Future Dilemmas: Options to 2050 for Australia's Population, Technology, Resources and Environment

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DIMIA

Dilemmas Distilled

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A Summary and Guide to the CSIRO Technical Report

CSIRO

Report to the Department of Immigration and Multicultural and Indigenous Affairs

By CSIRO Sustainable Ecosystems

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***Future Dilemmas**: Options to 2050 for Australia's population, technology, resources and environment*

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What impact will the size
of Australia's future population
have on the environment, the physical economy,
the national infrastructure and
our quality of life?

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Introduction

Discussions of future population levels are never easy. Different people hold different views, often passionately. Some believe population growth is necessary, others that our population is already too big. Regardless of the strength of the belief, there are no certainties. The real world is a complex place and our long-term future is impossible to predict. Common sense and past experience can guide us on what might happen in the near future but they quickly become inadequate the further we look ahead. The extent of uncertainty is highlighted by the range of views on the approach and conclusions in this report from the members of the External Reference Group (ERG) appointed by the Minister for Immigration and Multicultural and Indigenous Affairs, the Hon Philip Ruddock MP, to oversee the project (see Attachment A). And yet understanding the implications of population growth and the consequent impacts on our community is basic to the welfare of our children and their children.

In an effort to generate new insights on what lies over the horizon for Australia, researchers at CSIRO Sustainable Ecosystems have been developing new tools and new approaches to modelling Australia's physical economy in order to build scenarios of what the distant future might hold.

Future Dilemmas is a substantial technical report that encapsulates the results of research commissioned by the Commonwealth Department of Immigration and Multicultural and Indigenous Affairs (DIMIA). It explores the future effect of three population/immigration scenarios on infrastructure, resources and the environment out to the year 2050.

The first scenario considers what would happen if the net immigration rate was zero persons a year (described as the low scenario in this summary report). The second considers what happens if the rate was 70 000 a year (the current policy setting; the base case and described here as the medium scenario). The third examines the consequences of an immigration rate set at two thirds of one percent (0.67%) of the current population per year (described here as the high scenario).

The low scenario (zero immigration) represents the policy position of some environment groups. Based on current population growth, it would see a domestic population of 20 million by 2050. The medium scenario gives a population of 25 million by 2050. The high scenario (0.67% growth pa) is a position advocated by many business interests. It gives us 32 million people by 2050.

Future Dilemmas explores the consequences of these three scenarios for people, urban infrastructure, the natural environment, energy, water and a broad range of other issues. The exploration is a complex task because impacts of population on one sector interact and affect all other sectors with feedback effects on the original sector.

This report, *Dilemmas Distilled*, is a companion guide and summary to *Future Dilemmas*. It aims to draw out the results and key messages from *Future Dilemmas*, and assist the reader on where to look should they require more detailed technical information contained in the main report.

Key conclusions of *Future Dilemmas*

Ten overall conclusions arise from for three population scenarios and their effects on Australia's physical economy

1. Direct effects of population growth

Many aspects of Australia's physical economy are directly influenced by population growth and larger population sizes. More people means economic growth and development stimulated by the requirements for more infrastructure, more industrial output, more services, more food, more tourism, higher levels of consumption of energy and water, and more waste and emissions. Given these practical realities, the low, medium and high population scenarios tested in this study are all physically feasible out to 2050 and beyond.

If our population were to stop growing it would not cause the physical economy to stall, nor would it make key issues of resource use and environmental quality disappear. A number of drivers of the physical economy such as lifestyle and affluence, international trade and inbound tourism affect key resource and environmental issues. These are indirectly linked to population size and population growth rate.

Significant progress toward a sustainable physical economy in Australia requires more than just managing our future levels of population. It will also require the simultaneous management of infrastructure, lifestyle, energy, international trade, inbound tourism and the technology incorporated in key machines and processes.

2. The good news on population growth

Under all population scenarios, growth continues in a range of key sectors of the physical economy at least until 2020. Even under the low population scenario, declining household size, internal migration patterns and requirements for tourism accommodation will stimulate activity for the building industry — although less so than for the higher population scenarios. This growth occurs in many other sectors although there are some notable exceptions.

In terms of the physical economy, growth gives us cause to be optimistic in the short term for three reasons (although the same may not apply in the longer run).

- First, 20 years of assured activity gives the nation time to implement substantial institutional innovation in a robust marketplace.
- Second, stocks of buildings, motor cars, passenger transport and freight systems that incorporate the most advanced technology will have the time to penetrate the national system (and thereby allow for the stabilising of flows of energy, materials and waste).
- Third (provided points one and two eventuate), growth could underpin new export industries that are rich in services and information. These could substantially replace the current export mix (which consumes high levels of energy and materials).

3. Detailed demographic outcomes of three population scenarios

By the year 2050, the low, medium and high population scenarios give domestic populations of 20, 25 and 32 million people respectively. By 2100 the scenarios give 17, 25 and 50 million people. The results are broadly consistent with other national demographic analyses. The low scenario does not decline as precipitously as shown in some other studies due to slight differences in assumptions about the fertility rates of younger females.

The high population scenario gives a younger population in a proportional sense. By 2050, the proportion of people over 65 years will have stabilised at 20% of the population. This compares to 27% for the low scenario, and 25% for the medium scenario. By 2070, this will be 29% for the low scenario and 27% for the medium scenario.

The proportion of dependent people, a concept important for health and welfare issues, is greater for the low and medium scenarios. For indices of dependency that relate the number of younger and older people to those of working age, the next 20 years will see the lowest dependency ratio since the 1940s. However, by 2030 the low and medium scenarios will experience dependency ratios similar to those at the height of the baby boom in the 1960s, although dependency will be focused on older rather than younger people. After 2030, the low and medium scenarios reach a ratio of between 7 and 8 dependents per 10 of working age, whereas the high scenario stabilises at 6 dependents per 10 of working age.

The changing demographic structures raise three important issues.

- First, regional Australia tends to age more than the cities, due to assumptions about internal migration.
- Second, the impacts of regional ageing are compounded because of increasing aged-related medical problems in the regions, compared to younger cities.
- Third, the demand for services such as education will fluctuate, driven by slow moving changes in demographic structures. It is feasible to prepare the workforce, and its infrastructure, well ahead of time to better accommodate these issues.

4. Technological innovation offers promise *but*...

Aggressive implementation of technology to address key problems of resource use and environmental quality show much promise. For example, smart designs already in existence for houses and motor vehicles can significantly reduce energy use and greenhouse gas emissions.

However five important caveats limit the potential of technological solutions.

- Current consumer sentiment in general stimulates the requirement for larger buildings, more quality and luxury, more powerful motor vehicles and more frequent air travel.
- An efficient consumer-led economy generally embraces growing volumes of cheaper goods and services, which in turn consume increasing levels of energy and material.
- While pricing policies can moderate the use of resources such as energy and water, they are seldom applied to stabilise resource use in a physical sense, although there are exceptions.

- Furthermore, the direct and indirect requirements for energy, water and land are directly related to per capita expenditure. As per capita expenditure grows, so too does the resource quotient required to produce the sum total of goods and services included in total personal consumption.
- Finally, there is the 'rebound effect' where efficiencies gained in one sector give savings (in resources or money) that inevitably migrate to stimulate resource use in another sector.

Therefore, while technology can be a powerful ally, it will struggle to reach its full potential under the current structure and function of Australia's economic and social system. As the population and the economy grow, so too will the physical transactions required to underpin economic success.

5. Direct and indirect levels of population influence

To effectively gauge the effect of population growth on resource and environmental outcomes, a conceptual framework emerged from the CSIRO research where Australia's population is seen as having four levels or tiers of influence.

- The first level is the direct influence. More people consume more energy and materials and thereby produce more waste and emissions. This primary influence has been reasonably well documented over the last 30 years. Under all population scenarios, this study has confirmed that barring unforeseen catastrophes, Australia has enough land, water, and energy to provide food and a moderate lifestyle for all its citizens out until 2100. However there will be significant pressures on marine fisheries and domestic stocks of oil and gas.

- The second level of population influence is driven by discretionary, rather than obligatory, lifestyle factors. Rising affluence and its effect on consumption patterns is a strong driver of modern economies. However, affluence is underpinned by energy and material transactions that increase as discretionary spending rises. Rising affluence is one contributor to rising resource use, even in the low scenario where population is declining. Technical innovation must continue to outrun lifestyle requirements, if material and energy use is to stabilise.

- The third level of population influence is driven by international trade in goods and services. Most nations have export industries so that they can pay for imports. In a modern consumption-driven economy, import volume is related to population size, its growth rate and its per capita affluence. Many of Australia's commodity and manufacturing industries are export focused with only part of their production being consumed domestically. The outcomes of total production, be they profits, jobs or regional development, still flow back to the domestic population, at least in a theoretical sense.

- The fourth level of population influence is driven by international debt levels. Long-term investment funds flow in to assist project development and the expansion of industry and infrastructure. Whether this happens in anticipation of, or in response to population growth, is a moot point and the real answer is probably both. Failure to balance the costs of imports and exports (the third population influence), is another contributor to international debt as the nation borrows to fund its current account deficit.

Much media and policy analysis tends to ignore the second, third and fourth levels of the population debate.

6. Resource and environmental issues of concern

Direct population effects (the more people the greater the effect) are important in three areas of resource consumption and environmental quality: stocks of marine fish, stocks of oil, and air quality.

- Stocks of marine fish: Australia runs a sizeable deficit in the volumetric account of its fish trade while some of its marine fish stocks are considered over utilised. As population grows, per capita consumption is also expected to grow, bringing more tensions between volumetric supply and demand. Although managerial and technological responses are well underway, the response times are usually long and Australian waters are relatively unproductive by world standards. Pressure on fish stocks globally and in international waters near Australia, will increase with the steady expansion of consumer demand in developing countries, where disposable income and population are growing strongly. Part of this growing pressure will occur in Australian waters, thereby adding to the direct effect of domestic population.

- Stocks of oil: Modelling of domestic oil stocks shows some parallel with the fisheries situation. The study highlights a growing gap between domestic oil production and domestic requirements past 2010. This generally agrees with expert opinion in petroleum geology and oil industry circles. The higher the rate of population growth, then the bigger the gap will grow. While imports may fill the gap in the medium term, meeting demands in the longer term will need multiple responses including: the discovery of new petroleum provinces, the widespread use of energy efficient vehicles, and the development of other fuel sources such as natural gas, oil shale and biomass. In the 50-year timeframe, alternatives to cheap oil are possible, though there will be significant challenges in this transition. The higher the population, then the larger the challenge.

- Air quality: The quality of the airsheds of our capital cities could decline substantially if population and car use grows strongly (especially given that circulation patterns to disperse air pollutants are relatively ineffective in most city airsheds). Better car engines, cleaner fuel, car-free days and more public transport will all help. However, worldwide trends suggest that delivery vehicles and articulated trucks (central to the just-in-time service economy) will, to some extent, counteract lower emissions associated with better cars.

The study has not linked the problems of agricultural lands, loss of biodiversity and the decline of water quality of inland rivers directly to the primary population effect. Rather these are due to the third level of population influence (connected to our export industries). Most countries export goods and services to pay for imports. In a consumer driven economy, imports are strongly linked to population issues, but moderated by a range of volatile shorter-term issues such as currency exchange rates.

Surprisingly, the study identifies that water availability is not likely to be a constraining factor under any of the population scenarios, provided that big changes occur over the next 50 years. Although water is almost as important as energy as a precursor to social advancement and economic growth, the volume of water available to meet the demands of all population scenarios is sufficient. A wide range of institutional and technological opportunities exist for innovation.

Due to projected constraints on the availability of water in southern Australia under all population scenarios, the study has developed physically consistent scenarios that expand irrigated agriculture in northern Australia. This carries the same risks as the southern experience over the last century unless new technological and institutional innovations are implemented.

7. Management of big slow moving variables (stocks versus flows)

The size or structure of the slow moving variables (the stocks) in relation to the faster moving variables (the flows) determines the degree of resilience. In population terms, the slow moving variable is the population size (changes slowly) and the faster moving variables are the births, deaths, emigrants and immigrants (varies year to year) that determine the rate at which the stock will change.

The slow moving variables govern all the important issues linked to population outcomes in this study. Australia is poorly placed to understand such issues in aggregate (though there are some notable exceptions).

For example, the modelling suggests that better cars and better houses will have little moderating effect on total energy use and subsequent greenhouse emissions. If vehicle and housing policy is to affect future energy use, then each year's complement of new houses and new cars must meet the highest, rather than the average, technical standards. Only then will the characteristics of the stocks (and thence the flows driven by the stock characteristics) be improved over timescales of 20 to 40 years.

Without a focus on the slow moving variables, policy design for the physical economy is running blind. As an example of a slow moving variable, the demographic focus on population ageing with 50 year timeframes is appropriate. The same focus and timescale should be applied to most sectors of the physical economy. Policy design for guiding the slow moving variables is probably best left to government, while the discipline of the market is probably better at managing the fast moving flows in most cases.

The reality of control by slow moving variables leads to an important theoretical point that has emerged throughout the study. Most systems in the world, be they natural or human made, usually seek to maintain a measure of robustness or resilience. Forests store their nutrients in biomass, workers invest in superannuation and nations have constitutions. Resilience allows those systems to innovate, take new directions and resist shocks.

8. Challenges for the low population scenario

A number of environmental and political groups advocate the low population scenario (20 million people by 2050 driven by an assumption of zero net immigration). They believe population stability (or even population shrinkage) might reduce the consumption of resources and improve environmental quality

Within the assumptions and methodology used in this study, a lower population size resulted in the stabilisation of a range of environmental quality issues (emissions in the airsheds of capital cities) and resource use issues (household water use). Total greenhouse gas emissions were lower than in other scenarios and the physical trade balance was higher. The per capita material flow account was also higher (because of the dominating influence of international trade with less people).

The key challenges in this scenario relate to rapidly declining population after the year 2100, a larger proportion of aged citizens and the possibility that health care and pensions systems will not be able to cope. Under the scenario assumptions, the population declines in many rural areas. Key sectors of the economy such as building and motor vehicles stabilise, due to population decline. Other analyses show that the size of the labour force may not be sufficient to ensure both the maintenance and expansion of key economic sectors. It is suggested that without substantial structural change, maintaining economic growth in a declining population could be difficult.

