Garnaut CLIMATE CHANGE REVIEW

DRAFT REPORT

JUNE 2008

Garnaut
CLIMATE CHANGE
REVIEW

ISBN: 978-1-921337-34-5

The dollar amounts in this report are in Australian dollars, unless otherwise indicated.

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Editorial, design and artwork by WHH Publishing
Printed by Blue Star Print Group

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Preface

The Garnaut Climate Change Review was initiated by the then Leader of the Opposition, the Hon Kevin Rudd, and by the First Ministers of the eight states and territories of Australia. It was commissioned by the First Ministers on 30 April 2007. The Commonwealth joined the Review at the end of 2007.

The Review was required to examine the impacts of climate change on the Australian economy, and to recommend medium- to long-term policies and policy frameworks to improve the prospects of sustainable prosperity.

The Review's secretariat was established in June 2007. Based originally within the Victorian Department of Premier and Cabinet, it includes members from the Queensland, Western Australian and South Australian governments. A secretariat office within the federal Department of Climate Change was established in January 2008. The secretariat has provided invaluable expertise and support to this challenging exercise.

This draft report represents a detailed assessment of the implications of climate change for a single nation. It has built on the existing body of information in the fields of science and economics, and undertaken significant new work to illuminate the potential impacts on, and the most effective course of action for, Australia.

As part of its research and analysis, the Review has consulted widely with a wide range of experts in Australia and overseas: academics, officials, government departments and public bodies, business leaders and representatives, and non-government organisations. The Review thanks all these people and organisations for their generous support under compressed time frames.

The Review has also benefited substantially from interactions with other organisations and the community more generally at five specialist forums and eight public lectures held around the country between August 2007 and June 2008. These forums and lectures were held in almost every mainland capital city, with an attendance of more than 3200 people in the lead up to the release of the draft report.

A lengthy formal submissions process was also conducted, which attracted almost 4000 submissions. Interested stakeholders were encouraged to respond to a series of five issues papers, a discussion paper on the proposed emissions trading scheme and an interim report released in January 2008, all of which stimulated public discussion and debate on some of the most critical issues for climate change mitigation and adaptation in Australia. The submissions assisted in shaping the direction of the Review and a submissions report will be released in July 2008.

Issues of significance not considered in this draft report (such as the results of the economic modelling and the important issues of adaptation) will be further discussed in the supplementary draft report and the final report.

Terms of reference

30 April 2007

To report to the Governments of the eight States and Territories of Australia, and if invited to do so, to the Prime Minister of Australia, on:

1. The likely effect of human induced climate change on Australia's economy, environment, and water resources in the absence of effective national and international efforts to substantially cut greenhouse gas emissions;
2. The possible ameliorating effects of international policy reform on climate change, and the costs and benefits of various international and Australian policy interventions on Australian economic activity;
3. The role that Australia can play in the development and implementation of effective international policies on climate change; and
4. In the light of 1 to 3, recommend medium to long-term policy options for Australia, and the time path for their implementation which, taking the costs and benefits of domestic and international policies on climate change into account, will produce the best possible outcomes for Australia.

In making these recommendations, the Review will consider policies that: mitigate climate change, reduce the costs of adjustment to climate change (including through the acceleration of technological change in supply and use of energy), and reduce any adverse effects of climate change and mitigating policy responses on Australian incomes.

This Review should take into account the following core factors:

- The regional, sectoral and distributional implications of climate change and policies to mitigate climate change;
- The economic and strategic opportunities for Australia from playing a leading role in our region's shift to a more carbon-efficient economy, including the potential for Australia to become a regional hub for the technologies and industries associated with global movement to low carbon emissions; and
- The costs and benefits of Australia taking significant action to mitigate climate change ahead of competitor nations; and
- The weight of scientific opinion that developed countries need to reduce their greenhouse gas emissions by 60 percent by 2050 against 2000 emission levels, if global greenhouse gas concentrations in the atmosphere are to be stabilised to between 450 and 550ppm by mid century.

Consult with key stakeholders to understand views and inform analysis. A draft Report is to be distributed for comment by June 30 2008. The final Report is to be completed and published by September 30 2008. Interim draft reports on particular issues may be released before that time for public discussion. The Report will embody the independent judgments of its author.

1 AUSTRALIA'S CLIMATE CHANGE CHALLENGE

The weight of scientific evidence tells us that Australians are facing risks of damaging climate change. The risk can be substantially reduced by strong and early action by all major economies. Without that action, it is probable that Australians, over the 21st century and beyond, will experience disruption in their prosperity and enjoyment of life, and to longstanding patterns in their lives.

There is no doubt about the position of most reputed specialists in climate science, in Australia and abroad, on the risks of climate change (see Chapter 3). There is strong support for the mainstream science from the leaders of the relevant science academies in all of the major countries.[1] The outsider to climate science has no rational choice but to accept that, on a balance of probabilities, the mainstream science is right.

There are nevertheless large uncertainties in the science. While there is a clear majority view that there are high risks, there is debate and honest recognition of limits to knowledge about the times and ways in which the risk will manifest itself. Every climate scientist has his or her views on some issues that differ from the mainstream in detail.

There are prominent dissenters on this matter, gathered under the rubric of 'sceptic'. For the most part 'sceptic' is a misnomer for their position, because these dissenters hold strongly to the belief that the mainstream science is wrong. I exclude from this generalisation a small number of climate scientists of professional repute, who accept the theory of the warming effects of higher concentrations of greenhouse gases, but hold the view that these warming effects are relatively or even trivially small in comparison with many other causes of climate variations that are beyond the control of humans.

The dissent took a curious turn in Australia in 2008, with much prominence being given to assertions that a warming trend had ended over the last decade. This is a question that is amenable to statistical analysis, and we asked econometricians with expertise in analysis of time series to examine it. Their response, that the temperatures recorded in most of the last decade lie above the confidence level produced by any model that does not allow for a warming trend, is reported in Chapter 5 (Box 5.1).

Effective international action is necessary if the risks of dangerous climate change are to be held to acceptable levels, but deeply problematic. International cooperation is essential for a solution to a global problem. However, such a solution requires the resolution of a genuine prisoners' dilemma. Each country benefits from a national point of view if it does less of the mitigation itself, and others do more. If all countries act on this basis, without forethought and cooperation, there will be no resolution of the dilemma. We will all judge the outcome, in the fullness of time, to be insufficient and unsatisfactory.

Resolution of the international prisoner's dilemma takes time—possibly more time than we have. The world has squandered the time that it did have in the 1990s to experiment with various approaches to mitigation.

Climate change is a diabolical policy problem. It is harder than any other issue of high importance that has come before our polity in living memory.

Climate change presents a new kind of challenge. It is uncertain in its form and extent, rather than drawn in clear lines. It is insidious rather than directly confrontational. It is long term rather than immediate, in both its impacts and its remedies. Any effective remedies lie beyond any act of national will, requiring international cooperation of unprecedented dimension and complexity.

While an effective response to the challenge would play out over many decades, it must take shape and be put in place over the next few years. Without such action, if the mainstream science is broadly right, the Review's assessment of likely growth in global greenhouse gas emissions in the absence of effective mitigation tells us that the risks of dangerous climate change, already significant, will soon have risen to dangerously high levels.

Observation of daily debate and media discussion in Australia and elsewhere suggests that this issue might be too hard for rational policy making. It is too complex. The special interests are too numerous, powerful and intense. The time frames within which effects become evident are too long, and the time frames within which action must be effected too short.

The most inappropriate response would be to delude ourselves, taking small actions that create an appearance of action, but which do not solve the problem. Such an approach would risk the integrity of our market economy and political processes to no good effect.

We will delude ourselves if we think that scientific uncertainties are cause for delay. Delaying now will eliminate attractive lower-cost options. Delaying now is not postponing a decision. To delay is to deliberately choose to avoid effective steps to reduce the risks of climate change to acceptable levels.

The work of this Review is directed at nurturing the slender chance that Australia and the world will manage to develop a position that strikes a good balance between the costs of dangerous climate change and the costs of mitigation.

Australia has a larger interest in a strong mitigation outcome than other developed countries. Our location makes us already a hot and dry country; small variations in climate are more damaging to us than to other developed countries. We live in a region of developing countries, which are in weaker positions to adapt to climate change than wealthy countries with robust political and economic institutions. The problems of our neighbours would inevitably become our problems. And the structure of our economy suggests that our terms of trade would be damaged more by the effects of climate change than would those of any other developed country (see Chapter 9).

However, Australia carries some major assets into this challenge. Australians are facing this new kind of challenge in the best of times. These are the times that earlier generations of Australians hoped for their country.

Australia is fortunate that humanity is enjoying the harvest of modern economic development in Asia and beyond. More people are emerging from poverty more quickly than ever before in human history.

Australia is enjoying a double harvest. The internationally oriented market reforms from the 1980s were put in place just in time. We are now riding the extension of the beneficent processes of modern economic growth into the heartlands of the populous countries of Asia.

In the early years of our federation Australians took pride in the highest living standards in the world. On the eve of World War I, Australia's output per person was a bit above that of the United States, then and now the benchmark for economic modernity. Then, for seven decades, we turned in on ourselves, and paid the cost. For seven decades, we fell further and further behind the global frontiers of productivity and incomes. The value of our output per person fell to less than two thirds of the United States.

Then, a quarter of a century ago, we caught that tide which taken at the flood leads on to fortune. On such a full sea we are now afloat. In the first quarter of this year, for the first time since the onset of World War I, the value of output per person in Australia exceeded that of the United States when both are measured in the national accounts and converted into a currency at today's exchange rates.[2]

So we have much to contribute and much to lose as we face the diabolical policy challenge of climate change. Unmitigated climate change could lose this challenge. Or it could be lost by a bungled attempt to mitigate climate change, which would bring back into the centre of our national policy all of the self-interested pressure groups and arbitrary interventions that retarded our progress for so long.

Australians' recent return to material grace has had two direct causes. First was our decisive rejection and reversal of mistakes of the early decades after federation: the turning away from protectionism, xenophobia and the bureaucratic trammelling of the market.

The second cause is the Asian economic boom. Australia's resources and human capacities are more closely complementary to those of the densely populated countries of Asia than are those of any other economies on earth.

For other developed and many developing countries, the strong growth in industrial production and demand for raw materials and food that accompanies economic growth in China, India, Indonesia and other Asian countries is seen as a competitive and inflationary threat. For Australia, it is unbridled opportunity. Strong Chinese and other Asian economic growth has been the main factor behind the lift in Australia's terms of trade by about two-thirds over the past six years. This has lifted the average value of Australian output and incomes by over one-eighth from the effects of increased export prices alone.

The Asian economic boom, half the cause of our prosperity, is also the source of the sharper immediacy of the climate change problem. The increase in concentrations of greenhouse gases in the atmosphere over the last two centuries has generated the climate change that we have experienced to date and will experience over the next couple of decades. This is the result of economic activity in the countries that are now rich. The rapid increase in concentrations that are expected over the next several decades is primarily the result of activities in the developing countries that are becoming rich. This rapid increase is what makes action to avert dangerous climate change urgent.

The links between our own prosperity, and the increase in greenhouse gas emissions in Asian developing countries, is rather more direct than the general terms of trade effects would suggest. Fossil fuels have been a major component of increased Australian exports through the Asian boom of the early 21st century.

The contribution to the value of Australian exports of the increase in price alone, of just one fossil fuel commodity—coal—in 2008–09 is projected to equal in value about 2 per cent of Australian GDP.

It is neither desirable, nor remotely feasible, to seek to lower the climate change risk by substantially slowing the rise in living standards anywhere, least of all in developing countries. If such an approach were thought to be desirable in some expression of distant and idiosyncratic values, Australians would not accept it. Nor would it be in Australia's interests for Asia's developing countries to accept truncation of their people's hopes for rising living standards in the interests of climate change mitigation. Their prosperity or its end is translated quickly into our own.

The solutions to the climate change challenge must be found in removing the links between economic activity and greenhouse gas emissions

For Australia, the commitment to the mitigation of climate change can be seen as the reinvestment of a part of the immense gains that have come from accelerated Asian economic growth, in contributing to reduction of an adverse side effect of that growth. In this, we are in a privileged position. We are different from most other countries, and certainly from all other developed countries except Norway.

These realities need to be kept in mind if we are to retain perspective in the domestic debate about mitigation and the emissions trading scheme. Some elements of the Australian resources sector have been especially vocal about the perceived threat that a price on carbon poses to their competitiveness and to Australian prosperity.

Our trade-exposed, emissions-intensive industries have valid concerns. The Review has acknowledged these from the beginning, and sought to accommodate them in its proposals for emissions trading scheme design. Along with some of our farm industries, metals processing would be the most affected, and have the first claims for special measures. Every element of costs matters, and no increase in costs should be imposed on business without good reason. But when assessments of the reasonableness of arrangements for trade-exposed industries are made, we should be mindful of the wider context. The highest possible obligations under an emissions trading scheme, at the top end of the range of possibilities for permit prices for the foreseeable future, would represent a small fraction of the resource sector's increased revenue from higher export prices in recent years.

It is only to be expected that each firm, industry and sector will argue its own case in its own interests. Senior corporate executives are paid to do exactly that. But in taking these arguments into the national debate, let us make sure that there is also a strong and independent centre for the policy-making process that can keep sectoral claims in perspective.

Balance, reason and understanding of the premises and logic leading to policy conclusions are the keys to Australia and the world using well its last chance to get this difficult policy problem right.

The Review's first aim is to lay out the issues for policy choice in a transparent way. The Review will have done its job if Australian governments and the community make their choices in full knowledge of the consequences of their decisions.

No answers to questions as complex and difficult as those introduced in this chapter would seem right, or palatable, to everyone. Perhaps no answers, with their many parts, would seem right or palatable to anyone.

Many will disagree with elements or the whole of the conclusions of this Review. Many will disagree with the policy proposals that flow from the conclusions. They would prefer cheaper, more certain, later and less disruptive ways forward, or higher levels and urgency of Australian mitigation ambition.

The Review would prefer cheaper, more certain, later and less disruptive ways forward, if any were available that were not associated with large risks of damage from climate change.

Tempting though it is to do so, it is neither rational nor helpful to reject conclusions because we do not like them. The conclusions will only be 'wrong' if the premises or logic leading to them are wrong. The Review aims to be clear in its premises and methodology, so that they can be contested transparently. If the subsequent public policy debate follows these lines, we will improve the prospects of Australian governments taking good decisions in the year ahead on a sound basis and with widespread community support, and therefore with prospects of policy continuity.

1.1 The context of the draft report in the Garnaut Climate Change Review

This draft report describes the methodology that the Review is applying to evaluation of the costs and benefits of climate change mitigation; to the application of the science of climate change to Australia; to the international context of Australian mitigation; and to Australian mitigation policy. The draft report is a stage in the journey towards the final report at the end of September 2008. It follows the Interim Report in February and the discussion paper on the emissions trading scheme in March 2008.

A supplementary draft report will present the outcomes of all of the joint modelling with the Commonwealth Treasury on the costs of climate change mitigation. The supplementary draft report will also present the results of the Review's modelling of the benefits of climate change avoided. This will allow assessment of the costs and benefits for Australia of varying degrees of mitigation. This, in turn, provides the basis for the Review's recommendations on emissions reduction targets for Australia. Recommendations on targets, consistently with the Review's analysis, will be built around trajectories for emissions reductions over time.

The supplementary draft and final reports will respond to many of the questions to which the Australian community is anxious to have answers. What is the Review recommending about targets and trajectories for emissions reductions in Australia? What does the Review think that this will mean for the carbon price? What effect will this have on petrol and electricity prices?

The answers will have to wait for the completion of the modelling. The Review has avoided speculation on these matters. It would not be helpful to speculate now.

While the draft report does not present the results of modelling the costs and benefits of climate change, it does provide the first public exposure of aspects of the Garnaut–Treasury and Garnaut Review approach to the modelling. It reports some high-level results from the reference case, upon which subsequent economy-wide quantitative analysis will be built: a perspective on growth and structural change in the Australian economy over the 21st century, on the assumption that it is affected neither by climate change nor by climate change mitigation policies.

The draft report also presents the early results of the Garnaut Review's modelling of growth and structural change in the Australian economy over the 21st century in the presence of climate change and the absence of mitigation policies. The difference between the reference case and the case with climate change can be seen as the costs of climate change.

The modelling can cover only some of the benefits of climate change mitigation—those that are amenable to quantitative analysis and for which data were available in the tight time frames of the Review. Comprehensive analysis of the costs of climate change must take account of other factors. Chapter 2 describes the analytic framework that the Review is applying to the integration of all of the anticipated costs and benefits of climate change. While Chapter 2, and the beginnings of its application in Chapter 10, will not satisfy the curious, there is some advantage in discussing the analytic framework in advance of the results of most of the modelling. Like people behind the Rawlsian veil, we can take positions on principle in advance of knowing the precise implications for our own positions (Rawls 1971). The analytical framework presented in Chapter 2 is the essential foundation for public policy choice.

The final report will discuss the way in which the Australian economy responds and changes in the course of progress towards a low-emissions Australian and global economy. There will be separate chapters on the three broad sectors that will be at the centre of the mitigation effort: energy; agriculture and forestry; and transport. There will be an overarching chapter on Australia's transition to a low-carbon economy that brings the sectoral elements together.

These chapters draw in varying degrees on the econometric modelling, and so are left for the supplementary draft and final reports. The draft report does, however, contain a chapter on the energy sector's transformation. This is linked closely to the operation of the Australian emissions trading scheme, so there is value in exposing the Review's perspectives alongside the discussion of its views on the design of the emissions trading scheme.

The draft report generally does not make recommendations, although the tendency of policy analysis is clear. It is closest to recommendations on the design features of the emissions trading scheme, which require business and community discussion of the issues before the completion of the final report at the end of September 2008.

The Review will present in the final report the results of its work on the important question of adaptation to climate change. It is likely that Australians will have to manage difficult climate change, whatever the failure or success of the global mitigation effort from now on. The final report will cover the conceptual framework for looking at adaptation policies; the nature of the Australian adaptation challenge under business as usual and various degrees of effective global mitigation; some important adaptation policy options in key sectors and regions; and water, the central Australian adaptation challenge.

The final report will also present the Review's analysis and recommendations on the appropriate location within the Australian federation of policy and administrative responsibilities for various aspects of climate change mitigation and adaptation.

1.2 Main themes

Some general ideas recur through the draft report, and may be more important than others. They can be taken as central themes, summarised here.

The first theme is that the uncertainty surrounding the climate change issue is a reason for disciplined analysis and decision, not for delaying decisions. Under uncertainty, knowledge has high value, and this makes the case for increased investment in applied climate science. Uncertainty does not make the case for delay. Rigorous decision making under uncertainty recognises that options have value, and that option values decay with time.

The second theme is that in meeting the climate change contest, Australia's prime asset is the prosperous, flexible, market-oriented economy that has emerged from difficult reforms over the past quarter century. This gives us the resources to join other developed countries in sharing the global leadership responsibility for mitigation and adaptation. It provides a basis for market-oriented domestic approaches to mitigation and adaptation that can reduce their costs. It suggests the primacy of preservation of the integrity of market institutions in designing the approach to mitigation and adaptation.

It is a corollary of the second theme that an effective market-based system will be as broadly based as possible, with any exclusions driven by practical necessity and not by short-term political considerations. It will include transport and petroleum products. This will allow abatement to occur in the enterprises and industries and regions in which it can be achieved at lowest cost. We do not know now what those firms and industries and regions will be, and application of similar incentive structures over as much of the economy as possible allows market processes to guide the emergence of favourable outcomes.

The third theme is that domestic policy must be deeply integrated into global discussions and agreements. Only a global agreement has any prospect of reducing risks of dangerous climate change to acceptable levels. The costs of achieving any target or holding any trajectory for reducing Australian greenhouse gas emissions will be much lower within the framework of an international agreement. The continuation for long periods of strong Australian mitigation outside a global agreement is likely to corrode the integrity of the Australian market economy. It is therefore important to see any period in which an Australian mitigation effort is in place prior to an effective global arrangement as short, transitional and contributing to the achievement of a sound global agreement.

1.3 Main policy tendencies

Some main tendencies in the policy analysis are worth an early mention.

The first is the importance in engaging now in the international dialogue on a global mitigation regime. The good options on mitigation will soon be gone. The extraordinary growth in emissions from the major developing countries, first of all China, means that their early participation in a global agreement on mitigation is essential for success. This conclusion is at odds with the momentum of current international discussions. It may not seem fair to the developing countries, given their stage of development and the history of the international discussions. But it is essential for successful global mitigation.

The nature of the mitigation commitments can vary across countries (Chapter 13). The international community, and Australia, can improve the odds of the major developing countries becoming part of an effective global regime, by defining the terms of developing country engagement with a global regime with the objective of improving the odds. In China's case, cooperation in development and commercialisation of new, low-emissions technologies would be of special importance.

The Review attaches high importance to its proposal for expanding the global research, development and commercialisation effort on low-emissions technologies, because of what it will do for the cost of mitigation everywhere, and for the encouragement that it would provide for developing countries to participate in the global mitigation effort.

The Review's thoughts on the Australian mitigation regime have been much discussed since the release of its Interim Report and the emissions trading scheme discussion paper. It may be worth re-iterating the broad approach to emissions reductions targets and trajectories put forward in those earlier papers. Until 2012, Australia's emissions reduction trajectory is defined by its commitments under the Kyoto Protocol. Its first commitments for the post-2012 period should represent similar adjustment effort to that being made by other developed countries. Recent developments in political discussion in the United States and Japan suggest that the Commonwealth Government's commitments to a 60 per cent emissions reductions may fit this requirement. Beyond that, Australia should be prepared to go further within a comprehensive global agreement, with appropriate commitments from major developing countries. Those general principles will be developed further in the light of the modelling results, and presented in the supplementary draft and final reports. The emphasis on simplicity and credibility in the interim report and discussion paper has, we think, stood the test of public scrutiny.

The discussion has helped to take forward thinking within the Review on some matters raised in those earlier papers. We have been convinced by the evidence that while payments to trade-exposed, emissions-intensive industries to avoid 'carbon leakage' are justified in principle, their application raises dreadful problems. The danger of a process of allocation of balancing payments descending into a rush for government preferment has been emphasised by behaviour in the political marketplace.

Several implications follow. First, the development of international agreements which establish a more or less level playing field for the main affected Australian industries is an urgent matter. There is no prospect for comprehensive global agreements to play this role in years immediately ahead. The establishment of a special kind of sectoral agreement then becomes a matter of urgency. With priority in policy and diplomacy, it would be possible to establish appropriately structured sectoral agreements for several major commodities in time for the post-Kyoto world of 2013.

In the absence of such an agreement, we suggest that simple rules be established to govern payments to trade-exposed, emissions-intensive industries. General analysis should identify a maximum proportion of permit value appropriate for handling the 'carbon leakage' problem. The ratio would be less than or up to 30 per cent. Simply administered rules of thumb would be constructed around the principles for payments to trade-exposed industries articulated in the discussion paper and in Chapter 15. The rules would define a threshold of loss on an industry basis, with payments being made to offset costs of permits above that point, on a similar basis for all firms in an industry. To the extent that the sum of payments under the rules of thumb fell short of the value of permits under the defined ratio, the difference would be returned as tax cuts to business in some efficiency-raising way, focusing on reduction of distorting input and transaction taxes.

Much anxiety was expressed in consultations about the possibility of an unconstrained emissions trading scheme from 2010 generating high and unstable prices in the early years, and this being disruptive for the economy. The Review recognises that the high fossil fuel prices of 2008, which are likely to continue at least for some time, will force considerable emissions reduction below levels that would otherwise have prevailed in the years of Australia's Kyoto commitments, between 2010 and 2012.

While there are substantial advantages in moving directly to the unconstrained operation of the proposed emissions trading system in 2010, the Review accepts that there is a legitimate second best case for a fixed price for permits in the early years. The advantages and disadvantages of a transition period are discussed in Chapter 15, along with the conditions that would need to be applied in the transition case.

One advantage of such an approach is that, depending on the threshold and the price, it may obviate the need for payments to trade-exposed, emissions-intensive industries in these years of transition. This would allow time for some sectoral agreements to be put in place, perhaps permanently removing the need for such payments.

This would be a large advantage.

Against this, immediate entry into the full regime would see the earlier development of the full range of institutional arrangements to support market exchange of permits. An immediate start-up would remove the chances of industry pressure blocking the eventual movement to an unconstrained system.

The Review proposes that all permits be allocated on a competitive basis. This will generate substantial amounts of revenue. How this revenue is allocated by government will have a large influence on the economic effects of the mitigation effort.

The Review proposes that all of the revenue be returned to households or to business. The modelling that will be reported in the supplementary draft report will provide important guidance into likely amounts of revenue, and into the incidence of the burden of adjustment on various parts of the economy and community.

As a general guide, the Review has formed the view that about half of the permit revenue should be returned to the household sector, mostly as adjustments to the tax and social security systems that enhance efficiency, with some allocations to promote energy efficiency, especially among low-income households.

There are equity and economic management reasons for concentrating the return of permit revenue on the bottom half of the income distribution. This will overcome what would otherwise be regressive income distribution effects of the emissions trading system (Chapter 19). It will also remove pressure for adjustments to wages at the lower end of the wage distribution, that would otherwise introduce risks that what could be a once-for-all price adjustment would be converted into an inflationary spiral.

The Review has formed the view that in the years before there are effective international agreements removing the need for special support for trade-exposed, emissions-intensive industries, up to 30 percent of permit sales revenue could be returned to the business sector as payments to exposed firms, or as a general, efficiency-raising reduction in business taxation (Chapter 15).

The Review has formed the view that about 20 per cent of the permit sales revenue should be allocated to support for research, development and commercialisation of new, low-emissions technologies. This would fund a substantial part of Australia's obligations under the proposed International Low Emissions Technology Commitment (Chapter 13).

1.4 Adaptation: prospects and limits

The international community is too late with effective mitigation to avoid significant impacts. It may yet fail to put in place substantial mitigation, in which case the challenge of adaptation to climate change will be more daunting. Damage from climate change, perhaps immense damage, is likely to be part of the Australian reality of the 21st century and beyond.

Our final report will analyse the adaptation issues closely.

Adaptation to some of the possible consequences would test us and our values and preferences in profound ways. Contemplating the adaptation challenges of future Australians helps to focus our minds on the more difficult dimensions of mitigation choices.

We are led to think about how we value future against current generations. We are forced to decide what we would be prepared to pay in terms of consumption of goods and services foregone, to avoid uncertain prospects of thinly defined but possibly immensely unhappy outcomes. We are forced to decide what current and early material consumption we would be prepared to pay to avoid loss of things that we value, but are not accustomed to valuing in monetary equivalents.

In making their choices, Australians will have to decide whether and how much they value many aspects of the natural order and its social manifestations that have been part of their idea of their country. In the discussion of climate change, much is made of natural wonders—of the Great Barrier Reef, the wetlands of Kakadu, the karri forests. We know that we value them highly, and now we will need to think about whether we are prepared to pay for their preservation.

As a changed future approaches, Australians will find themselves thinking about how much they care about other dimensions of our national life that have always been taken for granted.

As we will see, with unmitigated climate change, the risks are high that there will be change beyond recognition in the heartlands of old, rural Australia, in Victoria, Western Australia, South Australia, and in the Murray-Darling Basin, which features prominently in our analysis of the possible impacts of climate change. The loss of these heartlands of old Australian identity would be mourned.

1.5 Synopsis

The draft report is structured into 20 chapters that address important dimensions of the huge arena on which the assessment of climate change and its interaction with Australian lives is being played out. Some chapters draw inevitably on the language of economics to a degree that may be unwelcome to the general reader. Others contain more detail than the busy person of practical inclination or responsibilities has time to absorb. Thus not everyone who is interested in climate change, its mitigation, its effects on Australia, and the policy issues that it raises will wish to read the draft report from beginning to end. To help readers to discover quickly its main lines of argument as well as the implications that it draws for policy, and to decide which parts they would like to read in detail, this synopsis provides a summary of key points in each of the following chapters.

The draft report begins by laying out a framework for policy analysis and decision making (Chapter Two). This framework seeks to take full account of uncertainty, risk aversion, and the complex interaction of material consumption, non-market services and time in the assessment of the policy outcomes that serve Australians' interests and values best. The framework seeks to define and, where possible, to quantify for Australians, the consequences of doing nothing about climate change, and of playing our proportionate part in global mitigation efforts of varying ambition.

Chapters 3 to 7 introduce the scientific and economic issues underlying the policy choice. Chapter 3 discusses the basic science of human-induced global warming, focusing on the critical role of atmospheric concentrations of greenhouse gases, the accumulation of which has been accelerating with global economic development.

Chapter 4 has a fresh look at what is happening to emissions, applying a realistic view of the implications of economic development in major Asian developing countries, first of all China, but now more broadly. The Review's work in this area has forced a reassessment of the global challenge: faster, more energy-intensive and more emissions-intensive growth in developing Asia is leading to substantially more rapid growth in emissions than had previously been understood by the international scientific community. The clear and unfortunate implication is that we have less time than previously understood to stem the growth of global emissions, if we are to avoid high risks of dangerous climate change, as defined by mainstream science.

Chapter 5 discusses the probable global climate impacts with no mitigation and with mitigation of varying ambition. Chapter 6 applies that framework to the impacts on Australia. Chapter 7 moves from climate to economic and social impacts, focusing on a limited number of issues of large importance. It provides a taste of the much wider and more detailed work on Australian impacts that has helped to provide the basis for subsequent modelling (Chapter 9) and assessment (Chapter 10). The full studies on which Chapter 7 is based are available on the Review website.

Chapter 8 is the Australian analogue of Chapter 4, looking at the structure of Australian emissions. It asks why Australian emissions are unusually high by global standards, and concludes that it is mainly as a result of our much greater use of coal for electricity generation.

Chapters 9 and 10 bring together the elements of policy choice. The modelling reported in Chapter 9 defines as precisely as possible the general economic effects of the climate impacts that emerge from Chapter 7. In the draft report, the analysis is confined to the costs of climate change—the analysis of the costs and benefits of mitigation raises different and more difficult questions, which will be addressed in the supplementary draft report.

Some important economic impacts of climate change cannot be defined precisely enough for economic modelling. Some involve judgments about the insurance value of avoiding improbable but extremely damaging outcomes. Some impacts are not felt through markets at all, and do not affect consumption of goods and services, but may nevertheless be valued by Australians. Chapter 10 makes a first effort to bring the various influences on value together.

Australian mitigation effort only makes sense as a contribution to effective global contribution. Chapters 11 to 13 discuss the interaction between global and Australian developments. They suggest some ideas on possible ways forward in an international scene that is less than encouraging in all ways except one. That one might just be decisive: the growing concern about global warming in many countries that may encourage governments to be more ambitious on mitigation in future than they have been in the past.

