratives are internally inconsistent and demonstrably false, some aspects of climate scepticism being an obvious contemporary example. Hoffman [16] reviews 'a growing body of work in the fields of psychology, sociology, anthropology and other social sciences that views climate change not only as a scientific issue, but also as a psychological, cultural and political one. This work helps explain why anthropogenic climate change has reached the level of a "scientific consensus", but is not yet a "social consensus"—namely a view held by society as a whole that emerges from individual and social values about what is true and what is not'. This view aligns with the present paper.

4 Expansion and sustenance narratives

This section addresses the sixth proposition in the introduction.

Given the intensity of the emerging collision between material growth and the finite planet as sketched in Section 2, it is no surprise that the opposing forces are each represented by a strong family of narratives. I will use the labels *expansion* and *sustenance* for these narrative families to distinguish them from the objectively identified colliding forces of growth and the finite planet. The narratives in these families are not the same as objective evidence or knowledge (though they may draw upon knowledge for support); rather, they are the stories that encode the values of people seeking to act on their convictions.

The expansion family of narratives stresses limitless human possibility and growth. These narratives emphasise the success of economic growth strongly coupled with growth in material consumption in raising living standards in developed nations through the last two centuries, and now in much of the rest of the world. Expansion narratives typically argue that continuance of economic growth is essential to maintain and further improve wellbeing, especially in the developing world. Expansion narratives coexist with narratives based on ideas of market liberalism or the supremacy of the free market, but the two are not the same and many who are motivated by expansion narratives do not subscribe to market liberalism. Both as an explanatory framework and a policy prescription, market liberalism has been greatly damaged by the 2008 global financial crisis, as outlined in numerous critiques [e.g. 17], though these have had little effect on faith in the narrative of market liberalism by its adherents. Expansion narratives are more broadly based than the narrative of market liberalism. For example, many economists grappling with responses to the challenge of reducing greenhouse gas emissions typically assume continuance of economic growth at near the present rate [18, 19] but do not advocate unfettered markets to achieve emissions reductions; rather, they advocate markets with governance and regulation to achieve common-good goals with continuing economic growth.

The sustenance family of narratives stresses the deep connections between humankind and the natural world, a theme appearing in a rich variety of forms in many cultures. In the present epoch these narratives are centrally concerned with the need to care for a fragile planetary life-support system at scales from local to global. Modern sustenance narratives often include science, drawing particularly on the Gaia hypothesis [20] and the emerging discipline of Earth System science [21, 4]. However, the sustenance narrative family includes many stories in addition to those based on science such as articulations of goals for the wellbeing of individuals and societies through lower material consumption and greater equity. Many recent books have articulated this narrative well; here I will point only to the work of Flannery [22, 23, 24].

Multiple factors contribute to the strength of these narratives. For example, one contributor to the strength of the expansion narrative is the timescale of intergenerational memory. The present epoch of rapid growth has been under way for about 200 years. This is a very small fraction of the time for which the human species has inhabited Earth (around half a million years) or the time since settled agricultural civilisations evolved (about 10 000 years), but it is also about eight human generations, much longer than the timescale for personal intergenerational memory. While many of us know our grandparents and perhaps a generation before them, we have only a faint idea—if any at all—about the lives and circumstances of our ancestors of eight generations ago. We therefore perceive the growth period since 1800 not as exceptional (which in the long view it certainly is) but as a culturally normal, business-as-usual state. It is difficult to imagine anything else.

The expansion and sustenance narratives are now colliding in public discourse and policy. This is evident in many arenas but nowhere more strongly than the public debate about human-induced climate change and measures to combat it. This debate has been so shrill, and often ugly, that climate change is widely perceived as the only significant human pressure on Planet Earth. In contrast, many objective assessments [e.g. 5] find climate change to be just one of a set of interacting pressures. The importance of climate change is not that it is the only pressure or even the greatest one; rather, human-induced climate change has been the first global pressure to demand global responses that involve restructuring economies and changing consumption patterns. Thus the climate debate has become a front between the expansion and sustenance narratives, and its development reveals much about the wider collision of those narratives.