Other countries further down the path in the transition to an ageing population may develop solutions to the problems presented by this scenario. Many of the problems may even disappear as the nation adapts to issues, long before they become critical. The low scenario could also stimulate home-grown innovations that could be turned to the nation's economic, social and environmental advantage, since the rest of the developed world will eventually be travelling along similar transition pathways.

9. Challenges for the medium population scenario

The medium population scenario (25 million people by 2050, driven by an assumption of 70 000 net immigration per year) represents approximately the average net overseas migration during the past decade. A range of analysts and social commentators support this scenario as rational in a demographic sense, practical in maintaining a balance between the economic and social aims of an immigration policy, and helping to maintain the contribution of population growth to economic growth.

The key element of this scenario is the stabilisation of population size after 2050. However, even with stabilisation, resource use and pressures on the environment keep growing due to scenario assumptions of growth in personal affluence, the growth of our export trade and inbound tourism and the failure (also common to the other population scenarios) to implement cutting-edge technology across all sectors.

The medium scenario maintains key elements of the past 50 years for the next 50 years. Thus it is sufficiently comfortable to avoid major decisions that might be forced by population decline in the low scenario, or rapid population growth in the high scenario. Its key challenge is to move from relative inactivity, into aggressive and positive action on several major fronts. How does the nation enable major investment to proceed while addressing failing marine fisheries, declining biodiversity, and land and water degradation? How do capital cities restrict edge growth while re-inventing urban transport and energy systems to provide low carbon transport and energy services with reasonable equity? How could the nation's endowments of domestic oil and gas stocks be diverted past short-term personal consumption, into capital stocks that produce low carbon electricity and transport fuels for subsequent human generations?

It’s possible that a moderate sized and stable population well endowed with natural resources could manage a physically intensive economy with steady adaptation well into the future. However, given the current success of information-rich economies versus commodity-based economies, this pathway has many risks.

10. Challenges for the high population scenario

A wide range of business leaders, politicians, economic analysts and technological optimists promote the advantages of growth and size that come with the high population scenario (32 million people by 2050, driven by an assumption of net immigration per year of two thirds of 1% of the total population)

Continuing growth is the key element of this scenario with an eventual population of 50 million by 2100. While resource use and environmental quality issues are more challenging than in the other scenarios, some ageing issues are moderated in a proportional sense. Possible constraints to the size of the labour force are less severe as are various dependency ratios that relate numbers of non-workers to workers. Melbourne and Sydney become megacities of 10 million people by 2100, with possible constraints to their resource requirements and efficient function.

The key challenge for the high population growth scenario is to come up with a ‘flight plan’ to cope with the accelerating growth. This 'flight plan' should ensure that material and energy issues do not interact to stimulate a condition of hyper-materiality (in which Australia’s physical economy locks into an ever expanding loop of construction and consumption). The dilemmas of resource use and environmental quality, already a challenge for low and medium scenarios, must be solved with faster moving trajectories. The balance of trade deficit for oil (by 2020) and natural gas (by 2040) becomes more critical and keeps growing to 2100 and beyond.

Finally, a key demographic challenge emerges if the required numbers of young immigrants cannot be found to fulfil the scenario assumptions. Then the high scenario rapidly defaults to the demographic profile of the low or medium scenarios it was designed to escape. The ageing problem will thus emerge, only in the high scenario it will be a much larger problem set within a larger physical-economy with the same set of protracted environmental dilemmas.

Genesis of *Future Dilemmas*

Some people believe Australia cannot sustain a population much larger than we have today and advocate a zero immigration policy. Others believe future prosperity lies with strong economic growth fuelled by an increasing population and propose increased levels of immigration. What are the long-term consequences of either approach? Or what’s the result of continuing on at the current levels of immigration?

This is not a new debate. Discussions of population targets for Australia and the carrying capacity of the country go back to the 1920's when a Sydney University geographer, Thomas Griffith Taylor, estimated Australia's carrying capacity at 65 million people. He later reduced this estimate to 20 million people.

During the 1980's and 1990's there have been several national inquiries on population, the most recent of which was the Jones Inquiry (Long Term Strategies Committee, 1994) which stopped short of recommending a specific national population policy. By default, Australia's population seems to be moving towards a more or less stable population of around 23 to 25 million people in one to two human generation's time.

During the 1990’s, techniques for population analysis evolved to include a wide range of issues such as the resilience of our ecological systems, levels of material consumption, sustainability and population size as a determinant of domestic market efficiencies, and Australia's place in world affairs.

It was against this background that CSIRO, Australia’s national science agency, initiated a strategic project to underpin the population debate (and its linkages to resource use and environmental quality) with scientific analysis. The project's aim was to focus on the environmental aspects of population impact with particular emphasis on the quality and quantity of water, soils, biodiversity, atmosphere and natural amenity.

Initially the work proceeded along a traditional scientific route with plans made to examine the effect of population on issues such as water resources, land resources and urban infrastructure. However, it soon became apparent that the complex linkages between all sectors of society and the economy were going to make this traditional approach (which set up tight boundaries around a well defined problems prior to analysis) was going to be difficult to implement. This was particularly the case when researchers were asked to look to the long-term future (up to 50 years ahead) and to integrate advice from experts in many sectors into their analysis in order to come up with a range of options to meet future challenges.

The CSIRO project, named Resource Futures, began searching for new ways of modelling the future. At this time the project became aware of two important methodological approaches. The first was the use of foresighting and scenario development, a technique used by multinational companies such as Royal Dutch Shell to build possible pathways of future development given different starting conditions.

The second was the implementation of population-development-environment simulators that modelled the physical economy of a country rather than the money economy. The term 'physical economy' describes the vast array of physical transactions that underpin the monetary economy.

By using these approaches, the scope of the project evolved to include the development of options for national policy on the impact of different levels of human population on the environment. Two linked themes of work emerged. The first was that of scenario development where a number of robust and well-documented national scenarios were developed to lead and inform debate on national development and sustainability.

The second theme of work was developed in order to underpin the scenario work with quantitative analyses. Within this theme, two system simulators were developed based on different philosophies of physical analysis. One of these was called *OzEcco*. It uses embodied energy (the direct and indirect energy required to create a good or service) to construct an energy-based simulator of Australia's physical economy. This analytical approach asserts that the delivery of goods and services is a function of the extraction, delivery and efficiency of use of energy resources (most of which are currently derived from fossil sources).

The second simulator, the *Australian Stocks and Flows Framework* (ASFF), is a disaggregated set of linked models which are grounded in a database that describes the key elements of Australia's physical function over the last 50 years. It's attractive because it treats the complete range of physical function as separate entities (crops, animals, people, cars, steel production, chemical production) and takes into account the age of most large items of physical infrastructure. It allows researchers to generate alternative future scenarios by re-running the simulations using different policy settings.

Using this physical economy approach, the CSIRO team began three years of workshopping, database improvement and model development that aimed to quantify and disentangle the many issues relating to three hypothetical population targets over the next 50 years and beyond.

Sixteen expert workshops were held during 1999 to critique the ASFF model and the many controlling assumptions that drove it to 2050. Following the workshopping, draft chapters of the report were reviewed by DIMIA policy analysts, CSIRO scientists and an external reference group appointed by the Minister for Immigration and Multicultural and Indigenous Affairs. The process was continued through several iterations of further model analysis and internal policy debate. Parallel to the internal process, a wide range of briefings to policy, scientific and business audiences were also held between 1999-2002.

The structure of *Future Dilemmas*

Future Dilemmas is comprised of eight chapters plus two appendices. Each chapter examines a different issue connected with the potential impacts of future population scenarios, but each chapter is also connected to insights from other chapters (i.e. each chapter builds on the one before). This serves to emphasise one of the important messages coming out the report: simple adjustments for any particular effect of population growth cannot be made without taking into consideration the flow-on effects to (and interactions with) other sectors of the economy, the environment and society. The indirect impacts and interactions may not appear at first to be important but they move through the system and then feedback to impact on the original sector being focussed upon.

The broad structure of *Future Dilemmas* is as follows:

Chapter 1: Modelling physical realities, discusses the history of population/environment studies, the methods used in this approach (ASFF, *OzEcco*, and scenario analysis), and provides background to the study.

Chapter 2: People and their needs, looks at projections of Australia's future overall population out to 2050 (and its age structure). Chapter 2 also introduces the concept that population levels have a variety of direct and indirect effects on the way we consume resources. These are important in considering the analyses in the remaining chapters. Four levels of population influence are described: primary, secondary, tertiary and quaternary (going from direct to indirect).

Chapter 3: The urban environment, focuses on the requirements of urban infrastructure for our towns and cities (these are primary effects directly linked to population level and secondary effects linked to the affluence of the population).

Chapter 4: Natural resources and environment, examines the ways in which four resource sectors (minerals, agriculture, fisheries and forestry) might respond to future domestic requirements and export opportunities (these are largely tertiary effects related more to our export requirements than our domestic consumption).

Chapter 5: The future of energy, looks at Australia's future energy requirements.

Chapter 6: The future of water, looks at Australia's future water requirements. Water (and energy) are critical physical contributors to economic productivity, national development, social well being, personal lifestyle and the maintenance of Australia's ecosystems.

Chapter 7: Challenges and conclusions, seeks to integrate this national population analysis by highlighting a set of challenges that operate at a higher level than the individual analyses presented in the previous chapters. Six challenges (described in this report as dilemmas) are presented which link population policy, ageing, physical trade, material flows, greenhouse emissions, natural resource depletion and environmental quality. Ten conclusions from the whole report follow the dilemmas.

Chapter 8: Overview of the report by the External Reference Group, presents the overview of a report put together by a group of external experts brought in to 'ground truth' the study. Economists, ecologists and demographers present their views on the approach taken by the CSIRO researchers, the robustness of the analysis and the value in this type of exercise.

Chapter 1: Modelling physical realities

Key messages in this chapter

- Analytical frameworks that describe how Australia functions in a physical sense are important requirements to any discussion of long-term sustainability.
- Generally these frameworks (or models) are designed to work in 50-100 year timeframes, well beyond the scope of nationally scaled economic and social models. They are designed to complement shorter-term policy analysis by testing pathways to the future that are physically feasible in an engineering sense.
- The timescales are appropriate to issues such as human demography, turnover in national infrastructure, and stocks of both renewable and non-renewable resources. They focus on the exploration of scenarios (possible futures) and do not predict in a traditional shorter-term policy sense.

This opening methodological chapter explains why the CSIRO researchers chose to explore Australia’s future by modelling the physical economy. It discusses the genesis of the modelling approach used – the Australian Stocks and Flows Framework (ASFF) – and explains how physical economy models are designed and applied.

Sustainability is all about dealing with the long term. Long-term issues can only be explored with long-term methods that can quantify slow moving variables such as population momentum and infrastructure inertia.

In order to examine the long term consequences of many policy interactions, analytical frameworks are required to design and test different functions and structures for the physical economy. **The term 'physical economy' is used here to describe the array of physical transactions that underpin the monetary economy.** For every dollar that is exchanged in Australia's gross domestic product, there is a chain of physical transactions that bring that final good or service to the shopkeeper's counter and the consumer's basket.

To supply our essentials, to maintain our lifestyle and to pay for our imports, Australia’s physical economy moves over 200 tonnes of material per person per year. By contrast, Japan moves around 40 tonnes, while the USA moves 80 tonnes per person.

The ability to analyse these transactions is described within the Australian Stocks and Flows Framework (ASFF), the foundation of this population analysis.

ASFF is a set of 32 linked calculators that follow, and account for, the important physical actions that underpin our everyday life. It is based on systems theory that focuses on connections and information flows. It is implemented as a dynamic model rather than with the equilibrium philosophy that underpins most nationally scaled economic models. This allows transition pathways towards new designs for the physical economy to be implemented and evaluated for physical feasibility. By ‘physical feasibility’ we mean that the design obeys physical laws and relationships such as thermodynamics and mass balance.

The foundation of the ASFF model is based on a historical database spanning the last 50 years. This data describes all the significant items that make up the physical economy (such as population, infrastructure and resources). A model grounded in the physical reality of the last 50 years is reasonably formulated to deal with the big, slow moving variables that will drive the next 50 to 100 years.

These big slow moving variables (their age, location and technical specifications) are what drive day-to-day issues such as health, housing, energy, greenhouse emissions and environmental quality. Understanding the trajectory of, and the interactions between, the big slow moving variables can provide reasonable approximations of the far view. These approximations, based on physical reality rather than market sentiment, can in turn inform and guide immediate day-to-day decision making. Better information can thus underpin more informed decisions.

The decision to act, however, is ultimately a social and political one. Effective modelling can now contribute to effective policy formulation, but it will never be a substitute for it.

Policy considerations arising from chapter 1

- Large, slow moving variables (such as population, infrastructure and resource use) lie at the heart of the physical-economy modelling used in this study. Contemporary policy decisions are more usually based on the smaller, fast-moving variables such as currency values, interest rates and unemployment rates (often without consideration that these faster-moving variables are actually driven by the slow-moving ones).
- Constructing the ASFF model of Australia's physical-economy revealed that appropriate information bases central to the task aren't consistent, are poorly documented and maintained, and are unequally distributed over many institutions. Any transition towards a functional national infrastructure and a sustainable physical-economy will require a complete and consistent information base. National policy forums for both development and sustainability may need to consider this issue.

Chapter 1: Modelling physical realities contains the following sections:

Chapter 2: People and their needs

Key messages in this chapter

Each of the three population scenarios has advantages and disadvantages.

- The low scenario stabilises the size of most capital cities at around current levels but many regional and rural areas may continue to have population shrinkage. The proportion of aged and dependent persons is similar to the medium scenario out to 2050, but the total numbers are lower and attendant health tasks are therefore smaller in an absolute sense. The overall population in the low scenario declines by 15%, or 3 million people, in the period 2050 to 2100. Beyond 2100 this scenario could accelerate into rapid population decline.
- The medium scenario gives a stable population number overall with continuing growth for the next 25 years in capital cities and main regional areas. While the size of the population might stabilise, the proportion of older people will increase with linked effects for health and aged care.
- The high scenario gives population growth in most cities and regions but with looming challenges in how Sydney and Melbourne will function as megacities each with 9-10 million people by 2100. While the proportion of aged persons and total dependants is appreciably smaller in this scenario, the absolute number is larger and continues to grow, producing an ever expanding health and aged care task.