Chapters 14 to 19 discuss Australian mitigation policy in a global context. They propose that a simple emissions trading system of broad coverage be relied upon to achieve the emissions reduction goals of the Commonwealth Government, selected for the role that they can play in supporting the emergence of an effective global mitigation regime. Other measures have a role if, and only if, they remove or reduce the costs of various market failures, the presence of which would otherwise raise the cost of adjustment to the emissions trading scheme. Support for research development and commercialisation of new, low-emissions technologies (Chapter 16), network infrastructure (Chapter 17) and information and agency issues (Chapter 18) are analysed in this context.

The introduction of an emissions trading scheme may have large and regressive effects on the distribution of income. These effects and possible policy responses will be modelled and the results presented in the supplementary draft report. Effective management of this issue is going to be crucial to the success of the emissions trading scheme. Chapter 19 addresses the issues in advance of the modelling results.

The emissions trading scheme and associated mitigation policies will contribute to large structural change throughout the Australian economy. The changes will be most profound in the sectors in which emissions are most important—first of all energy, and then transport, and agriculture and forestry. The draft report presents some preliminary views on the energy transformation that will be triggered by the suite of recommended mitigation policies. This analysis can be taken further in the final report, when the modelling results are in hand. The other economic adjustment chapters will be presented in the final report.

1.5.1 Key points

Chapter 2

The central policy issue facing the Review can be stated simply: what extent of global mitigation, with Australia playing its proportionate part, provides the greatest excess of gains from reduced risks of climate change over costs of mitigation?

Answering the question draws on our capacity to model conventional economic effects, to measure and to value uncertain outcomes, to value effects that are not felt through markets for goods, services or factors of production, and to value costs and benefits incurred and received by different people at different times.

This chapter puts forward a framework for looking at these issues. It favours transparent reporting of the premises of subsequent discussion, and the introduction of analysis of the sensitivity of outcomes to variables.

The reserves and resources of fossil fuels are finite, which means that their costs are likely to rise over time. This reduces the costs of mitigation, which brings forward an inevitable eventual adjustment away from fossil fuels.

Chapter 3

The Review takes as its starting point, on the balance of probabilities and not as a matter of belief, the majority opinion of the Australian and international scientific communities that human activities resulted in substantial global warming from the mid 20th century, and that continued growth in greenhouse gas concentrations caused by human-induced emissions would generate high risks of dangerous climate change.

A natural carbon cycle converts the sun's energy and atmospheric carbon into organic matter through plants and algae, and stores it in the earth's crust and oceans. Stabilisation of carbon dioxide concentrations in the atmosphere requires the rate of greenhouse gas emissions to fall to the rate of natural sequestration.

There are many uncertainties around the mean expectations from the science, with the possibility of outcomes that are either more benign—or catastrophic.

Chapter 4

Greenhouse gas emissions have grown rapidly in the early 21st century. In the absence of strong mitigation, strong growth is expected to continue for the next two decades and in only somewhat moderated rates beyond.

So far, the biggest deviations from earlier expectations are in China. Economic growth, the energy intensity of that growth, and the emissions intensity of energy use are all at, or above, projections embodied in these earlier expectations. China has recently overtaken the United States as the world's largest emitter, and, in an unmitigated future, would account for about 35 per cent of global emissions in 2030.

Other developing countries are also becoming major contributors to global emissions growth, and will take over from China as the main growing sources a few decades from now. Under the unmitigated case, developing countries would account for about 80 per cent of emissions growth over the next two decades and more after that.

High petroleum prices will not necessarily slow emissions growth, because of the ample availability of large resources of high-emissions fossil fuel alternatives, notably coal.

Chapter 5

As a result of past actions, the world is already committed to a level of warming that could lead to high-consequence climate change outcomes.

Extreme climate responses are not always considered in the assessment of climate change impacts due to the high level of uncertainty and a lack of understanding of how they work. However, the potentially catastrophic consequences of such events means it is vitally important that the current knowledge of these outcomes is incorporated in the decision-making process.

Continued high emissions growth with no mitigation action carries high risks. These risks would be reduced by ad hoc mitigation, but remain high for some elements. Ambitious global mitigation would reduce the risks further, but some systems may still suffer critical damage.

There are advantages in aiming for an ambitious global mitigation target in order to avoid some of the high-consequence impacts of climate change.

Chapter 6

Australia's dry and variable climate has been a challenge for the continent's inhabitants since human settlement.

Temperatures in Australia rose slightly more than the global average in the second half of the 20th century. Streamflow has reduced significantly in the water catchment areas of the southern regions of Australia. Some of these changes are attributed by the mainstream science to human-induced global warming.

Effects of future warming on rainfall patterns are difficult to predict because of interactions with complex regional climate systems. Average expectations are for significant drying in southern Australia, with risk of much greater drying. The mainstream Australian science estimates that there may be a 10 per cent chance of a small increase in average rainfall, accompanied by much higher temperatures and greater variability in weather patterns.

Chapter 7

This chapter provides a taste of conclusions from detailed studies of Australian impacts. These studies are available in full on the Review's website.

Growth in emissions is expected to have a severe and costly impact on agriculture, infrastructure, biodiversity and ecosystems in Australia.

There will also be flow-on effects from the adverse impact of climate change on Australia's neighbours.

These impacts would be significantly reduced with ambitious global mitigation.

The hot and dry ends of the probability distributions, with 10 per cent chance of realisation, would be profoundly disruptive.

Chapter 8

Australia's per capita emissions are the highest in the OECD and among the highest in the world. Emissions from the energy sector would be the main component of an expected quadrupling of emissions by 2100 without mitigation.

Australia's energy sector emissions grew rapidly between 1990 and 2005. Total emissions growth was moderated, and kept more or less within our Kyoto Protocol target, by a one-off reduction in land clearing.

Relative to other OECD countries, Australia's high emissions are mainly the result of the high emissions intensity of energy use, rather than the high energy intensity of the economy or exceptionally high per capita income.

The high emissions intensity of Australian energy use is mainly the result of our reliance on coal for electricity. This is a recent phenomenon: Australian and OECD average emissions intensity of primary energy supply were similar in 1971.

Chapter 9

The joint Garnaut–Treasury reference case suggests that, in the absence of climate change or costs from its mitigation, from 2005 to 2100, the Australian population will more than double to nearly 47 million, per capita output will almost quadruple, and economic output will expand by over 700 per cent.

Over the same period, the reference case sees global population increasing by about 40 per cent and stabilising, and then starting to decline late in the second half of the century. Global output increases by about 15 times, mostly in the developing world, led by the large Asian developing economies—China, India and Indonesia.

The median temperature and rainfall outcomes for Australia from climate change with unmitigated growth in global emissions—particularly from impacts on infrastructure, agriculture and international terms of trade—may see GDP fall from the reference case by around 4.8 per cent, household consumption by 5.4 per cent and real wages by 7.8 per cent by 2100.

This would represent significant reduction of economic growth and welfare from what it would have been in the absence of climate change.

These are not the total costs of climate change. Nor can these costs be avoided entirely by mitigation.

Chapter 10

An examination of the range of impacts through market processes with median expectations of climate impacts suggests that the modelling covers 65 to 85 per cent of total market impacts. Non-market impacts of climate change would be valued highly by Australians, but are not quantified in the draft report.

The insurance value of some lower probability outcomes could be extremely costly. An assessment of more extreme low rainfall outcomes for Australia, near the 10th percentile of the distribution, suggests that GDP costs could be in the order of 8 per cent in 2100, with household consumption of around 9.1 per cent in 2100, and reduction in real wages of around 14.8 per cent relative to the reference case.

Extreme economic disruption in developing countries from climate change could exacerbate severe economic effects on Australia.

The extent to which Australian mitigation is justified will be assessed by analysing the benefits of avoided climate change in the modelling and in sectors not subject to formal modelling, the insurance value of mitigation in relation to lower probability but high cost outcomes, and the value to Australians of non-market impacts avoided by mitigation. The application of a range of approaches to discounting for time will be brought into the formulation of advice on whether and how much mitigation is justified.

Chapter 11

Climate change is a global problem that requires a global solution.

Mitigation effort is increasing around the world, but too slowly to avoid high risks of dangerous climate change. The recent and projected growth in emissions means that effective mitigation by all major economies will need to be stronger and earlier than previously considered necessary.

The existing international framework is inadequate, but a better architecture will only come from building on, rather than overturning, established efforts.

Domestic, bilateral and regional efforts can all help to accelerate progress towards an effective international agreement.

Chapter 12

Only a comprehensive international agreement can provide the wide country coverage and motivate the coordinated deep action that effective abatement requires.

Global emissions reduction goals can best be defined in terms of emissions trajectories and multiyear budgets.

The only realistic chance of achieving the depth, speed, and breadth of action that is now required from all major emitters is explicit allocation of internationally tradable emissions rights across countries. For practical reasons, allocations across countries will need to move gradually towards a population basis.

All developed and high-income countries, and China, need to be subject to binding emissions limits from the beginning of the new commitment period in 2013.

Other developing countries—but not the least developed—should be required to accept one-sided targets below business as usual.

Chapter 13

International trade in permits lowers the global cost of abatement, allows greater flexibility for developed countries in meeting their commitments, and provides a financial incentive for developing countries to take on commitments.

Trade in emissions rights is greatly to be preferred to trade in offset credits, which should be restricted.

A global agreement on minimum commitments to investment in low-emissions new technologies is required to ensure an adequate level of funding of research, development and commercialisation. Australia's commitment to support of research, development and commercialisation of low-emissions technology would be up to about $2.8 billion in 2007—or more than $3 billion per annum by the time the proposed International Low Emissions Technology Commitment took effect in 2013.

An International Adaptation Assistance Commitment would provide new adaptation assistance to developing countries that join the global mitigation effort.

Early sectoral agreements would seek to ensure that the main trade-exposed, emissions-intensive industries face comparable carbon prices across the world. These would include international civil aviation and shipping.

A WTO agreement is required to support international mitigation agreements and to constrain unilateral action against countries thought to be doing too little on mitigation.

Chapter 14

Australia's mitigation effort is our contribution to keeping alive the possibility of an effective global agreement on mitigation.

Any effort prior to effective, comprehensive global agreement should be short, transitional, and directed at achievement of global agreement.

The emissions trading scheme is the central instrument of Australian mitigation.

A well-designed, broadly based emissions trading scheme has important advantages over other market-based arrangements (such as carbon taxes and hybrid schemes). In particular, it is able to accommodate more easily international trade to lower mitigation costs and to facilitate developing country participation in international agreements. However a carbon tax would be better than a heavily compromised emissions trading scheme.

The role of complementary measures is to lower the cost of meeting the emissions reduction trajectories of the emissions trading scheme by correcting for market failures.

Once a fully operational emissions trading scheme is in place, the Mandatory Renewable Energy Target will not address any additional market failures. Its potentially distorting effects can be phased out naturally as the emissions trading scheme takes up the load of encouraging low-emissions technologies.

Chapter 15

The emissions trading scheme will issue permits for greenhouse gas emissions up to limits and release them in line with the scheme's emissions reduction trajectories. Trade will move permits to entities for whom they have most value. The trajectories will be firm for five years, and indicative through to mid century. Permits should be sold through a competitive process.

The more sectors included in the emissions trading scheme, the more efficiently costs will be shared across the economy. The transport sector should be included.

While there are advantages in moving directly to an unconstrained scheme, 2010–12 could be a transition period. If there were a transition period, the Kyoto Protocol would define Australia's emissions reduction trajectory and permits would be sold at a low fixed price. These years would be used to pursue effective international sectoral agreements, en route to a global agreement.

Unlimited hoarding of permits will be allowed, and the independent regulator, the Independent Carbon Bank, will be able to lend permits within five-year periods. No hoarding of 2010–2012 permits could be allowed if there were price constraints in a transition period.

International linking will play an important role in the scheme, with fewer constraints in later years within an international agreement.

Chapter 16

Basic research and development of low-emissions technologies is an international public good, requiring high levels of expenditure by developed countries.

Australia should make a proportionate contribution alongside other developed countries, in its areas of national interest and comparative research advantage. This would require a large increase in Australian commitments to research, development and commercialisation of low-emissions technologies, to over $3 billion per annum.

There are externalities associated with private investment in commercialising new, low-emissions technologies.

To achieve an effective commercialisation effort on a sufficiently early time scale, an Australian system of matching grants should be available where private investors demonstrate externalities, low emissions and innovation.

A new research council should be charged with elevating, coordinating and targeting Australia's effort in low-emissions research.

Chapter 17

There is a risk that network infrastructure market failures relating to electricity grids and carbon dioxide transport systems could increase the cost of adjustment to a low-emissions economy.

The role of the proposed national transmission planner should be expanded to include a long-term economic approach to transmission planning and funding.

A similar planning approach is necessary to ensure that network infrastructure failures do not unnecessarily delay deployment of large-scale carbon capture and storage.

The Building Australia Fund should be extended to cover energy infrastructure.

There is a case for special feed-in tariffs for household electricity generation and co-generation. The case can be quantified by reference to timing and transmission considerations.

A well-integrated national energy network with the capacity to cope with potentially large shifts in flows will allow for structural change and the smoothing of shocks following the introduction of an emissions trading scheme and recent fuel price volatility.

Chapter 18

There are potentially large and early gains from better utilisation of known technologies, goods and services, including energy efficiency and low-emissions transport options.

Externalities in the provision of information and principal–agent issues inhibit the use of distributed generation and energy-saving opportunities in appliances, buildings and vehicles.

Some combination of information, regulation and restructuring of contractual relationships can address many of the market failures blocking optimal utilisation of proven technologies.

Chapter 19

Low-income households spend much higher proportions of their incomes than other households on emissions-intensive products.

The direct price effects of the emissions trading scheme will be regressive. The effects will fall heavily on low-income households, so the credibility, stability, efficiency and longevity of the scheme require the correction of these regressive effects by other measures.

Correction of income effects in the lower half of the distribution is also necessary for anti-inflationary reasons through the early years of the scheme.

Approximately half the proceeds from the sale of all permits could be allocated to households.

Part of the payments to households could assist energy efficiency adjustments. The bulk could be passed through the tax and social security systems, with heavier energy efficiency commitments in the early years. The Henry taxation review could consider these issues.

Chapter 20

Australians have become accustomed to low and stable energy prices. This is being challenged by rapidly rising capital costs and large price increases for natural gas and black coal. These cost effects will be much larger than the impact of the emissions trading scheme for some years.

Australia is exceptionally well endowed with energy options. Support for research and development and for structural change in transmission infrastructure will allow Australia's natural endowments in renewable energy to be efficiently brought to account.

The interaction of the emissions trading scheme with support for research, development and commercialisation will assist transition to a near-zero emissions energy sector by mid century.

The future for coal-based electricity generation, both domestic and exported, and for mitigation in developing Asia depends on carbon capture and storage becoming commercially effective. Australia should lead a major international effort towards the testing and deployment of this technology.

Specific support for emissions-reducing investment in the coal-based electricity-generating regions is warranted, for smooth energy sector adjustment and established generating regions.

Notes

1 Issued in a statement by the national academies of science of Brazil, Canada, China, France, Germany, India, Japan, Mexico, Russia, South Africa, the United Kingdom and the United States in 2008 (Joint Science Academies 2008) .

2 In May 2008 the US Bureau of Economic Analysis put seasonally adjusted first quarter US per capita GDP in current dollars at an annualised level of $US46 716. The Australian Bureau of Statistics put Australian seasonally adjusted first quarter per capita GDP at an annualised level of $US48 376, when converted from Australian to US dollars at the average exchange rate for the quarter, 0.906143.)

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2 POLICY CHOICE ABOUT CLIMATE CHANGE MITIGATION

Key points

The central policy issue facing the Review can be stated simply: what extent of global mitigation, with Australia playing its proportionate part, provides the greatest excess of gains from reduced risks of climate change over costs of mitigation?

Answering the question draws on our capacity to model conventional economic effects, to measure and to value uncertain outcomes, to value effects that are not felt through markets for goods, services or factors of production, and to value costs and benefits incurred and received by different people at different times.

This chapter puts forward a framework for looking at these issues. It favours transparent reporting of the premises of subsequent discussion, and the introduction of analysis of the sensitivity of outcomes to variables.

The reserves and resources of fossil fuels are finite, which means that their costs are likely to rise over time. This reduces the costs of mitigation, which brings forward an inevitable eventual adjustment away from fossil fuels.

How do we assess whether Australian mitigation action is justified? Would the substantial costs of mitigation be exceeded by avoided costs of climate change? What degree of mitigation would lead to the largest net benefits?

These turn out to be immensely complex questions. The answers are affected by judgments about the prospects for effective international mitigation. They depend on the efficiency of the means chosen to achieve reductions in greenhouse gas emissions, including supporting measures that affect the market response to the mitigation regime, and therefore on the costs of achieving various levels of abatement. They depend on the efficiency of supporting measures that determine how equitably the costs of mitigation are distributed across the Australian community, and on the international distribution of the mitigation burden. They depend on the options for and costs of adaptation. And the decisions need to be taken under uncertainty and risk.

The answers are also affected by our ability to measure accurately the conventional economic effects of climate change, and the likely reduction in those effects due to mitigation. Not all of the effects on output and consumption through market processes are amenable to precise quantification, so our conclusions depend on our ability to form sound judgments about the magnitude of changes that are excluded from attempts at formal measurement simply because adequate information is not available at this time. The answers are affected fundamentally by the approach that is taken to decision-making under conditions of risk and uncertainty, and in particular, on the insurance value that is placed on avoiding the possibility of large negative outcomes independently of the effect of those possibilities on expectations of average outcomes.

The answers depend also on the value that is placed on outcomes that are not related to consumption of goods and services, relating to Australians' valuation of environmental amenity in many dimensions. These assessments are affected by how we see the inter-relationship between these and other non-material values with conventional consumption in determining welfare.

The answers are affected by the relative value that is placed on the welfare of people living in the future relative to the welfare of those living at present.

This chapter introduces an approach to decision-making that deals with these immensely complex and difficult issues. The Review seeks to form and to present judgments relating to the key mitigation choices for Australia in a transparent way. This allows people who are uneasy or unhappy about the conclusions to understand and take issue with the premises and the logic that led to them.

This chapter seeks to address the methodological issues in a simple way. We are seeking to assist community choice on the extent of mitigation that provides the greatest excess of gains from reduced climate change over costs of mitigation. The complexity of the influences on that choice make simplicity especially challenging as well as particularly important. Here, even more than in other areas of public policy choice, focus on the central issues is essential if we are to reach conclusions through a transparent process that is open to challenge, and which can lay a basis for long-term community support and policy continuity and stability.

Climate change mitigation decisions in 2008, and for the foreseeable future, are made under conditions of great uncertainty. There is large uncertainty about the climatic outcomes of varying concentrations of greenhouse gases, about the impact of various climate outcomes, and about the costs and effectiveness of adapting to climate change (chapters 3, 6, 8 and 10 in particular). There is uncertainty about the costs of various degrees of mitigation in Australia (chapters 10, 15 and 16). There is large uncertainty about the extent to which the international community will make effective commitments to mitigation, and about the relationship of global to Australian mitigation efforts (chapters 12, 13 and 14).

Under such uncertainty, it is always sensible to ask whether it would be better to delay decisions, while information relevant to the decision is gathered and analysed. However, it is as much a decision to do nothing, or to delay action, as it is to decide to take early action. The issue is whether delay would be a good decision.

When human-induced global warming first became a major international public policy issue nearly two decades ago, it may well have been good policy to take only modest and low-cost steps on mitigation, and to invest heavily in improving the information base for later decisions.

In 2008, the costs of delay—in the probabilistic terms that frame a good decision under conditions of uncertainty—are high. Work for the Review, reported in Chapter 4, has already changed international perceptions of the rate at which emissions will grow over the next several decades under business as usual, which is running Australia and the world towards high risks of dangerous climate change at a more rapid rate than is generally understood. The opportunity costs of delaying decisions are high.

Australia and its partners in the international community will, for good reasons, make historic and fateful decisions about their approaches to climate change mitigation in the three years ahead. They will do this on the basis of currently available information and analysis, however sound or weak that may be.

The sceptical economist—and the Review counts itself within this tradition—insists on equally rigorous evaluation for a decision to delay as for a decision to take action now.

The Review's approach to the important questions about mitigation policy starts with scientific assessment of the costs of climate change to Australia and Australians. We have to be able to compare the costs of climate change without mitigation, and with varying degrees of effective mitigation and adaptation effort. These costs include indirect costs through effects on other countries, to the extent that these feed back into impacts on Australia, or are felt by Australians in themselves. The scientific assessments are highly uncertain, and their impacts on human activity and welfare even more so. We have no alternative to making decisions on complex issues of valuation under great uncertainty.

2.1 Risk and uncertainty

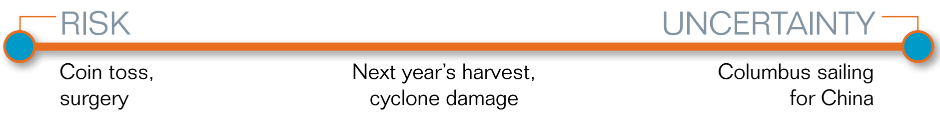
Climate change policy requires us to come to grips with both risk and uncertainty. Keynes (1921), and Knight (1921) drew a distinction between the two that is still useful today.

Risk relates to an event that can be placed on a known probability distribution. When we toss a coin, we do not know whether or not we will see a head. If we toss the coin enough times, it will fall as head about half of the time.

In many spheres of human life, an activity has many similarities with others that have been repeated many times, so that participants have a reasonable idea of the odds. A piece of surgery with some risk of death, and short-term investments in financial markets, have these same properties. No new piece of surgery, and no new investment, is exactly the same as any other. But there have been enough similar events for players to feel that they can form judgments with some confidence about the probabilities.

There is uncertainty when an event is of a kind that has no close precedents, or too few for a probability distribution of outcomes to be defined, or where an event is too far from understood events for related experience to be helpful in foreseeing possible outcomes. Humans are often required to form judgments about events that are unique, or so unusual that analysis based on secure knowledge and experience is an absent or weak guide. Columbus sailing west in search of China is a historically important example.

Figure 2.1 The risk–uncertainty spectrum

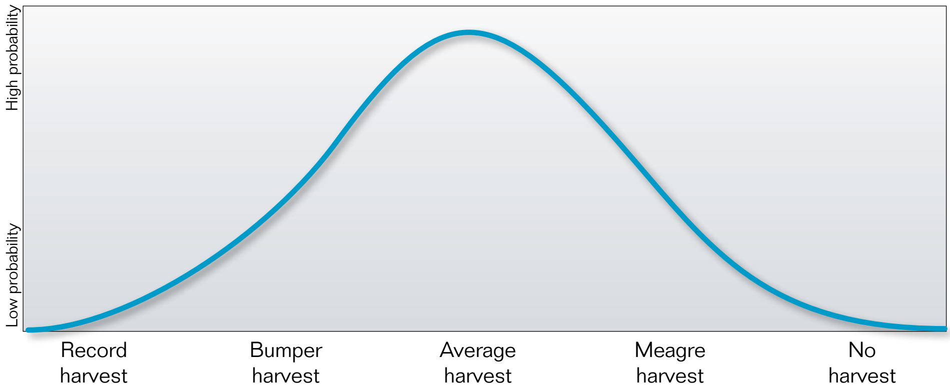


The 18th century British philosopher Bayes has given his name to what is now a well-developed approach to decisions under uncertainty. Bayesian decision theory encourages us to treat decisions under uncertainty as if we were taking a risk (Raiffa 1968; Raiffa & Schlaifer 1961). Bayesian decision theory advises us that we will make the best possible decisions under uncertainty if we force those who are best placed to know to define subjective probabilities that they would place on various outcomes, and work through the implications of those assessments as if they were probability distributions based on experience. These subjective probability distributions can then be updated on the basis of emerging experience.

While the distinction between risk and uncertainty is analytically helpful, it does not distinguish discrete and separate phenomena. Rather, risk and uncertainty are the extreme ends of a single spectrum. Next year's harvest can be assessed as a risk on the basis of past experience but carries an element of uncertainty, because it is affected by various climatic parameters that are not at all predictable from experience or with current knowledge. The risk of a cyclone hitting a tropical city can be assessed using data on past occurrence of cyclones, but many aspects of the potential damage are uncertain.

If it is correct to treat a subjectively formed assessment of a probability distribution as if it were drawn from a distribution based on repeated experience, what is the difference between risk and uncertainty? Perceptions of the probability distribution formed under conditions of uncertainty are more likely to change materially with a small number of new observations or amount of experience or further analysis.

Figure 2.2 A probability distribution



The Review's work on climate change over the past year has made some contact with risk, more with uncertainty, and most of all with the wide territory between them. The mainstream science, embodied in the work of the Intergovernmental Panel on Climate Change (IPCC), sometimes discusses possible outcomes in terms of fairly precise probability distributions (see chapters 3 and 6), yet describes its assessments in terms of 'uncertainties'. This suggests that they are applying Bayesian approaches to decisions under uncertainty.

The decision framework is rarely made explicit, and sometimes is not clear.

The climate models on which the assessments are based are themselves diverse. The climate models provide numerous observations on possibilities out of their diversity, as well as from each generating numerous results from repeated experiments. These are the senses in which the IPCC science draws from probability distributions. There are many points at which judgment rather than experience informs the model relationships. The resulting conclusions are therefore located somewhere on the uncertainty side of the middle of the risk–uncertainty spectrum.

2.2 The costs of mitigation

The increase in greenhouse gas emissions is a product of the advances in science, technology and economic organisation that have transformed humanity as well as its natural context over the last two centuries. In the history of life on earth, and even of human life, we are talking about an almost infinitesimally short period of extraordinary dynamism.

A modern acceleration in rates of human-induced greenhouse gas emissions is the source of contemporary concerns about climate change.

Economic development over the past two centuries has taken most of humanity—but certainly not all—from lives that were insecure, ignorant and short, to personal health and security, material comfort and knowledge that were unknown to the elites of the wealthiest and most powerful societies in earlier times.

In the first millennium after the life of Jesus Christ, global economic output increased hardly at all—by only one sixth. All of the small increase was contributed by population growth, and none by increased production per person. By contrast, output increased 300-fold in the second millennium, with population increasing 22 times and per capita production 13 times. Most of the extraordinary expansion took place towards the end of the period. From 1820 until the end of the 20th century, per capita output increased more than eight times and population more than fivefold (Maddison 2001).

In most of its first two centuries, the cornucopia of modern economic growth was located in a small number of countries, in Western Europe and its overseas offshoots in North America and Oceania, and in Japan. In the third quarter of the 20th century it extended into a number of relatively small economies in East Asia.

A new era began in the fourth quarter of the last century, with the rapid extension of the beneficent processes of modern economic development into the heartland of the populous countries of Asia, including China, India and Indonesia. From this has emerged what can be described as the Platinum Age of global economic growth in the early 21st century (Garnaut 2007). Incomes are growing rapidly in a large proportion of the developing world. In the absence of a major dislocation of established trends, this is likely to continue for a considerable period. Analysis presented in the draft report points to the Platinum Age contributing a greater absolute increase in annual human output and consumption in the first two decades of the 21st century than was generated in the whole previous history of our species, and then adding almost that much again in the next following decade to 2030 (chapters 4 and 9).

Increasingly through the 21st century, the expansion of production will be associated with rising output per person, rather than increase in population. In all of the economically successful countries, higher incomes, together with the increased expectation of survival of children and the expansion of education and choice for women with which it is associated, are leading to marked falls in fertility and declining rates of population increase. Before the end of the 21st century, a continuation of these processes is expected to have led to stabilisation (by about 2080), and then, at least for a while, gradual decline in global human population (Chapter 4). But by that time, nearly three billion will have been added to the global population.

The era of modern economic growth has been intimately linked to rapid expansion in the use of fossil fuels. This is returning to the atmosphere a part of the carbon that was sequestered naturally over billions of years, through a process that created the conditions that were necessary for the emergence of human life on earth. The share of carbon returned to the atmosphere is small relative to the stock, but large enough to throw the equilibrium of heat trapping in the atmosphere out of balance.

The amount of fossil fuel in the earth's crust, in the forms of petroleum, natural gas, coal, tar sands and shale, is obviously finite. However, the amount is so large that its limits are of no practical importance for climate change policies.

However, there is a much tighter engineering limit to the availability for human use of fossil fuels: the point at which the energy used to extract the resources would be greater than their energy content.

Tighter still is the economic limit: the availability of fossil fuels in forms and locations that can be extracted for human use at costs below the prices of oil, gas and coal in global markets. There is debate about whether the economic limits will constrain global economic growth in the period immediately ahead or in the foreseeable future. The limit will be reached much earlier for liquid petroleum than for natural gas, and for gas much earlier than for coal (Chapter 4).

It was once common for eminent economists to see constraints on the availability of natural resources and in particular fossil fuels as placing limits on modern economic growth (Malthus 1798; Jevons 1865). The success of technological improvement and economic processes in easing supposed constraints in the first centuries of modern economic growth established confidence that these constraints would be overcome in ways that allowed global economic growth to continue.

The sustained rapid growth through much of the world from the early nineteen fifties to the early seventies, and the contribution of extraordinary Japanese growth to pressure on global resources at the end of that period, rekindled old concerns about resource constraints on growth.

Concerns about the availability of fossil fuel resources was one element in the analysis and cautions of the Club of Rome, and their ill-fated prophecy about limits to growth in the early 1970s (Club of Rome 1972). The cautions turned out to be ill-judged because the Club of Rome failed to give sufficient credit to human ingenuity applied to discovery, extraction, refining, transport and utilisation of fossil fuels. The extraordinary growth in demand for fossil fuels in the early years of the Platinum Age—and the immense and unexpected increases in prices which have accompanied it—have rekindled interest in resource limits to growth. Will the supply conditions of fossil fuels slow down the growth in greenhouse gas emissions enough to do the mitigation task for humanity?

It is clear from the present state of knowledge—as it was not to earlier generations—that it would be possible for the world economy to adjust to the approach of economically relevant limits to fossil fuel availability, without bringing the increase in human consumption of goods and services to an end.

For the time being, the pervasive and rapidly growing use of fossil hydrocarbons in economic activity is a matter of economic optimisation and not of technological necessity. If the human species avoids some catastrophic truncation of the triumphs of modern economic development, it will need to make a transition out of reliance on fossil fuels, and it will succeed in doing so.

The constraints on the economic availability of fossil fuels will aid the climate change mitigation process. But the Review's analysis suggests that in the time available, the reduction in use of fossil fuels, associated with scarcity and high prices, will be nowhere near enough to avoid high risks of dangerous climate change.