The climate debate has degenerated into a media counterpart of trench warfare. Given the wider issues at stake it is not surprising that the debate has become a fierce contest for cultural ascendancy rather than a polite academic discussion. Few tactics are out of bounds: widely employed tactics include the dismissal, debasing and distortion of empirical evidence (practised mainly but not exclusively by the 'climate sceptic' side of the argument); wild exaggeration or complete misstatement of the opposing position for the purpose of attack (by both sides); and the use of pejorative labelling ('warmists', 'denialists' etc.) and the lumping of many views with an extreme one that can then be attacked (also by both sides).

The debate is also being shaped by rapidly evolving media institutions and cultures, including the transformations brought about by the internet and interactive social media. Many factors are at work. The speed and transience of the news cycle lead to a continual search for new angles and an impatience with issues and stories like climate change that, by nature, unfold over decades. Interactive social media have brought about a great democratisation: vast amounts of information, previously only within professional reach, are now instantly available and readily disseminated, though often without filters for objectivity or reliability that are (in the main) part of the ethical code of professional journalists. Opinion (ranging in quality from excellent to awful) is also available in vast amounts, enabling us to select opinion to reinforce our own narratives. Globalisation has also led to increasing centralisation (often transnational) of ownership and control of traditional print and electronic media, thereby adding to their homogenisation and decreasing diversity.

In combination, the nature and intensity of the debate, coupled with changing media dynamics, are leading to an increasing hardening of positions and entrenchment of existing narratives. This is directly counter to what is really needed—the evolution of new narratives.

5 Evolving new narratives

This final section addresses the last two propositions in the introduction.

The two dominant existing narratives are being pulled in opposite directions and are increasingly locked in a no-win contest. However, these narratives play a critical role in shaping the evolution of the human–Earth system over coming decades and therefore the outcome and severity of the inevitable collision between growth and the finite planet. We therefore face the challenge of developing more subtle and resilient narratives capable of empowering the transition to a society that lives within the means of a finite planet and improves wellbeing at the same time.

What strategies are suggested by this line of thinking? I suggest here that a possible key is the evolutionary nature of narratives, which are simultaneously inner stories that express conviction and also meme sequences. Narratives therefore evolve, adapt and transform. The basic process was first understood through the Darwinian revolution in biology, but is now seen as the universal engine of the emergence of complexity in domains including technology, social systems and economics [15, 25]. In essence, this process involves just three interacting steps: diversification, selection and amplification.

Diversification is about the development of a wide 'meme pool' of narratives. The arts, the natural and human sciences have important roles to play here along with professions such as journalism.

Selection is about framing the goal. A well-articulated and compelling goal will select for—and become part of—the narratives which support it. For Australia this means articulating realistic and compelling visions for how the nation might look and function in several decades, consistent with the requirements of living within the means of a finite planet.

Amplification is about strategies for interaction and dialogue. Some parts of the existing pool of narratives are repelled by other narratives in immune-style reactions thus preventing their spread and amplification. Can these parts adapt while maintaining the integrity of the overall narrative?

A critical aspect of this conclusion is that the needed new narratives are likely to include elements from both the expansion and sustenance families. Both are rich, and have motivated great human aspiration and achievement. Mechanisms for evolutionary emergence of shared narratives, such as the 'living scenarios' approach advocated elsewhere in this volume, provide the opportunity for combining the best elements of these great narrative families. An example is the search for growth in human possibility and fulfilment that is fully decoupled from growth in material throughput in economies once material consumption has reached a sufficient level to provide adequately for human physical wellbeing.

Finally, a view of narratives as evolutionary entities suggests that we should be developing resilience (an evolutionary concept) not only in the natural and human systems that make up the external world but also in the inner world of narratives. This is because in the present epoch of close human–Earth interaction, inner human worlds plays a greater role in shaping the external world than most natural scientists have recognised until recently.

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