By 2050, Australia could be home for 20 million people (if we follow a population trajectory set by zero net immigration), 25 million people (if we allow net immigration of 70 000 persons per year) or 32 million people (if we set immigration levels at 0.67% of the population each year). Subsequently these population scenarios will be described as **low** (20 million)**, medium** (25 million) and **high** (32 million).

This chapter compares these three populations in terms of size, trajectory, age profile, household formation, location and labour force composition. It also explores their education, health and age care requirements and their basic food and material needs.

The characteristics of the three populations set out in this chapter form the starting point for the assessment of their environmental and resource implications in the following chapters. This chapter also examines possible future levels of tourism (which will have significant physical impacts additional to those of the resident population).

Key findings of this chapter include:

- **The size of our cities:** By 2050 both Sydney and Melbourne might each remain the same size (low), each grow by one million (medium) or each grow by three million people (high). By 2100 under the high scenario, both Sydney and Melbourne could become megacities with populations of around 10 million people.
- **The age structure:** The number of Australians aged 65 years and over by the year 2050 varies from 5 million in the low scenario to between 6 and 7 million for the medium and high scenarios. However, the proportion of the population over 65 in 2050 represents 25-26% for the low and medium scenarios, and 20% for the high scenario. The population requiring institutionalised aged care by 2050 is 470 000 for the low scenario and greater than 600 000 for the high scenario.
- **The labour force:** The total labour force declines to 9 million in the low scenario, stabilises at around 11 million in the medium scenario and increases to 15 million for the high scenario.

- **Tourism:** Domestic tourism stabilises slightly below 600 million visitor-nights by 2020 for the low scenario, increases to 700 million visitor-nights for the medium scenario and increases continuously to 900 million visitor-nights by 2050 for the high scenario. Under all population scenarios, numbers of international inbound visitors are projected to increase from 4.7 million currently to 32 million by 2050, with nearly 600 million visitor nights.
- **Food requirements:** The food required for the domestic population (and inbound travellers) increases with the population number in each scenario. Apart from fish production, it is reasonable to assume that Australia will retain a positive food balance out to 2050 and beyond. However domestic consumption under the high population scenario may reduce the amount available for export trade and international trade balances may be affected.
- **Paper and plastic:** The requirement for general consumables such as paper and plastic continue to rise in line with growing population and rising affluence. By 2050 the requirement for paper could exceed 4 million tonnes for the low scenario and 7 million tonnes for the high scenario. Similarly the requirement for plastics could vary from 1.5 to 2.5 million tonnes per annum. In both cases recycling will reduce the requirement for virgin materials but increase the requirement for process inputs, energy and transport.

Most of the issues discussed in Chapter 2 are related directly to the size of the total population. The number of people in Australia will directly affect the size of the major capital cities, the domestic consumption of food, paper and plastic, and the requirements for urban water supply.

However, the size of the population has other, less direct (more diffuse) impacts on the use of resources and environmental quality. These need to be considered and factored in to policy formulation. In this study, four key drivers have been defined

- **Primary** (or first order) drivers are linked directly to individuals who require food; households who require houses, cars, newspapers, televisions and refrigerators; and communities who require schools, hospitals, public transport and sporting ovals.
- The **secondary** (or second order) drivers of population growth are linked to affluence, lifestyle and scale issues. Affluence and lifestyle issues describe the expansion of a direct requirement or need into a higher level of consumption or quality that could require more energy and materials to deliver that good or service. Everyone needs a house (primary driver) but affluence might lead to the construction of a larger house (secondary driver). Scale issues relate to threshold effects such as the presence of international airports, convention centres and five star hotels that expand opportunities for industries such as tourism and thereby stimulate transactions in the physical economy.
- The **tertiary** (or third order) drivers of population growth occur when the domestic requirements for imported goods and services have to be covered by revenue from the goods and services from the nation's export industries. These rising level of imports are linked to consumption growth on a per capita or per household basis. They have to be paid for by exporting commodities such as coal, aluminium and wheat and importing international tourists. Traditionally, the national population debate ignores this tertiary driver of population effect.

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- The **quaternary** (or fourth order) drivers occur when the lagged effects of previous population growth and economic development have contributed to issues such as international debt and weakness of currencies. These may drive the requirement for physical activity particularly in export industries well into the future until these pressures are reduced.

Policy considerations arising from Chapter 2

- Food security out to 2050 and beyond is reasonably assured under all population scenarios. However higher population growth rates may consume domestically what might have been exported, affecting trade balances.
- The number of people in Australia will directly affect the size of the major capital cities, the domestic consumption of food, paper and plastic, and the requirements for urban water supply. However, the size of the population has other, less direct (more diffuse) impacts on the use of resources and environmental quality. These need to be considered and factored in to policy formulation. In this study, four key drivers have been defined. The simple effects of population growth are made much larger as the four drivers multiply and interact in complex ways.

Chapter 2: People and their needs contains the following sections:

Chapter 3: The Urban Environment

Key messages in this chapter

- Population numbers are the primary driver of resource requirements in urban Australia. However the role of lifestyle and affluence (a secondary driver not directly connected to the size of the population), is also significant. As these two factors begin to interact, the eventual outcomes in terms of material and energy usage will depend on a range of interactions, rather than just population numbers.
- The key concept introduced in this chapter is the importance of understanding the size, distribution and longevity of the nation's stocks of infrastructure. The resources required by each set of infrastructure on a day-to-day basis (and the wastes they generate) are determined to a large degree by the design and technology present in that stock. These technological factors determine whether resource use and waste generation will rise in line with growing population number and growing affluence.

This chapter examines the requirements for a number of key infrastructure items that are central to the function of Australia's cities and towns. These include the requirements for housing, transport and roads, as well as a number of key resource issues such as how much water is consumed in the production of the building stock, and the requirement for energy (and the subsequent generation of emissions).

Population numbers are the primary driver of resource requirements in urban Australia. Consequently the different outcomes for each of the three population scenarios for most of the items discussed in this chapter relate directly to the size of the population.

However the role of lifestyle and affluence (a secondary driver), is also significant, and this is less directly connected to the size of the population. Lifestyle and affluence drives the steady expansion of floor area of dwellings and retail space, the maintenance of car ownership levels and yearly driving distance, and the relatively minor part that mass transportation systems play in our daily lives.

Consider domestic housing as an example that highlights the difference between primary and secondary population effects. Currently we have around 7 million houses. The modelling suggests that by 2050 the low scenario will require an additional 30% of housing stock, 60% for the medium scenario and 100% for the high scenario. The total number of people directly affects the number of houses we will require (a primary effect).

However, levels of lifestyle and affluence (a secondary effect) will also have profound influences on the amount of resources consumed. One of the physical parameters used to describe this is that of dwelling size in square metres. During the historical period for the simulation from 1940 to the present, the area of the single dwellings in metropolitan areas rose from 100 to 150 square metres per dwelling. In the scenario period from the present to 2050, it is assumed is that dwelling area will continue to increase and will saturate or plateau at approximately 200 square metres per single dwelling.

These lifestyle choices for larger houses will significantly influence the amount of material required for housing and the amount of energy used in homes. This effect is quite separate from changes in demand for housing arising from changing levels of population or changing patterns of household formation. As these relationships begin to interact, the eventual outcomes in terms of material and energy usage will depend on a cascade of interactions rather than just population numbers.

The key concept introduced in this chapter is the importance of understanding the size, distribution and longevity of the nation's stocks of infrastructure. The resources required by each set of infrastructure (and the wastes they generate) are determined to a large degree by the design and technology present in that stock. The longevity of the infrastructure refers to how long it will be in operation and acknowledges that technological improvements aren't introduced as soon as they are available, but rather when it's time to replace or upgrade equipment. These technological factors determine whether resource use and waste generation will rise in line with growing population number and growing affluence.

Any national policy that aims to stabilise the consumption of resources (and then reduce it) within a human generation of 25 years, would require that every new unit of infrastructure from the year 2000 incorporates leading-edge technology. Another way of achieving this would be to change human behaviour so that household consumption of energy and water was reduced by 50%.

The report suggests that a combination of both (improved technology and reduced consumption) could provide the best way forward. There are however a number of high level economic and social issues posed by these possibilities. The wide scale privatisation of energy and water utilities over the past two decades has been based on reasonable expectation of increasing physical levels of usage, increasing cash-flow and profits, and reasonable returns on investment. If resource usage is stabilised or declines, then unit price to the consumer must continue to rise to maintain reasonable business expectations. This could increase the cost of living for a household and the costs of doing business for a company. Taken to an extreme, decreasing physical consumption and increasing price, could produce consumer backlash. On the other hand, countries such as Japan have twice the electricity costs of Australia and seemingly thrive in globalised world markets. (However many of their physical transactions are undertaken in other countries.)

A number of subsidiary scenarios are evaluated within this chapter. One of these is: what would happen if we could halve resource use (per unit of service delivery) by 2020. In the areas of energy and water used by built infrastructure, and in motor car transportation services, the evaluation indicates that by 2050 that the higher population levels in the high scenario could function at levels of resource usage similar to those in the year 2000 (when the nation houses approximately 19 million people). The degree to which consumers, markets and governments are open to the fundamental changes that would be needed to produce this outcome remains a topic for considerable debate.

Policy considerations arising from Chapter 3

- The increased sophistication and quality of Australia's urban areas are steadily increasing the direct and indirect requirements for materials and energy in an overall sense. Meeting national energy requirements while curbing greenhouse gas emissions therefore present a dual challenge as the physical realities of increasing affluence are compounded by the population growth rate.
- There are many innovations and behavioural changes that could stabilise and reduce the consumption of key resources by urban Australia. However, the payback periods for superior urban designs are likely to be in decades. Many political and commercial tensions will arise if pricing mechanisms are introduced that significantly raise prices.

Chapter 3: The Urban Environment contains the following sections:

Chapter 4: Natural resources and environment

Key messages in this chapter:

- The three main areas of resource and environmental concern are:
  - the adequacy of future oil and gas production levels,
  - the loss of agricultural land and linked effects on water quality, and
  - a trade imbalance in fish products for domestic dietary requirements.

  These concerns exist under all three population scenarios.
- Other than this, there appear to be few resource constraints to Australia meeting increased global requirements for its mineral products provided that technology and exploration develop new provinces and processes to access high quality mineral resources.
- Given Australia's large land mass, agricultural production can meet the domestic requirements for food production out to 2050 and beyond.

This chapter examines the ways in which four resource sectors of the Australian economy might respond to future domestic requirements (the primary population effect) and export opportunities (the tertiary population effect). The four sectors are minerals (with a major focus on oil and gas), agriculture (both plant and animal based), fisheries (with a particular emphasis on the wild caught marine fishery) and forestry (with emphasis on the expected expansion of managed plantations).

Most sectors dealt with in this chapter seek to supply export markets. These sectors are only indirectly affected by the population size and the modelling showed resource use was similar in all three population scenarios. The exceptions are oil, natural gas and fisheries where available resources may not meet domestic demand, let alone over seas demand. In these situations domestic population levels do have more of a direct influence on these resources.

The minerals sectors (except for oil and gas) generally expand out to 2050 on the assumption that Australian commodities will maintain a trading advantage in the world marketplace and that improved exploration will continue to locate high-grade ore deposits

Production characteristics of the minerals and agriculture industries, and to a lesser extent the forestry and fisheries industries, are driven not by domestic population levels, but by demand from global export markets. Those export markets are in turn driven by populations in the globalised marketplace, and their requirements for subsistence, lifestyle and affluence.

Australia engages in export activities in order to pay for the goods and services that it chooses to import. Apart from oil and natural gas, there appear to be few resource constraints to Australia meeting increased global requirements for its mineral products provided that technology and exploration develop new provinces and processes to access high quality mineral resources.

Tensions between the domestic production and requirement for oil may be evident from 2010 and natural gas production from 2040. Because of the critical importance of oil and gas to the nation's physical metabolism, it may be necessary to develop a 50 to 100 year view of these resources and the possible transition pathways to other energy sources such as shale oil, biomass, methane hydrates on the seafloor and liquefaction of extensive coal resources. These transitions may themselves be constrained by national and global requirements relating to greenhouse gas emissions.

Given Australia's large landmass, agricultural production will meet the domestic requirements for food production out to 2050 and beyond. A large number of substitutions over relatively short timeframes are feasible in dealing with issues such as domestic dietary change, encroachment of agricultural land by urbanisation and changes in globalised trade requirements.

However the environmental effects of agricultural production are substantial and may become further evident from 2020 onwards. Modelling indicates that more than 10 million hectares of agricultural land may be lost to dryland salinity, irrigation salinity and soil acidification by 2050. This will produce a flow on effect in making rivers and streams more saline and acidic. This in turn may increase the difficulty and cost of water treatment for urban and industrial use and may limit the productive potential of many irrigation areas.

Forestry production, mainly from managed plantations, is likely to expand two to three fold by 2050. This is driven by trade opportunities such as the reduction of wood and wood fibre imports, and by environment-economy opportunities such as carbon sequestration and the mitigation of dryland salinity.

Domestic fisheries production and domestic dietary demand will continue to extend the current physical deficit, although expansion of aquaculture may moderate this outcome. There are a number of financial and trade nuances where more valuable fisheries exports (lobsters, tunas and pearls) may pay for the higher volumes of less valuable fish imports from neighbouring countries.

Policy considerations arising from Chapter 4

- Stocks of some natural resources such as domestic oil and many marine fisheries are directly influenced by requirements of the domestic population, i.e. the primary population effect. Use of most mineral resources and agricultural land is driven by international trade opportunities which capture export income to pay for our imports ie the tertiary population effect.
- While fish protein is not a critical requirement for our population, it represents one of the icons of Australian lifestyle. Locally and globally, fish stocks are under pressure from efficient technologies and increasing consumer demand. The growing imbalance between domestic requirements and domestic production will place increased pressure on a finite natural resource. Our marine fish stocks require careful and sensitive management for the long term.

Chapter 4: Natural resources and environment contains the following sections:

Chapter 5: The future of energy

Key messages in this chapter:

- Energy use is instrumental to economic growth. In every dollar of Australian GDP there is the energy equivalent of one quarter of one litre of petrol.
- Over the past century, Australian GDP has become more energy intensive in spite of new and efficient technologies. Much of this can be traced back to growing affluence stimulating personal consumption, and the replacement of human labour with machines.
- Critically important to Australia's future are the domestic stocks of high quality energy resources such as oil and natural gas.
- Designing the transition to the new energy economy (beyond coal, oil and gas) is critical to the social and economic well being of all Australians and their neighbours, whatever the future population size in 2050 and 2100.
- These energy issues lie at the core of future sustainability.