To the extent that mitigation is effective, reduced demand for petroleum and other fossil fuels associated with effective mitigation would reduce the global price of these resources, improve the terms of trade of importing countries, and probably have favourable effects on global economic growth. This would be an offset for some countries against the cost of mitigation.

The beneficiaries of lower fossil fuel prices would not necessarily include Australia, whose terms of trade rise with high global energy prices. However, lower global prices would benefit many groups within Australia. Lower export prices for resources hurt producers in these industries, and the beneficiaries of government revenue generated from the resource industries. But they also tend to lower interest rates and the exchange rate, and so reduce pressures on rural and much of the manufacturing and service industries, and many households.

Adjusting to limits on the use of fossil fuels required to mitigate climate change would be less costly than naturally imposed economic constraints on the availability of fossil fuels. This is because sequestration through physical processes (geosequestration) or biological processes (biosequestration) can ease the mitigation task but cannot ease natural constraints on fossil fuel supply. But mitigation needs to be imposed through political processes. Decisions of this kind in single countries are hard enough. The necessity to achieve mitigation outcomes through cooperation of many sovereign entities, each with an incentive to shift as much of the cost of adjustment as possible to other countries, increases the challenge.

A revolution in humanity's use of fossil fuel-based energy would be necessary sooner or later to sustain and to extend modern standards of living. It will be required sooner if the world is to hold the risks of climate change to acceptable levels. The costs incurred in making an early adjustment will bring forward, and reduce for future times, the costs of the inevitable eventual adjustment away from fossil fuels. How much sooner and at what extra cost is the central question before the Review.

Later chapters will discuss approaches to mitigation (8 to 18). Costs of mitigation depend on the extent to which, and the time over which, reductions in emissions are achieved. Costs depend on the efficiency of the instruments chosen to implement policy. There are cost advantages in having a single price on emissions as the main instrument of policy, supported by measures to correct market failures in utilisation of the commercial opportunities created by the price on emissions.

If mitigation is approached through an efficient set of policies, its costs are determined by the extent and the rate of emissions reductions to be achieved. These, in turn, are determined by the ambitions of a global effort to which Australia has subscribed, and by what Australia is prepared to do in the context of global action.

The cost of mitigation can be calculated for various levels and rates of reductions in emissions. Each level and rate of Australian mitigation can be related to a global mitigation outcome. The global mitigation outcome will define a benefit to Australia in terms of reduced risks of climate change. The benefits of reduced risks of climate change to Australia can be (roughly) estimated. The costs and benefits of mitigation can then be compared. The policy task in setting Australian mitigation objectives, therefore, begins with identification of the costs and benefits (in reduced risks of loss from climate change) for various mitigation ambitions.

The higher the market prices of petroleum, coal and natural gas, the lower the costs of mitigation will be. This is because the costs of business as usual, compared with the costs of using alternative, low-emissions technologies, will be higher. This is a matter of high current interest at this time of historically high fossil fuel prices.

The more ambitious the extent and speed of reductions in emissions, the higher the costs of mitigation will be. It will be lower the more efficient the instruments chosen to give effect to policy.

An economically efficient approach to mitigation would generate a rising carbon price over time, and therefore impose increasingly strong pressure for adjustment out of high-emissions technologies, and increasingly strong incentives for sequestration. For a given abatement task, emissions costs will be lowest if the emissions price rises at the interest rate, which will lead to optimal timing in investment in the mitigation effort.

We are seeking to allocate efficiently over time access to a limited global capacity to absorb additional greenhouse gases without unacceptably high risks of dangerous climate change. The allocation problem is familiar as one of optimal depletion of a finite resource. This frames the economics of the timing of the mitigation effort, and suggests the relevance of the 'Hotelling curve' to the price curve for the right to emit (Hotelling 1931).

The annual costs of mitigation are likely to rise for some time, as a rising emissions price forces deeper abatement. While the price of emissions would be expected to continue to rise over time at the interest rate, the cost to the economy would not rise at that rate. At some time, the tendency for costs to rise would be moderated and eventually reversed by improvements in the technologies that emerge to replace fossil fuels and other sources of emissions.

At some time in the future—perhaps around the time when economic constraints on the use of fossil fuels would in any case be forcing structural change comparable with what had been achieved for mitigation purposes—the incremental costs of mitigation will become negative. The sunk costs of technological improvement and structural change associated with mitigation will avoid the need for some investments to accommodate the constraints on availability of fossil fuels.

Past mitigation will become a positive contributor to current annual economic output at the point where the global economy would have been forced to use substitute technologies whose emergence had been facilitated by the greenhouse gas abatement effort.

Above all else, the cost of mitigation in Australia, and not only the benefits in avoided climate change, will be affected by the nature of the global mitigation effort. An effective global effort would make available a wider range of opportunities for trade in mitigation responsibilities, assigning higher effort to countries in which it can be achieved at lowest cost. A global effort would increase and distribute more efficiently and equitably the world's investment in new technologies to develop lower emissions paths to consumption and production. And it would obviate the need for special policy measures to avoid carbon leakage, or the shift of emissions-intensive industries from high-mitigation to low-mitigation countries—a policy requirement that is likely to be profoundly distorting of domestic economic efficiency and political integrity.

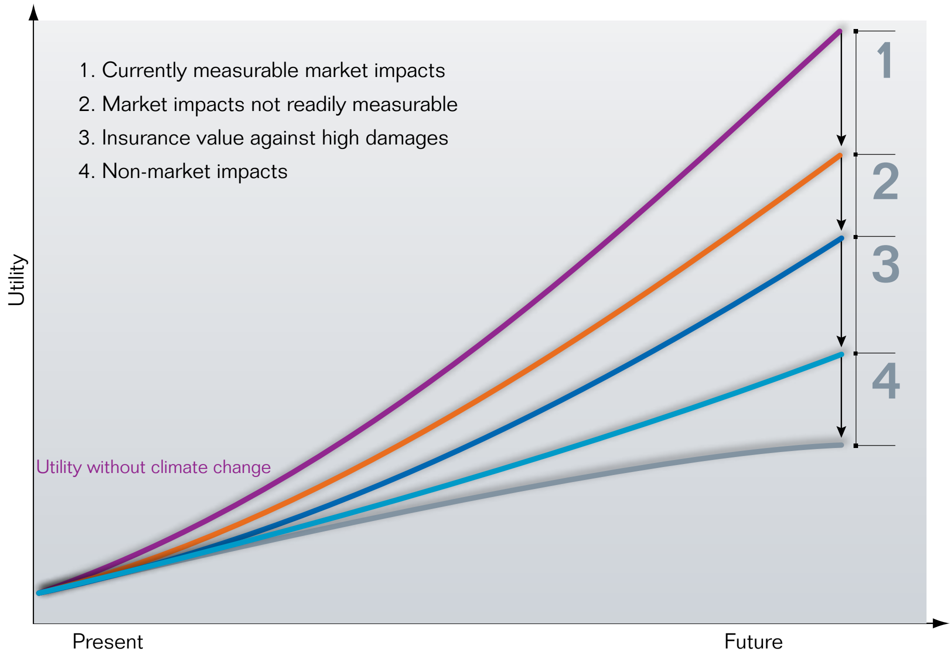
2.3 Four kinds of benefits from mitigation or avoided climate change

Three kinds of benefit from avoided climate change—that is, mitigation—can be measured in monetary values, as a change in the value of output or consumption. The fourth kind of benefit of mitigation requires a different measurement unit. Let us evoke an old tradition in economics, and talk about units of utility. (We could just as well call it welfare, if we removed ourselves from a modern interpretation in terms of social security for disadvantaged people.) That unit, 'utility', is used in economics to represent welfare in a demonetised fashion.

The four kinds of climate change impacts, which in part can be mitigated, are illustrated in Figure 2.3.

The first kind of benefit from mitigation comprises currently measureable market impacts of climate change, which are avoided by mitigation (Chapter 9). The measurement can be brought together through a computable general equilibrium economic model. The starting point for assessment is the estimation of climate impacts based on the means of the relevant probability distributions for these outcomes. These effects are typically measured as an impact on GDP or consumption, with monetary values as the unit of measurement.

Figure 2.3 The four kinds of climate change impacts



The second kind of benefit of mitigation comprises market impacts that are similar in nature to the first, but which are not amenable to measurement in the current state of knowledge. For the Review, these comprise impacts that were not defined precisely enough in time for the modelling, but which are, in principle, amenable to quantitative analysis. We seek to use what we know of these effects roughly to compare their possible size with the impacts that have been subject to formal modelling. As with the effects that are subject to modelling, we focus on the means of the probability distributions of possible outcomes. We are drawing these judgments from views of the impacts that are closer to the uncertainty than the risk end of the risk-uncertainty spectrum. There is no reason to expect our estimates of these impacts to be too low rather than too high, but they are more likely than the estimates of the first kind of benefits to be subject to large adjustments, in one direction or another, with the advance of knowledge. Examples from the Review include the impact of climate change on the tourism industry. As with the first type of benefits, the estimation of these effects would be in monetary values of GDP or consumption (chapters 7 and 10).

The third kind of benefit of mitigation is the insurance value that it provides. On many impacts, there is large asymmetry between human evaluation of outcomes that are much more benign and much more damaging than the mean. Humans tend to be risk averse when the outcomes include the possibility of large loss. Some of the possible outcomes near the more damaging end of the probability distribution would be thought by many people to be catastrophic. In such cases, mitigation has additional insurance value. What would we be prepared to pay to avoid a small probability of a highly damaging or possibly catastrophic outcome? It is probably more than we would be prepared to pay to avoid the certain prospect of the catastrophic event's contribution to the mean outcome. Like the first and second kinds of benefit from mitigation, insurance value of mitigation could also be measured in monetary value—though in most instances it is not obvious how to value them, and they are not estimated quantitatively in the draft report. Uncertainty strongly plays into this category of benefits, as the probability of extreme or catastrophic climate impacts is not known from experience, and must instead be deduced from expert judgment.

It is not a new idea for governments to make large financial commitments for insurance against low-probability, high-impact events. Defence absorbs several percentage points of GDP per annum, most of it on insurance against genuinely low-probability developments.

The possibility of outcomes that most people would consider to be catastrophic makes this a particularly important element of the assessment. Weitzman (2008) sees it as the main element:

> …the burden of proof in the economics of climate change is presumptively upon whoever wants to model or conceptualize the expected present discounted utility of feasible trajectories under greenhouse warming without considering that structural uncertainty might matter more than discounting or pure risk per se. Such a middle-of-the-distribution modeler should be prepared to explain why the bad fat tail of the … distribution is not empirically relevant and does not play a very significant role in the analysis.

The focus of Australian policy making is on maximising the welfare—or utility—of Australians. We can think of a utility function as rising with Australian consumption of goods and services, and also with a number of non-monetary services, such as environmental amenity (which itself may have a number of components), longevity, health, and welfare of people in other countries. If the comparisons of costs and benefits of the first three categories of gains from mitigation suggest a particular outcome, and it is clear from inspection that inclusion of the fourth might lead elsewhere, it is necessary explicitly to compare the monetary with the non-monetary effects on welfare of a particular position. This could in principle be done by forcing a monetary value onto particular non-monetary outcomes. An alternative is to leave the comparison of the monetary and non-monetary outcomes until after the two outcomes and the possible conflict between them is known.

Examples of such non-market impacts include Australians' valuation of environmental amenity. They include the value that Australians place on the integrity of the Great Barrier Reef and other features of the Australian and international landscapes, on inherited shorelines, on genetic diversity and on the survival of species (biodiversity). They include the value that Australians place on long-established communities and social structures built around particular patterns of climate, or the use of green urban gardens and playing fields for recreation. To include such elements in an Australian utility function is not to place intrinsic value on environmental conservation, as some people argue that we should. It is only necessary to accept that many Australians value such things, including as options for their offspring and future generations more generally, and would be prepared to sacrifice some consumption of goods and services to have more of them. Another example of a non-market impact that Australians value would be the avoidance of poverty and trauma in other countries (again, as valued by the sum of individual Australians). The proof of the importance of such matters lies in the continued support by Australians of public and private international development assistance and disaster relief.

Non-market elements in a utility function, and the level of utility when the function includes market and non-market elements, are in their natures difficult to measure. Any politically derived mitigation policy decision will implicitly value them alongside changes that can be measured more easily.

Traditional welfare economics contains a few important insights into the roles that non-market factors, such as environmental amenity and concern for the welfare of others, might play in determining utility in a world of climate change and of possibilities of mitigation.

The non-market values are likely to be 'superior goods', in that the relative value that people assign to them rises with incomes. In the late 21st century, when the average purchasing power of incomes over material goods and services is likely to be several times the present level (Chapter 4), much higher relative value will be placed on any truncation of the natural estate that has occurred in the intervening years.

It is likely that at higher incomes, the price elasticity of substitution between conventional consumption and access to such non-market values as environmental amenity and concern for others' welfare will be low, and much lower than today. Near subsistence levels of consumption, few people would willingly sacrifice much access to material goods and services for greater environmental amenity, or for improved development prospects of others at home or abroad. But in the likely material affluence of the late 21st century, many more people are likely to want to trade substantial amounts of access to material consumption for small amounts of improved values of services that are not available through market processes.

An extremely low rate of substitution between non-market services and conventional consumption of goods and services at high incomes, in the presence of large impacts from climate change, would challenge the proposition that continuing economic growth would necessarily lead to higher average utility in the distant future.

One implication of these insights is that the utility of Australians under policies that allocate high priority to such non-market values as the services provided by the natural environment, and provision of a favourable environment for development in poor countries, is likely to be much higher than the application of today's preference systems at today's material consumption levels would suggest.

2.4 How effective adaptation reduces the cost of climate change and the benefits of mitigation

Some of the costs of climate change can be diminished by the adaptive behaviour of individuals and firms, and by policies that support productive adaptation.

As we will discuss in the final report, effective adaptation requires a strong applied science base, good markets for reallocation of resources, goods and services, and capital for investment in defensive structures and new productive capacity that is more suitable to the new environment.

All of these capacities are more abundant in developed than low-income developing countries. For the latter, the impact of climate change is likely to be undiluted and more severe. Australia's location in an immediate region of vulnerable developing countries will make some of its neighbours' challenges its own. Investment in adaptive responses in the arc of island countries and regions from Timor-Leste through eastern Indonesia, Papua New Guinea and the South Pacific is likely to become an important component of Australia's own cost-reducing adaptation to climate change.

The modifying impact of adaptation is exemplified by Australian agriculture. Better and earlier knowledge will allow farmers to make timely decisions on whether new money should continue to be invested in locations that seem to be severely damaged by climate change, or whether it is better to find new livelihoods in less challenging locations. Investment in plant and animal genetics may be able to diminish the loss of productivity associated with higher temperatures and changing rainfall patterns. Investment in water retention or storage will sometimes be an economically sensible response to more variable rainfall.

Hardest of all, the most effective adaptive responses in agriculture to climate change will sometimes require fundamental changes in attitudes, policies and institutions. For example, as we will see in Chapter 7, the loss in irrigated agricultural value under moderate warming and drying scenarios could be greatly reduced by shifting from established to free market allocation patterns of water allocation, so that limited water resources are directed without qualification to their most productive uses. Livestock industries in these same circumstances would suffer less, if established patterns of quarantine on feed imports were to be relaxed. We can presume that change of such a fundamental kind would not be achieved without rancour and disputation over policy, and would require public policy management of exceptional dexterity and quality.

In assessing the costs and benefits of mitigation, the costs of adaptation need to be subtracted from business as usual and mitigated output and consumption. The benefits of adaptation through reduced climate change damage need to be subtracted from the gains from mitigation. In Chapter 7, the Review takes this partly into account by presuming substantial adaptive response in assessing the costs of climate change at various levels of mitigation. For example, the presumed wheat yields are based on expectation that planting times and new seed varieties will be developed rapidly for changing conditions. These effects are carried forward from Chapter 7 to the modelling reported in Chapter 9.

The costs of adaptive responses will generally come early, and the benefits from reduced costs of climate change later. On the whole, the Review has only been partially able to to take account of the costs of adaptation; and the assessment of reduced costs of climate change on output and consumption is incomplete.

Some of the most important adaptive responses to climate change, and the most difficult to bring to account in analysis of optimal levels of mitigation, involve changes in attitudes and values. The city dwellers of densely populated regions of Northeast Asia have long been accustomed to life that is almost entirely separated from the natural environment. If climate change separates more and more humans from natural environmental conditions, will they simply change in their values and preferences, and learn to accept without a feeling of loss what they have never known, or knew only in distant memory? Will it matter to Australians of the future if their children do not enjoy the grassed playing fields that were once formative in what we imagined as our community culture? Could Australians learn to love living in a country and a world shorn of many of the natural features that are now enjoyed with comfortable familiarity?

Humans adapt to changed and difficult environments when they must. There will still be joys of learning and life even in the most unhappy scenarios of future climate change. But it must be doubted that humans will have changed so much that they fail to regret what they still had in the Australian natural environment in the early 21st century. For want of reason to do otherwise, the Review will assess the value that Australians place on environmental amenity in terms of today's perspectives and preferences, manifested in a future world of greatly increased consumption of conventional goods and services.

2.5 Measuring the benefits of mitigation against the costs

To a sceptical economist, the case for action is not made simply by comparing the cost of unmitigated climate change with the cost of mitigation. Chapter 9 makes this comparison, but cannot go on to an assessment of whether mitigation is worthwhile until more of the modelling is completed.

The relevant comparator is the reduction in the cost of climate change that is achieved as a result of the mitigation action. If we are evaluating Australian mitigation action, the reduction in costs of climate change that is relevant is that associated with the total global mitigation action that it enables—either by Australia, or by the set of countries which are undertaking joint action.

The benefit from mitigation is the costs of climate change avoided, after the costs and ameliorating effects of adaptation had been taken into account. Do the benefits of mitigation exceed the costs for Australians?

The costs of mitigation come earlier and are more certain. The benefits come later and are less certain. How do we compare later with earlier benefits? How do we compare more with less certain outcomes? Here we must come to grips with challenging issues about discounting for time.

The costs and benefits of mitigation, in Australia and in other countries, fall on and accrue to different groups in the community. They are also felt and valued in various ways by different people. How do we weigh the relative effects on welfare of different people? In particular, what relative weight do we give to costs and benefits to the rich and to the poor? It may be that an overall assessment of whether mitigation is worthwhile will depend on the distribution of costs and benefits across the community.

The landmark Stern Review (2007) addressed the question of whether mitigation action was justified for the world as a whole. This turns out to be an easier question than whether mitigation action is justified from the point of view of an individual country. An assessment of whether mitigation action is justified for an individual country must deal with all of the complexities that Stern addressed for the world as a whole, plus one. And the additional source of complexity is perhaps the most difficult of all.

The relevant mitigation is global. A single country's action is relevant only in its direct and indirect contribution to global mitigation. The costs of various levels of mitigation for a single country depend mainly on the extent of its own mitigation—although these costs are substantially reduced for any given level of mitigation by its embodiment in a global agreement within which at least major economies apply similar emissions pricing regimes. The benefits depend overwhelmingly on what other countries are doing. Each country's evaluation of whether some mitigation action of its own is justified depends on its assessment of the interaction between its own decisions and those of others. Thus its own decision framework must depend on its assessment of the dynamics of complex games, among many countries. The games are framed within an awful reality, that each country has a narrow national interest in doing as little as it can, whatever others do, so long as its own action does not diminish the mitigation action that others actually take.

The global mitigation effort is the sum of the separate but inter-related mitigation decisions of individual sovereign countries. It is the sum of implicit or explicit decision processes in all countries, of the kind that we are attempting for Australia. The sum of the decision processes in many countries—democratic and authoritarian, soft and hard states, rich and poor—will determine the global mitigation effort.

The Review's terms of reference require it to analyse the degree of Australian mitigation effort that would be necessary to support a global agreement to hold greenhouse gas concentrations to 550 ppm, and separately to 450 ppm. The final report, with the support of the modelling reported in detail in the draft supplementary report, will examine the choice of Australian mitigation ambitions comprehensively.

2.6 A graphical representation of the benefits and costs

Let us plot our expectations of the level of national utility or welfare over time in the absence of national mitigation, national or global (Figure 2.4). National utility will generally rise over time, in line with the Australian experience through its history. On the same graph, now plot expectations of welfare over time at a given level of national mitigation, which is associated with a defined degree of global mitigation.

Figure 2.4 Utility with and without mitigation

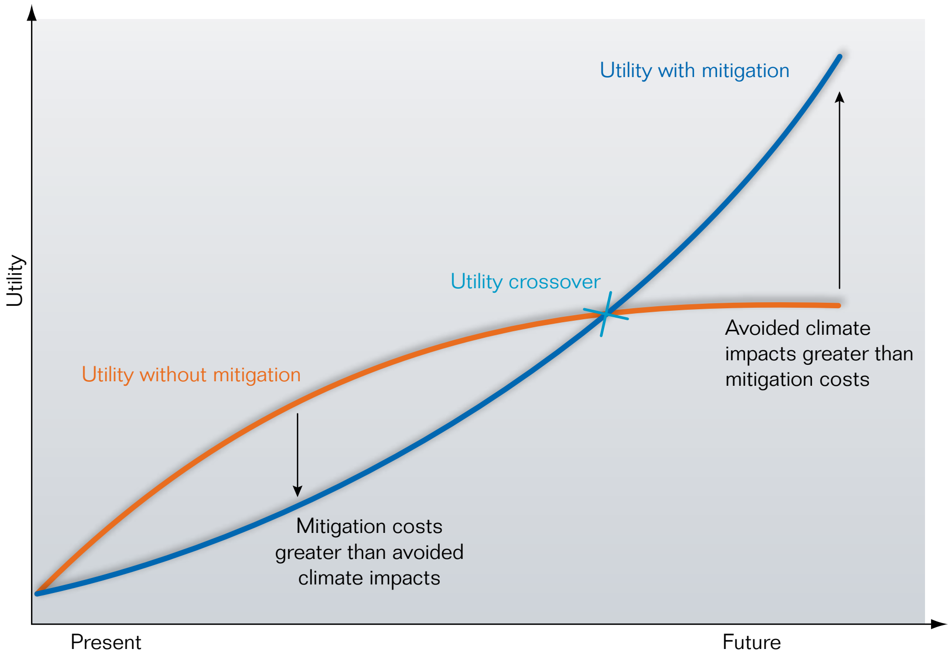


Figure 2.5 Utility under a more ambitious level of mitigation

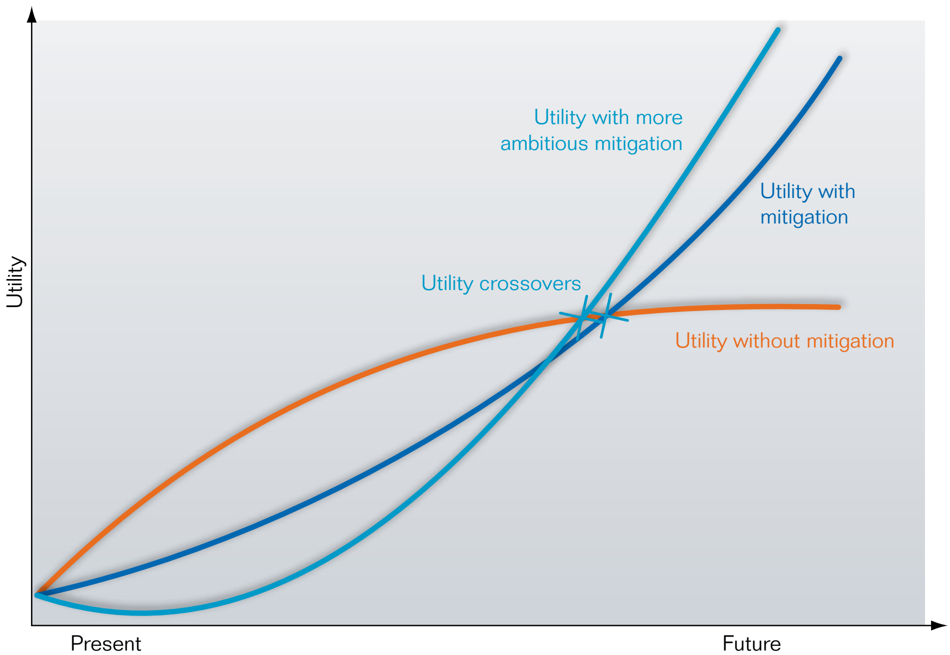
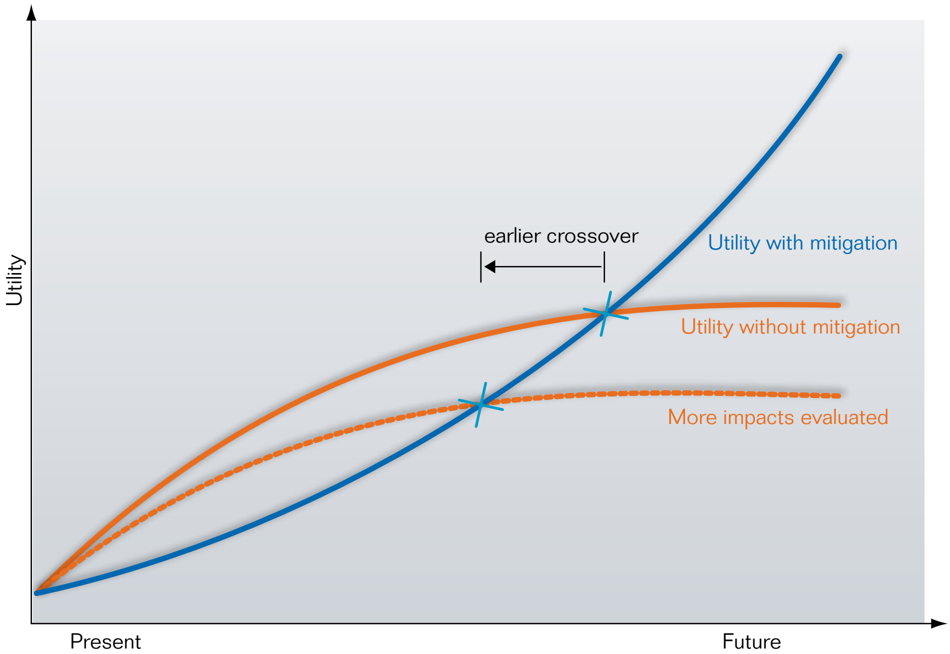


Figure 2.6 Utility with more climate change impacts taken into account



As shown in Figure 2.4, the utility curve in the absence of mitigation is above the utility curve with mitigation in the early years. This follows simply from the reality that mitigation has a cost. However, in cases in which national mitigation is associated with substantial global mitigation, at some point the mitigation utility curve may rise above the utility curve in the absence of mitigation. Let us call the point at which utility associated with mitigation exceeds utility in the absence of mitigation for the first time, the utility crossover point.

The two curves together describe the shape of a fish. The body of the fish covers years in which the net benefits of mitigation are negative. The area of the body of the fish represents the excess costs of mitigation in the years to the crossover point. The tail of the fish covers years in which the net benefits of mitigation are positive. The tail of the fish grows in depth and total area with time.

Figure 2.5 shows the utility curves with and without mitigation for a more ambitious level of mitigation. The fish will tend to have a fatter body and tail, as both the costs of mitigation and the benefits are increased. The relative sizes of body and tail, and locus of the crossover point, are an empirical issue.

Figure 2.6 shows the utility curves with a greater degree of climate change impacts being taken into account. As more costs of climate change are quantified, the utility curve for the unmitigated case shifts downward.[1] The crossover point comes earlier and the tail becomes larger relative to the body of the fish—implying higher net benefits from mitigation. These are also matters for empirical analysis and judgment.

The policy question is whether the area of the body of the fish exceeds that of the tail of the fish. Future utility has to be valued at present values, so the difference in the annual levels of utility between the two curves defining the fish have to be discounted to the present at an appropriate rate. The choice of discount rate will have a major influence on the size of the body relative to the size of the tail. We turn to the discount rate after looking more closely at other influences on the sizes of the body and tail of the fish.

The cost of mitigation (augmented somewhat, and more in the low-mitigation cases, by the greater cost of investment in adaptation in the low-mitigation scenarios) will determine the depth of the fish's body.

For any chosen mitigation outcome, there will be an optimum distribution of the mitigation effort over time. For purposes of presentation, we assume that ideal mitigation policies, including ideal allocation of emissions reduction over time are chosen for implementation of the policy.

The length of the body is the time it takes to get to the crossover point.

Beyond the crossover point, the length of the tail is determined only be any limit that society may place on the future time over which it remains concerned for the utility of Australians.

2.7 Valuing the future relative to the present

Should society place any limit on the future time over which it remains concerned for the utility of Australians? It is not obvious why it should do so.

The value of avoided irreversible effects of climate change extends forward to the point at which the life of the human species would have been extinguished by some separate influence. There is some chance of extinction at any time, at least in the contemporary human state of knowledge about weapons of mass destruction and certain capacity to control their use, and the low level of knowledge and capacity relevant to avoidance of the ever-present risks of the earth colliding with extra-terrestial bodies. The probability of extinction is not high in any year and perhaps in any century, but it is above zero.

So if we are to include the welfare of all future generations in our assessment of utility, how should we value the future relative to the present?

In comparing utility across generations, we need to determine the discount rate. There are two key variables: the pure rate of time preference; and the elasticity of the marginal utility of consumption.

The rate of pure time preference is the rate at which future utility is discounted simply because it is in the future.

Many of the philosopher kings of economics, from Ramsey (1928) to Sen (1961), have argued for a pure rate of time preference that is close to zero. This approach was followed by Stern, who placed it at 0.1 per cent, corresponding to a view on the probability in any year of human extinction. Some have commented that if the probability of extinction were as high as that, it is unlikely that the human species would still be here. Stern might respond that the human capacity to construct truly fateful weapons of mass destruction has not been with us long.

There is another view, that market discount rates reflect the time preferences that are revealed in actual decisions on savings and investment, which are the vehicles for arbitrage between future and current economic activity. This was the main criticism of Stern's approach.

The issue is whether the pure rate of time preference is a normative or a positive issue.

The second determinant of the discount rate is the marginal elasticity of utility with respect to consumption. This is a measure of society's concern for equity in income distribution. We accept that a dollar of incremental income means less to the utility of the rich than of the poor. How much less? Higher and lower values have been suggested, but no-one contests that income has diminishing marginal utility with increased income.

In the expected circumstances of continually rising incomes, this argues for placing higher value on current than future income.

This argument for being careful about the sacrifice of current utility through expenditure on mitigation in pursuit of future utility from avoided climate change is a powerful one. It would be the more powerful if a substantial part of the burden of current mitigation were to be placed on people in low-income countries, to the extent that their prospects for economic development were to be significantly diminished.

There is one qualification of this case for caution about strong mitigation on inter-generational income distribution grounds. To the extent that there is a low rate of substitution between conventional consumption and non-market services when incomes are high, and to the extent that climate change introduces a possibility that the availability of non-market services may be greatly diminished for future generations, one cannot be sure that, despite much higher material consumption, the average utility of people in future will be greater than the average utility today.

If anything like a market discount rate is used, later benefits arising over the time periods that are necessary for mitigation policy to have substantial effects have relatively low value. At a real discount rate of 4 per cent—the rate judged to be appropriate for modelling the future price curve for emissions permits (the Hotelling curve)—a dollar in 50 years' time is worth just 13 cents today.[2] The real annual rate of return on long-term US Treasury bonds trading in commercial markets is around 2 per cent. At a real discount rate of 2 per cent, a dollar in 50 years' time is worth just 36 cents today.

Are we comfortable about living for the moment to the extent suggested by the use of market discount rates?

Is there tension between our normative (what should be done) and positive (what seems to happen in markets) view of discounting for the future? Should we treat the interest rates generated in financial markets as market failures?

The application of a social discount rate, lower than market rates, is recommended as best practice in one highly practical area of applied, policy-oriented economics: cost-benefit analysis. Little and Mirrlees (1968) recommend the application of lower rate of discount for future income than is generated in financial markets.

Any case for using social discount rates that are lower than market rates could be seen has having two elements. These work in opposite directions in the conventional case where average incomes and utility rise over time. The market's myopia might be expected to price in a higher rate of time preference than consciously expressed human preferences might suggest. On the other hand, the preferences of the poor are under-represented in financial markets, where a dollar of savings and investment is the basis of the franchise. The non-enfranchisement of the poor tends to reduce the discount rate below what it otherwise would be. The enfranchisement of the poor in financial markets would argue for higher weight being given to current incomes, and therefore for the application of a higher discount rate.

Of course, if considerable weight is given to the bad end of the probability distribution of outcomes from climate change, there is a possibility that utility may be lower for many people in future than at present. The future poor get no votes anywhere, and least of all on Wall Street and in the City of London.

The Review's inclination is towards the use of a low pure rate of time preference, alongside recognition that in dealing with the means of the probability distributions, future incomes should be valued at substantially less per dollar on intergenerational equity grounds. The final report will show the sensitivity of the policy conclusions to variations in the discount rate.

A different calculus becomes necessary for consideration of the future values of the worst possibilities.

2.8 The Review's recommendations in a world of uncertainty and important immeasureable impacts

The draft report can go no further than explain the methodology that it is applying to evaluation of the optimum level of mitigation for Australia. It sets out in Chapter 9 the approach that is being taken to the modelling that will seek to define the cost of mitigation and the first of the four categories of mitigation described in this chapter. Chapter 10 explains how the other three categories will be taken into account.

Doing all of these things in a transparent way will, it is hoped, reveal to the governments to which the Review will be reporting, and to the Australian community, the implications of the climate change policy choices that must be made over the period ahead.

Notes

1 For ease of exposition, Figure 2.6 assumes that utility with mitigation already accounts for the lesser economic consequences of the additional impacts. If this were not the case, the utility-with-mitigation curve would shift downwards but the downward shift would be less than the downward shift of the utility-without-mitigation curve. The crossover point would still be earlier.

2 Four per cent is higher than the rate at which price rises over time in the gold market with its characteristic contango. Gold provides the nearest commercial market to the permit market that would be created by the emissions trading scheme once the market's credibility had been established. The higher premium is used in the modelling because of the presumption that market participants will perceive greater risk in the permit market.

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3 THE SCIENCE OF CLIMATE CHANGE

Key points

The Review takes as its starting point, on the balance of probabilities and not as a matter of belief, the majority opinion of the Australian and international scientific communities that human activities resulted in substantial global warming from the mid 20th century, and that continued growth in greenhouse gas concentrations caused by human-induced emissions would generate high risks of dangerous climate change.

A natural carbon cycle converts the sun's energy and atmospheric carbon into organic matter through plants and algae, and stores it in the earth's crust and oceans. Stabilisation of carbon dioxide concentrations in the atmosphere requires the rate of greenhouse gas emissions to fall to the rate of natural sequestration.

There are many uncertainties around the mean expectations from the science, with the possibility of outcomes that are either more benign—or catastrophic.

Climate change policy must begin with the science. When people who have no background in climate science seek to apply scientific perspectives to policy, they are struck by the qualified and contested nature of the material with which they have to work. Part of the uncertainty derives from the complexity of the scientific issues. In the public discussion of the science, additional complexity derives from the enormity of the possible consequences, which calls for a millennial perspective. Part derives from the large effects of possible policy responses on levels and distributions of income, inviting intense and focused involvement in the discussion by those with vested interests.

The Review is not in a position to independently evaluate the considerable body of scientific knowledge, and it is not the intent of this chapter to debate the existence or extent of human-induced climate change.

In the terms introduced in Chapter 2, there is a great deal of uncertainty about the magnitude of the effects of increased greenhouse gas emissions on science. The scientifically reputed 'sceptics', to the Review's understanding without exception, accept that an increase in carbon dioxide concentrations in itself leads to warming (Lindzen 2008). The 'sceptics' variously contest the relationship between human-induced anthropogenic emissions and atmospheric concentrations, or the relative importance of the enhanced greenhouse effect and other factors that influence climate.

It is the nature of uncertainty that new information and analysis can fundamentally change the odds about most particular statements being true. The Review takes as a starting point, on the balance of probabilities and not as a matter of belief, the majority opinion of the Australian and international scientific communities that human-induced climate change is happening, will intensify if greenhouse gas emissions continue to increase, and could impose large costs on human civilisation.

This chapter draws extensively on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, and on detailed reports prepared by Australian scientists, research published since the IPCC Fourth Assessment Report and work commissioned specifically for the Review. It aims to build an understanding of the way humans can influence the climate and the limitations in our current understanding of the climate system, and introduces key terminology and concepts relevant to policy makers.

The final section considers the science that underlies climate change mitigation, and considers how the complexities and uncertainties can be addressed in long-term policy decisions.

The Review therefore draws on what it describes as mainstream or majority science. In drawing on the work of the IPCC, and the large majority of Australian scientists who are comfortable working within that tradition, we are still faced with immense uncertainties. These are the uncertainties that are carried through in the Review's analysis. These perspectives may cease to be the mainstream or majority science as the development of climate science proceeds. At this time, the Review believes it is appropriate to give the main weight to them.

3.1 The earth's atmosphere and the natural greenhouse effect

3.1.1 The changing composition of the atmosphere

The earth is surrounded by an atmosphere that protects it from high-energy radiation and absorbs heat to provide a moderate climate that supports life.

The earth's atmosphere has not always been the same as it is today. Billions of years ago, the atmosphere was composed mainly of ammonia, water vapour and methane, but over time release of gases from within the planet through volcanic eruptions and discharge of gases from ocean vents changed conditions so that carbon monoxide, carbon dioxide and nitrogen became dominant.

Around 3.5 billion years ago, algae-like organisms first began to use the energy from the sun to convert carbon dioxide from the air into carbohydrates, with a by-product of oxygen. Over time, oxygen levels rose so that when dinosaurs flourished between 230 and 65 million years ago, oxygen levels were around half of what they are today. Between 40 and 50 million years ago levels rose rapidly, after which there was a slight decline to current levels of 21 per cent of atmospheric volume. The rapid rise in oxygen content is linked to the evolution of large mammals (Falkowski et al. 2005).

3.1.2 The natural greenhouse effect

The earth's atmosphere behaves like the roof of a greenhouse, allowing short-wavelength (visible) solar radiation from the sun to reach the surface, but absorbing the long-wavelength heat that is emitted back. This process is also referred to as 'the greenhouse effect', and the gases that absorb the emitted heat are known as greenhouse gases. 'Global warming' refers to the expected increase in average surface temperature due to increasing concentrations of greenhouse gases in the atmosphere. The main naturally occurring greenhouse gases are water vapour, carbon dioxide, methane, nitrous oxide and ozone. These and other greenhouse gases are discussed in detail in section 3.3.

Compared to nitrogen and oxygen, which collectively comprise 99 per cent of the volume of the atmosphere, greenhouse gases occur only at trace levels, making up just 0.1 per cent of the atmosphere by volume (IPCC 2001a).

Despite the low concentration of greenhouse gases in the earth's atmosphere, their presence means that the earth has an average global surface temperature of about 14°C—about 33°C warmer than if there were no greenhouse gases at all (IPCC 2007a: 946).

The importance in the earth's atmosphere in creating the conditions for life is demonstrated by the very different surface conditions on the earth's moon. On the moon there is no atmosphere at all, and the temperature fluctuates dramatically as the level of sunlight reaching the surface changes. The moon's surface temperature fluctuates between -233°C to 123°C (NASA 2008).

3.1.3 Changes in greenhouse gases and temperature over time

Records of carbon dioxide concentrations taken from 'proxy' measures such as fossil plants and algae are available for the last 400 million years. These records indicate that atmospheric concentrations of carbon dioxide have fluctuated between levels similar to pre-industrial concentrations of 280 ppm (parts per million by volume), and levels higher than 4000 ppm (Royer 2006).

During the last 2.5 million years, climate records document a 'saw-tooth' pattern of changes in temperature and ice volume. In the last 600 000 years the fluctuations show a periodicity of around 100 000 years (Ruddiman 2008). The periods when polar ice caps were greatly expanded, which resulted in large ice sheets covering large parts of the northern continents, are known as glacial periods or ice ages, while those without extended polar ice caps are known as interglacials. The last glacial maximum occurred 21 000 years ago; for the last 10 000 years the earth has been in an interglacial period (IPCC 2007a: 447)

Glacial periods occur when summer solar radiation in the northern hemisphere is reduced, and interglacials when solar radiation is more intense. Fluctuations in carbon dioxide and methane concentrations have also occurred in the 600 000-year period before the present, but the role of greenhouse gases in contributing or responding to the glacial–interglacial fluctuations is complex and still unclear.

Consistent changes in the intensity of solar radiation from regular variations in the shape of the earth's orbit and the tilt of its axis, as well as the sunspot cycle, are seen as drivers of these cyclical climate changes (Ruddiman 2008).

There is a high degree of uncertainty in historical measurements of temperature before modern times, which must be estimated from a range of indirect sources such as annual growth rings in trees and corals, and small fossils in ocean and lake sediments.

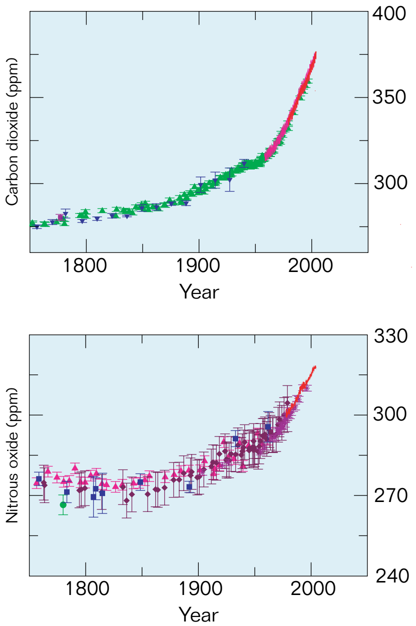
There is high natural variability in global temperatures in recent millennia. The current high temperatures, though unusual over the last 1000 years, are not unusual on longer time frames. However, the rapid rate of the current warming is highly unusual in the context of the past millennium (CASPI 2007).

How are the recent changes different?

Why are we so concerned about the current changes in climate and greenhouse gas concentrations if they have fluctuated so much over the earth's history?

Apart from the earliest identified hominids, which existed as early as seven million years ago, the history of our species has been within the period of relatively low carbon dioxide concentrations. Our direct ancestors, *Homo erectus*, appeared around 1.6 million years ago, and modern forms of our species, *Homo sapiens*, first appeared only around 200 000 years ago. The last 10 000 years have seen the development of agriculture, large-scale social organisation, writing, cities and the behaviours we associate with modern civilisation. The period in which human civilisation has developed, located within an interglacial period known as the holocene, has been one of equable and reasonably stable temperatures.

Figure 3.1 Trends in atmospheric concentrations of carbon dioxide, methane and nitrous oxide since 1750



Note: Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines).

Source: IPCC (2007a: 3), formatted for this publication.

Current concentrations of carbon dioxide are very unusual for the last two million years, and particularly in the last 800 000 years, including the period over which human civilisation has emerged. Concentrations now exceed the natural range of the last two million years by 25 per cent for carbon dioxide, 120 per cent for methane, and 9 per cent for nitrous oxide (IPCC 2007c: 447). In fact, the anthropogenically driven rise in carbon dioxide since the beginning of the industrial revolution (around 100 ppm) is about double the normal 'operating range' of carbon dioxide during glacial–interglacial cycling (180–280 ppm) (Steffen et al. 2004). Trends in atmospheric concentration of carbon dioxide, methane and nitrous oxide for the last 250 years are shown in Figure 3.1, which demonstrates the accelerated growth in recent years. It is not just the *magnitude* of the post-industrial increase in greenhouse gas concentrations that is unusual, but also the *rate* at which it has occurred.

3.1.4 Are humans causing the earth to warm?

The rapid development of climate-related research and modelling has allowed increasingly more definitive assessments of the human impacts on climate. The IPCC Fourth Assessment Report (2007) noted an improvement in the scientific understanding of the influence of human activity on climate change.

The report concluded that the warming of the climate system is 'unequivocal' (IPCC 2007a: 5), that there is a greater than 90 per cent chance that 'the global average net effect of human activities since 1750 has been one of warming' (IPCC 2007a: 3). Confidence in the influence of humans on other elements of climate change, such as droughts and severe weather events, is not as high, but is increasing as modelling techniques and observation databases improve.

Some people with relevant scientific credentials (and many who lack them) argue that the warming trend may be mainly the result of factors independent of human activity—the same factors that have been responsible for a continuously changing global climate throughout the earth's history. However, those who argue against a strong human influence in the contemporary warming trend are a small minority of scientists with competence in relevant fields.

If there are natural as well as anthropogenic causes of recent warming, it is not obvious that this would reduce the urgency or importance of reducing anthropogenic greenhouse gas emissions. It could be argued that the presence of additional sources of warming actually increases the importance of early and strong action to moderate the contributions over which humans have some control. This perspective argues most strongly for more scientific research on natural sources of climate change and their interaction with anthropogenic global warming.

Chapter 5 contains a more detailed discussion of human attribution of other elements of observed climate change.

Box 3.1 The history of climate change science

The properties of greenhouse gases were first identified by French physicist Jean Baptiste Fourier in the 1820s. In 1859, Irishman John Tyndall suggested a link between the ice ages and low amounts of atmospheric carbon dioxide, and in 1896 a Swedish electrochemist, Svante Arrhenius, first argued that variations in trace constituents in the atmosphere could greatly influence the heat budget of the earth.

From the 1960s, global warming began to be taken seriously by scientists. In 1958 long-term measurement of atmospheric carbon dioxide began at the Mauna Loa observatory in Hawaii, and over time the results showed an indisputable annual increase in carbon dioxide concentrations.

In response to the growing recognition of global warming and climate change as issues requiring action at an international level, the World Meteorological Organization and the United Nations Environment Programme jointly established the Intergovernmental Panel on Climate Change in 1988. Since this body's first report in 1990, understanding and quantification of the complex processes underlying global warming and climate change have greatly increased.

3.2 Understanding climate change

3.2.1 Definitions of climate change

The IPCC (2007a: 943) defines climate change as 'a change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer'. Climate change may be due to natural internal processes or external influences, or to persistent anthropogenic changes in the composition of the atmosphere or land use.

By contrast, the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as 'change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods' (UN: 1992).

This report uses the IPCC's definition, so the discussion of climate change includes changes to the climate caused by natural phenomena, such as volcanic eruptions.

3.2.2 The climate system

In a narrow sense, climate can be defined as the 'average weather' and described in terms of the mean and range of variability of factors such as temperature, rainfall and wind speed (IPCC 2007a: 96).

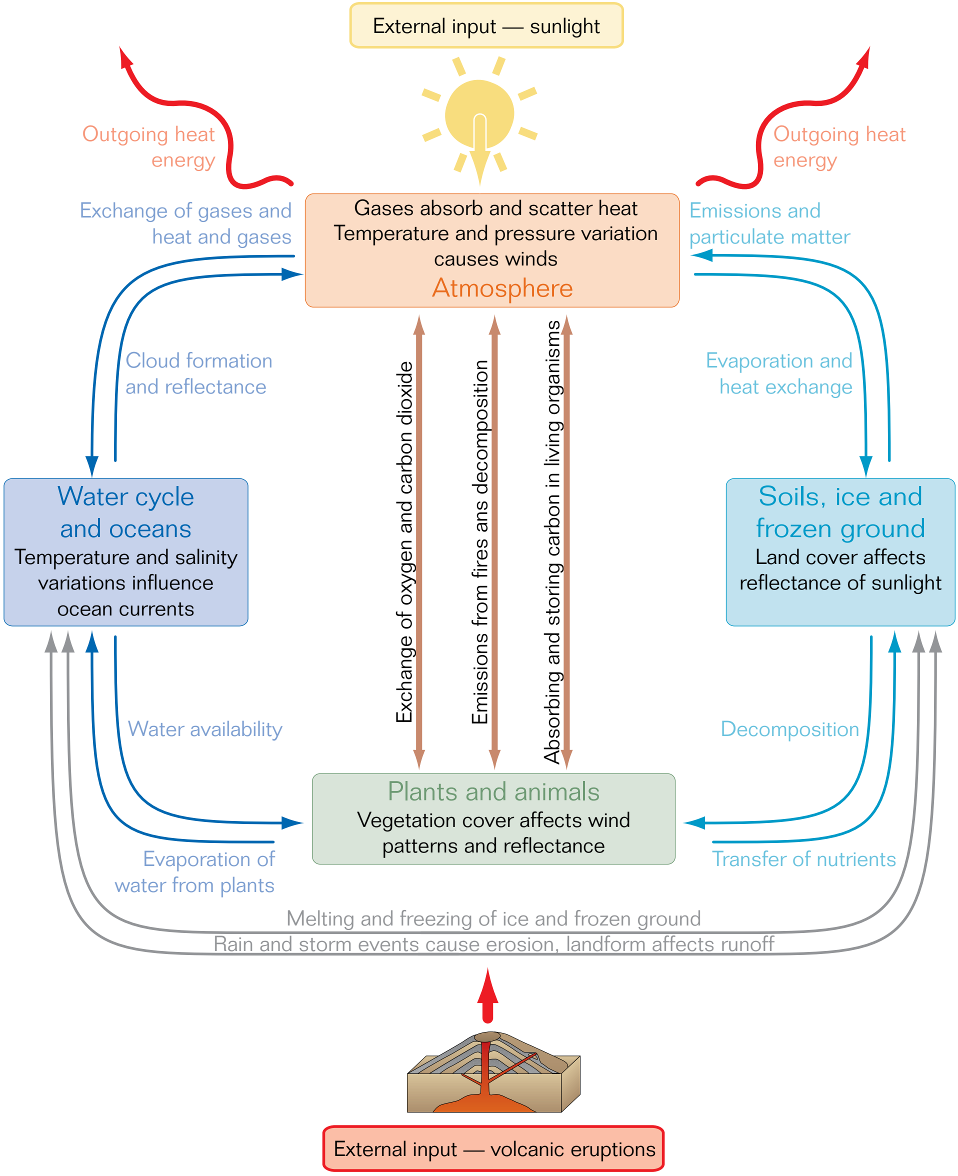
More broadly, the climate can be described as a system involving highly complex interactions between the atmosphere, the oceans, the water cycle, ice, snow and frozen ground, the land surface and living organisms. This climate system changes over time in response to internal dynamics and variations in external influences such as volcanic eruptions and solar radiation (IPCC 2007a: 943). Examples of the internal interactions in the climate system and key external influences are shown in Figure 3.2.

Larger increases in temperatures occurring on land compared to ocean surfaces, or to land or ocean at higher latitudes than low latitudes, are likely to lead to changes in the patterns of winds and storm tracks. As a result, climate change can cause some areas to receive more rain, or stronger winds from colder areas, even though the climate as a whole is warming (CASPI 2007).

In any location weather patterns may shift on a daily and even hourly basis. Climate is weather averaged over a longer timescale, but it still possesses some degree of natural variability.

The atmosphere component is the most unstable and rapidly changing part of the climate system (IPCC 2001a). The atmosphere is divided into five layers with different temperature characteristics, with the lower two having the most influence on the climate system.

Figure 3.2 Internal interactions and external influences on the climate system



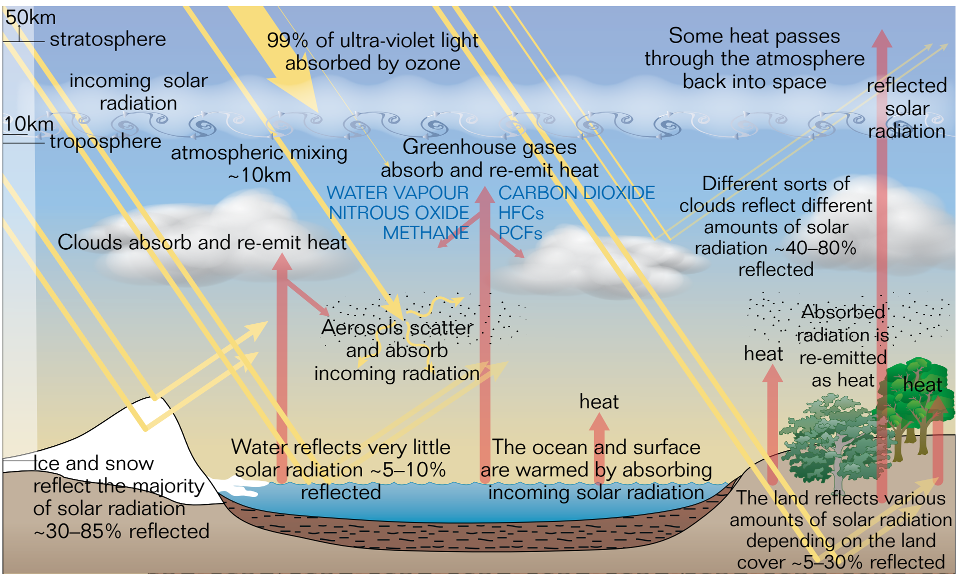
The troposphere extends from the surface to an altitude of between 10 and 16 km. Clouds and weather phenomena occur in the troposphere, and greenhouse gases absorb heat radiated from the earth so that temperature decreases with altitude.

The stratosphere, which extends from the boundary of the troposphere to an altitude of around 50 km, is the second layer of the atmosphere. The stratosphere holds a natural layer of high ozone concentrations, which absorb ultraviolet radiation from the sun so that temperature increases with altitude (Figure 3.3). The balance of energy between the layers of the atmosphere is a major driver of atmospheric and ocean circulation that leads to weather and climate patterns (IPCC 2007a: 610).

3.2.3 The energy balance of the climate system

Energy enters the system as visible and ultraviolet radiation from the sun, and is absorbed, scattered or reflected, re-emitted as heat, transferred between different elements of the system, used by organisms and emitted back into space (Figure 3.3).

Figure 3.3 A stylised model of the natural greenhouse effect and other influences on the energy balance of the climate system



The balance between the energy entering and leaving the system is what determines whether the earth gets warmer, cooler or stays the same. Changes in the strength of radiation from the sun change the energy that enters the system, while the flow of energy within the system and the amount that is released can be modified by a wide range of factors.

As discussed earlier, the composition of gases in the atmosphere plays a big part in the amount of heat that is retained in the climate system, but there are many other influences. Particles and droplets in the air known as aerosols can scatter the incoming radiation so that it never reaches the surface, and can also cause changes in cloud cover. More clouds will reflect more sunlight from their upper surfaces, but also absorb more heat radiating from the earth. Variations in land cover affect the amount of sunlight that is reflected from the surface (the 'albedo' effect), and how much is absorbed and re-emitted as heat (IPCC 2007a: 94).

Human activities can affect the energy balance of the climate system in a number of ways. Examples include changes in land use; emissions of aerosols and other pollutants; emissions of greenhouse gases from activities such as agriculture, energy production, industry and land clearance; emissions of other pollutants that react in the atmosphere to form greenhouse gases; and influences on cloud formation through aviation activities.

3.2.4 Factors leading to warming of the climate system

The warming of the climate system that is evident in the last half century is a result of the cumulative effect of all the natural and human drivers that influence the amount of warming or cooling in the system. In the context of understanding and mitigating climate change, then, which factors are causing the largest amount of warming?

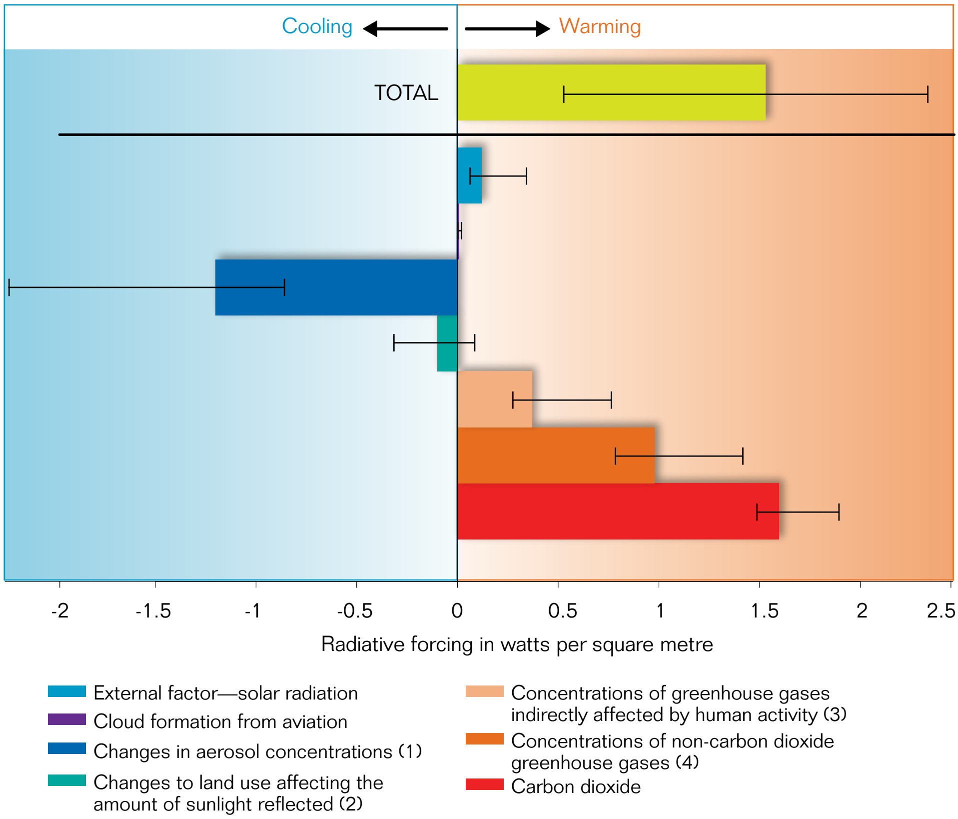
'Radiative forcing' is a measure of the induced change to the energy balance of the atmosphere at the junction of the troposphere and stratosphere. It is a useful way to compare the influences on the energy balance from external, natural and human factors.

The contribution of different factors leading to an overall warming of the atmosphere since 1750 is shown in Figure 3.4.

The dominant influence since 1750 has been an increase in concentrations of carbon dioxide. Aerosols have had a net cooling influence, although this effect is poorly understood. Natural variability in solar radiation has had a small warming influence, but the interactions are complex and there is a high level of uncertainty in the magnitude of this influence (IPCC 2007a: 192).

Even if there were no further induced changes in aerosols and greenhouse gases, the long-lived greenhouse gases would remain for hundreds and even thousands of years, leading to continued warming. Aerosols would be removed from the atmosphere over weeks to months, so their cooling effect would no longer be present. Therefore, in the long term, the major influence of humans on the climate will be through activities that lead to increased concentrations of long-lived greenhouse gases in the atmosphere.

Figure 3.4 Contribution of human and natural factors to warming since 1750



Note: Warming and cooling influences are indicated by positive and negative values, respectively. When elements are grouped, uncertainty bands are approximated from the highest uncertainty in an individual element.

(1) Includes both the direct effect and the cloud albedo effect.

(2) Includes the cooling effect of changes to land use and the warming effect of black carbon on snow.

(3) Includes tropospheric and stratospheric ozone and stratospheric water vapour.

(4) Includes methane, nitrous oxide, HFCs, PFCs and SF_6.

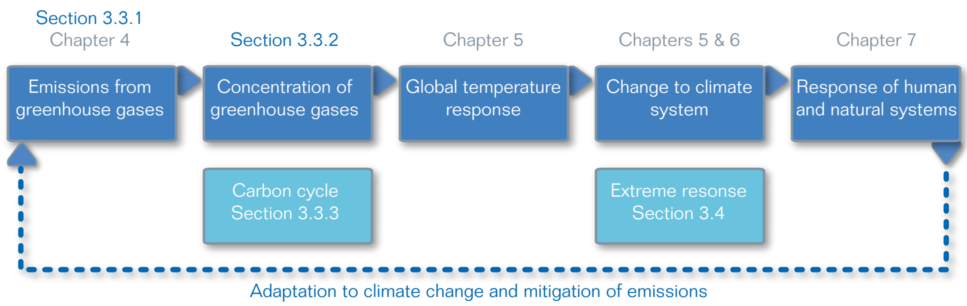
Source: Based on IPCC (2007a: 204).

3.3 Linking emissions and climate change

The high natural variability and complex internal interactions create uncertainty in the way the climate will respond to increased emissions. Figure 3.5 illustrates the relationship between emissions from human activities and climate change as a causal chain. A summary of each step in the chain is provided in this chapter, with a particular focus on the associated uncertainties. This causal chain does not explicitly include feedbacks and non-linearities in the climate system that are important in its response to human forcings. Some of these steps are discussed in more detail in other chapters of this draft report.

The potential impacts of climate change in Australia, and the associated uncertainty, are discussed in detail in Chapter 7.

Figure 3.5 Steps in the causal chain of greenhouse gas emissions leading to climate change



3.3.1 Emissions of greenhouse gases from human activities

The greenhouse gases with the greatest influence on warming of the atmosphere are water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3). In addition, there is a range of human-made halocarbons (such as perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF_6) that exist in small amounts but are very potent and contribute to the total warming.

Only some of these gases are directly emitted by human activities. Humans have less direct control over gases such as water vapour and ozone, although concentrations of these gases can be affected by human emissions of other reactive gases.