From the physical perspective of a modern economy, energy is responsible for at least half of the industrial growth while representing less than one tenth of the costs of production. This unseen or unacknowledged contribution of energy to modern economic systems needs to be appreciated and taken into consideration when planning future strategies aimed at responding to challenges of global warming.

In addition, there is considerable evidence to suggest that, at the level of the whole economy, increases in energy efficiency may lead to increases in energy consumption rather than allowing more production for the same or less energy usage. This counter-intuitive effect is known as Jevons' Paradox.

Simulations of the population scenarios show that primary energy use might grow from current levels of 4800 petajoules per year, to between 6000 to 8000 petajoules per year by 2050 (1 petajoule is the equivalent of 170 000 barrels or 23 000 tonnes of oil). And these simulations assume the implementation of a wide range of aggressively optimistic technology within the current energy streams. These outcomes do not include a revolution in energy production (eg solar, nuclear or the hydrogen economy) but do include significant changes in composition of primary fossil fuel use.

The greenhouse gas implications (expressed in terms of carbon dioxide from the energy sector) suggest that by the year 2050, emissions may rise to between 170% (low population) and 230% (high population) of the 1990 baseline levels, even under exacting technological assumptions. Failure to meet the technical assumptions underpinning all population scenarios may mean that greenhouse emissions rise to more than 300% of 1990 levels by 2050.

Possible oil constraints in the transport sector can be moderated by a transition to the widespread use of natural gas for transport fuel. However this also constrains natural gas self-sufficiency and lessens export income towards the end of the simulation period.

When a number of subsidiary scenarios from previous chapters (ie, more efficient buildings, cars, freight etc) are implemented in combination, then primary energy use is capped and begins to fall, and with it the carbon dioxide emissions to 140% of 1990 levels by 2050 for the medium population scenario. This shows what innovation can achieve. However, while implementing these subsidiary scenarios in combination is judged to be technically feasible, there are considerable political and social challenges to be met.

The direct effect of the population scenarios on total energy use and carbon dioxide emissions is 6% to 9% lower than the raw population numbers at the year 2050 would suggest. This is due to the energy used in our export industries and international inbound tourism (ie the tertiary population effect).

Policy considerations arising from Chapter 5

- The critical importance of energy use to the maintenance and growth of our economic system is not properly acknowledged in most national analyses (that have a shorter term focus). Long run analyses suggest that energy use is responsible for 50% of production in a modern economy but represents only 5-10% of the cost. This tension between physical and economic realities effectively blocks the transition to a physical economy with low carbon energy sources.
- The greenhouse gas emissions from Australia's energy sector grow steadily under all population scenarios out to 2050 suggesting that any international obligations are unlikely to be met under the current structure and function of the Australian economy. This growth in emissions occurs in spite of fuel switching from coal to gas and the aggressive implementation of advanced and efficient technologies.

Chapter 5: The future of energy contains the following sections:

Chapter 6: The future of water

Key messages in this chapter:

- Water like energy, is a critical resource for the economic and social well being of Australia. Its direct cost generally does not reflect the full ecological and social costs of its acquisition, supply, use and disposal.
- While direct use of water by households is often targeted in public policy, the amount of water embodied in, or contributing to, each individual's total consumption, is the key issue. This extends the footprint of consumption activities in urban Australia well beyond the suburb. It links the current consumption decisions of an individual to the water futures for the nation.
- Water quality rather than quantity is the key issue for the future, although Sydney and Melbourne may face quantity constraints at 2100, under the high population scenario.

This chapter reports on the requirements of the amount of water required for the maintenance of national productivity (as defined by the assumptions in the base case/medium scenario). In particular it reports on:

- Analytical approaches that integrate the physical aspects of the water system with economic and other measures (including process analysis, water accounting, embodied water analysis and water vapour flows).
- The water required by manufacturing, mining and urban areas to 2050.
- The water required by agriculture including a major expansion in Northern Australia.
- Issues that relate to the trade in virtual water, the water embodied in goods and services that nations import and export.
- The particular population dependent issues for water in Australia, and how they link to the tertiary population issues of trade.

Water, like energy, is essential to the nation's economic productivity, its lifestyle characteristics and the maintenance of biodiversity values and ecosystem services. In economic terms however, its undervaluation has resulted in a number of unintended environmental consequences in Australia with salinity and high water tables in irrigation areas, as well as degraded river systems.

By 2050 the water requirement for urban Australia could vary from 5000 to 8000 gigalitres per year depending on the population scenario.

Under all population scenarios there was a simulated increase of total managed water usage from 24 000 gigalitres per year (current levels) to over 40 000 gigalitres per year by 2050. This is due to a major expansion of irrigated agriculture in northern Australia as constraints on the availability and quality of water are experienced in southern Australia. This expansion is not without its risks, and it is possible that the southern experience could be repeated in the north.

The water requirements for industry, mining and domestic use represent about 20% of total consumption and while there is a population effect in each of the scenarios, projected demand could be met by transfer of water from agriculture.

It is assumed that the integrity of key urban water catchment areas will be improved and that with appropriate regulation and technology innovations, high quality water supplies will be maintained for domestic use. The Australian water system appears to have many similarities to water systems in developing countries and it is critical that the transition is made to equitable and just water allocation between competing uses.

In international trade terms it could be to Australia's advantage to quantify the embodied water content of the goods and services that it imports and exports. Australia currently exports an estimated 4000 gigalitres of embodied water more than it imports. This is approximately the same amount used each year by urban Australia. If relatively poor trade prices are received for these products, then the nation accepts a double loss as funds are sought to repair the integrity of its river systems.

It is possible that technical and management innovations could reduce the overall requirements from the managed water resource, and allow the delivery of similar water services for less water.

The most critical issue for the future of water in Australia does not relate to finding and acquiring enough to use. Rather, it relates to the plethora of side effects associated with the use of that water. The issues of irrigation salinity, river salinity, depletion of inland fisheries, maintenance of economic and social vitality in regional areas, heavy metal and pesticide contamination and the beauty and amenity of our urban areas are tied to water use.

It is relatively easy to promote the cause of water use efficiency as there are many private and corporate benefits tied to the manufacture and sale of water reticulation infrastructure. Much more difficult are the challenges of just and equitable allocation of water.

Tied into this allocation challenge is the physical aspect of how much water is embodied in each product we consume domestically or export, and whether sufficient monetary, environmental and social costs are being obtained in the international market place for the water used. It could be concluded that a country with a balanced physical trade account, and a low level of international debt, would not have to rely on water based agriculture to the same extent as today's international trading structure. The nation's water system could then function at a more relaxed and possibly more natural level.

Water is precious to its people, its industries and its environmental integrity. A nation with a long term strategic view would know the extent to which water is embodied in each good and service that it produces for domestic consumption, for export or that it imports. Such analyses could form the basis for the equitable allocation of water with appropriate integration into economic, social and environmental systems.

Policy considerations arising from Chapter 6

- By 2050 the direct use of water by Australian households varies from 12-20% of the total managed water use under the three population scenarios. However embodied water analysis shows that 30% of water use is required for domestic food production and another 30% for exports. When direct household use and services are included, over 80% of total water use can be attributed to the primary, secondary and tertiary drivers of population. Population analyses that focus only on the adequacy of water supplies for direct urban use, are thus myopic and misleading.
- Australia currently runs a deficit of 4000 gigalitres of embodied water in its international trade. This is approximately the same amount currently supplied to household use. By 2020 many of our trading partners will be water poor. Opportunities exist to develop economically rewarding trade arrangements that acknowledge the water content and the ecosystem services that are embodied in each unit of our international trade.

Chapter 6: The future of water contains the following sections:

Chapter 7: Challenges and conclusions

Key messages in this chapter:

- The exploration of the population scenarios has highlighted six high level challenges (described in the report as dilemmas) which require resolution in order to balance social, economic and environmental outcomes of population growth. These dilemmas link population policy, population ageing, physical trade, material flows, greenhouse emissions, natural resource depletion and environmental quality.
- These dilemmas interact in non-intuitive ways and eventual solutions may require substantial structural and social change.
- It is difficult to conceive of an institutional framework within which the resolution of such dilemmas might take place. For example, the population ageing and greenhouse issues are strongly liked in physical terms and time spans, but are effectively decoupled in institutional and philosophical settings.

This chapter seeks to integrate this national population analysis by highlighting a set of challenges (described in the report as dilemmas) that operate at a higher level than the individual analyses presented in the previous chapters.

Six dilemmas are presented which link population policy, population ageing, physical trade, material flows, greenhouse emissions, natural resource depletion and environmental quality.

Throughout the previous five chapters, individually focussed problems in the physical economy have generally been resolved, or potentially so, by the introduction of an improved technology or the alteration of a requirement in the face of different rates of population growth. Examples of this include better engines in motor cars to reduce energy use and airshed emissions, reduced energy use in houses and commercial buildings to reduce greenhouse gas emissions, and the transition to compressed natural gas to avoid possible constraints in domestic oil supplies.

However many subsidiary scenarios have flow-on effects that accumulate at higher levels in the economic and social parts of national function. Potential examples of the higher order effects are posed by the transition to a factor-4 economy where, if material and energy flows were halved, then the industries that generated those flows might offer fewer employment opportunities, unless compensating opportunities in the service economy opened up to replace the employment based on material flows.

This chapter brings together a number of cross cutting issues. The first four dilemmas aggregate at the level of the whole economy and present system-wide views of potential effects of population size and structure.

The fifth and sixth dilemma relate to a number of resource-depletion and environmental-quality topics, some of which are not directly related to future size of the population. Each challenge is presented as a dilemma because there are several options for a solution, each option having its own set of consequences. Some of the potential solutions discussed here are open to a wide range of behavioural, political or economic unknowns.

- **1. The ageing dilemma**: The population is ageing and birth rates seem destined to decline. High immigration can offset this to a limited degree, but absolute numbers of aged citizens continue to rise and the supporting and caring tasks may not decline.

One choice in this dilemma is whether to accept that Australia will age markedly over the next two human generations with possible challenges to the cost of health care and pension schemes. Another choice is to marginally improve the age structure, making it relatively younger through increasing levels of younger immigrants or by increasing the fertility rate. This choice has flow-on effects to the following five dilemmas.

- **2. The physical trade dilemma:** is that higher populations might maintain a poorer balance of trade in physical goods and commodities. Expanding populations require more imports and consume more domestically so that physical exports are less.

  One option here is to continually expand production levels from the physical economy with the goal of maintaining reasonable levels of monetary balances with the rest of the world. Another option is to constrain physical trade flows in an attempt to manage the greenhouse gas and material flow dilemmas.

- **3. The material flow dilemma:** is that larger populations run a lower per capita material flow account than smaller populations. This is due to a large proportion of the nation's total material flow being driven by export orientated industries rather than domestic activities for subsistence and lifestyle.

  One option here is to accept that Australia's future in the globalised trading world lies in being a materially intensive economy on a per capita basis. Negotiations could ensure that international agreements acknowledge and reward this reality by attribution of environmental loading to the consuming country, rather than the producing country. Another option is to undertake the transition away from materially intensive products and commodities into new industries characterised by low material and embodied energy content of product, along with a high intellectual and information content.

- **4. The greenhouse gas dilemma:** is that greenhouse emissions from energy at a national level are directly related to future rates of population growth. However restraining population growth does not enable the low population scenario to meet internationally expected emission levels over the next 50 years. This is due primarily to the three factors of increasing per capita affluence, the content and amount of export trade and growing international inbound tourism.

  One choice in this dilemma is to continually improve the technology and efficiency of the nation's energy metabolism but with the knowledge that the emission goals set by the Kyoto Protocol negotiations will still not be met. Another option is to halve the levels of material consumption for all citizens with possible short term effects on economic growth, personal affluence and social cohesion.

- **5. The resource depletion dilemma:** is that domestic requirements and trade activities will inevitably cause overuse of agricultural soils, marine fisheries, and domestic stocks of oil and gas.

One choice here is to accept that resource depletion over timescales of centuries is inevitable and to ensure that finite resources such as arable soils, marine fisheries and domestic stocks of oil and gas are used effectively to maximise social and economic returns for the nation's citizens within and between generations. Another option is to fully embrace the concept of sustainability and to ensure that stocks of agricultural land and marine fish do not decline. Domestic oil and gas reserves could underpin the transition to a low carbon, renewable energy economy rather than satisfying immediate requirements for lifestyle, economic growth and company profits.

- **6. The environmental quality dilemma:** is that environmental quality issues such as urban air quality, river water quality and biodiversity quality seem destined to decline unless radical solutions are found for the other dilemmas.

  One choice then is to use technology to deal with negative aspects of declining water quality, biodiversity quality and urban air quality. Another choice is to treat the cause rather than the symptom. This requires that our water catchments are reforested, our biodiversity habitat and ecological function re-established and that future personal mobility in cities quickly makes the transition to low-carbon low-emission forms of personal transportation.

Single dilemmas are mostly open to resolution within the current settings of technology and ideology. However the resolution of two, three or more dilemmas in parallel is difficult because to do so requires a sophisticated understanding of human behavioural dynamics. Such an understanding lies outside the capability of this analytical framework (it’s also outside the comprehension of contemporary policy development).

An integrated resolution to dilemmas three, four, five and six might require that the nation's complete set of physical transactions be reduced. Flow-on effects might reduce the physical trade balance, and require services exports, or trade in information, to fill the gap.

An information rich economy with low material transactions requires a highly educated workforce who might be willing to moderate lifestyle and physical demand as their contribution to the resolution of dilemmas three to six. How radical requirements for change such as this might feed back to the key factors (births, deaths, emigration and immigration) that drive population number and age structure, is beyond the scope of this current study, but does require investigation if concepts such as 'ecologically sustainable development' are to be implemented at an economy-wide level.

For further discussion on the important findings of the report, please refer to the 10 key conclusions set out in the beginning of this report.