Projections of future climate change are highly dependent on the pathway of global greenhouse gas emissions. If emissions continue at the current rate, concentrations in the atmosphere will continue to increase and the magnitude and rate of climate change could be considerable. If emissions are reduced, the climate change outcomes will also be reduced.

Chapters 4 and 5 look at past trends in greenhouse gas emissions, their drivers, and future trends, and how these are used in making climate change projections.

3.3.2 Accumulation of greenhouse gases in the atmosphere

The accumulation of greenhouse gases in the atmosphere that leads to warming is a function of both the rate of emissions and rate of natural removal from the atmosphere.

Each greenhouse gas has specific characteristics that affect how long it stays in the atmosphere. The 'lifetime' of a gas in the atmosphere is a general term used for various timescales that characterise the rate of processes affecting the destruction or removal of trace gases.

With the exception of carbon dioxide, physical and chemical processes generally remove a specific fraction of the amount of a gas in the atmosphere each year. In some cases, the removal rate may vary with atmospheric properties such as temperature or background chemical conditions (IPCC 2007a: 23).

The lifetime of a gas affects the speed at which concentrations of that gas change following changes in the level of emissions. Gases with short lifetimes such as methane respond quickly to changes in emissions. Other gases with longer lifetimes respond very slowly. Over the course of a century, half of the carbon dioxide emitted in any one year will be removed, but around 20 per cent will remain in the atmosphere for millennia (IPCC 2007a: 824).

Carbon dioxide

After water vapour, carbon dioxide is the most abundant greenhouse gas in the atmosphere. Most gases are removed from the atmosphere by chemical reaction or are destroyed by ultraviolet radiation. Carbon dioxide, however, is very stable in the atmosphere. When it enters the atmosphere, carbon dioxide exchanges rapidly with plants and the surface ocean, and is then redistributed on timescales of hundreds to thousands of years through various forms of carbon storage, or 'sinks', as part of the carbon cycle, discussed in detail in section 3.3.3.

As discussed in section 3.1.3, the concentration of carbon dioxide in the atmosphere increased from about 280 ppm in 1750 to 383 ppm in 2007. Over the last 10 years, carbon dioxide in the atmosphere has increased at an average rate of 2 ppm per year (Tans 2008).

Key natural sources of atmospheric carbon dioxide are respiration from living organisms, volcanic eruptions, forest fires, decomposition of dead animals and plants, and outgassing from the ocean. The dominant human activities leading to carbon dioxide emissions are the combustion of fossil fuels and cement manufacture, which account for more than 75 per cent of the increase in concentration since pre-industrial times (IPCC 2007a: 512). Other contributors include land-use changes, dominated by deforestation and changing agricultural practices.

Methane

Methane is a reactive compound of carbon and hydrogen that is short lived in the atmosphere, where it reacts to form water vapour and carbon dioxide. The main natural sources of methane include forests, oceans and termites; the largest source is natural wetlands. Anthropogenic sources include fossil fuel mining, vegetation burning, waste treatment, rice agriculture, ruminant livestock and landfill, which account for 60 per cent of present-day emissions. The main route for methane removal is oxidation in the atmosphere. Considerable methane is stored in frozen soils and as methane hydrates in ocean sediments.

The methane concentration in the atmosphere has doubled to about 1774 ppb since pre-industrial times, after a slow fluctuation, between about 580 ppb and 730 ppb over the last 10 000 years. Since the early 1990s growth rates have declined, and virtually no growth occurred between 1999 and 2005 (IPCC 2007a: 27), which implies that emissions over that time matched the rate of natural removal.

Nitrous oxide

Nitrous oxide is relatively stable in the atmosphere, but is eventually destroyed in the stratosphere when it reacts with ultraviolet light and charged oxygen molecules. The main natural sources are processes in soils and oceans and oxidation of ammonia in the atmosphere. Tropical soils are a particularly important source (IPCC 2007a: 513).

Anthropogenic sources include fertiliser use, biomass burning, cattle production, fossil fuel combustion and industrial activities such as nylon manufacture.

Nitrous oxide concentrations have increased by about 18 per cent to 319 ppb since pre-industrial times.

Fluorinated gases

Generally, fluorinated gases (HFCs, PFCs, sulphur hexafluoride) are non-flammable and non-toxic and have a low boiling point, which makes them useful for a number of manufacturing processes. HFCs and PFCs have been developed as replacements for ozone-depleting gases being phased out under the Montreal Protocol on Substances that Deplete the Ozone Layer, which entered into force in 1989.

Fluorinated gases are purely human in origin. HFCs are used in refrigeration, air conditioning, solvents, fire retardants, foam manufacture and aerosol propellants. The major source of PFCs is aluminium production, while sulphur hexafluoride is used in the electricity supply industry in switches and high-voltage systems.

The main paths of removal of these gases from the atmosphere are destruction through reaction with ultraviolet light and other agents in the atmosphere such as chlorine, uptake in oceanic surface waters, and chemical and biological degradation processes. Concentrations are relatively small but increasing rapidly (IPCC 2007a: 28).

Water vapour

Water vapour is the most abundant and important greenhouse gas in the atmosphere, accounting for around 60 per cent of the natural greenhouse effect for clear skies (IPCC 2007a: 271). The amount of water vapour in the atmosphere is a function of temperature and tends to fluctuate regionally and on short timescales. Humans have a limited ability to directly influence its concentration (IPCC 2007a: 135).

Stratospheric water vapour has shown significant long-term variability (IPCC 2007a: 275). Stratospheric water vapour is produced by the oxidation of methane; the rate of reaction increases as methane concentrations rise (IPCC 2007a: 274). However, this effect is estimated to be equivalent to only about 1 to 4 per cent of the total change caused by long-lived greenhouse gases.

Humans generate some direct emissions of water vapour—largely from irrigation and fossil fuel production—but these emissions are equivalent to less than 1 per cent of emissions from natural sources (IPCC 2007a: 28).

Human activities that contribute to warming indirectly affect the amount of water vapour in the atmosphere, because a warmer atmosphere can hold more water vapour than a cooler one. Increases in global temperature as a result of climate change are likely to affect water vapour concentrations substantially (IPCC 2007a: 135).

The lack of understanding in the way water vapour will respond to climate change, specifically its role in cloud formation, is a key factor in the uncertainty surrounding the response of the climate to increased temperatures.

Chlorofluorocarbons and hydrochlorofluorocarbons

Chlorofluorocarbons and hydrochlorofluorocarbons (CFCs and HCFCs), like fluorinated gases, are human-made gases that are odourless, non-toxic, non-flammable and non-reactive. This makes them popular for a variety of uses such as propellants in aerosol cans, as refrigerants in refrigerators and air conditioners and in the manufacture of foam packaging.

There are a number of different CFCs and HCFCs with different industrial applications. Each has a different lifetime in the atmosphere and different effects on warming. These gases are at low concentrations but have a strong warming effect: as a group they contribute to about 12 per cent of the warming from long-lived greenhouse gases.

The low reactivity of CFCs and HCFCs allows them to remain in the atmosphere for long periods and cycle up to the stratosphere. Through a series of chemical reactions, CFCs destroy ozone and other similar compounds in the stratosphere.

The Montreal Protocol has caused a substantial reduction in emissions of these gases. Emissions of two major CFCs (CFC-11 and CFC-13) decreased substantially between 1990 and 2002 (IPCC 2007a: 513), but with lifetimes of 45 and 85 years, respectively, their concentrations in the atmosphere are reducing much more slowly.

Due to their coverage under the Montreal Protocol, which aims to phase out emissions of these gases by 2030, CFCs and HCFCs are not considered in detail in this report.

Aerosols

Aerosols are tiny particles or droplets in the atmosphere, including sulphates, ash, soot, dust and sea salt, that can be natural or anthropogenic in origin. The major anthropogenic source is fossil fuel combustion.

A major natural source of aerosols is volcanic eruptions. The eruption of Mt Pinatubo in the Philippines in 1991 produced an aerosol cloud that spread around the globe in the year after the eruption, contributing to a reduction in global average temperature of around 0.5°C between 1991 and 1993 (Newhall et al. 1997).

Aerosols generally create a cooling effect, but there is great uncertainty about the magnitude of this effect. Black carbon, or soot, has a warming effect because it absorbs solar radiation. Recent research suggests this effect may be considerably higher than previously estimated (Ramanathan & Carmichael 2008). Because the lifetime of aerosols in the atmosphere is much shorter than those of greenhouse gases, the effects are more likely to be felt in the region in which the aerosol is produced.

Aerosols are associated with poor air quality and have negative effects on human health. A decrease in aerosol emissions is expected to result from measures to improve air quality (IPCC 2007a: 78).

Tropospheric ozone and precursor species

Tropospheric ozone is a short-lived greenhouse gas produced by chemical reaction between other gases known as 'precursor species', which include carbon monoxide, chemicals from industrial uses, methane, and nitrogen oxides. Increases in tropospheric ozone have accounted for 10–15 per cent of the positive change in the earth's energy balance since pre-industrial times (IPCC 2007a: 204).

While humans have limited direct influence over tropospheric ozone concentrations, they can affect the concentrations of precursor species. Methane has a range of natural and anthropogenic sources as described above, while sources of nitrogen oxides from human activity include industry, power generation and transport.

As with aerosols, ozone precursor gases are known air pollutants associated with the formation of photochemical smog, and recently emissions of these gases have decreased as a result of air quality policy implementation.

How is the warming from different gases compared?

Global warming potential is an index that compares the radiative forcing from a given mass of that of a greenhouse gas to the radiative forcing caused by the same mass of carbon dioxide (CASPI 2007). Global warming potential depends both on intrinsic capability of a molecule to absorb heat, and the lifetime of the gas in the atmosphere. Thus, global warming potential values will vary depending on the time period used in the calculation.

The global warming potential values take into account the lifetime, existing concentration and warming potential of gases. Sulphur hexafluoride has the highest global warming potential of all gases at 22 800 times that of carbon dioxide, but has a low impact on overall warming due to its low concentrations.

Global warming potential is used under the Kyoto Protocol to compare the magnitude of emissions and removals of different greenhouse gases from the atmosphere. It is also the framework being used in the design and implementation of multi-gas emissions trading schemes for calculating the value of a trade between the reductions in emissions of different greenhouse gases.

While the global warming potential framework is useful for comparing the relative impact of different gases, there are limits to its use in modelling and analysis.

3.3.3 The carbon cycle

The ‘carbon cycle’ refers to the transfer of carbon, in various forms, through the atmosphere, oceans, plants, animals, soils and sediments. As part of the carbon cycle, plants and algae convert carbon dioxide and water into biomass using energy from the sun (photosynthesis). Living organisms return carbon to the atmosphere when they respire, decompose or burn. Methane is released through decomposition of plants, animals and waste when no oxygen is present.

Carbon dioxide dissolves in the ocean and is returned to the atmosphere through dissolution in a continuous exchange. Dissolved carbon dioxide is carried deep into the oceans through the sinking of colder water and waste and debris from dead organisms, where it is either buried or re-dissolves. The transfer of carbon to the deep ocean is very slow. Water at intermediate depths mixes with the surface water over decades or centuries, but deep waters mix only on millennial timescales and thus provides a long-term carbon sink.

Carbon sinks

The parts of the carbon cycle that store carbon in various forms are referred to as 'carbon sinks'. The majority of carbon that was present in the early atmosphere is now stored in sedimentary rocks and marine sediments. Other carbon sinks are the atmosphere, oceans, fossil fuels such as coal, petroleum and natural gas, living plants and organic matter in the soil.

Box 3.2 The importance of oceans as a carbon sink

The oceans are a significant sink of carbon, as is evident when their volume is compared to that of the atmosphere. Although the atmosphere extends hundreds of kilometres above the surface of the earth, it gets thinner as altitude increases. The lowest layer of the atmosphere, the troposphere, extends to a height of only 10–16 km, and contains 80 per cent of the air in the atmosphere. If all the air in the atmosphere were liquefied, that liquid mix would create a layer around the planet only 12 m in depth. In contrast, if all the water in the oceans were spread evenly over the earth's surface in the same way (and the earth was smooth), it would be around 2500 m deep. Using the same method, liquefied greenhouse gases would form a layer 3 mm thick (Yeomans 2005).

Table 3.1 provides estimates of the amount of carbon stored in different sinks in 1750 and how they have changed up to the end of the 20th century.

Table 3.1 Estimates of the amount of carbon stored in different sinks in 1750 and how they have changed

Carbon sink	Giga tonnes carbon stored	Percentage of total cycling carbon	Net change in sink between 1750 and 1994	Percentage change
Atmosphere	597	1.3%	165	27.6%
Vegetation, soil and detritus	2 300	5.1%	-39	-1.7%
Fossil fuels	3 700	8.3%	-244	-6.6%
Surface ocean	900	2.0%	18	2.0%
Marine biota	3	0.0%	–	–
Deeper ocean	37 100	82.9%	100	0.3%
Surface sediments	150	0.3%	–	–
Sedimentary rocks*	> 66 000 000	n/a	–	–

Note: Due to the very slow exchange with other carbon sinks, percentages of total carbon do not include storage in sedimentary rocks

*UNEP/GRID–Arendal (2005).

Source: IPCC (2007a: Figure 7.3).

The high solubility of carbon dioxide in sea water makes the ocean a key reservoir for carbon, with the deep and surface ocean accounting for more than 85 per cent of the carbon being cycled more actively. Although the atmosphere accounts for just over 1 per cent of carbon storage, it shows the largest percentage increase since pre-industrial times. Vegetation and soil have had a net decrease in carbon stored—a considerable loss from land-use change has been partially offset by carbon uptake by living organisms.

The major change to the carbon cycle from human activity is increased emissions of carbon dioxide to the atmosphere from the burning of fossil fuels. This returns carbon to the air that was captured by plants earlier in the earth's geological history and stored away from the atmospheric–terrestrial–ocean cycle. The rate of exchange between the ocean and the atmosphere has increased in both directions, but with a net movement to the ocean. Terrestrial ecosystems are also a significant sink of carbon dioxide from the atmosphere. However, absorption by both the ocean and land cannot keep pace with emissions from fossil fuels. Almost 45 per cent of human emissions since 1750 have remained in the atmosphere.

Carbon–climate feedbacks

There is a high level of uncertainty in how the carbon cycle will respond to climate change, and how this will affect the amount of carbon dioxide removed from the atmosphere through absorption by carbon sinks.

Carbon–climate feedbacks occur when changes in climate affect the rate of absorption or release of carbon dioxide from land and ocean sinks. In general, higher atmospheric concentrations of greenhouse gases, and the resulting changes to the climate system, reduce the absorptive capacity of the carbon cycle so that a larger fraction of emissions remain in the atmosphere compared to current levels (IPCC 2007a: 750). Examples of climate–carbon feedbacks include the decrease in the ability of the oceans to remove carbon dioxide from the atmosphere with increasing water temperature, reduced circulation and increased acidity (IPCC 2007a: 531); and the weakening of the uptake of carbon in terrestrial sinks due to vegetation dieback and reduced growth from reduced water availability, increased soil respiration at higher temperatures and increased fire occurrence (IPCC 2007a: 527; Canadell et al. 2007).

Large positive climate–carbon feedbacks could also result from the release of carbon from long-term sinks such as methane stored deep in ocean sediments and in frozen soils as temperatures increase (IPCC 2007a). Positive climate–carbon feedbacks are discussed further in Chapter 5.

3.3.4 The relationship between greenhouse gas concentrations and temperature rise

How do different greenhouse gases change the energy balance?

The way the climate responds to changes in the energy balance is highly complex. In section 3.2.4 the concept of radiative forcing was introduced to demonstrate the relative influence of different human and natural 'forcings' on the energy balance of the atmosphere. This section looks at radiative forcing in more detail, specifically in relation to the different greenhouse gases.

The radiative forcing of a greenhouse gas represents the change in the effect of that gas on the energy balance of the atmosphere, and takes into account its concentration in the atmosphere at the start of the period (in this report pre-industrial), the amount the concentration has changed due to human activities, and the way a molecule of that gas absorbs heat. Radiative forcing is a measure of change between two specific points in time, so the lifetime of a gas in the atmosphere has a considerable influence on future forcing.

For most gases, removal from the atmosphere is minimally influenced by changes in the climate. However, for the calculation of carbon dioxide concentrations, the complexity of the carbon cycle and the uncertainty over how it will change over time as the climate changes must be taken into account.

Carbon dioxide molecules absorb heat in a particular range of wavelengths, and as concentrations increase additional heat of those wavelengths gets absorbed. If concentrations keep growing, carbon dioxide added later will cause proportionately less warming than carbon dioxide added now. The relationship is approximately logarithmic. The same amount of warming will occur from a doubling from 280 ppm (pre-industrial levels) to 560 ppm as from another doubling from 560 ppm to 1120 ppm.

In contrast, one of the key features of gases such as HFCs, PFCs and CFCs is that they did not exist in the atmosphere before humans. Some of these gases absorb heat at wavelengths that are not absorbed by naturally occurring gases, so they have a larger impact on the energy balance. For HFCs and PFCs, the relationship between their concentration and the warming they cause is approximately linear (IPCC/TEAP 2005: 21).

The forcing due to carbon dioxide, methane, nitrous oxide and halocarbons is relatively well understood. However, the contribution of factors such as ozone at different levels in the atmosphere, aerosols and linear clouds from aviation is poorly understood (CASPI 2007), as demonstrated by the uncertainty bands in Figure 3.4.

A measure used commonly in the literature and policy discussions is the concept of carbon dioxide equivalent (CO_2-e) of a gas *concentration*, measured in parts per million—a different but related measure to carbon dioxide equivalent *emissions* calculated using the global warming potential index. This is the concentration of carbon dioxide that would cause the same amount of radiative forcing as a particular concentration of a greenhouse gas. This term is often used in discussions of global stabilisation or concentration targets, discussed further in section 3.6.

Table 3.2 summarises the characteristics of the long-lived greenhouse gases, in terms of their current concentration, lifetime and global warming potential. Carbon dioxide is by far the most abundant greenhouse gas in the atmosphere and despite having a lower warming effect for a given amount, it still dominates the overall warming influence.

Table 3.2 Long-lived greenhouse gas concentrations and radiative forcing

Greenhouse gas	Lifetime in the atmosphere (years)	2005 concentration (units vary)*	Current radiative forcing	Warming potential (radiative efficiency) (W/sq m/ppb)	100 year global warming potential
Carbon dioxide	Variable	379 (± 0.65) ppm	1.66 (± 0.17)	0.000014	1
Methane	12	1,774 (± 1.8 ppb)	0.48 (± 0.05)	0.00037	25
Nitrous oxide	114	319 (± 0.12 ppb)	0.16 (± 0.02)	0.00303	298
PFCs	Range: 740 to 50 000	Range: 3 to 74 ppt	0.34 (±0.03)	Range: 0.1 to 0.57	Range: 7400 to 17 700
HFCs	Range: 1.4 to 270	Range: 3 to 35 ppt		Range: 0.09 to 0.4	Range: 124 to 14 800
Sulphur hexafluoride	3200	5.6 (± 0.038) ppt		0.52	22 800
Montreal gases	Range: 1 to 17 000	Range: 15 to 538 ppt		Range: 0.06 to 0.33	Range: 5 to 14 400

Note: The ranges are indicative only. The 90% confidence interval is shown in brackets where it is available.
* ppm = parts per million, ppb = parts per billion, ppt = parts per trillion.
Source: IPCC (2007a).

The total radiative forcing of the long-lived greenhouse gases is 2.63 (± 0.26). In terms of carbon dioxide equivilance, this equates to a concentration around 455 ppm CO_2-e (range: 433–477 ppm CO_2-e).

However, the warming that would result from this is offset by the cooling effects of aerosol and land-use changes, which reduce the concentration to a range of 311 to 435 ppm CO_2-e, with a central estimate of about 375 ppm CO_2-e (IPCC 2007c: 102). It is the combined effect of all the influences on radiative forcing that is most relevant to the consideration of changes to the climate system.

Climate sensitivity

The relationship between warming and the change in the energy balance of the climate system is complex, largely due to the presence of internal feedbacks within the system that amplify or dampen the effect. Climate models provide a wide range of estimates of climate response. The variation in estimates results from limitations both in scientific understanding and in the ability of climate models to reflect the complexity. Key feedbacks that add to this complexity include:

'Water vapour feedback'—Warmer air holds more water vapour, and as a strong greenhouse gas it adds to the warming of the atmosphere, which in turn leads to further warming. The feedback mechanisms in this relationship are not well understood.

Cloud formation—Changes in temperature, water vapour content and aerosols will influence cloud formation. By reflecting sunlight from their upper surface and absorbing radiated heat, clouds have competing effects on the climate response. The balance depends on many factors and understanding and agreement is low—this is the largest source of uncertainty in current estimates of climate response.

Ice and snow feedbacks—As ice and snow melt, the darker surface that replaces them (oceans, soil and forest) absorbs more heat. There is reasonable confidence in the impact of this effect on warming.

'Climate sensitivity' is the measure of the climate system's response to sustained radiative forcing. It is strictly defined as the global average surface warming (measured in degrees Celsius) that will occur when the climate reaches equilibrium following a doubling of carbon dioxide concentrations above the pre-industrial value. A doubling of carbon dioxide levels is approximately equivalent to reaching 560 ppm carbon dioxide, which is twice pre-industrial levels of 280 ppm. Models predict a wide range of climate sensitivities due to differing assumptions about the magnitude of feedbacks in the climate system.

Climate sensitivity usually relates to the equilibrium temperature reached when all elements of the climate system have responded to induced changes to the climate system. Due to the long timescale of response, this may not occur for thousands of years. The IPCC estimates that it is likely that a doubling of carbon dioxide will lead to a long-term temperature increase of between 2°C and 4.5°C (IPCC 2007a: 12). It is considered unlikely that climate sensitivity will be less than 1.5°C. For fundamental physical reasons and data limitations, values substantially higher than 4.5°C cannot be excluded, but these higher outcomes are less well supported (IPCC 2007a: 799). The best estimate of the IPCC is about 3°C (IPCC 2007a: 12).

When considering the impacts of climate change on human society in the coming century, and how to respond to those impacts, temperature change over shorter time frames is more relevant. The effective climate sensitivity reflects the warming occurring in the short term, and takes into account climate feedbacks at a particular time. It can also be better related to observed temperature data. Assumptions on rate of warming of the oceans in different models have a considerable effect on the short-term temperature outcomes.

Climate sensitivity is the largest of the uncertainties affecting the amount of warming when a single future pathway of greenhouse gases is selected (IPCC 2007a: 629).

Climate variability

Climate variability refers to the natural variations in climate from the average state, and occurs over both space and time—over years or decades.

Natural climate variability occurs as a result of variations in atmospheric and ocean circulations, larger modes of variability such as the El Niño – Southern Oscillation (see Box 3.3), and events such as volcanic eruptions and changes in incoming solar radiation.

The extent of natural climate variability differs from place to place. In Australia, a notable feature of the climate is the high variability in rainfall from year to year, influenced by the El Niño – Southern Oscillation. This affects the ability of scientists to identify long-term trends in the climate system and establish whether the changes result from human activities.

Sustained changes to the energy balance of the climate system will cause a change in the long-term means of elements of the climate system such as temperature and rainfall, but may also lead to a change in the pattern of variability about a given mean. In Australia, observed changes in the climate suggest that the frequency of extremes in rainfall events is increasing at a faster rate than the mean (CSIRO & BoM 2007). Changes in extremes of climate variability are discussed further in section 3.4.

Box 3.3 Large-scale patterns of climate variability

Analysis of variability in global climate over time has shown that a significant component can be described in terms of a relatively small number of large-scale patterns of variability in atmospheric and oceanic circulation (IPCC 2007a: 39).

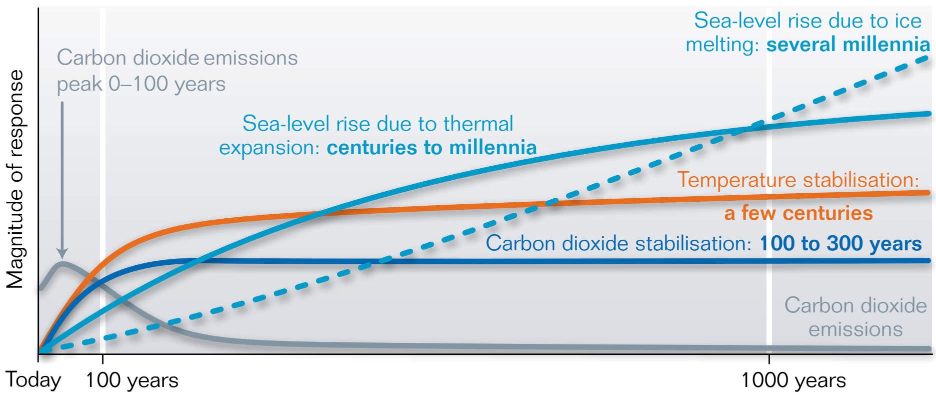
A key example is the El Niño – Southern Oscillation, which is a coupled fluctuation in the atmosphere and the equatorial Pacific Ocean. The El Niño – Southern Oscillation leads to changed conditions in sea surface temperature across the central equatorial Pacific Ocean every three to seven years, which in turn leads to changes in rainfall, floods and droughts on both sides of the Pacific. It is characterised by large exchanges of heat between the ocean and atmosphere, which affect global mean temperatures but also have a profound effect on the variability of the climate in Australia.

Another example relevant to Australia is the Southern Annular Mode, which is a fluctuation in sea surface pressure in the Antarctic, and strong westerlies in the mid-latitudes (IPCC 2007a: 39). The Southern Annular Mode has a considerable influence over climate in much of the southern hemisphere, affecting sea surface temperatures in the Southern Ocean and the distribution of sea ice. It influences rainfall variability and storm tracks in southern Australia.

The slow response of the climate system

Figure 3.6 shows estimates of the time it takes for different parts of the climate system to respond to a situation where emissions are reduced to equal the rate of natural removal. While greenhouse gas concentrations stabilise in around a hundred years, the temperature and sea-level rise due to thermal expansion of the oceans takes much longer to stabilise. Sea-level rise due to the melting of ice sheets is still increasing even after a thousand years.

Figure 3.6 Schematic of inertia in the climate system



Source: IPCC (2001b: Figure 5.2), reformatted for this publication.

Rate of change in climate response

Much of the analysis undertaken in relation to projections of climate change impacts focuses on the temperature increase under a certain emissions pathway by a point in time, often 2100. However, it is not just the magnitude of temperature rise, but also the rate at which it occurs that determines climate change impacts, as a higher rate of change in temperature affects the adaptive capacity in natural and human systems (Warren 2006; Ambrosi 2007; IPCC 2007a: 774).

3.4 Adressing the extremes: severe weather events, low likelihood outcomes, and thresholds

Due to the high level of uncertainty and the range of possible climate responses, there is a tendency in the policy community to focus on the mean, or median, or best-estimate, outcomes of climate change. An understanding of plausible extremes in the response of the climate system is vital to assessing risk.

3.4.1 Definitions and terminology

When considering outcomes other than the mean, it is important to make a distinction between a climate *event* and a climate *response* or *outcome*.

An *event* is an element of climate or weather that can occur repeatedly as a function of climate variability. The occurrence of an event of a given intensity does not exclude the occurrence of a related event at a different intensity—average rain and intense rain, for example, can both occur in a single location, but the average will occur more frequently. The uncertainty relates to when an event will happen, not whether it will happen. The likelihood of these events is often identified by a factor that reflects the magnitude of the outcome as well as the likelihood—such as a 'one-in-a-hundred-year storm event'.

By contrast, the occurrence of a particular *response* or *outcome* excludes the occurrence of a different one—the uncertainty relates to whether it will happen, when it will happen and the magnitude of its impact.

For all climate outcomes, there is a level of change that can be considered as *extreme*. Which outcomes are considered extreme is a subjective judgment dependent on many factors—including the sensitivity of the rest of the climate system to the change, and the vulnerability or adaptive capacity of the human or natural systems affected. Regardless of the definition, the likelihood of extreme climate responses generally increases with temperature.

Some climate responses involve singular events that have a large impact on the rest of the climate system, such as changes to large-scale patterns of variability or the melting of ice sheets. These outcomes are better assessed in terms of the likelihood of the event occurring for a given temperature.

For some of the better understood elements of the climate system, such as precipitation, different assumptions and model outcomes allow the identification of a range of outcomes for a given temperature increase. To better understand the potential impacts that could result for a given temperature rise, it is appropriate to consider the less likely outcomes—the bounds of the probability distribution—as well as the mean response to a given temperature increase.

3.4.2 Severe weather events

In this report, a 'severe weather event' is defined as an event of an intensity that is rare at a particular place and time of year. Definitions of 'rare' vary, but severe weather events are usually as rare as, or rarer than, the 10th or 90th percentile of probability (IPCC 2007a: 945). Examples of severe weather events include:

- hot days and nights (including heat waves)
- cold days and nights (including frosts)
- heavy rainfall events
- droughts
- floods
- hail and thunderstorms
- tropical cyclones
- bushfires
- extreme winds.

The characteristics of what is called severe weather may vary from place to place in an absolute sense—for example, the temperature required to define a heatwave in Hobart would be lower than in Darwin.

In some cases, an increase in the frequency of one extreme will be associated with a decrease in the opposite extreme—an example is an increase in record hot days and a decrease in frost events with an increase in mean temperature (see Figure 3.7). However, if the variability (or variance) were to change rather than the mean, hot days and frosts would both increase. If both the variability and the mean were to change, there would be fewer frost events but a more significant increase in hot days.

Weather events may also be considered severe if they cause extensive damage due to timing or location, even if they are not considered rare in relation to their likelihood.

3.4.3 High-consequence climate events and outcomes

Understanding the potential risk from climate change requires consideration of both the likelihood and the consequence of an event or response occurring. The extent of the impact of a change to the climate system will depend on various factors related to the change, such as its magnitude and timing, but also on the way natural or human systems respond to that change.

Severe weather events, or climate change outcomes or responses could be considered of high consequence, or 'catastrophic' due to a range of factors including:

- the magnitude, timing, persistence or irreversibility of the changes to the climate system or impacts on natural and human systems
- the importance of the systems at risk; the potential for adaptation
- the distributional aspects of impacts and vulnerabilities (IPCC 2007b: 781).