Policy considerations arising from Chapter 7

- The key issue for the six dilemmas is that they all interact. Proposing a solution for one dilemma in isolation, will produce a cascade of flow-on effects for all the other dilemmas. Making a future Australia younger by high rates of population growth will inevitably make the greenhouse gas account unacceptable. While numerical solutions can be developed, many key input assumptions (for a successful physical-economy design) carry high political and social risks. Different institutions may be required to help guide the complexity of policy design.
- From the purely physical perspective it will help to set eventual bounds around aggregated social issues (ageing, trade, employment) and physical issues (energy, greenhouse and material flows) to enable physical reality to be infused into future population analyses. Between agreed social and physical bounds, there are probably a number of acceptable designs for the physical economy that allow reasonable levels of social, economic and environmental function to be achieved, perhaps even by the year 2020.

Chapter 7: Crosscutting issues and tensions contains the following sections:

Chapter 8: Overview of the report by the External Reference Group

Key messages in this chapter:

- We are in an age of specialisation characterised by efficiency, speed, niche markets and increasing complexity. In dealing with the detail we are tending to lose sight of the “big picture”. We manage tactically rather than strategically.
- The population study, and the modelling framework behind it, provides a big view that takes us beyond the normal time horizon. While the individual parts of the study are not always leading edge, the linking between the disciplines is robust and provides a 'total that is bigger than the sum of the parts'.
- This study contributes to the population debate as a 'policy neutral' or balanced contribution, made so by the separation of physical reality (in its equations and data) from the social options (implemented in its scenarios).

In assessing the merit of the CSIRO study, the External Reference Group notes the tension between the depth and understanding of each of the disciplines represented in the group, the extent to which these intricacies are portrayed in the modelling approach, and the results reported. Inevitably, each portion of the study does not itself represent the state of the art in each of our disciplines. However the study effectively brings together many individual issues in demography, the physical sciences, ecology and economics that normally remain unconnected in many national policy processes. Therein lies the strength, in both the scale and the connectedness of the study.

The CSIRO model is different from most national models in that it simulates the physical processes that underpin the functioning of the nation, the so called 'physical economy'.

In our critique of the approach and the results, we asked to what degree the disciplines of demography, economics and ecology were appropriately represented in the study.

In general we were satisfied that the conclusions of the study are robust and defensible. We found that the results related well to the published literature, including in those areas where the analyses themselves were necessarily limited.

The responses of individual ERG members from diverse disciplines to the report and its methodology contained in this chapter add considerably to our understanding of how the same issues can be analysed in several different ways (see Attachment A). This exercise may well provide the basis of greater cross-disiplinary understanding in the future on such issues.

From our perspective, there are three important learnings from the study, and the social process that surrounded it:

- **1.** The complexity and richness of the analytical approach affords both government and business the ability to look across sectors and institutional silos in a long-term context that spans human generations.
- **2.** The study provides an empirical basis to refresh the national debate on sustainable development.
- **3.** The study suggests that federal government policy should focus mainly on managing national stocks (people, infrastructure, energy and natural resources) rather than national flows. In the main, the shorter-term national flows should be left to the fleet footedness of market forces.

Finally the study demonstrates that no one population scenario represents an unalloyed good – a clear and unrestricted path to the future. Instead it shows that each scenario creates its own opportunities and challenges that need resolution at the policy table, and eventually at the household level. A moment's reflection suggests that this is good common sense. We would be alarmed and suspicious, knowing what we do about the way the world works, if there appeared to be some 'Yellow Brick Road' to the future.

Policy considerations arising from Chapter 8

- The analytical approach used in the population study, while lacking the fine detail and deeper theoretical basis of individual disciplines, allows policy analysts to see across the many institutional silos that in the end, have to be integrated round the policy table. The approach promises many advantages at national and state level. However the institutional setting and the route to policy acceptability for such a capability is far from clear.
- Government should keep track of, and help strategically manage, a limited set of nationally important stocks. These stocks (sometimes called slow moving variables) generate the shorter-term flows that are often the focus of intense policy deliberation. In the main, the management of flows should be left to the fleet-footed interactions determined by market decisions.

Chapter 8: Overview by the External Reference Group contains the following sections:

Introduction

Approach – context and critique

Context

- The use of models in science
- How to read the CSIRO model
- The modelling traditions in the natural and social sciences
- The problem of sustainable development

Critique

- Are there 'issue' sub-models with counterpart 'disciplinary' model?
- How are the soft systems joined to the hard systems, and what can we say about it?
- How is 'the physical economy' distinguished from 'the (monetary) economy' –or how does economics get a look in?
- Creating the link between people and their environment – or how does demography get a look in?
- How does the model deal with essentially spatial notions implicit in the concepts of sustainable development – or how does ecology get a look in?
- How does the model deal with innovation and change, both technological and social – or how does 'Factor 4' thinking get a look in?

Conclusion

- What emerges from the study?
- Are the report's conclusions robust?
- What are the report's implications?

ABSTRACT

In assessing the merit of the CSIRO study, the External Reference Group notes the tension between the depth and understanding of each of the disciplines represented in our group and the extent to which these intricacies are portrayed in the modelling approach and the results reported. Inevitably, each portion of the study does not itself represent the state of the art in each of our disciplines. However the study effectively brings together many individual issues in demography, the physical sciences, ecology and economics that normally remain unconnected in many national policy processes. Therein lies the strength, in both the scale and the connectedness of the study. The CSIRO model is different from most national models in that it simulates the physical processes that underpin the functioning of the nation, the so called 'physical economy'. In our critique of the approach and the results, we asked to what degree the disciplines of demography, economics and ecology were appropriately represented in the study. In general we were satisfied that the conclusions of the study are robust and defensible. We found that the results related well to the published literature, including in those areas where the analyses themselves were necessarily limited. From our perspective, there are three important learnings from the study, and the social process that surrounded it. The first is that the complexity and richness of the analytical approach affords both government and business the ability to look across sectors and institutional silos in a long-term context that spans human generations. Secondly it provides an empirical basis to refresh the national debate on sustainable development. Thirdly it suggests that federal government policy should focus mainly on managing national stocks (people, infrastructure, energy and natural resources) rather than national flows. In the main, the shorter-term national flows should be left to the fleet footedness of market forces. Finally the study demonstrates that no one population scenario represents an unalloyed good – a clear and unrestricted path to the future. Instead it shows that each scenario creates its own opportunities and challenges that need resolution at the policy table, and eventually at the household level. A moment's reflection suggests that this is good common sense. We would be alarmed and suspicious, knowing what we do about the way the world works, if there appeared to be some 'Yellow Brick Road' to the future.

INTRODUCTION

What are we to make of something that tries to look at everything when we usually spend our days looking at some particular thing? In an age of ever-increasing specialisation, how are we to cope with generalisation? This is the task and dilemma facing the External Reference Group, specialists all, in commenting on this report. It is a dilemma compounded by the fact that our specialities are all different – that while we each know a lot about our own specialisation, we know much less about our colleagues'. But we have come together, at the request of the Department of Immigration and Multicultural Affairs, to provide an independent frame of reference for the report.

Our group comprised Roger Bradbury (Australian National University, chair, ecology), Ian Burnley (University of New South Wales, human geography), Chris Murphy (Econtech, economics), Chris Ryan (RMIT University, technology) and Mark Wooden (University of Melbourne, economics) and was ably assisted by Neil Mullenger of the Department.

EXTERNAL REFERENCE GROUP COMMENTS

Within each of our specialities – whether it is economics or ecology, demography or technology – our task seems relatively simple: we need only to compare those aspects of the report that bear on our native discipline with what we understand to be ‘best practice’ or ‘leading edge’ or whatever is the current jargon for what the best and most creative people are doing. And if we do that, the answer will be simple and crisp: this report is not ‘leading edge’ in any of our disciplines. However a moment’s thought reminds us why this is a trivial response, one which sidesteps the reason we have come together. On reflection, we should expect that a study of everything, using tools and techniques which are not mainstream within any of our disciplines, cannot produce insights or understanding within a discipline that are better than a study of some discrete phenomenon, using finely honed tools and specialised techniques peculiar to that discipline.

The very things that make for the success of specialisation also create its own Achilles’ heel. We spend so much time mastering the details, that we have trouble with the whole.

To gain the benefits of specialisation, and to survive in the modern world, we have had to forego our heritage from Renaissance Man, that ideal creature, personified by Leonardo da Vinci, who knew everything there was to know. To reclaim that heritage we need to become a Renaissance Team. Thus our Group needs to take a different tack in its approach to the report, one that does not dismiss the claims and arguments of the specialist, but rather one that puts those claims and arguments into the context of the whole. We need to see, say, the ecology or economics in the report from two points of view: one which looks into the discipline concerned and examines it from the perspective of that discipline, and one which looks out from the discipline and examines it from the perspective of the ‘problem of everything’. And we need to have these perspectives simultaneously.

We need to ask, not ‘What does this piece of the report contribute to the discipline?’ but rather ‘What does the discipline contribute to the whole problem, through this piece of the report?’

Thus the fact that the report cannot mix it with the ‘leading edge’ within any particular narrow discipline does not mean that it is not ‘leading edge’ in itself. The report needs to be judged on its own terms as an attempt to look at the whole and not the parts. It needs, to be sure, to offer competent and thoughtful analyses from the perspective of any one discipline, but it also needs to be judged on the extent to which new understandings of the larger problems emerge from the interplay of the various specialisations and disciplines.

In our discussions during the course of the project this tension was obvious, as it is in our comments here. Nevertheless we have striven to provide a framework within which specialised issues may be discussed and argued on their own terms and in terms of their contribution to the whole enterprise.

In addition to the broad analysis and critique for which we take collective responsibility, we have also included some amplifying material in separate boxes. These comments focus on some disciplinary issues a little more deeply, and are attributed to individual members of the External Reference Group.

APPROACH – CONTEXT AND CRITIQUE

Our objective in this chapter, therefore, is to provide a context for, and a critique of, the CSIRO project, drawing on the range of expertise within the External Reference Group.

The discussion of the **context** will seek to embed the report within the large body of work in both the natural and social sciences on population issues in particular and modelling in general. It will explain where the CSIRO approach fits *vis à vis* other work in these areas. It will acknowledge and describe the report's multidisciplinary 'heritage' while providing an overview of its own contribution to the population and sustainable development debates.

The key contextual issues we will examine are:

- The use of models in science – and how to read them – with particular reference to the report.
- The biological tradition *vs* the economic tradition (that is, natural *vs* social sciences traditions) – the key similarities and differences between modelling and simulation in the social and natural sciences, with particular emphasis on the approaches of economic and ecological modelling – as sources of understanding and confusion.
- The problem of sustainable development as an interaction between biophysical and socio-economic processes – and, thus, how to place the report in the context of sustainable development.

The **critique** will be a more focussed analysis of the general strengths and weaknesses of the issues chapters and the crosscutting analysis.

- Are there 'issue' sub-models with counterpart 'disciplinary' models? One of the strengths of the design framework approach is that it can produce both single-issue models, such as population, employment, energy and water, as well as holistic models synthesising all the issues. But for each of these issues models, other 'disciplinary' models exist. How well do these models relate to each other? What can we say of any differences that we observe?
- How are the soft systems joined to the hard systems, and what can we say about it? The report makes much of its basis in physical reality, but much (beyond the actual three population cases driving the scenarios) depends on how the softer, more subjective aspects of the problem (such as the degree of acceptance of technological change, or of different lifestyles) intrude into the analysis. Does the report handle this well, and are there other ways that could be used?
- How is 'the physical economy' distinguished from 'the (monetary) economy' — or how does economics get a look in? The report makes it clear that it is not a 'traditional' economic analysis, and argues that it should sit side by side with such economic analyses. It argues that its strength is that it provides policy makers and the public with additional avenues of understanding. That said, there is still room for some analysis on how notions from the one approach can be represented in the other, beyond relatively trivial procedures like contingent valuation. Can we use the notion of information (as a notion as fundamental as energy or mass) to give some scope for ideas about markets (which are essentially information processing objects) to penetrate the model?

- Creating the link between people and their environment – or how does demography get a look in? An analysis of how the sustainable development debate often does not include one of the key drivers – human population – and how this report makes a significant attempt to remedy that problem.
- How does the model deal with the essentially spatial notions implicit in the concepts of sustainable development – or how does ecology get a look in? In linking population to the physical environment, the report moves solidly into the debate on sustainable development. One of the key concepts here is that of spatial distribution – it matters not only how much or how fast things happen, but exactly where they happen. From this flows an idea about the graininess or heterogeneity of processes. The present model makes some attempts at this, particularly in terms of population. We will examine the sufficiency of the report's spatial thinking, and the effects this may have on its conclusions.
- How does the model deal with innovation and change, both technological and social – or how does 'Factor 4' thinking get a look in? The report attempts to project not only physical trends but also intellectual, technology and social trends, with its thinking being informed by the results of the workshops. How well is this aspect of the work done, and what can be said about it in comparison to what else is being done around the world?

CONTEXT

The use of models in science

Modelling is so very close to what doing science mostly is that we often confound them (Bradbury, 1997). More than that, we often make the assumption (either implicitly or explicitly) that, since there is really only one kind of science, that there must be only one kind of modelling. And that leads to all sorts of misunderstandings not only about modelling, but also about the science that flows from it (Bradbury, 1999). In its simplest form, this problem is expressed in the inability or unwillingness to understand another's models. In a more perverse form, it is seen in the inability or unwillingness to accept the contribution to understanding that another's models might make.

Here, we will explore the nature of the model used in the report and its relation to other sorts of modelling, remembering that the model is the tool, the means to an end. It is the scientific understanding that is the end. While the model may colour that understanding, may inhibit or enhance it, it is not the understanding itself.

Modellers choose their models not only for the job in hand – their intended use (Pielou, 1981) – but also for their ease of use – their structure (Hogeweg and Hesper, 1985) – and the type of understanding they seek – their philosophical bias (West, 1985). These three different characteristics of models are more or less independent of one another. The result is that there are potentially a lot of different classes of models, many more than most modellers believe. Indeed, when modellers talk of different models, they usually mean different models within the one class – the class they use. Much of the debate and confusion about modelling – a sort of academic white noise – is caused by this myopia.

Most workaday models in both the natural and social sciences have as their intended use some sort of prediction, but there are at least three other quite distinct uses of models: explanation, hypothesis generation and as standards of comparison. Similarly, most models have an underlying structure that is variable-oriented, which is to say a structure built on the behaviour of variables linked together in mathematical equations. But individual-oriented (sometimes called agent-based) and event-oriented models are each distinctive alternatives. Finally, there are at least five kinds of truth that models may seek: Lockean or empiric; Leibnizian or analytic; Kantian or synthetic; Hegelian or dialectic; and Heisenbergian or pragmatic. Most modellers see themselves as synthesisers, but the other classes are just as justifiable.