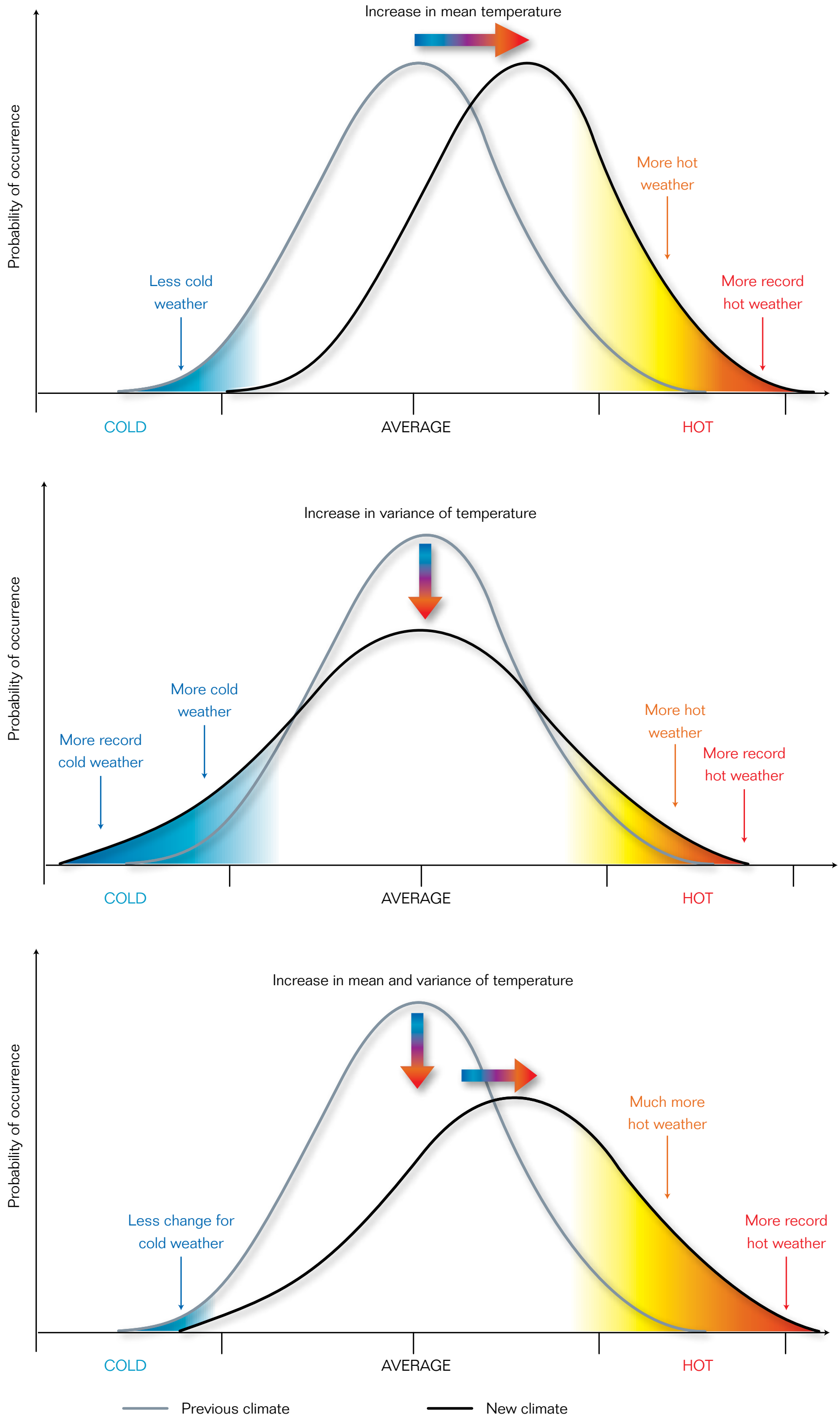
The uncertainty behind the likelihood, timing and extent of extreme climate responses is considerable. A selection of high-consequence climate events and outcomes are considered in more detail in Chapter 5.

3.4.4 Tipping points or thresholds

The threshold at which a system is pushed into irreversible or abrupt climate change occurs is often referred to as the 'tipping point'.

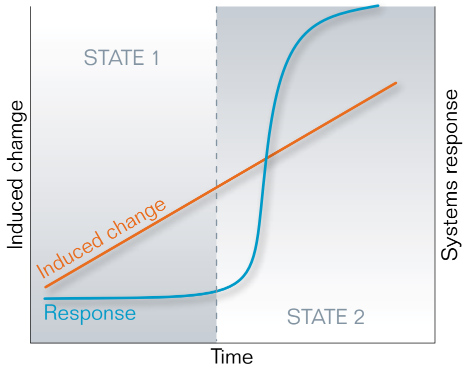
Many processes within the climate and other earth systems (such as the carbon cycle) are well buffered and appear to be unresponsive to changes until a threshold is crossed. Once the threshold has been crossed, the response can be sudden and severe and lead to a change of state or equilibrium in the system—this is often referred to as rapid or abrupt climate change (see Figure 3.8). Under abrupt climate change, a small change can have long-term consequences for a system (Lenton et al. 2008).

Figure 3.7 Effect on extremes of temperature from an increase in mean temperature, an increase in variance, and an increase in both mean temperature and variance



Source: IPCC (2001b: Figure 4.1), reformatted for this publication.

Figure 3.8 Abrupt or rapid climate change showing the lack of response until a threshold is reached



Source: Based on Steffen et al. (2004).

In other cases, the crossing of a threshold may lead to a gradual response that is difficult or even impossible to reverse. An example is the melting of the Greenland ice sheet, which may occur over a period of 300 to 1000 years, but once started would be difficult to reverse.

3.5. Uncertainty in the climate science

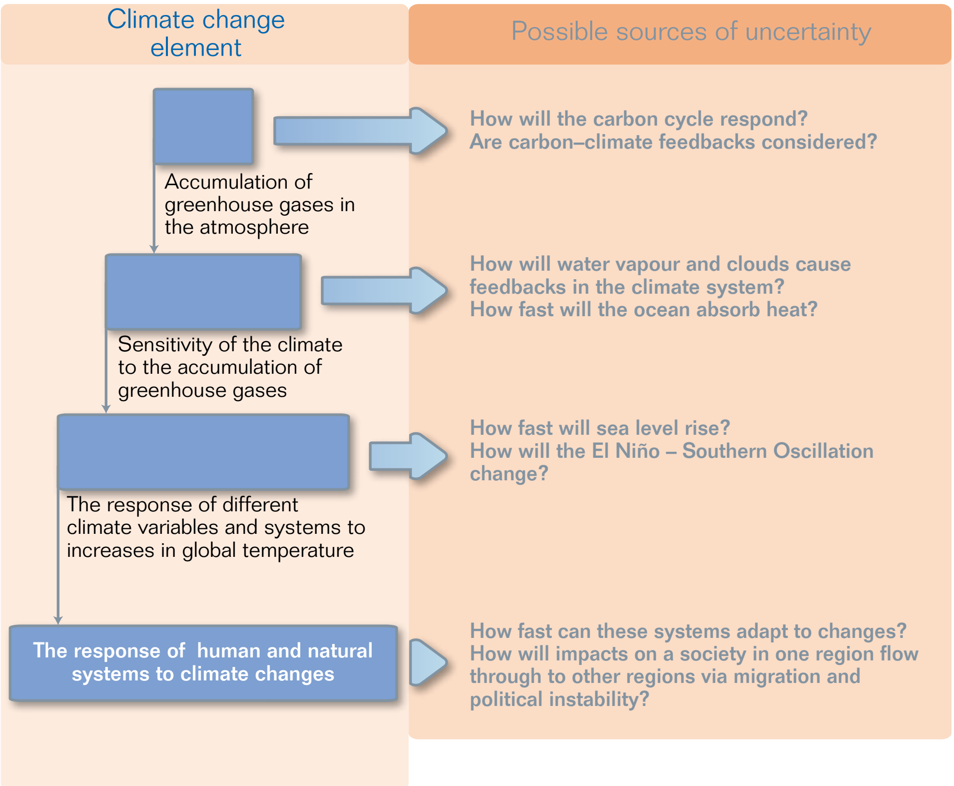
3.5.1 Addressing and communicating scientific uncertainty

The fact that many key aspects of the science of climate change are now well understood and agreed has not eliminated all uncertainties in relation to how the climate has and will respond to increases in greenhouse gas concentrations.

An understanding of the uncertainties in the climate science is essential to the assessment of climate risk. Uncertainty is not the same as low likelihood, but if it is not communicated well it can be difficult to incorporate into the decision-making process. It is therefore important that the approach taken to establishing an outcome be clearly communicated, transparent and reproducible (CSIRO & BoM 2007).

There is uncertainty at each step involved in assessing the past and future effects of human activity on climate change. A key point when considering and communicating uncertainty is how it ‘propagates’ when all the unknowns are taken into account. This is illustrated in Figure 3.9 (the blue bands demonstrate that as each layer of uncertainty is considered, the total range of uncertainty gets larger).

Figure 3.9 Cumulative nature of uncertainties in the climate change science for a given pathway of future emissions



3.5.2 Techniques for quantifying uncertainty

Uncertainty can be treated and quantified in different ways. Preferred approaches depend on the type of uncertainty and the time and modelling resources available.

The range of possible outcomes for a given set of assumptions can be assessed with multimodel simulations, which use a number of models with differences in their underlying mechanisms. This approach provides a useful assessment of the level and sources of uncertainty, but is both resource and time intensive.

To test the effect a given input assumption may have on a result, a sensitivity analysis is sometimes undertaken. This kind of analysis involves varying certain inputs in both plausible and implausible ways in order to explore how they change the outputs. If the outputs of interest are found to be insensitive to a change in a particular input, uncertainty in that input can be overlooked (CSIRO & BoM 2007).

The uncertainties in a range of different input assumptions can be tested through techniques such as the Monte Carlo analysis, which involves thousands of simulations being run which draw randomly from a set of input values. Where computing power is more limited, an analysis of the high, medium and low ends of probability of a certain outcome can be used to explore the potential range of impacts.

Additional information on the extent of uncertainty can be obtained through the consideration of expert judgment and other analytic techniques. Inclusion of these additional techniques in the consideration of total uncertainty recognises that models may underestimate uncertainties if they only include those aspects of the climate system in which scientists have confidence (Hansen 2007).

3.6 The science behind global mitigation

Goals for mitigation have typically been cast in terms of stabilisation of greenhouse gas concentrations in the atmosphere. Article 2 of the UNFCCC, which provides the international framework for climate change mitigation, states as the ultimate objective of the Convention:

> Stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (UN 1992).

However, the UNFCCC does not define the point at which 'dangerous anthropogenic interference with the climate system' or 'dangerous climate change' might occur. Even if the climate change resulting from a given pathway of future emissions were known with certainty, there would be different approaches to defining 'danger', and interpretation of the UNFCCC goal will not be defined only by the science. Ethical, economic and political judgments will also be required (IPCC 2007c).

The Review's terms of reference require it to analyse two specific stabilisation goals: one at which greenhouse gases are stabilised at 550 ppm CO_2-e (strong global mitigation) and one at which they are stabilised at 450 ppm CO_2-e (ambitious global mitigation). A stabilisation target of 450 ppm CO_2-e gives about a 50 per cent chance of limiting the global mean temperature increase to 2°C above pre-industrial levels (Meinshausen 2006), a goal endorsed by the European Union (Council of the European Union 2005) among others. Stabilisation at 500 ppm or 550 ppm CO_2-e would be less costly than a more ambitious target, but is associated with higher risks of dangerous climate change.

Based on a 'best estimate' climate sensitivity of 3°C, stabilisation at 550 ppm CO_2-e is likely to lead to an equilibrium global mean temperature increase of 3°C above pre-industrial levels (IPCC 2007c; Meinshausen 2006).

3.6.1 What is stabilisation?

'Stabilisation' of a greenhouse gas is achieved when its atmospheric concentration is constant. For a group of greenhouse gases, stabilisation is achieved when the combined warming effect (radiative forcing) of the gases is maintained at a constant level.

Stabilisation of long-lived greenhouse gases does not mean the climate will stop changing—temperature and sea-level changes, for example, will continue for hundreds of years after stabilisation is achieved.

How does the lifetime of a gas influence stabilisation?

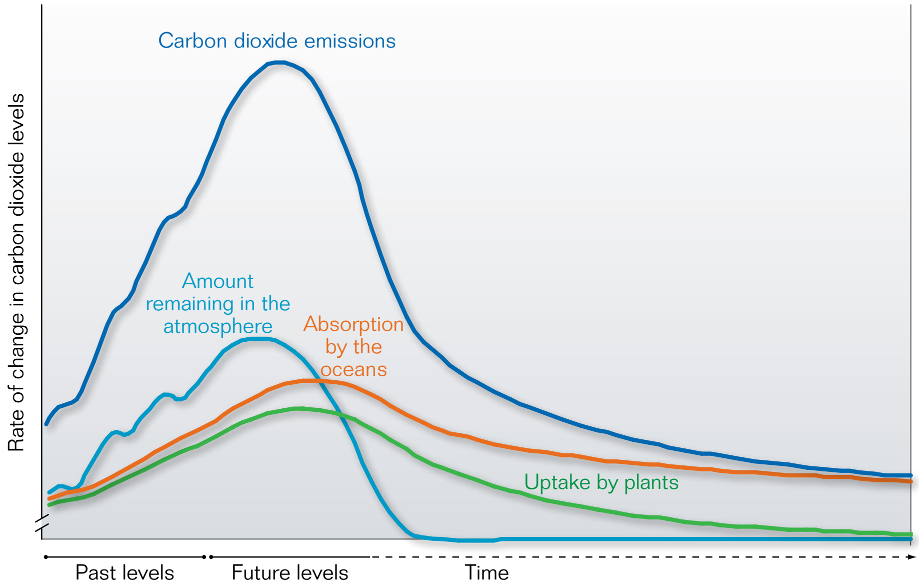
For all greenhouse gases, if emissions continue to increase over time their atmospheric concentration will also increase. However, the way in which the concentration of a gas will change in response to a decrease in emissions is dependent on the lifetime of the gas (IPCC 2007a: 824). Stabilisation of greenhouse gas emissions is therefore not the same as stabilisation of greenhouse gas concentrations in the atmosphere.

Carbon dioxide is naturally removed slowly from the atmosphere through exchange with other parts of the carbon cycle. The current rate of emissions is well above the natural rate of removal. This has caused the accumulation of carbon dioxide in the atmosphere. If carbon dioxide emissions were stabilised at current levels, concentrations would continue to increase over this century and beyond. To achieve stabilisation of carbon dioxide concentrations, emissions must be brought down to the rate of natural removal.

The rate of absorption of carbon by sinks depends on the carbon imbalance between the atmosphere, the oceans and the land, and the amount already contained in these sinks. Once stabilisation in the atmosphere is reached, the rate of uptake will decline (Figure 3.10). Long-term maintenance of a stable carbon dioxide concentration will then involve the complete elimination of carbon dioxide emissions as the net movement of carbon dioxide to the oceans gradually declines (IPCC 2007a: 824; CASPI 2008).

The response of other greenhouse gases to decreases in emissions is more straightforward: the level at which concentrations are stabilised is proportional to the level at which emissions are stabilised. For gases with a lifetime of less than a century (such as methane) or around a century (such as nitrous oxide), keeping emissions constant at current levels would lead to the stabilisation of concentrations at slightly higher levels than today within decades or centuries, respectively (IPCC 2007a: 824). If emissions of these gases were to cease completely, concentration levels would eventually return to pre-industrial levels.

Figure 3.10 Response of different carbon sinks to the rate of emissions over time



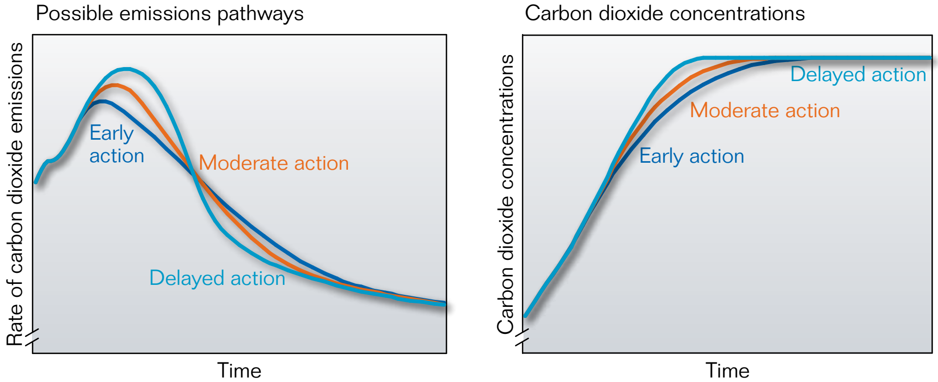
Source: Based on CASPI (2008).

For non-carbon dioxide greenhouse gases with lifetimes of thousands of years (such as sulphur hexafluoride), stabilisation would only occur many thousands of years after emissions stopped increasing. The response to decreases in emissions would thus happen over timescales that are largely irrelevant to current considerations. Therefore, in the policy context they should be treated in the same way as carbon dioxide, with the long-term aim of bringing emissions to zero in order to stabilise their warming effect.

How to achieve stabilisation?

There are any number of emissions pathways that could lead to stabilisation of a gas at a given concentration. For carbon dioxide, these pathways generally involve a trade-off between the level at which emissions peak and the maximum rate of reductions required in the future. Figure 3.11 shows some of the possible emissions pathways to achieve the same stabilisation target. These curves are stylised—in the real world, annual emissions would fluctuate. The pathways that have a higher peak in emissions have a much greater rate of reduction at a later point in time, shown by the steepness of the curve.

Figure 3.11 Different pathways of emissions reductions over time to achieve the same concentration target



Source: Based on CASPI (2008).

The timing of emissions reductions influences the efficiency of uptake of carbon dioxide by sinks, the rate of temperature increase and potentially the timing of climate–carbon feedback effects. For any given concentration stabilisation target, reaching the stabilisation target later by more rapid mitigation will give greater environmental benefits (O'Neill & Oppenheimer 2004), although small differences will not have material effects. In contrast, delaying mitigation, within limits, can reduce the upfront costs of mitigation (Wigley et al. 2006).

Is a target of 450 ppm CO_2-e or below scientifically possible?

The concentration of long-lived greenhouse gases in the atmosphere for 2005 is equivalent to the warming effect of 455 ppm of carbon dioxide. However, when the cooling influence of aerosols is included, the equivalent carbon dioxide concentration is estimated at 375 ppm CO_2-e. The concentration of carbon dioxide in 2007 was 383 ppm (Tans 2008).

Due to the short lifetime of aerosols in the atmosphere, it is not appropriate to include their influence in a long-term target. Aerosols are expected to lessen through a reduction in the burning of fossil fuels as a result of climate change policies as well as through separate efforts to reduce air pollution.

The 2005 long-lived greenhouse gas concentration of 455 ppm CO_2-e includes the warming influence of gases such as methane, which can be reduced in a relatively short period of time. If the target were set for some point in the future (such as 2050 or 2100), it would be scientifically feasible to bring CO_2-e emissions down to a target level of 450 ppm CO_2-e if immediate and deep cuts were made in emissions of most greenhouse gases.

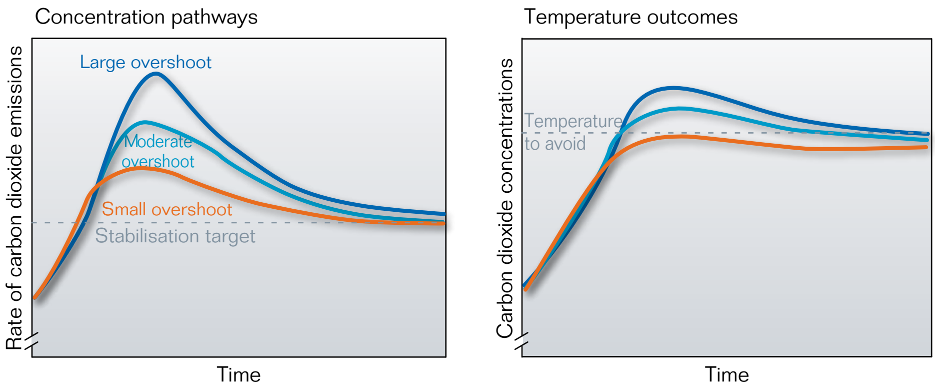
However, to achieve a target of 450 ppm CO_2-e would mean that global emissions would have to peak and fall almost immediately and a very high rate of reduction would be required. When viewed in the context of current emissions trends these fairly dramatic changes in emissions are not considered feasible. Hence, the 450 ppm CO_2-e stabilisation scenario being considered by the Review includes the assumption of an 'overshoot' in greenhouse gas concentrations.

Overshooting

There is increasing recognition in both science and policy communities that stabilising at low levels of CO_2-e (around or below 450 ppm) requires 'overshooting' the concentration target (den Elzen et al. 2007; Meinshausen 2006; IPCC 2007a: 827).

The climate change impacts of the higher levels of greenhouse gas concentrations reached in an overshoot profile are dependent on the length of time the concentrations stay above the desired target, and how far carbon dioxide overshoots.

Figure 3.12 Temperature outcomes of varying levels of overshooting



Source: Concentration and temperature pathways developed using SIMCAP (Meinshausen et al. 2006).

Figure 3.12 shows the different temperature outcomes for a range of cases of overshooting. All three cases show stabilisation at the same level in a similar time frame, but with varying amounts of overshooting. The temperature output demonstrates that while the 'small overshooting' case remains under the target temperature, the other cases do not. Hence, due to inertia in the climate system, a large and lengthy overshooting will influence the transient temperature response, while a small, short one will not (den Elzen & van Vuuren 2007).

Increasing attention is being paid in the environmental and scientific communities to low stabilisation scenarios. In particular, a number of organisations in Australia have suggested that the Review should focus as well on a 400 ppm objective. They argue that the risks of immense damage to the Australian environment, including the Great Barrier Reef and Kakadu National Park, are unacceptably high at 450 ppm. Some scientists have also expressed the view that stabilisation at 450 ppm is too high (Hansen et al. 2008). For any such scenarios to be feasible, there will need to be a considerable period of overshooting.

What is a peaking profile?

An overshooting profile requires a period in which emissions are below the natural level of sequestration before they are stabilised. Another mitigation option is to follow a 'peaking profile'.

Under a peaking profile, the goal is to cap concentrations at a particular level (the peak) and then to start reducing them indefinitely, without aiming for any explicit stabilisation level. Stabilisation is therefore not conceived as a policy objective for the foreseeable future.

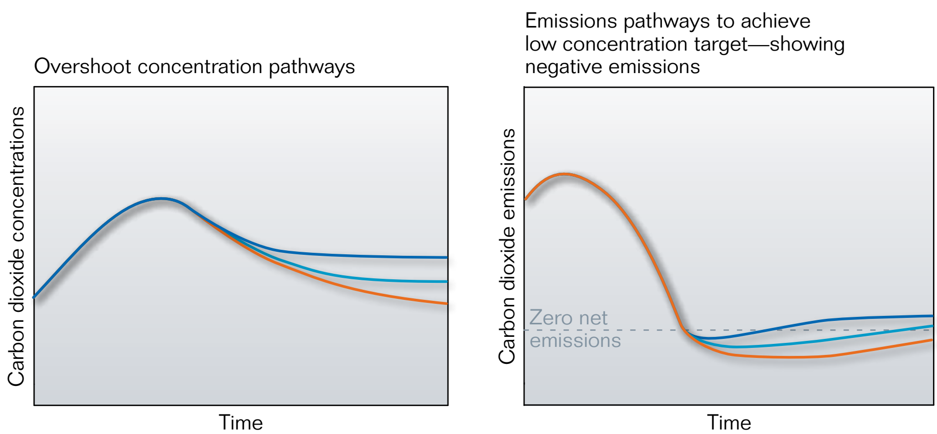
The key benefit of a peaking profile is that it allows concentrations to increase to or above the level associated with a given long-term temperature outcome, but reduces the likelihood of reaching or exceeding that temperature outcome. The higher level of peak concentrations means that current trends in emissions growth do not need to be reversed as quickly to achieve any given temperature goal. This decreases the costs of meeting a given temperature target (den Elzen & van Vuuren 2007).

A disadvantage of a peaking profile is that if the climate is found to be more sensitive to increases in greenhouse gases than anticipated, the more of the mitigation task left until later by delaying emissions reductions, the less flexibility there is to adjust to a lower concentration target later and an increased risk that a threshold may be crossed.

Is overshooting feasible?

Designing a mitigation pathway—whether an overshooting or a peaking profile—that requires a decrease in the concentration of greenhouse gases assumes that emissions can be brought below the natural level of sequestration. Figure 3.13 shows overshooting profiles. A lower concentration target following an initial overshoot will require negative emissions net of natural sequestration for a longer period.

Figure 3.13 Emissions pathways required to achieve a low concentration target following an overshooting



Source: Based on CASPI (2008).

The costs of reducing emissions below natural sequestration levels would be lower if controls on gross emissions were supported by cost-effective means of removing carbon dioxide from the atmosphere. Bringing emissions below the natural rate of sequestration would require rigorous reduction of emissions from all sources, but might also require extraction of carbon dioxide from the air. Possible methods include:

- increasing absorption and storage in terrestrial ecosystems by reforestation and conservation and carbon-sensitive soil management
- the harvest and burial of terrestrial biomass in locations such as deep ocean sediments where carbon cycling is slow (Metzger et al. 2002)
- capture and storage of carbon dioxide from the air or from biomass used for fuel
- the production of biochar from agricultural and forestry residues and waste (Hansen et al. 2008).

The simplest way to remove carbon dioxide from the air is to use the natural process of photosynthesis in plants and algae. Over the last few centuries, clearing of vegetation by humans is estimated to have led to an increase in carbon dioxide concentration in the atmosphere of 60 ±30 ppm, with around 20 ppm still remaining in the atmosphere (Hansen et al. 2008). This suggests that there is considerable capacity to increase the level of absorption of carbon dioxide through afforestation activities. The natural sequestration capacities of algae were crucial to the decarbonisation of the atmosphere that created the conditions for human life on earth, and offer promising avenues for research and development.

Technologies for capture and storage of carbon from the combustion of fossils fuels currently exist (Chapter 16), and the same process could be applied to the burning of biomass.

Today, there are no large-scale commercial technologies that capture carbon from the air. Yet some argue that it will be possible to develop air capture technologies at costs and on timescales relevant to climate policy (Keith et al. 2006). Captured carbon dioxide could be stored underground or used to produce biofuels.

Under a carbon price applying broadly across all opportunities for carbon dioxide reduction and removal, and with strong research and development support, there will be more rapid commercial development of both existing and new technologies to achieve negative emissions at a large scale (see chapters 13 and 16).

3.6.2 Other methods of mitigating climate change

So far this section has focused on efforts to mitigate climate change by reducing the concentrations in the atmosphere of greenhouse gases. But other factors influence global temperatures, which could be influenced by humans. Geo-engineering is a term used to describe 'technological efforts to stabilise the climate system by direct intervention with the energy balance of the earth' (IPCC 2007c: 815).

A range of geo-engineering proposals have been put forward, including:

- the release of aerosols into the stratosphere to scatter incoming sunlight (Crutzen 2006)
- cloud seeding through the artificial generation of micro-meter sized seawater droplets (Bower et al. 2006)
- fertilisation of the ocean with iron and nitrogen to increase carbon sequestration (Buesseler & Boyd 2003)
- changes in land use to increase the albedo (reflectivity) of the earth's surface (Hamwey 2005).

Geo-engineering proposals appear to have several advantages. First, they may be very cheap in comparison to reductions in greenhouse gas emissions. They can be implemented by one or a small number of countries and thus do not require the sort of widespread global action which stabilisation of greenhouse gases will require (Barrett 2008). They may be quick acting, with a lag from implementation to impact of months rather than decades. Geo-engineering techniques could potentially be deployed to avoid reaching a tipping point related to temperature increase.

However, geo-engineering proposals also have several disadvantages.

- Those that focus on reducing solar radiation will do nothing to prevent the acidification of the ocean as a result of increased atmospheric concentrations of carbon dioxide, and therefore only provide a part solution to the wider environmental problem.
- Geo-engineering techniques are generally untried. Some studies have been undertaken including through small-scale experiments on ocean fertilisation (Buesseler & Boyd 2003), investigation of similar natural phenomenon such as the release of aerosols from Mount Pinatubo in 1991, and computer simulations (Wigley 2006; Govindasamy & Caldeira 2000), but there will always be the risk of unanticipated consequences which could be significant and need to be further understood.
- The fact that these solutions can be implemented unilaterally may also give rise to risks of conflict.

So far, the disadvantages of geo-engineering approaches have tended to outweigh the advantages in most minds that have turned to the issue. However, in recent years such proposals have received more support from a number of prominent scientists and economists, with calls for more research into the feasibility, costs, side effects and framework for implementation (IPCC 2007c: 79; Crutzen 2006; Cicerone 2006; Barrett 2008).

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4 EMISSIONS IN THE PLATINUM AGE: THE RAPID, RECENT AND PROJECTED FUTURE GROWTH OF GREENHOUSE GAS EMISSIONS

Key points

Greenhouse gas emissions have grown rapidly in the early 21st century. In the absence of strong mitigation, strong growth is expected to continue for the next two decades and in only somewhat moderated rates beyond.

So far, the biggest deviations from earlier expectations are in China. Economic growth, the energy intensity of that growth, and the emissions intensity of energy use are all at, or above, projections embodied in these earlier expectations. China has recently overtaken the United States as the world's largest emitter, and, in an unmitigated future, would account for about 35 per cent of global emissions in 2030.

Other developing countries are also becoming major contributors to global emissions growth, and will take over from China as the main growing sources a few decades from now. Under the unmitigated case, developing countries would account for about 80 per cent of emissions growth over the next two decades and more after that.

High petroleum prices will not necessarily slow emissions growth, because of the ample availability of large resources of high-emissions fossil fuel alternatives, notably coal.

4.1 Greenhouse gas emissions by source and country

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) estimates that in 2004 greenhouse gas emissions from human activity were about 50 Gt carbon dioxide equivalent (CO_2-e).

Almost 60 per cent of this total was emissions of carbon dioxide from fossil fuel combustion and other industrial processes that emit carbon dioxide (such as cement production and natural gas flaring).

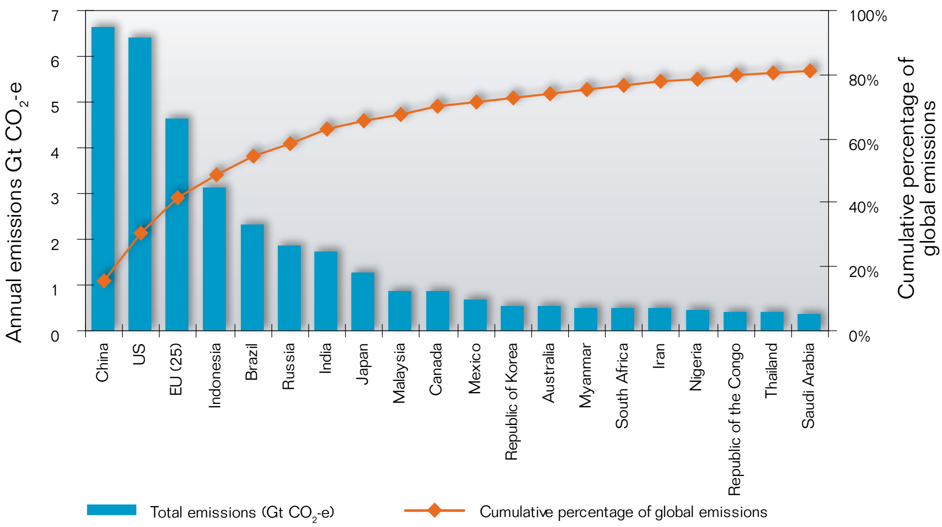
Other greenhouse gas emissions are measured with less accuracy. The IPCC (2007) reports that carbon dioxide emissions from land use and forestry make up 17 per cent of total emissions. Slightly less than one-quarter of emissions are other gases (which are converted to CO_2-e using their global warming potential—see Chapter 3). Methane is the second most important greenhouse gas, responsible for 14 per cent of the total; nitrous oxide is responsible for 7 per cent; and a range of industrial gases for the remaining 1 per cent.

The bulk of greenhouse gas emissions arise from the countries that are the centres of global economic activity. The largest emitters are China, the United States and the European Union (Figure 4.1), which between them are responsible for more than 40 per cent of global emissions. The 20 largest emitters (including emissions from land-use change and forestry) are responsible for over 80 per cent of global emissions (Figure 4.1).

Richer countries tend to have much higher per capita emissions than poorer countries. The exceptions are poorer countries with high emissions from land-use change and forestry (Figure 4.2).

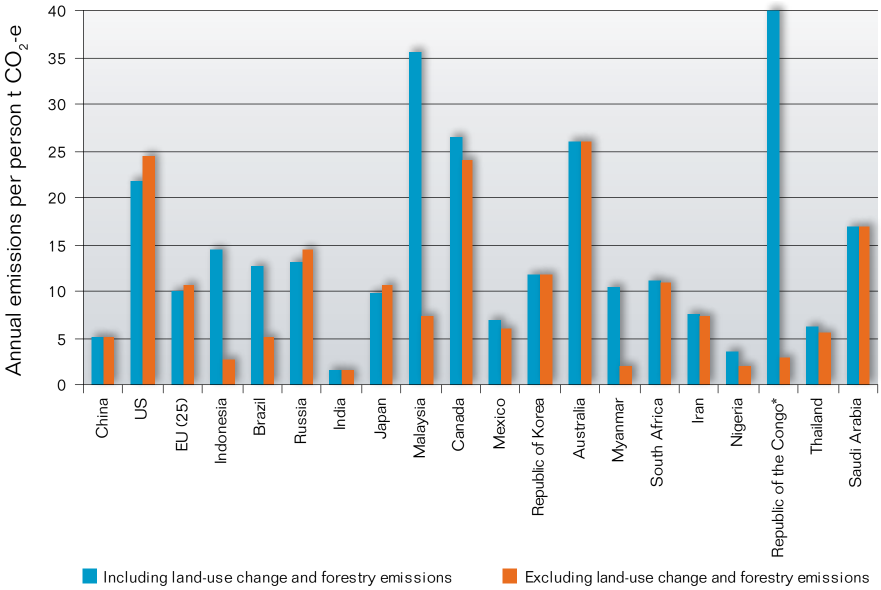
Developed and transition countries make up about half of current global emissions. However, the growth of emissions is much faster in developing countries, and their share of global emissions will grow over time (Table 4.2).

Figure 4.1 The 20 largest greenhouse gas emitters: total emissions and cumulative share (%) of global emissions, c. 2004



Source: UNFCCC (2007) 2004 data for US, EU (25), Russia, Japan and Canada; Department of Climate Change (2008) 2004 data for Australia (using UNFCCC accounting); and World Resources Institute (2008) for other countries (2000 data except for CO_2 emissions from fossil fuels, which is for 2004).

Figure 4.2 The 20 largest greenhouse gas emitters: per capita emissions excluding and including emissions from land-use change and forestry, c. 2004



Note: Estimates of forestry-related emissions are subject to large uncertainties in many of the main emitting countries.

* Dark blue bar is truncated; per capita emissions including land-use change and forestry emissions are 105 t.

Source: UNFCCC (2007) 2004 data for US, EU (25), Russia, Japan and Canada; Department of Climate Change (2008) 2004 data for Australia (using UNFCCC accounting); and World Resources Institute (2008) for other countries (2000 data except for CO_2 emissions from fossil fuels, which is for 2004) and for population (2004).

4.2 Recent trends in carbon dioxide emissions from fossil fuels[1]

Carbon dioxide emissions from fossil fuels are the largest source of greenhouse gases and the fastest growing. They are the main focus of this chapter.

Carbon dioxide emissions from fossil fuel combustion increased by about 2 per cent per year in the 1970s and 1980s, and by only 1 per cent a year on average in the 1990s. They have expanded by 3 per cent a year in the early 21st century (Table 4.1).

Disaggregating between OECD (developed) and non-OECD (developing including transition) countries shows that the latter group is driving global trends (Table 4.1). In the early 1970s, non-OECD countries were responsible for roughly one-third of global emissions, energy use and output. In 2005 they were responsible for just over half of global energy use and emissions, and

45 per cent of global output. Since 2000, non-OECD emissions have been growing almost eight times faster than OECD emissions, accounting for 85 per cent of the growth in global emissions.

The OECD countries show a slowdown in growth in emissions, GDP and energy in this decade compared to the last. In the non-OECD countries, the rate of growth in all three has increased significantly in this decade. The high rate of global economic growth seen this decade, at times even above that seen in the 'Golden Age' of the 1950s and 1960s, defines the new 'Platinum Age' the world has entered (Garnaut & Huang 2007).

Table 4.1 Growth in CO_2 emissions from fuel combustion, GDP and energy

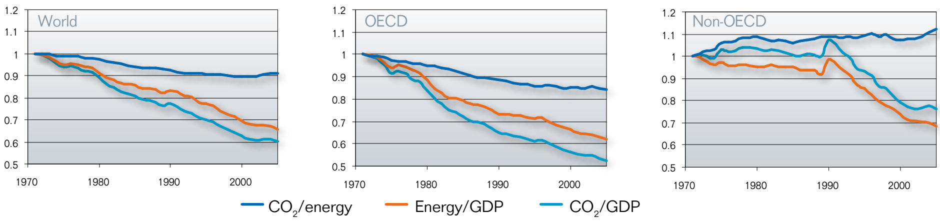
	Average annual growth rates (%)		
	1971–90	1990–2000	2000–05
World			
Emissions growth	2.1	1.1	2.9
GDP growth	3.4	3.2	3.8
Energy growth	2.4	1.4	2.7
OECD			
Emissions growth	0.9	1.2	0.7
GDP growth	3.2	2.7	2.1
Energy growth	1.5	1.6	0.8
Non-OECD			
Emissions growth	4.2	0.9	5.5
GDP growth	3.8	4.0	6.2
Energy growth	3.8	1.0	4.6

Notes: Emissions growth is CO_2 from fossil fuel combustion. Energy growth is total primary energy supply measured in millions of tonnes of oil equivalent. GDP growth is measured using 2000 US$ purchasing power parities.
Source: IEA (2007b).

There has also been a significant reduction among non-OECD countries in the rate of decline of the energy intensity of economic activity and the carbon intensity of energy use. The 1990s saw a rapid decline in energy intensity in the non-OECD group. Energy use grew at only a quarter of the rate of GDP, and emissions at below the rate of energy. This decade has seen the resumption of energy-intensive and carbon-intensive growth in the developing and transition world: energy use has grown at three-quarters the rate of GDP, and carbon emissions 20 per cent faster than energy use.

Figure 4.3 shows just how differently energy intensity (the energy/GDP ratio) has behaved in OECD and non-OECD countries. In the developed world, the energy/GDP curve has declined smoothly and continuously. In the developing world, energy intensity fell only slowly over the 1970s and 1980s, plunged in the 1990s, and has now flattened out, at around 70 per cent of its 1971 level.

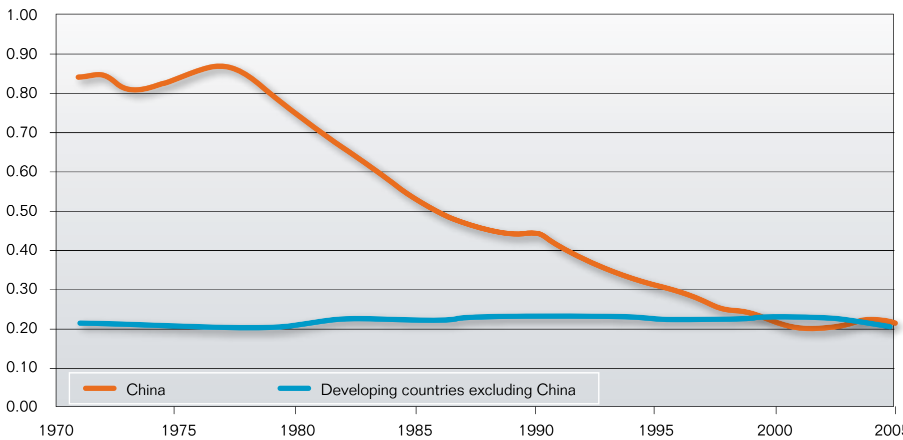
Figure 4.3 CO_2 emissions/GDP, energy/GDP and CO_2 emissions/energy for the world, OECD and non-OECD, 1971–2005 (1971 = 100)



Notes: Emissions are CO_2 from fossil fuels. Energy is total primary energy supply measured in millions of tonnes of oil equivalent. GDP is measured using 2000 US$ purchasing power parities.
Source: IEA (2007b).

Figure 4.4 shows energy intensity separately for China and other developing countries. Energy intensities are remarkably steady for developing countries once China is excluded. China started out with an enormously high energy intensity in the 1970s. The ratio declined through the 1980s and 1990s, due to a shift away from subsidised prices and central planning. It flattened only at the turn of the century.

Figure 4.4 Energy intensities of GDP for China and other developing countries



Note: The ratio is of energy (total primary energy supply measured in millions of tonnes of oil equivalent over GDP (in 2000 US$ purchasing power parities).
Source: IEA (2007b).

Globally, increasing reliance on coal, which is more carbon-intensive than oil and natural gas,[2] has kept the carbon intensity of energy roughly constant, with a slight upward trend in recent years. In the 1980s and 1990s, a reduction in the share of oil in total energy demand was associated with an increase in the share of gas. But since 2000, the share of gas has remained constant, and the share of coal has increased.

The same trends in relation to coal are evident in both developed and developing regions, though in much more dramatic terms in the latter. Between 2000 and 2005, coal use increased in developing countries on average by 9.5 per cent per year, and by 11.7 per cent in China.[3] In 2005, 61 per cent of the world's coal was consumed in developing countries, up from 51 per cent just five years earlier. In 2005, coal provided 63 per cent of China's energy, 39 per cent of India's, and only 17 per cent of the rest of the world's (IEA 2007a).

In summary, the acceleration of emissions this decade has been caused by three factors: the rapid acceleration of growth in the developing world; the ending of the period of rapid decline in energy intensity in China, which lasted from the 1970s to the 1990s; and the end to the decarbonisation of energy supply in both the developed and (especially) the developing world.

4.3 Existing emissions projections

The most influential projections used in climate change analysis are still those set out in the *Special Report on Emissions Scenarios* (SRES) of the IPCC (2000). These provide a wide range of future emissions paths out to 2100 under four different 'storylines' about growth and technology.

The SRES authors did not assign likelihoods to particular scenarios, but rather argued that they were all equally plausible. In practice, most attention has been given to low- and mid-range emissions growth scenarios.

The high-end scenarios have often been dismissed as extreme or unrealistic. Other analyses give all SRES scenarios equal weight, rather than asking which ones are more soundly based. Reliance on only the more pessimistic SRES scenarios is seen as unbalanced. One of the criticisms of the Stern Review has been that the SRES scenario it relied on showed 'high range greenhouse gas emissions' (Baker et al. 2008: xi). Stern himself, however, in his recent Ely lecture (2008), and following interaction with the Garnaut Climate Change Review, has noted that his review underestimated the likely growth of emissions.

Post-SRES scenarios do not show very different results to those of SRES. GDP growth, total energy use and carbon dioxide emissions are all lower in the median post-SRES no-mitigation scenario than in the median pre-SRES/SRES scenario (IPCC 2007). Energy forecasting agencies have not significantly adjusted emissions forecasts upwards despite the acceleration of growth seen so far this decade. The US Energy Information Administration reference scenarios for emissions and energy consumption growth over the period 2000 to 2020 were no higher in 2007 than in 2000, despite the higher levels in both variables seen so far this decade.[4]

Results from a range of existing projections are shown in figures 4.8, 4.9 and 4.10 along with the results from the updated projections carried out for the Review.

4.4 The Review's no-mitigation projections: methodology and assumptions

Two new sets of projections were developed for the Review. Both are constant policy scenarios where no further policies are put in place to mitigate climate change, and no additional impacts of climate change are felt. (The case with climate change impacts is discussed in Chapter 9.)

The Review's 'Platinum Age' projections cover the period out to 2030, and are based on work by Garnaut et al. (forthcoming). These projections utilise the most recent International Energy Agency projections (IEA 2007a), which make use of extensive information on energy systems in a partial equilibrium framework. Using an emissions growth decomposition framework, adjustments are made to selected macroeconomic assumptions. The strength of this approach is that it builds on the specialist knowledge of the IEA, and identifies the assumptions that need rethinking. Its limitation is that it does not capture the general equilibrium effects that would derive from the changes in assumptions.

The Review's reference case runs to 2100, and was developed by the Australian Treasury and the Garnaut Review in consultation with other experts. This scenario was implemented in the Global Trade and Environment Model (GTEM), a computable general equilibrium model of the world economy used in the joint modelling exercise by the Review and the Treasury.[5] The top-down modelling of GTEM is complemented by a series of bottom-up models of electricity generation, transport, and land-use change and forestry.

Key GDP and population assumptions up to 2030 are broadly consistent for the two projections. Population projections are the United Nations 'medium variant' population projections to 2050, and UN long-term population projections to 2100 (figures 4.5 and 4.6). (Population projections for Australia, however, are based on Australian Treasury (2007) population projections, revised in the light of Treasury's most recent analysis of immigration trends. These are higher than UN projections, significantly so in the second half of the century.) By the end of the century the world's population is over 40 per cent larger than at the start.

Population growth is above 1 per cent per year in the current decade, then steadily falls to zero annual growth around 2080, when global population peaks. After 2080, population falls by 0.1 per cent a year on average, with nearly all regions showing zero or negative growth. Many developing countries including India gain in population share over the century; Australia, Canada and the United States hold a broadly constant share as a result of immigration; the shares of China, Europe, Russia and Japan and others drop.

Assumptions on nearer-term GDP per capita growth rates are based on growth accounting, and by judgments informed by recent experience, both of which suggest the continuation of high growth, albeit falling over time, in the developing world. Longer term, GDP per capita is assumed to converge over time with that of the United States, which is assumed in the long term to grow at 1.5 per cent a year. (Note that GDP is measured using purchasing power parities rather than market exchange rates in both sets of projections.) Growth slows in developing countries as the income gap with the United States diminishes. Countries are assumed not to close the gap completely by the end of the century, with average world per capita incomes around half US levels at 2100. The global annual per capita GDP growth peaks at just over 3 per cent in the middle of the 2020s, then falls to 2 per cent by the end of the century. Global annual GDP growth peaks around 4 per cent in the early 2020s, then falls to just below 2 per cent by the end of the century (Figure 4.6).

Figure 4.5 The reference case: global population, GDP and GDP per capita, 2001 to 2100 (2001=1)

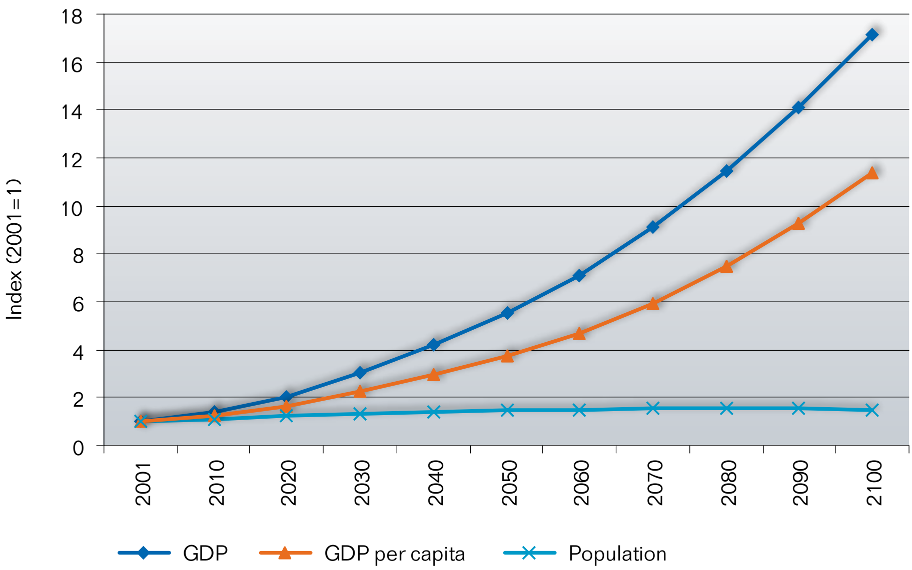
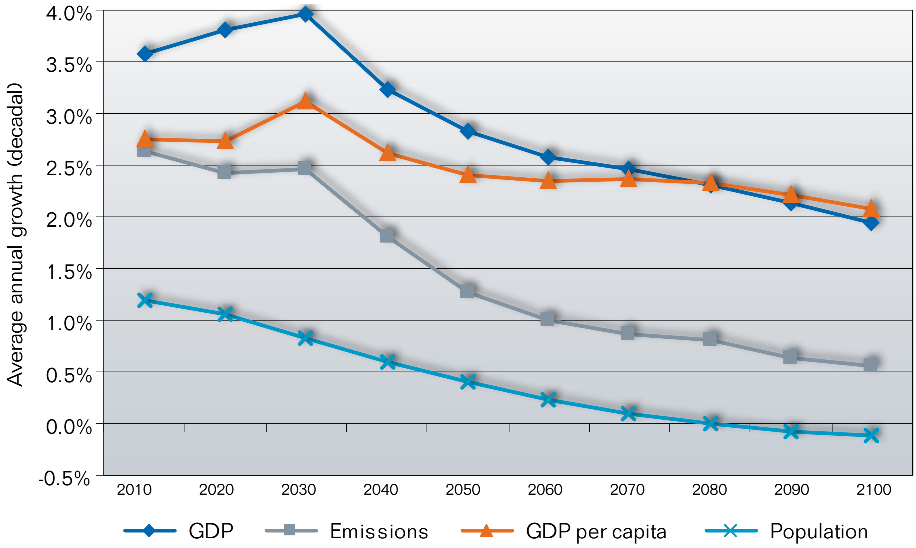
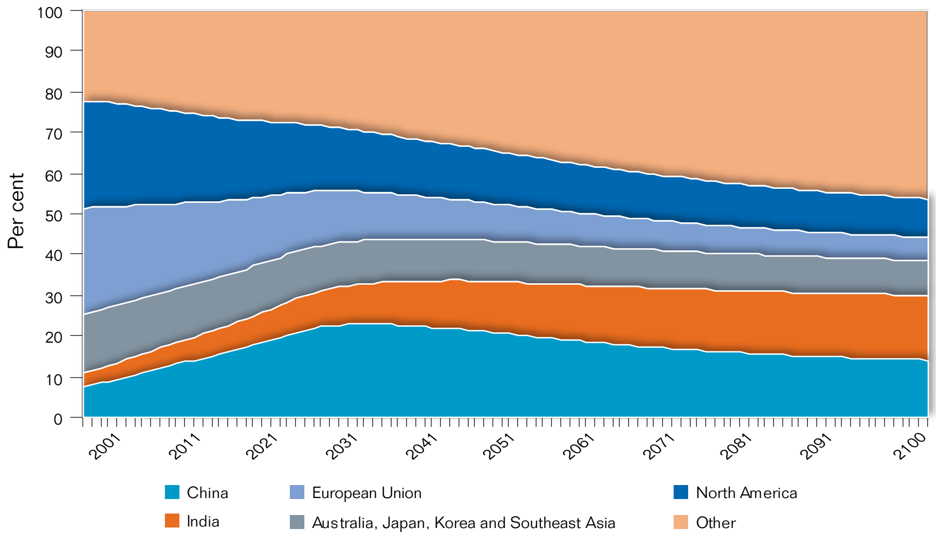


Figure 4.6 The reference case: global population, GDP, GDP per capita, and CO_2-e emissions, 2000 to 2100—average growth rates by decade



By 2100, total global GDP is 17 times its 2000 level, and average per capita GDP increases by 11 times over the century. The distribution of global output is also very different to that seen today (Figure 4.7). The share of China in global output rises sharply until the 2030s, but then declines. The share of India continues to rise and by about 2080 overtakes that of China. The share of the European Union, North America and the rest of Asia declines. The share of the rest of the world rises over the period, reflecting high population growth in many low-income developing countries.

Figure 4.7 Shares in global output of various countries and regions, 2001 to 2100



Growth in greenhouse gas emissions in the reference case are a function of changes in production and consumption structures in different countries, changes in relative prices including for different sources of energy, and improvements in energy efficiency and the efficiency of intermediate input use. The reference projections also include emissions of methane, nitrous oxide and various industrial gases, as well as a subset of forestry-related emissions and sequestration.

Carbon dioxide emissions from fossil fuel are modelled in the Platinum Age projections as a function of the carbon intensity of energy, and the energy intensity of GDP. Carbon intensity is assumed to remain roughly constant over time, in line with IEA projections: the share of oil decreases, with substitution towards coal as well as low-emissions energy sources. Energy intensity is assumed to decline in both developed and developing countries. This is in contrast to the historical experience in developing countries, where energy intensities have been constant (see Figure 4.4) and is assumed to represent the effect of high energy prices. In particular, in contrast to the experience of the past few years, energy intensity is assumed to fall in China, but not as rapidly as projected by the IEA (see Box 4.1). Platinum Age projections for methane and nitrous oxide update US Environmental Protection Agency projections for higher forecast global growth. Platinum Age projections for forestry-related carbon dioxide emissions are based on IPCC baselines, and assume a constant value in these emissions out to 2030. Detailed assumptions are available in Garnaut et al. (forthcoming).

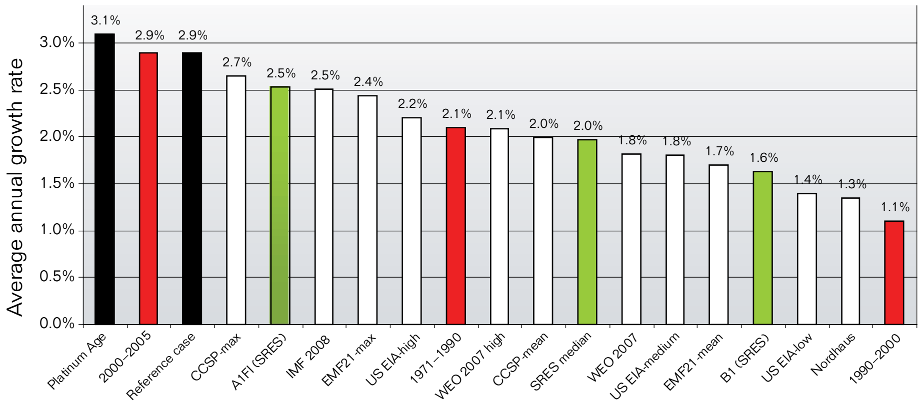
4.5 Results from the Review's projections and comparisons with existing projections

Figure 4.8 compares the average growth rates for carbon dioxide emissions from fossil fuels for the Platinum Age and Garnaut–Treasury reference case with a number of SRES (in green) and post-SRES (white) scenarios for the period circa 2005–30. It also shows (in red) average emissions growth in the 1970s and 1980s, the previous decade and so far in this decade (2000 to 2005).

Most carbon dioxide emissions projections for growth out to 2030 forecast annual average growth significantly below the 2.9 per cent annual average growth seen between 2000 and 2005. Even A1FI, the SRES scenario that shows the most rapid emissions growth over the century, and which is often regarded as extreme, projects carbon dioxide emissions growth of only 2.5 per cent out to 2030. The SRES median scenario shows growth of 2.0 per cent, and the moderate B1 SRES scenario shows growth of only 1.6 per cent. The post-SRES scenarios lie in a similar range.

The Platinum Age projections and the reference case, however, project growth in carbon dioxide emissions of 3.1 per cent and 2.9 per cent out to 2030. They suggest that the existing range of scenarios underestimates the future growth of emissions in the early 21st century. In the absence of unexpected dislocations in the global economy, emissions growth is unlikely to ease significantly over the next two decades from current levels.

Figure 4.8 Global CO_2 emissions growth rates from fossil fuels to 2030: a comparison of Garnaut Review no-mitigation projections with SRES and post-SRES scenarios and historical data

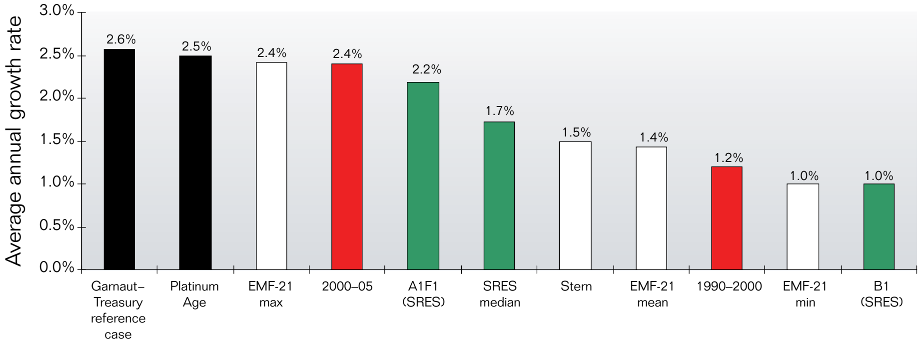


Note: The red bars show average annual emissions growth for various historical periods. The green bars show various SRES scenarios, and the white bars post-SRES scenarios. The black bars give the projections of the Review.

Sources: This figure is modified from Garnaut et al. (forthcoming). Historical data is from Table 1. The SRES scenarios (IPCC 2000) used are A1FI (AIG MINICAM), which shows the most rapid emissions growth, both to 2030 and to 2100; B1 (BI IMAGE), which is at the lower end of the range; and the median SRES scenario (which is defined as the median for each variable and each decade of the four SRES marker (or main) scenarios). The SRES scenarios give projections for every 10 years from 1990 to 2100; we report here projections for 2000 to 2030. Post-SRES scenarios included are the mean and maximum emission baselines from the EMF-21 project (Weyant et al. 2006), which included 18 different emission projection models for 2000–2025; the mean and maximum projections from the US Climate Change Science Program (Clarke et al. 2007), which used three models; the base case from the well-known Nordhaus (2007) model for 2005 to 2035; projections for 2005 to 2030 from IEA (2007a) (both the base case and a rapid-growth scenario with higher growth projected for China and India); the high, medium and low projections from the US Energy Information Administration (2007) for 2004 to 2030; and the IMF World Economic Outlook baseline for 2002–30 (IMF 2008).

Figures 4.9 and 4.10 project greenhouse gas emissions from human activity (section 4.1) for the Review's no-mitigation projections and other projection exercises. The Platinum Age projections and the reference case give annual average growth in greenhouse gas emissions of 2.5 per cent and 2.6 per cent respectively over the period 2005–30, at the top end of existing projections and comparable with the growth rate in emissions seen in the first years of this decade (Figure 4.9).

Figure 4.9 Global greenhouse gas emissions growth rates to 2030: a comparison of Garnaut Review no-mitigation projections, SRES and post-SRES scenarios, and historical data



Note: The red bars show average annual emissions growth for various historical periods. The green bars show various SRES scenarios, and the white bars post-SRES scenarios. The black bars give the projections of the Review.

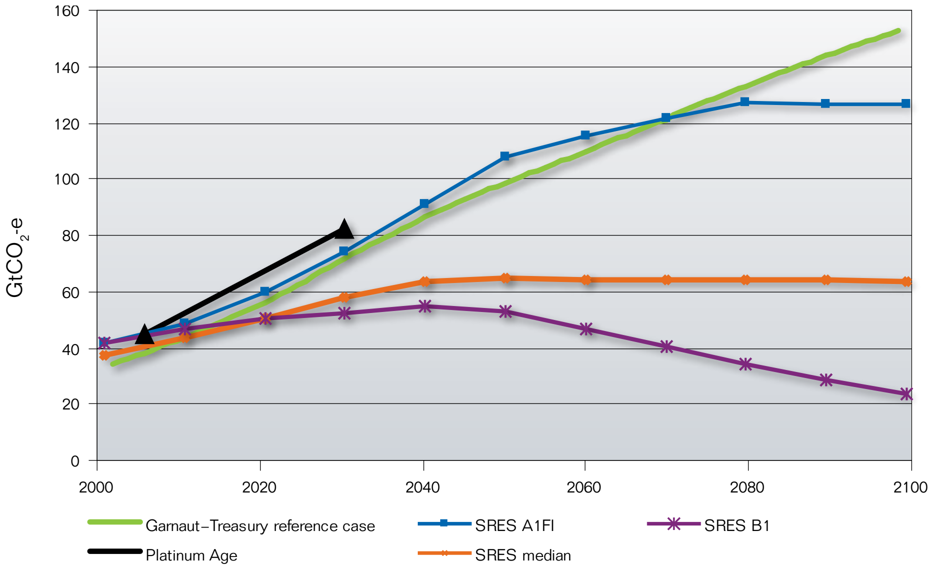
Sources: This figure is modified from Garnaut et al. (forthcoming), which includes detailed notes. See also the notes to Figure 4.8.

Emissions levels at 2030 are significantly higher in the Platinum Age than in existing rapid-growth scenarios because of the higher forestry-related emissions built into the base. The Platinum Age projects emissions of 83 Gt CO_2-e by 2030, almost double their current level, 11 per cent higher than the A1FI scenario, and a level of emissions reached only in 2050 in the business-as-usual scenario used by the Stern Review (Stern 2007: 202). Reference case emissions are lower in 2030 at 72 Gt CO_2-e due to lower base-year estimates of forestry-related and non-carbon dioxide emissions.