The CSIRO model that underlies the report is quite different from most models in use today. Firstly, in its emphasis on scenarios, it is being used to generate hypotheses not to test them. So it immediately distinguishes itself from the raft of models that seek to predict (many of which also claim to explain). Secondly, it is event-oriented, the different components of the model sending messages to other components to which those components then respond. This is quite different from many ecological, economic or demographic models based on sets of mathematical equations. Lastly it is empiric in its attempt to describe its world as a physical economy – a practical, hard-nosed realistic description of how this world actually works. This is quite distinct from more analytic or synthetic models that embed their work in a framework of theory.

How to read the CSIRO model

Since the CSIRO model does not aim for prediction, its results need to be treated differently from those of more traditional predictive or explanatory models. In such models, the results purport to inform us about the way the world is – by explaining – or about how it will be – by predicting. Thus their results form part of a story whose beginning is a description of how the world is, whose middle is an argument about how the bits of the world interact, and whose ending – the model results – is the dénouement: either why it is so (the explanation) or what it will become (the prediction). Thus such models can be read quite easily as the ending to the story.

Models that develop scenarios are different because they have a different relationship to the rest of the story. And so they need to be read differently. Scenaric models are not an ending to a story about the way the world is. Instead they are beginnings of new stories, but fictions to the facts of the earlier ones. That is, they take, as a beginning, the way the world is, and then, as a middle, they ask ‘What if …?’ – making a plausible case for the way things might be. Finally they unfold their ending as the working through of the interactions of the model.

It is important to note what we mean here by ‘fictions’: a plausible, scientifically lawful description of the possible. We do not mean ‘fantasies’ – things that are beyond the possible.

If traditional predictive or explanatory models are detective stories, revealing at the end ‘whodunit’, then scenaric models are romances, exploring possibilities, revealing unexpected intricacies. They are sustained by their links to the real world, and also inform it, but, in their focus on the possible rather than the contingent, they are a wholly richer enterprise.

Thus we need to read scenaric models differently. We need to treat them as helpful lies, whereas we might treat predictive or explanatory models as unhelpful truths.
Almost the first thing we should do with such model outputs is to disbelieve them. But we should do this with the results of any scientific enterprise, since science thrives on and depends on scepticism. This proper posture of disbelief is not to be confused with our pursuit of understanding that emerges from it. We should examine the results to find the source of our disbelief – that is, we should look for surprises. What unexpected things emerged from the analysis? How did this or that surprise arise, given our prior knowledge of the system?

Then we should check the results against those of other studies. In the present case, this is one of the most important things we need to do, but we need to do it carefully. Each of the major components of the model will have equivalent 'single issue' studies against which they may be compared. We need to be mindful of the strictures discussed above about the relationship between the multidisciplinary and single discipline studies, and keep our checks and comparisons at a suitably high level. Thus we need to ask 'Does the broad thrust of some component of the model accord with the broad understanding within the discipline?' rather than 'Do the nuts and bolts of this component of the model match the nuts and bolts of the standard disciplinary model?'

Finally, we should look for deeper links in the system. The surprises we find in the results are due as much to our inability to imagine the (non-linear) consequences of the relationships that we have faithfully described in the model as to the emergence of truly novel phenomena. With the wisdom of hindsight, we can now track back our surprises to their sources, and examine the ways in which the links and relationships allow the propagation of surprises through the system. The use of different scenarios may help significantly in revealing these tracks, since the scenarios each emphasise different forces in the model.

The modelling traditions in the natural and social sciences

It used to be a sort of 'Sydney or the bush' thing, scientific modelling. It could be like physics, proper and grand, or it could be a less reputable activity altogether, hardly worth considering as real science. Respectability in science, for many new scientific disciplines struggling for respectability, has usually been measured by closeness to physics, or at least adherence to its mores. Thus we see in the emergence of the three main disciplines represented in the report – the natural science discipline of ecology, and the social sciences of economics and demography – an adherence to the physics of the time of their emergence. The neo-classical synthesis in economics depends on a mathematics and world-view of 19th century physics (Reder, 1999), just as surely as the demographic transition theory of demography (Lutz, 1996) or trophodynamics of ecology (Bradbury et al., 1996) depends on an early 20th century physics.

In this sense the modelling traditions in the natural and social sciences of the report are more alike than they might realise. They share some implicit assumptions about how to do scientific modelling: it should be informed by theory (how the world should be), it should be describable in a mathematics that stresses linearity and equilibrium (sets of differential equations, usually), and it should be predictive or explanatory. Whether the mathematics harks back to Newton as in much of economics, or uses post-Einstein work as in some ecology, the message is the same.

It is not our intention here to argue the merits of this sort of modelling within any of these disciplines, even as we acknowledge that even physics has moved on in its own approach to modelling, no longer asserting the primacy of theory in all cases (Wolfram 1984). Instead, we note that modelling approaches that work well within a discipline may not work at all well in a multidisciplinary context. By far the best example of both hubris and naiveté has been the Club of Rome program (Meadows et al., 1972), which sought to apply the common modelling approach of the economics and ecology of the 1950s to the multidisciplinary problem of the interaction of the human population and its environment. The failure of that program, in terms of furthering our scientific understanding of the problem, is due in no small part to the naïve adoption of a theory-bound modelling approach.

The empiric approach of the CSIRO report, then, has much to commend it in the present circumstances. It sits to one side of the mainstream modelling tradition in both the natural and social sciences. That is a strength rather than a weakness, since that tradition makes an (often implicit) assumption of theory, and at our present level of understanding of the larger problem, we are in advance of a comprehensive theory. The CSIRO approach allows us to push forward the frontier of our understanding of the problem, and gives space for theory to grow up behind it. It allows us to get on with the job.

The problem of sustainable development

If there is a ‘theory of everything’ underlying the multidisciplinary problems addressed by the report, it may well be found in the ideas of sustainable development. These ideas have exercised the minds of policy makers and the public for the last decade or so, and have firmly entrenched themselves in the public policy agenda of all developed countries. They seek to reconcile environmental, social and economic concerns, so they are explicitly multidisciplinary. They also seek a global perspective, so are explicitly systems-oriented. They try to articulate a coherent argument about the interdependence of environmental, social and economic concerns, so they are a precursor to a theory. But it is not a theory (or not yet) in a scientifically accepted sense. It is more an intellectual scaffolding that could support the construction of theory.

The empiric modelling work reported here then has an unusual, but potentially enormously productive, relationship with the ideas of sustainable development. To understand this, we need to understand a little more deeply, the depth of the failure of the Club of Rome program discussed above. This work preceded the formalisation of the central ideas of sustainable development, and was implicitly and rigidly theory-bound in a modelling formalism called system dynamics. Hence it has been unable to contribute effectively to the evolution of sustainable development ideas that necessarily go into ‘soft’ areas where system dynamics fears to tread. It has also been unable to benefit from the continuing evolution of those ideas that are seeing a progressive merging of soft and hard sciences. The CSIRO work is able to contribute directly to the development of a theory of sustainable development. Its scenaric results yield statements that have meaning across the full spectrum of thinking on sustainable development, since they do not presuppose an underlying theory. Conversely, the work can be informed by sustainable development thinking in an unconstrained way. It has no theory to be defended at all costs, and so its results can stand the test of time, and are worthy of progressive reinterpretation in the light of unfolding theory.

Much more than any theory-bound approach, the CSIRO modelling is the precisely right partner to today's sustainable development thinking. It can be seen as catalysing rather than inhibiting the emergence of the new ideas that will be essential if we are to construct a coherent theory and robust policy for sustainable development.

CRITIQUE

Are there 'issue' sub-models with counterpart 'disciplinary' models?

As an approach, the 'design framework' modelling protocol is not focussed on any particular discipline (Gault et al., 1987). It is not peculiarly economic, ecological, demographic or whatever. Nor is it focussed on any particular level of problem. It makes no difference if the problem is within some small bit of the economy, an entire ecosystem or the world's whole human population. It is an entirely generic construction, and is given its meaning by the problem under attack.

It is also naturally hierarchical. We may think of each calculator as a model of some bit of the system in its own right – as a sub-model. Thus we might expect to find calculators that represent disciplines, that there might be an economic calculator and a technology calculator and so on.

This is only partly true, but mostly untrue. The world is not really divisible into non-overlapping bits called disciplines. Even the sectoral workshops referred to in the report that preceded the model-building are highly multidisciplinary. Where it is partly true – that is, where a calculator is mostly concerned with the problems of one discipline – we may compare the sorts of results the calculator produces with the sorts of results that a standard disciplinary model produces.

We see this best in the population area. The five demography calculators together generate population projections. While the way in which each of these calculators works might not mimic exactly the standard processes of the discipline of demography, the results should at least be directly comparable. It is comforting to find, as described in the report's appendices, that the population calculators not only 'hindcast' the Australian population accurately over the last 50 years, but that they produce projections which are in very close agreement with the standard projections produced by official sources such as the Australian Bureau of Statistics. Where the power of the present approach exerts itself, of course, is in the way that these projections are able to interact intimately with the rest of the model because of the way in which they have been constructed.

However, there is really nowhere else in the model where discipline maps closely to calculator. Areas such as forestry, fisheries or transport are thorough mixtures of disciplines. This can become a problem if the theory underpinning a discipline has no path into the model given the model's focus on an empiric, data-intensive protocol. The very thing that the proponents of the 'design framework' proclaim as a virtue – its empiricism – could then become a vice.

Disciplines are deeply bound with theory, often to the point where the theory is so embedded that it is no longer even recognised as such. Theory is, after all, what gives a discipline its distinctiveness. Economics would be unrecognisable without its general equilibrium theory, ecology has its underpinning of evolutionary theory, and demography, its demographic transition theory. None of these has a place in the model proper, but yet each has an important contribution to make, not only to understanding the immediate problem but also to setting it in a wider context.

But being excluded from the model proper does not mean theory is excluded from the whole framework. Theory intrudes, properly, in the workshops where the relationships among the variables are argued out. For example, the types of growth exhibited by fish and human populations are informed by ecological and demographic theory respectively. Similarly, human demand for food and fibre or the human propensity to substitute one technology for another are informed by economic theory and ‘Factor 4’ ideas respectively.

Disciplinary theory may also intrude in the part of the framework the modellers call ‘control space’ – the place where the model is interpreted and decisions start to be made. It is here that disciplines and their theories mix it with the ideas, values and goals of the users of the model. This will be explored further in the next section.

A final caveat is needed however. The fact that the disciplines are mostly smeared out across the model carries a sting in its tail. If there are important aspects of a discipline that are not adequately accounted for in the model, then the model is weakened systemically. We will consider this issue in the sections that follow.

How are the soft systems joined to the hard systems, and what can we say about it?

We argued above that disciplines are spread across the model’s components to the point that there is not a one-to-one correspondence of discipline to calculator. And we have also argued that the modellers see as a strength their focus on the material world, the thing they call the physical economy. Together these two parts of the protocol create problems for the soft sciences – the sciences concerned with the non-material, such as human behaviour or human ideas.

We might expect that a solution to the problem might be to locate the soft sciences (such as political science and sociology) in the control space of the framework where the users observe and control the model. Then we would locate the hard sciences (physics, biology, geology and so on) in the machine space where they would describe the material world or physical economy. We could then say that all the sciences are joined within the design framework.

But this is not a complete solution. Some sciences straddle the boundary between hard and soft – the distinction is not at all clear. The problem is most acute with economics, since it is the most chimeric of the sciences, with both hard and soft tightly entwined. In its use of reasonably sophisticated mathematics and empirical data, it looks like a hard science. In its reliance on behavioural processes in the dynamics of markets, and its existence in ideological flavours – market economics, Marxist economics, political economy – it looks decidedly soft.

Clearly, disciplines like economics need to be able to find homes in both the control space and the machine space. If the framework is faithfully representing economic phenomena and at least acknowledging economic theory, we should expect to find evidence of the harder parts of economic thinking in the machine space and the softer parts in the control space.

To a large extent, this is what we find when we examine the framework. We find, for example, a neat conjunction between the hard economics of national accounting (Leontief, 1966) and the ideas of embodied energy and embodied water. They each use a highly empirical data system, and rely on notions of balanced accounts to reveal their dynamics. This conjunction goes even further, allowing national accounts data to be used to create embodied energy accounts.

But we do not find Adam Smith's invisible hand in the model proper. We do not find, in fact, market behaviour – the automatic adjustments between supply and demand through the price mechanism. Nor should we expect to, since these are not material processes. We must seek for such soft dynamics in the control space.

The control space is where tensions or dilemmas are resolved and it is here that soft dynamics like market behaviour are revealed in the ways in which users respond to the dilemmas and rework the model.

How is 'the physical economy' distinguished from 'the (monetary) economy'– or how does economics get a look in?

With a complex area like economics, as we have just described, the problem is not simply reducible to deciding that this or that should reside in machine space or control space.

The fact that the physical economy does not include prices does not imply that prices are not important. The scenarios provide a physical description of transactions in possible future economies. If those transactions come to pass it will be because, in some sense, people choose them. There may be many reasons for people's choices, but economic conditions as reflected in prices will certainly be among the most important.

The framework omits prices, not because they are not important, but because of the timescale and scope of its concerns. The empirical base for economics (and related behavioural sciences) is observed behaviour under current conditions. Its theories are based on the choices people are observed to have made, and are summarised in parameters such as elasticities of various kinds. This may be a sound basis for predicting the consequences of small changes from the status quo, but it provides little guidance if we are concerned with the possibility of major structural changes when choice sets or even the psychological bases of preference may differ.

Future developments will be the result of people's (dynamically changing) preferences and the physical world in which those preferences are expressed. Whatever the merits of economics (and related behavioural sciences) for predicting short-term marginal developments about the status quo, it provides no basis for long-term predictions of substantial dynamic change. We just do not, and cannot, know the future elasticities. That is why ideas of the scenario and the control space are so important: they allow for the choice component to be guided as much as possible by actual human input (consultation, discussion, workshops – all the social activity in 'control space').

On the other hand, we do know a fair bit about the physical world. There is a wealth of scientific, engineering (and economic) information about energy efficiencies, material intensities, crop yields, consumption patterns, labour productivities, and so on. These can change, but the changes are bounded. Existing technologies can be improved, but the improvements are subject to saturation (as will be discussed below). Radically new technologies may be introduced, but they cannot come in overnight. New infrastructures need to be provided and, while they build up (absorbing resources) old infrastructures need to be maintained to 'keep the show on the road'. Evaluation of such scenarios in physical terms is the first step in identifying directions for sustainability policy.

But there is no question that the implementation of such policies will need to take account of – and manipulate – the prices of goods and resources.

An economic modeller's perspective

In *Future Dilemmas*, Barney Foran and Franzi Poldy of the CSIRO conduct an exercise in assessing alternative migration policies. They feed three alternative assumptions about future migration policy into a complex model to generate three scenarios for Australia to 2050. The reader is invited to compare the three scenarios to make judgements about which migration policy best serves the national interest.

The contribution of such work can be assessed by comparing it with related work that is already in the public domain. In the early 1990s in a consultancy for a bureau of the immigration department, Econtech developed a system for assessing the economic effects of alternative migration policies. Alternative migration scenarios are fed into a demographic model which in turn generates inputs for a widely-used model of the Australian economy known as MM2. This system has been used often, its most recent use being earlier this year.

In this most recent analysis, Econtech used the system to estimate the economic impacts on Australia of the 2002/03 migration program for the immigration department. These economic impacts were relative to a baseline scenario in which the 1995/96 migration program continued without change.

The economic impacts for 2007/08 were as follows:

- a net addition to the total population of 0.29 per cent or 60,000 people;
- an addition to the population of working-age (15-64 years) of 0.89 per cent or 126,000 people (the populations for the younger and older age groups were lower);
- a gain in labour force participation of 0.71 per cent;
- a gain in annual funds transferred to Australia by migrants of about $1.7 billion;
- a gain in the skill level of the Australian workforce of 0.24 per cent;
- a gain in GDP per head of 1.15 per cent; and
- a gain in annual consumption per head of 1.22 per cent or $344.

The most important result is the bottom line for Australian living standards, as measured by consumption per head. The significant gain in living standards of 1.22 per cent reflected the following policy developments in the 2002/03 program compared with the 1995/96 program:

- the capping of the parent component of the family stream, making the migrant intake younger;

- the shift since 1995/96 in the composition of the migration program from the family stream to the skill stream; and
- measures taken to improve the skill level of components of the skill stream.

These results confirm that the various changes in migration policy are likely to yield an economic dividend. They also provide ballpark estimates of the amount of that dividend taking into account an extensive set of linkages from demographic to economic outcomes. It is interesting to compare this Econtech analysis with the CSIRO analysis.
The CSIRO modelling only provides estimates of the first three of the seven economic impacts listed above. These cover demographic and labour force outcomes, which rely on relatively simple mechanical modelling. The remaining four economic outcomes are not covered by the CSIRO model, reflecting the simple nature of its economic component. The lack of any recognised summary measure of the net economic benefit of alternative migration policies, such as the effect on GDP or consumption per head, is the first limitation of using the CSIRO model to assess migration or other policies.

Similarly the CSIRO model does not capture the effects of the migration policy developments that affect the average skill level and wealth of migrants, neither of which appear as variables in the CSIRO model. So a second limitation of the CSIRO model is that it cannot be reliably used to assess the impact of changes to the composition of the migration program.

Indeed, Foran and Poldy appear to realise this and instead focus on the impact of changes in the level of migration, in the three scenarios referred to at the outset of this note. In three scenarios, annual net immigration is varied from zero to 70,000 to 0.67% of existing population.

However, even this approach raises problems. The economic effects on Australia of these changes to the level of the migration program are quite different depending on the balance of the program between migrants with high economic attributes (young, wealthy, high-skilled) and low economic attributes. For example, this balance has changed to an important extent since 1995/96, as demonstrated by the Econtech economic modelling described above. Foran and Poldy do not explain what this may mean for their results.

The CSIRO model includes a standard demographic model based on the cohort-component method, as well as physical relationships which are better assessed by scientists rather than economists such as myself.

The economic component of the model is simple. Everything is measured in physical quantities such as kilograms, joules and litres, leading the authors to describe it as a model of the ‘physical economy’. Production and consumption decisions are assumed to be based on simple physical relationships. It is a mistake to believe that such an approach avoids reliance on economic theory. Rather, it assumes that decisions by consumers and businesses are not systematically affected by prices and costs, when there is a mountain of empirical evidence to the contrary. Indeed, prices do not even appear in the CSIRO model, even though they play a fundamental role in balancing supply and demand right across a market economy such as that of Australia. This is a third limitation of the CSIRO model.

The suggestion that modelling the ‘physical economy’ is a novel or new idea is incorrect. In fact it is a form of the input-output method that was set out far more comprehensively by Wassily Leontief in his 1941 book on ‘The Structure of the American Economy’.

In the last 60 years this strand of economy-wide modelling has developed considerably to cover prices, and to allow for the price-sensitive nature of decisions by consumers and businesses (in CGE models), but Foran and Poldy have not taken on board these important developments.

One potential contribution of the CSIRO modelling is in addressing the issue of possible economies and diseconomies of scale from expansion of the Australian economy. Econtech's modelling does not address this difficult topic, but rather takes a neutral position on the basis that one can point to economies of scale in some areas (e.g. communications networks) and diseconomies in other areas (e.g. a fragile natural environment that can be degraded by economic activity).

Both economies and diseconomies of scale need to be considered as part of any balanced consideration of the issue of economies/diseconomies of scale. Indeed, one reason for Australia's large-scale post-war migration program was a belief that there was a need to boost Australia's population to generate a local market that was large enough to take advantage of economies of scale for a manufacturing industry that was protected from import competition.

Foran and Poldy ignore economies of scale, including in communications networks, and instead focus purely on diseconomies of scale. This exclusive focus on diseconomies of scale loads the deck against the migration program and is a fourth limitation of the CSIRO model.

What has happened before the Club of Rome produced its projections and has happened since is that real prices of natural resources have tended to fall. When scarcity has threatened, the resulting price rises have stimulated more efficient use of the resource as well as increased exploration leading to increases in proven reserves. Further, continuing improvements in mineral exploration and extraction technology have kept real prices low.

The CSIRO model does not include prices and therefore is missing the main feedback mechanisms whereby, through price rises, an emerging scarcity of reserves can be overcome through increased exploration activity and more efficient resource use. This omission leads to unduly pessimistic projections of Australian reserves, which is a fifth limitation of the CSIRO model.

The same point holds for Foran and Poldy's modelling of a connection between Australia's migration program and Australian greenhouse gas emissions. Greenhouse gas emissions are a global issue, and so in modelling the migration program one should only take into account the net difference in emissions from someone living in Australia rather than another country. Foran and Poldy do not do this, which is a sixth limitation of their model

The more interesting side of the CSIRO model is in its modelling of urban air quality, water quality and land quality. However, again it is a stretch to view these environmental issues as being mainly the concern of migration policy.

Foran and Poldy generate their scenarios based on the possible extremes of net migration. More realistic scenarios for annual net migration would be 60, 90 or 120 thousand leading to an Australian population in 2050 of 24, 26 or 28 million. These fairly narrow variations in population outcomes would lead to similarly narrow variations in environmental outcomes.Of much greater consequence for environmental outcomes are environmental policies themselves. For example, the shift to lead free petrol and the looming shift to clean diesel have major implications for urban air quality. Examining these sorts of issues is where one might expect the CSIRO model to come into its own.

However, where environmental policies are market based, as is increasingly the case, the CSIRO model is again not much help, which is a seventh limitation of the CSIRO model. A model that omits prices, and consumer and producer responses to price changes, cannot contribute much to analysis of the effects of policies that operate by raising prices where there are negative externalities and reducing prices where there are positive externalities.

At a broader level, the population debate is always evolving and increasingly is focussing on emerging problems for developed countries arising from prolonged low fertility. While the collapse in fertility maintained since the 1970s is no doubt primarily due to the introduction of the contraceptive pill and the feminisation of the workforce, the false alarms of the Club of Rome, with its claim that responsible couples should limit themselves to two children, is no doubt an unwanted contributor.

Developed countries now have to develop policies to deal with populations that are projected to age rapidly in the next few decades and then start declining. This shift in policy focus may make the CSIRO model, with its negative message about population and economic activity, increasingly less relevant.

As members of the External Reference Group, fellow economist Professor Mark Wooden and I have made these points throughout the course of the project but note that the current CSIRO model is currently unable to incorporate the economic perspective as outlined above. This area of research straddles the physical and social sciences, and the obvious way to address the seven limitations of the CSIRO model that are identified in this note would be a multi-disciplinary approach in which physical and social scientists work side-by-side. Such an approach has already been followed elsewhere in modelling policies affecting global greenhouse gas emissions.

Chris Murphy
Mark Wooden

Creating the link between people and their environment – or how does demography get a look in?

Our discussions above about 'issue' sub-models and the problems of joining soft systems to hard systems describe to some extent how demography is treated in the framework. It remains here to consolidate that argument with particular reference to demography.

A useful place to start is to note that the whole framework is an extension of demographic thinking, since it is based on the idea that the purpose of economic activity is to meet the needs (and wants) of people. People need houses, food, transport, and so on. Houses require bricks, timber, glass, and so forth. Food implies crops, animals, tractors, etc. As we unfold this logic, we eventually get to land degradation, water consumption, pollution, resource depletion, and other mainstays of the sustainable development debate. Thus the framework has clear physical links and a direction in which we do all the accounting.

But demography is more than accounting identities and projection models, which are essentially simple arithmetic constructions. It also includes understanding and explaining the values of fertility, mortality and so on. In other words, like all disciplines, it is embedded in theory, such as demographic transition theory. This aspect of the discipline describes choice and behaviour, which are left in control space along with similar parts of economics and sociology - i.e. the values are set exogenously after consultation – or instruction – from the client.

Similarly, the feedback link from the environment to fertility and mortality is in control space and is not modelled.

How does the model deal with the essentially spatial notions implicit in the concepts of sustainable development – or how does ecology get a look in?

There are two traditions in ecology that might be drawn into the framework (Bradbury et al., 1996). In the event, only one really is. In this section we will examine if this is a reasonable thing to do.

The first, and oldest, tradition is that of natural history leavened with the theory of evolution (Hutchinson, 1965) and is called population dynamics. It talks about populations of organisms and their distribution in space. It is concerned with the origins, lives and fates of individuals and populations. It is also intensely interested in how the higher structures of the natural world – communities and ecosystems – emerge from the lower structures – individuals and populations – through ecological interactions – predation, competition and symbiosis – and how these structures then become evolutionarily coercive. We might call this the biodiversity view.

The second tradition is called trophodynamics (Morowitz, 1968). It looks at the problems of ecology from the point of view of flows of materials and energy. It has always been intimately associated with systems analytic approaches to biology and provides powerful descriptions of ecosystems as systems of stocks and flows. But it has a major drawback in that it does not recognise the primary locus of evolutionary action – the species – and so finds it hard to provide an evolutionary perspective. We might call this, in contrast, the biomass view.

It does not really matter in a trophodynamics analysis that the entities have an evolutionary history, while it is the thing that matters most in a population dynamics analysis.

Population dynamics is very similar to much human demographic analysis. Indeed, some of the first mathematical formulations of population growth were used in both ecology and demography with great effect (Pearl, 1925). So we might expect the model to use population dynamics calculators in its ecological parts – agriculture, fisheries and forestry – just as it has used demography calculators in its human population parts. That this is not so is due to the biodiversity problem: while it is feasible to calculate the population dynamics for one species – *Homo sapiens* – for which we have a lot of life history data, it is not feasible to do such calculations for each of the thousands of species in any real ecosystem for which we have very little data.

The model thus resorts to a trophodynamics approach, not so much because of its implicit stocks and flows structure, but because it is aggregated in a way that allows us to make progress. It is not a pure trophodynamics approach however. We see, in the equations that govern the growth of the stocks, echoes of population dynamics equations.

The thing we do not see, and the thing that has the potential to reduce our understanding of the contribution of biology to the model, is the spatial graininess or heterogeneity of the biological processes. The aggregation of species and the focus on biomass that are direct consequence of making the model tractable (rather than being consequences of the approach) reduce perforce the heterogeneity that is both a feature of the ecosystem and an important factor in its dynamics. That factor is lost to us.

To the extent that sustainable development is about the harmonisation of the biophysical systems of the natural world with the socio-economic structures of man, then it is about processes and structures operating at various spatial and temporal scales. Spatiality is thus as important as dynamics for our understanding. If spatiality is to be reinserted as a coercive factor with the dynamics in the system, it must be done somehow in the control space.

The spatial dimension

Australia is a country of continental dimensions and its metropolitan-hinterland relationships of the traditional kind have spread over hundreds of linear kilometres in each direction within the country in the case of each mainland state capital city.

The climatic variations and biotic and soil condition contrasts on a continental scale and from the deep interior of each state to the coasts mean that there are major environmental gradations and variations.

Considering metropolitan and non-metropolitan spatial entities is not really sufficient for understanding the nature of likely human and economic impacts on this great diversity of environments. For instance, in considering the “ecological footprints” of large cities, are the impacts greater where there has been migration away from the cities to the coastal zones- particularly the belt south from Hervey Bay in Queensland to the Bass Strait coast in Victoria, coastal areas southeast of Adelaide and the south west of Western Australia?

Are the environmental impacts worse in the relatively more watered non-metropolitan coastal areas, or in inland dry zone farming areas, in semi -arid grazing areas or in deserts- the inland areas being far less populated by humans? Is the nature of the material economy fundamentally different between the metropolis, the high amenity non-metropolitan coastal areas or the inland? Does the lateral expansion of the metropolis create more environmental damage than other forms of urbanisation and consumption in the coastal zone?

To answer these and related questions, analytical modelling of the multi-regional kind should be undertaken, with at least the following components: the metropolis and its perimetropolitan zone; urbanising areas in other parts of coastal Australia, and changes in inland areas. That is, a minimum of a three region model for each state, and taking account of the eccentric locations and their possible differential impacts of some cities like Brisbane. Such modelling should include stocks and flows, and alternating growth scenarios within each type of region.

Ian Burnley

How does the model deal with innovation and change, both technological and social – or how does 'Factor 4' thinking get a look in?

As much as everyone agrees that scientific breakthroughs and technological innovation are major drivers of societal change, no one has a good theoretical basis for predicting either the long-term direction of science and technology or its impact on society. Almost the opposite is the case, with eminent scientists and technologists like Lord Kelvin and Thomas Watson making spectacularly wrong predictions about the fate of the solar system and the need for computers respectively. For deep reasons to do with the nature of complex systems, we just cannot pick winners in science and technology.

The CSIRO modellers rightly avoid such traps. However, there is a sense that short-term incremental change can be brought within the scope of the project. One way to do this is to develop scenarios that mimic the potential impact of so-called 'Factor 4' technologies (von Weizsacker et al. 1997). This is essentially a call for a new set of technologies. Because the inputs and outputs of these technologies are specified – broadly half the resources as inputs, with twice the efficiency of processing resulting in quadrupled outputs – even if we do not know what the technologies actually are, they can be incorporated into the framework as a feasible scenario, after making some further assumptions to ensure that they are scientifically 'lawful'.

Thus the framework can do useful work to decide, in the first place, if various Factor 4 strategies are feasible, and then, if so, it can work through the consequences of such technologies for the whole framework as for any other scenario, by creating and exploring dilemmas. And, as with the other scenarios, resolving the dilemmas, deciding whether or not to embrace Factor 4 or other innovation strategies, and developing public policy to introduce the innovations are all activities to be handled in control space.

There are a vast number of possible permutations and combinations of different feasible Factor 4 technologies in such a well-specified framework as the present one. The CSIRO modellers have wisely chosen to describe the potential for using the framework in this way through only a few examples. They describe the consequences for the whole framework of halving the material and energy inputs to a group of important components in construction and transport – broadly, the manufacture and maintenance of buildings and vehicles.

However, we need to keep clear in our minds that the projection of these incremental, short-term changes, even if carried out over long time scales, is not the same as predicting the impact of future scientific and technological innovation on society. These future innovations will undoubtedly create dilemmas for society that, in their novelty, are unaccounted for in anyone's scenarios.

A technology analyst's perspective

Management of flows, through appropriate policy formulation, will clearly remain a critical area for government attention and action. In fact the positive environmental effects of reducing the energy and materials intensity of the economy, demonstrated by the two sub-scenarios in the study (buildings and transport) will probably drive government towards a policy stance of 'architect' rather than 'observer'.

However, even if this is not driven by local community concern and public values, it seems bound to be an outcome of economic survival in a global market. Many of Australia's trading partners in the OECD are taking a much more interventionist approach to industry and environmental policy, seeking to stimulate infrastructural change and technical innovation, to de-link economic growth from resource consumption. In these countries, combinations of resource taxes, procurement programs, targeted public R&D funds, information systems, standards and regulations, are being used to stimulate a progressive dematerialisation of production and consumption.

New systems of pollution and waste prevention, eco-products and services, and intelligent transport logistics and distribution systems, are the intended outcomes of such a policy framework, which assumes that it is possible to achieve 'win-win' economic and environmental outcomes through innovation. Resource efficient goods and services are seen as critical to reducing 'over-consumption' in developed countries (the Rio and Johannesburg agreements) and for development in countries which are resource and infrastructure poor.

Government attention to effectively managing resource flows (in the EU for example), has seen the growth of research organisations able to model the resource economy and support policy formulation by life-cycle thinking. The result of this shift in thinking is evident in the submissions from international business organisations to the World Summit for Sustainable Development in August 2002. In the face of such hand-on (industry and government) management approaches, a hands off 'leave it to the market' stance would simply run the risk that the Australian economy, infrastructure and technical development, would settle into a backwater, increasingly isolated from the new dynamics of the global economy.

Chris Ryan

CONCLUSION

What emerges from the study?

A key argument for modelling the whole system rather than its parts is that it is supposed to reveal something more than what is revealed by a set of models of the parts – the whole is believed to be more than the sum of the parts. Thus 'whole system' modellers look for 'emergence' – the generation of processes and structures that would not be seen at the level of partial models (Holland, 1998).

But what is the whole we wish to consider? Any reading of the CSIRO study confirms that the model itself is always seen in a larger context. There is a strong sense that the stakeholder workshops are an integral part of the process. There is also a sense that the model's users are also part of a whole system. This last point is made quite forcefully in the overall modelling strategy – the model (in the narrow sense) produces dilemmas or tensions that cannot be resolved within it. Instead, we seek resolution in a more embracing context where the users of the model – such as policy makers – can offer potential solutions whose efficacy can then be examined within the model. Thus, users and model are in a feedback loop, and together form a larger system out of which we might expect 'emergent behaviours'.

In a sense, users and model now become partners in a broader endeavour, and their previous roles as, respectively, subject and object become blurred. The boundaries between them are open, as are the boundaries between the disciplines within the model itself (Sherman and Schultz 1998). This openness is one of the particular strengths of the approach.

Thus, it is with this larger idea of emergence that we make our observations.
Perhaps the most striking, and first, thing to emerge from the study is the sheer diversity and intricacy of the interactions that make up the whole system. When viewed as a whole, and informed by the tremendously detailed workshop reports, we are see a new picture of Australia, one in which there is both 'devil in the detail' and some long-term strong processes driving the system. We see primary, secondary, tertiary and quaternary drivers – some direct, some indirect, some immediate, some greatly lagged – influencing the system of the human population and its environment.

This complexity just cannot be seen with single-issue models, and so this feature alone is a strong justification for the approach, even in the absence of more detailed analysis. It can be used as a reality check for disciplinary models, helping them acknowledge the richer world in which they exist.

However the richness of the system has greater uses than this. It is the primary source of a new understanding of the system being revealed by the study.

The study shows that we need to understand and manage both the stocks and the flows in the system, but that, by and large, we traditionally tend to focus on the flows. Stocks, as extremely slow moving variables in the system, may seem to be us, with our short time horizons, to be constants in the system, in contrast to the fast moving flows. But stocks have tremendous potential to modulate system behaviour over the longer haul, and indeed, drive the system in unexpected and sometimes undesirable directions. We see this in the present study in the way technology can 'saturate', resulting in environmental variables coming to drive some outcomes, and in the knock-on effects of resource stocks becoming constrained.

This attention to stocks as well as flows provides both a rationale for an expanded role for public policy and a setting within which the resulting tensions or dilemmas may be handled.

The distinction, in the study, between stocks and flows mirrors a distinction in our society between the concerns of public policy and the market. There is a sense in which the management of flows – fast moving variables in the system – is one of the key concerns of the market economy. There is also a recognition by government that it should get out of the business of the management of flows and 'leave it to the market'. This is reinforced if one observes that, in recent years, government has not only deregulated many of the markets it once managed (electricity, water, dairy and so on), it has also attempted to create new (deregulated) markets for previously unregulated and unexploited flows (carbon credits, salinity credits and so on).

The CSIRO report implicitly suggests and justifies a new role for public policy, even as public policy passes the management of flows to the market. This new role is the management of stocks, and this discovery is the second key thing to emerge from the study. The study shows emphatically that the stocks have time scales of decades or centuries, far beyond the concerns of the market, but it also shows that the management of stocks is as important, and probably more important than managing flows in resolving the dilemmas generated by the model.

The existence of the dilemmas is the last important feature to emerge from the study. The report identifies six dilemmas that cannot be resolved within the model. They each require policy intervention. Each of the dilemmas is important, involving major components of the system, and having strong effects on the behaviour of the whole system. The report shows that, while it may be possible to solve any single dilemma with concerted national action over a generation or two, in reality solutions will need to be sought for more than one dilemma at a time. Because dilemmas interact, the complexity of the problem will grow as more dilemmas are considered. The report offers no solution to this problem, instead only identifying it, and noting the importance of a whole-system approach to deeper understanding. It also notes that public debate is required to further bound the range of each dilemma.

Are the report's conclusions robust?

We need to consider two different aspects of robustness in examining this issue. The first has to do with the structure of the model itself – its grounding in physical reality, and its superstructure of progressively 'softer' sciences – with attendant questions about the robustness of the different components and their dependence on different disciplines with different conceptions of robustness. The second has to do with the use of the model to generate scenarios – with attendant questions about the robustness of the scenarios.

We may conceive of the model more or less as a hierarchy of calculators, each itself a model of some particular bit of the system. But we should not confuse this hierarchy with the implied scientific hierarchy above of natural sciences through to social sciences. In the individual calculators, soft and hard sciences are mixed up. Depending on the purpose of a calculator, it may derive its data and relationships from several disciplines.

Despite this mix of hard and soft science, three features of the modelling protocol ensure a high level of scientific rigour. In the first place, the whole model is highly empiric. It is based on actual data and known relationships over a long 'training set', which in the present case is the last 50 years. The model is grounded in this 'training set' by 'hindcasting': key individual calculators are progressively tuned and refined until they are able to 'predict' the known history accurately. Secondly, the model seeks to represent 'only' physical reality, for which the modellers use the term 'the physical economy'. This means that they only accept into the model those variables and processes that can be represented scientifically – they must be able to be measured in standard SI units – and hence are part of the real or material world. This is not to say that non-material variables, such as money, are not important to the way the world works. It argues instead that, because such non-material variables, if they are important, would have effects in the physical economy, their effects can be represented appropriately in the model. The last feature of the modelling protocol contributing to rigour is its 'lawfulness': the relationships between the variables follow known scientific laws. Thus, for example, matter and energy are conserved as required by physical law, and calculators may only interact in lawful and not arbitrary ways.

The effect of this rigour permeates the whole model and allows us to say that, if we accept that the calculators have captured the physical reality of their part of the world, then we should accept that the results the calculators produce will represent the path that their part of the world will take. The degree to which this is not true will be due solely to the degree to which we have not captured the physical reality and not to any other extraneous factor, such as the adequacy of any underlying theory. Empirical, physical modelling thus comes with an important intrinsic source of rigour: the 'truth' of the model comes from only one source – the data – and it is a source that may be progressively and rationally refined.

We may conclude that, as a modelling protocol, the CSIRO study is highly robust.
The matter of the use of that protocol for the development of scenarios demands its own analysis, even though the present study tends to confound them by assuming that the protocol is usually used for scenaric work.

We have discussed above the important differences between predictions and scenarios. And it is in the light of these differences that these comments on the robustness of the scenarios need to be understood. The two key points that bear on such robustness are the existence of dilemmas and their nature.

The first point is easy: dilemmas or tensions manifestly exist in the real world. It is our common human experience that issues continually arise within a frame of reference that can only be resolved by resort to a larger, more embracing frame of reference. This is a fundamental feature of all complex systems from social systems to mathematics (Gödel, 1931). It gives us some comfort that the study generates dilemmas. Indeed, it would be alarming if it did not. In this sense, the study is robust.

The nature of the dilemmas is trickier. The actual dilemmas arise in the model as a consequence of the working through of the scenarios, and we have argued that the scenarios should not be held to be true, in the sense that we expect explanations or predictions to be true. We ask no more of the scenarios than that they should be plausible and interesting: plausible in the sense of being a story that is continuous with the real 'story so far'; and interesting in the sense that, of all possible scenarios, the ones we choose have resonance with our concerns. We assume that, given the modelling protocol, scenarios will always be feasible, that is scientifically lawful. So it is not immediately clear how we should judge the robustness of some particular dilemma arising from some scenario.

Perhaps the best we can say is that the scenarios inherit their robustness from the modelling protocol, and the dilemmas inherit theirs from the scenarios. This line of argument leads us to suggest that while a particular dilemma may not be 'real', because it is robust and its antecedent scenario is both plausible and robust, then the dilemma surely resides in the neighbourhood of a real dilemma. We would be wise to take it seriously.

What are the report's implications?

Most research studies conclude with the mantra 'more research is needed'. This is also the case here. But this report offers us more than such an introverted implication. It offers a nested set of implications, deriving from the whole project, the model itself, the scenarios and the dilemmas.

Consideration of the whole project leads to the implication that it is feasible to analyse complex policy problems holistically rather than in a reductionist way. That is, we are not confined to thinking of such complex problems in a compartmentalised way. We are not forced, by a lack of tools or imagination, to analyse, say the demography, the ecology and the economics separately, and later merge them at the policy table in some *ad hoc* integrative way. We may, of course, choose to analyse our complex problems in discrete partitions, but the strong point made by the project is that we are no longer forced to. We have a choice.

An important corollary of this is that the object that goes to the policy table is, in a sense, balanced. The different disciplines make their contributions more or less equally in the policy-neutral and discipline-neutral language of physical reality, and none is 'subservient' to the other.

The model itself reveals that both stocks and flows contribute to the system's behaviour. The strong implication is that we are much better at managing the flows than stocks, in part because of the great difference in their time scales (days and weeks *vs* decades and centuries), in part because we usually think of stocks as a system constant rather than variable, and in part because we have tools to manage flows – the market – but none to manage stocks. We tend to do what we can do.

This implication has an important corollary too: as public policy relinquishes its interest in the direct management of flows (through deregulation and freeing of markets), it should envisage an emerging role in the management of stocks. Government needs to enhance its capacity to have long views of the system.

EXTERNAL REFERENCE GROUP COMMENTS

The scenarios, as argued above, are plausible stories about possible futures. They were chosen because they each represent the particular concerns of different protagonists in the public policy debate on Australia's future population. The model demonstrates that no scenario is an unalloyed good – a clear and unrestricted path to the future. Instead it shows that each creates tensions that need resolution at the policy table. A moment's reflection suggests that this is good common sense – we would be alarmed and suspicious, knowing what we do about the way the world works, if there appeared to be some 'Yellow Brick Road' to the future.

The strong implication of the scenarios is that the future involves dilemmas, no matter which path we take. But the corollary of the implication that there are choices among dilemmas is that we actually have a choice. The future is not determined.

When we consider the dilemmas or tensions, we immediately observe that the system has emergent properties, as discussed above. This observation is not available to disciplinary analysis. This adds to our implication above – the feasibility of holistic analysis – the further implication of its necessity if we wish to understand the whole system. This necessity is compounded when we consider, as discussed in the report, the need to resolve dilemmas in parallel.

The dilemmas create a final implication. While they cannot be more 'real' than the scenarios from which they unfold, they strongly imply the existence of real dilemmas in their neighbourhood, because of the way in which they inherit their 'reality' from the model itself. They merit further research.

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