Emissions under the reference case continue to rise post-2030. Figure 4.10 compares emissions over the century under the two Garnaut Review business-as-usual projections with the three SRES scenarios highlighted in figures 4.8 and 4.9. Although the rise in emissions in the reference case is much slower in the latter decades of the century (the annual growth rate drops to 0.6 per cent at the end of the century), emissions in the reference case are more than twice those in the SRES median scenario by the end of the century. Over the course of the century, emissions in the reference case are comparable with those of the 'extreme' A1FI scenario.

Table 4.2 shows the projected composition of emissions across countries in the reference case using the regional breakdown which GTEM deploys. The share of most developing countries is growing rapidly. More than 90 per cent of the future growth in emissions occurs in developing countries.

Figure 4.10 Global greenhouse gas emissions to 2100: comparing Garnaut Review no-mitigation projections and various SRES scenarios



Sources: See notes to Figure 4.8.

China emerges as the most important country determining emissions, especially up to 2030. By 2030, its emissions exceed by about 20 per cent all Annex I (developed and transition countries) combined. The factors behind the explosive growth in emissions in China are explored in Box 4.1.

Table 4.2 Shares of total greenhouse gas emissions by country/region in the Garnaut–Treasury reference case

	Share of emissions (%)		
	2005	2030	2100
United States	18.7	11.2	5.5
European Union	12.9	7.4	3.5
Former Soviet Union	8.3	6.4	3.8
Japan	3.5	1.8	0.6
Canada	2.0	1.3	1.0
Australia	1.5	1.1	1.0
China	18.7	33.8	23.2
India	4.9	8.7	19.3
Indonesia	1.8	1.7	2.4
Other Southeast Asia and Korea	3.0	2.2	2.8
South Africa	1.3	1.3	1.3
OPEC	4.7	5.3	7.7
Rest of World	18.6	17.9	27.8
World	100.0	100.0	100.0

Box 4.1 Determinants of China's emissions trajectory to 2030

China has the world's largest population, and the highest economic growth rate of any major country. Its energy is very carbon-intensive: out of 51 countries with a population greater than 20 million, China has the fifth most carbon-intensive energy mix (IEA 2007b). China's energy supply is carbon intensive because coal is the only domestic energy source in which China is even moderately well-endowed per capita on a global basis.

In the coming decades, China will have more impact on global emissions than any other country. Assumptions about future economic growth and energy patterns in China are therefore of critical importance to emissions projections.

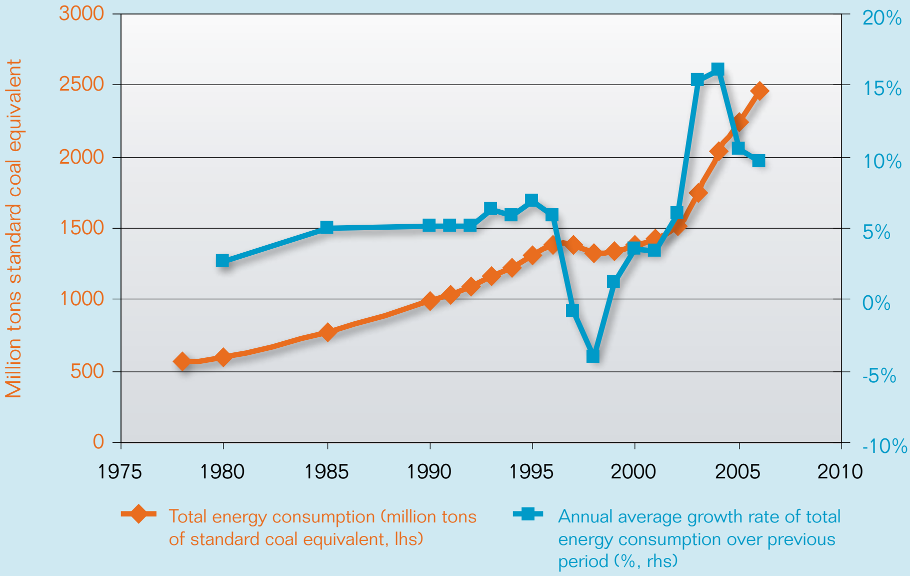
China's influence out to 2030 is particularly pronounced. The reference case projects China's share of global emissions to rise from 19 per cent in 2005 to 34 per cent in 2030. This follows from average annual growth in emissions of 5.1 per cent. After 2030, China's growth is projected to slow, as its population starts to fall and per capita incomes reach relatively high levels. Emissions growth slows to just 1.3 per cent for 2030 to 2050.

What will drive China's rapid growth in emissions to 2030? First, China's economy will continue to grow rapidly. Using growth accounting, Garnaut et al. (forthcoming) project GDP growth of China of 9.0 per cent from 2005 to 2015 and 6.8 per cent from 2015 to 2025. This rapid GDP growth will take place on the back of continued very high investment levels and total factor productivity growth. This projection is higher than most literature forecasts, but below performance seen in recent years.

Second, China's economic expansion will continue to be energy intensive. Figure 4.11 shows the acceleration in China's energy consumption in recent years. This reflects rapid growth in China in heavy energy-intensive industry: between 2000 and 2006, crude steel production has grown in China by an annual average of 22 per cent, pig iron by 21 per cent, and cement by 13 per cent (National Bureau of Statistics of China 2007a). Analysts differ on the extent to which energy efficiency will improve in China, even without a concern for climate change. The Review expects that, in the absence of deliberate mitigation, and given China's high level of investment and the rapid growth of its heavy industry, the energy intensity of output in China will decline no more rapidly than in other developing countries. The Review's Platinum Age projections adjust the IEA's more rapid energy efficiency improvements downwards to be broadly consistent with the analysis of Sheehan and Sun (2007), who predict elasticities of energy with respect to GDP of 0.8 declining to 0.7.

Box 4.1 Determinants of China's emissions trajectory to 2030 *(continued)*

Figure 4.11 China total energy consumption, levels and growth, 1978 to 2006



Source: National Bureau of Statistics of China (2007a).

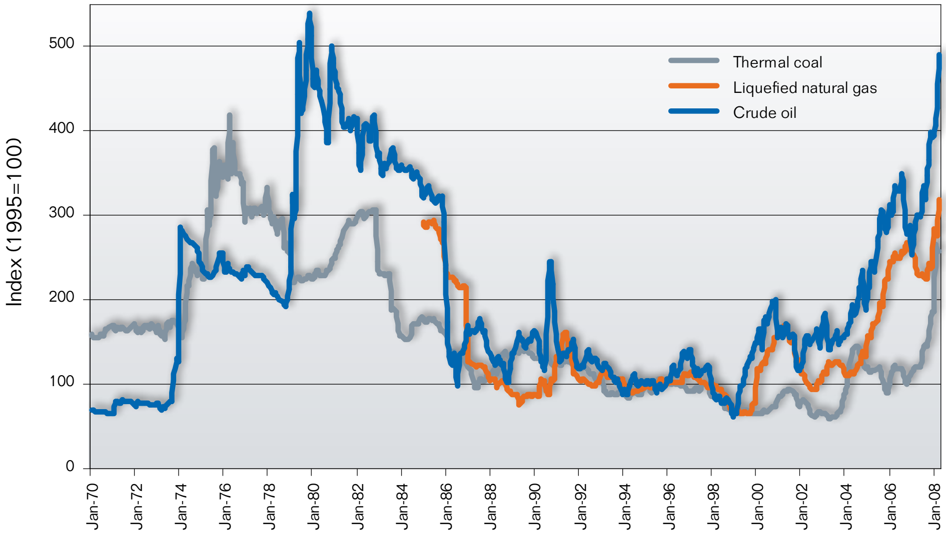
Third, in the absence of a price on carbon, China is unlikely to move away from its heavy reliance on coal, or make any movement towards sequestration of emissions from coal combustion—the only factors that would reduce the high carbon intensity of its energy system.

While the Review's emissions growth projections for China are substantially higher than those by the IEA, they are supported by other recent studies. Auffhammer and Carson (2008), using Chinese provincial 1985 to 2004 data, project 11–12 per cent annual growth in CO_2 emissions from fossil fuel combustion for the period 2000 to 2010.

4.6 The impact of high energy prices

Global energy prices have risen dramatically over the last few years. The oil price is now at a historic high, above the peak in the early 1980s in real terms (Figure 4.12). Natural gas prices are following suit. Most recently, coal prices have also risen sharply. The price rises are driven by increasing demand and limitations on expansion of production. In the case of oil and gas, there is a resource constraint, whereas for coal the supply constraint is purely in terms of mining and transport capacity.

Figure 4.12 Oil, gas and coal prices, 1970 to 2008



Note: Nominal prices converted to SDRs and deflated by the G7 CPI. Indexed to 1995.

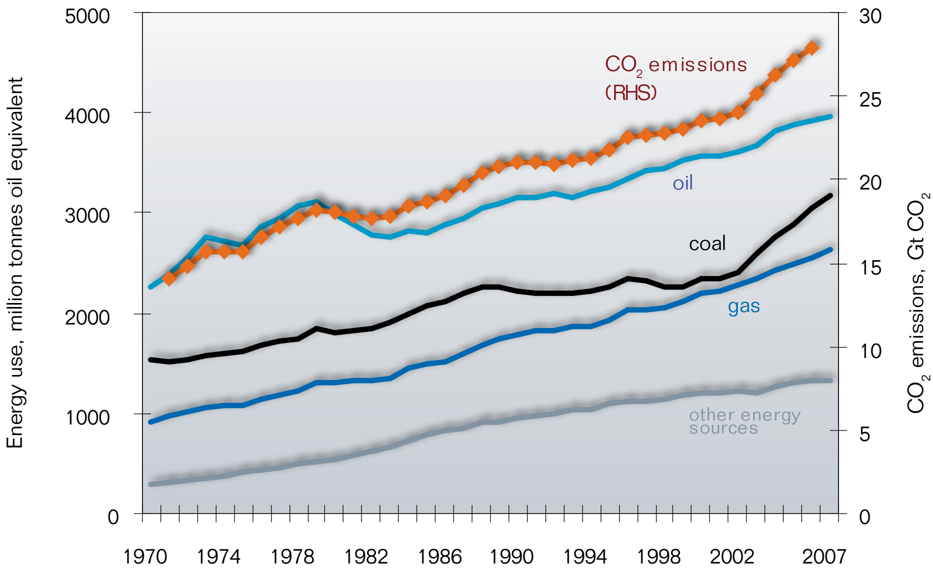
Source: Table compiled by the Centre for International Economics based on IMF IFS Statistics, OECD Main Economic Indicators, *Financial Times*, and CIE estimates.

Continued high fossil energy prices, if across the board, will cause reductions in energy consumption and a substitution towards non-fossil-fuel energy sources. These effects by themselves would dampen growth in carbon dioxide emissions. However, substitution away from oil and gas towards coal and synthetic liquid hydro-carbons (derived from coal, tar sands or natural gas) will increase growth in emissions. Making liquid fuels from coal can be cheaper than petroleum at oil prices reached in 2008, and for many countries is attractive because it represents a more secure supply. In the medium term, coal prices are expected to fall as supply capacity is increased in response to excess demand. This in turn will reduce incentives to shift into renewable energy sources and nuclear power, and to reduce energy use. The share of high-carbon fuels in the energy mix, and with it the carbon intensity of energy, will not necessarily fall as a result of high oil prices.

Recent data suggests that the increase in oil prices is not resulting in lower global emissions (Figure 4.13). Since 2005, growth in global oil use has slowed to around 1 per cent per year, but total energy use has grown by almost 3 per cent annually. Gas use has grown roughly in line with total energy use, while coal consumption has grown at 5 per cent, and other energy sources (principally renewables and nuclear) have grown at only around 2 per cent (BP 2008). Energy-related carbon dioxide emissions have grown slightly faster than total energy use. There is strong momentum in growth of liquid fuel production from Canadian tar sands. Looking ahead, investment in coal-fired electricity generation remains strong, particularly in Asia but also other parts of the world. China is investing in coal-to-liquid plants and is expected to start operating the largest such facility outside South Africa later in 2008 (Nakanishi & Shuping 2008). Coal liquefaction is also being considered in the United States.

It is also instructive to examine the oil price shocks in the 1970s and especially the 1980s (Figure 4.12). In both episodes coal prices rose later than oil prices, and fell back to or below earlier prices more quickly than oil prices. In both cases, the drop in global oil consumption was more pronounced than that for other fuels (Figure 4.13). Electricity generation from renewables and nuclear power in particular grew in the aftermath of the oil price shocks, but by less than energy from coal in absolute terms. The carbon intensity of global energy supply fell markedly in the first half of the 1980s, then stagnated. It fell in the 1990s primarily because of restructuring in the former Soviet Union, and in this century has been on the rise again.

Figure 4.13 Global energy use and CO_2 emissions, 1970 to 2007



Sources: Energy use from BP (2008); CO_2 emissions from IEA (2007b) and Carbon Dioxide Information and Analysis Centre (2008).

The upshot is that high petroleum prices do not necessarily mean lower greenhouse gas emissions, and may actually lead to higher emissions. On the one hand, high prices will accelerate improvements in energy efficiency and promote non-fossil-fuel energy. On the other, high oil prices will increase demand for coal. Coal prices will remain high only if investment in new capacity cannot keep up with growth in demand. If this eventuates, it will make renewable energy more attractive at the margin, but only in a context of rapid growth in demand for coal. Although it is impossible to know which influence will dominate, recent experience suggests that high petroleum prices are as consistent with an acceleration as with a deceleration of emissions growth.

4.7 Resource limits

By 2100, under reference case projections, global output will be 17 times its current level. Australia's real per capita income would be US$137 000, compared to US$36 000 in 2005.

By 2100, today's developing countries would achieve higher levels of per capita expenditure than today's rich countries. India, which only has 5 per cent of Australia's per capita income today, has in the reference case in 2100 a per capita income 2.3 times Australia's current level. Does the world have the resources to support consumption based on today's preferences at these levels of income?

Concerns about natural resource limits to growth were raised by the Club of Rome and others in the period of high resource prices associated with the latter stages of Japanese industrialisation and rapid growth in the early 1970s (Club of Rome 1972). This group included eminent Japanese economist Saburo Okita, who had been Director of Japan's Economic Planning Agency at the high tide of rapid Japanese post-war growth. In that capacity he had been author of the Ikeda administration's income-doubling plan of 1960. The Club of Rome was not from the fringe of modern development policy. Similar pessimistic expectations about the availability of natural resources to support rising human living standards had been raised by eminent economists from time to time in the first century of modern economic development (Malthus 1798; Jevons 1865).

These prophesies failed spectacularly, mainly through underestimation of human ingenuity and of the capacity for markets to support far-reaching structural change. The failures immunised the economics profession against acknowledgment of the possibility of resource supplies being a fundamentally important constraint on growth. But the possibility at least that natural resource constraints might force fundamental changes in consumption patterns has been seeping into the professional consciousness, as real commodity prices across a wide front have now been sustained at exceptionally high levels for longer than ever before. High commodity prices across the board, despite the US economy teetering on the edge of recession, are concentrating many minds. The prospects of much higher levels of income for high proportions of the world's people later in the 20th century focuses minds even more keenly. Will resource constraints prevent total global output from increasing by 17 times from the levels of the early 21st century that are already stretching supplies of many natural resource–based commodities?

There are many potential limits that could conceivably constrain output, from fuel to food to water. Pressures on global agricultural resources could be particularly problematic, especially if climate change diminishes productivity, and could seriously undermine political stability in some developing countries.

Could limits on minerals and fossil fuels could also constrain growth? Table 4.3 looks at the number of years that reserves and the known reserve base can sustain production at current and at assumed 2050 levels for several important mineral resources and fossil fuels. By 2050, global output is projected in the reference case to be almost five times its current level. For this illustrative exercise, it is assumed that the production of metals and minerals is at three times current levels in 2050. Predicted production of oil and coal in 2050 is based on US Energy Information Administration projections. These rates of production are compared to estimates of reserves and the reserve base. Reserves are that portion of the reserve base which can be economically extracted. For fossil fuels, the reserve base is the total global 'ultimately recoverable' resource base, including an estimate of undiscovered resources. For metals and minerals, the reserve base is that portion of the global resource which has been identified, whether or not it is economic. (For the precise definitions used, see the notes to Table 4.3.)

Current reserves for several metals will not last long, especially at 2050 levels of production. High prices will push more of the reserve base into reserves. The current reserve base will support current production levels for all the minerals reported for at least 30 years, but will support production at 2050 levels for 20 years or less. This suggests that shortages of minerals and metals, if they arise, will not do so until towards or after the middle of the century. Whether they do arise then depends on the gap between the reserve base and the total resource base. This can be large. For example, the US Geological Survey estimates the global reserve base for copper to be 940 million tons, but world resources (including deep-sea nodules) to be 3.7 billion tons. Note that any tendency towards exhaustion of reserves would raise prices, which would convert resources into reserves. It would also stimulate exploration, leading to expansion of reserves and the reserve base.

In relation to fossil fuels, Table 4.3 suggests that conventional oil reserves may well come under pressure over the next several decades, but that there are ample supplies of coal. Some argue that conventional oil reserves are exaggerated (Campbell & Laherrère 1998). But unconventional sources, including oil sands in Canada, extra-heavy oil in Venezuela and shale oil in the United States, Australia and several other countries, which are not included in the table below, are thought to amount to at least 1 trillion barrels, or almost 50 per cent of ultimately recoverable conventional oil resources (IEA 2006).

Table 4.3 Time to exhaustion of current estimates of reserves and reserve base for various metals and minerals, and fossil fuels

	Number of years after which exhaustion will be reached of			
	Reserves		Reserve base	
	At the production rates of			
	2007	2050	2007	2050
Metals and minerals				
Nickel	40	13	90	30
Zinc	17	6	46	15
Copper	31	10	60	20
Bauxite	132	44	168	56
Platinum group metals	154	51	173	58
Lead	22	7	48	16
Tin	20	7	37	12
Tungsten	32	11	70	23
Iron ore	79	26	179	60
Fossil fuels				
Coal	139	66		
Gas	60	32	110	58
Oil	40	23	70	40

Note: For metals and minerals, current production, reserves and reserve base are the latest estimates from the US Geological Survey (http://minerals.usgs.gov/minerals/pubs/commodity). Reserves are defined by the US Geological Survey to be 'that part of the reserve base which could be economically extracted or produced at the time of determination'. The reserve base is 'resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence'. Production rates for 2050 are simply assumed to be three times current levels.

Fossil fuel figures are the latest estimates from the US Energy Information Administration and the International Energy Agency. Coal includes both black and brown coal. Fossil fuel reserves are recoverable reserves: those quantities which geological and engineering information indicates with reasonable certainty can be extracted in the future under existing economic and operating conditions.' (US EIA 2007: Table 8, Chapter 5). The reserve base for fossil fuels is the global resource base: all 'ultimately recoverable resources,' including an estimate of 'undiscovered conventional resources that are expected to be economically recoverable.' (IEA 2006: 91). The reserve base for coal is not provided.

Source: Table compiled by the Centre for International Economics.

This analysis suggests that mineral and fossil-fuel shortages will not be a constraint on growth in the first half of this century. By that time, if the world were still on a business-as-usual path, the environmental damage would have already been done, as dangerous levels of temperature increase would already have been locked in, if not already realised (Chapter 5). Shortages of minerals and fossil fuels will not solve the world's emissions problems.

The recent and projected continued rapid growth in emissions has major implications for the global approach to climate change mitigation. As explored in Chapter 11, earlier and more ambitious action than previously thought will be required by all major emitters if the world is to limit climate change risks to acceptable levels.

Notes

1 This section draws on Garnaut et al. (forthcoming). See also Raupach et al. (2007).

2 The US Energy Information Administration (1998) reports that on average oil emits 40 per cent more carbon dioxide than gas, and coal 27 per cent more than oil per unit of energy input.

3 In 2006, China's coal consumption grew by 11.9 per cent and in 2007, according to preliminary estimates, by 7.8 per cent (see National Bureau of Statistics of China 2007a, 2007b).

4 See annual US Energy Information Administration *International Energy Outlooks*. See IMF (2008) and Sheehan et al. (forthcoming) for two recent projections with more rapid rates of emissions growth.

5 The modelling results, including the reference case, will be described in detail in the Review's supplementary draft report. Other models are also used, including the MMRF-GREEN model for domestic analysis for Australia and the G-Cubed model for additional international analysis.

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5 OBSERVATIONS AND PROJECTIONS OF GLOBAL CLIMATE CHANGE

Key points

As a result of past actions, the world is already committed to a level of warming that could lead to high-consequence climate change outcomes.

Extreme climate responses are not always considered in the assessment of climate change impacts due to the high level of uncertainty and a lack of understanding of how they work. However, the potentially catastrophic consequences of such events means it is vitally important that the current knowledge of these outcomes is incorporated in the decision-making process.

Continued high emissions growth with no mitigation action carries high risks. These risks would be reduced by ad hoc mitigation, but remain high for some elements. Ambitious global mitigation would reduce the risks further, but some systems may still suffer critical damage.

There are advantages in aiming for an ambitious global mitigation target in order to avoid some of the high-consequence impacts of climate change.

This chapter looks at changes to the global climate that have been observed to date, and describes possible future changes under a range of assumptions about mitigation. It looks at both the 'best-estimate', projections, the possibility of extreme climate responses, and the likelihood of crossing thresholds that might lead to abrupt or irreversible climate change.

Much of the research literature on observed and projected climate change has been summarised and evaluated in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007). Here the Review summarises the key observations and illustrates some of the main possible changes. Where relevant, the discussion makes use of evidence from research undertaken since the Fourth Assessment Report was compiled and considers alternative views.

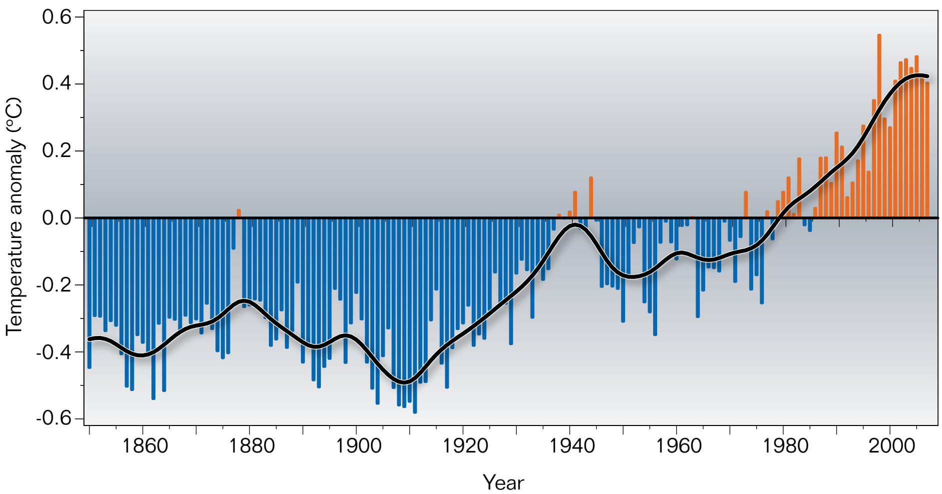
5.1 How has the climate changed?

The IPCC states that 'warming of the climate system is unequivocal', and that this is evident in the measured increase in global average air and surface temperatures, and also in the widespread melting of snow and ice and the rising global sea level (IPCC 2007: 5).

5.1.1 Changes in temperatures

Global average temperatures have risen considerably since measurements began in the mid-1800s, as shown in Figure 5.1. Since early industrial times (1850–1899) the total global surface temperature increase has been estimated at 0.76°C ± 0.19°C.

Figure 5.1 Average global average air temperature anomalies, 1850 to 2005



Source: Brohan et al. (2006, updated 2008).

Note: The data shows temperature difference from the 1961–1990 mean. The black line shows the annual values after smoothing with a 21-point binomial filter.

Since 1979, the rate of warming has been about twice as fast over the land as over the ocean. During the last century, the Arctic has warmed at almost twice the global average rate.

The warming of the ocean since 1955 has accounted for more than 80 per cent of the increased energy in the Earth's climate system (IPCC 2007: 47). Warming in the top 700 m is widespread, with deeper warming occurring in the Atlantic Ocean.

The rate of warming in the lower atmosphere (the troposphere) has exceeded surface warming since 1958, while substantial cooling has occurred in the lower stratosphere. The pattern of tropospheric warming and stratospheric cooling is most likely due to changes in stratospheric ozone concentrations and greenhouse gas concentrations in the troposphere (IPCC 2007: 10). Both the troposphere and the stratosphere have reacted strongly to events that have suddenly increased the volumes of aerosols in the atmosphere (IPCC 2007: 270).

Box 5.1 Is there a warming trend in global temperature data?

Observations show that global temperatures have increased over the last 150 years (Figure 5.1). The data also suggests that the warming was relatively steep over the last 30–50 years. A comparison of three datasets shows that they differ slightly on the highest recorded temperatures—data from the Hadley Centre in the United Kingdom shows 1998 as the highest year, while data from the National Aeronautics and Space Administration and the National Climatic Data Centre in the United States show 2005 as the highest year.* All three datasets show that seven of the hottest 10 years on record have been in the last nine years between 1999 and 2007. There has been considerable debate in recent months on the interpretation of the global temperatures over the past decade. Questions have been raised about whether the warming trend ended in about 1998.

To throw light on this question, the Review sought assistance from two eminent econometricians from the Australian National University to investigate the question. Trevor Breusch and Farshid Vahid have specific expertise in the statistical analysis of time series—a speciality that is well developed in econometrics. They were asked two questions:

- Is there a warming trend in global temperature data in the past century?
- Is there any indication that there is a break in any trend present in the late 1990s, or at any other point?

They concluded that:

> It is difficult to be certain about trends when there is so much variation in the data and very high correlation from year to year. We investigate the question using statistical time series methods. Our analysis shows that the upward movement over the last 130–160 years is persistent and not explained by the high correlation, so it is best described as a trend. The warming trend becomes steeper after the mid-1970s, but there is no significant evidence for a break in trend in the late 1990s. Viewed from the perspective of 30 or 50 years ago, the temperatures recorded in most of the last decade lie above the confidence band produced by any model that does not allow for a warming trend (Breusch & Vahid 2008).

* Three datasets were used in this analysis—1) Hadley Centre Hadcrut3 (Brohan et al. 2006), <www.cru.uea.ac.uk/cru/data/temperature/hadcrut3gl.txt> accessed 7 May 2008; 2) the Goddard Institute for Space Studies, NASA, <http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts.txt>, accessed 17 May 2008; 3) the National Climate and Data Centre, US Department of Commerce, <ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/annual.land_and_ocean.90S.90N.df_1901-2000mean.dat>, accessed 16 May 2008.

5.1.2 Observed oceans and sea level

The ocean has an ability to store a thousand times more heat than the atmosphere. The heat absorbed by the upper layers of the ocean plays a crucial role in short-term climatic variations such as El Niño (IPCC 2007: 46).

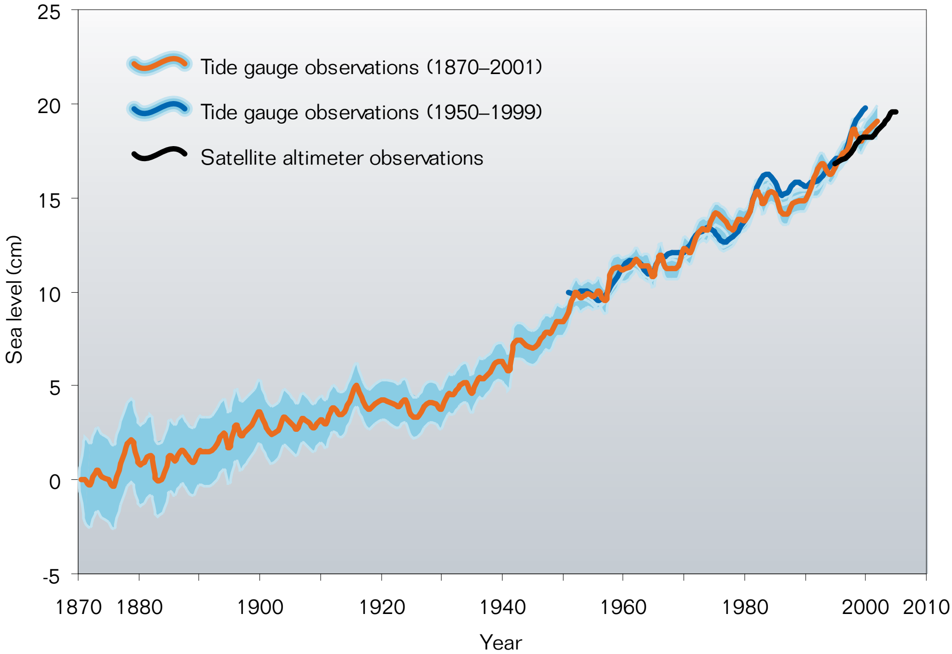
As oceans heat up, they expand, causing the volume of the ocean to increase and global mean sea level to rise. Sea level also rises when mass is added through the melting of grounded ice sheets and glaciers. Measurements show that widespread decreases in non-polar glaciers and ice caps have contributed to sea-level rise. The Greenland and Antarctic ice sheets are also thought to have contributed, but the proportions resulting from ice melt and the instability of the large polar ice sheets have yet to be fully understood (IPCC 2007: 49).

The total sea-level rise for the 20th century, including contributions from thermal expansion and land ice-melt, was 170 mm (Figure 5.2). Measurements show that the average rate of sea-level rise in the period 1961–2003 was almost 1.8 ± 0.5 mm per year. For 1993–2003 it was 3.1 ± 0.7 mm per year (IPCC 2007: 387).

Sea level varies spatially due to ocean circulation, local temperature differences, land movements and the salt content of the water. Regional changes in ocean salinity levels have occurred due to changes in precipitation that affect the inflow of freshwater. Changes in salinity have the potential to modify ocean currents and atmospheric circulation at the global scale. On an inter-annual to decadal basis regional sea level fluctuates due to influences such as the El Niño – Southern Oscillation. Regional changes can lead to rates of sea-level change that greatly exceed the small annual increases in global average sea level (Cazenave & Nerem 2004).

Ocean acidity has increased globally as a result of uptake of carbon dioxide, with the largest increase in the higher latitudes where the water is cooler (IPCC 2007: 405). The oceans are now more acidic than at any time in the last 420 000 years (Hoegh-Guldberg et al. 2007).

Figure 5.2 Global average sea-level rise from1870 to 2005



Note: Observed global average sea-level rise inferred from tide-gauge data (with 95% confidence limits shown as blue shading) and satellite altimeter data.

Source: Church & White (2006); Holgate & Woodworth (2004); Leuliette at al. (2004).

5.1.3 Changes in water and ice

The climate system varies considerably on a local and regional basis, so that consideration of global averages can mask large regional variations (see Figure 5.3).

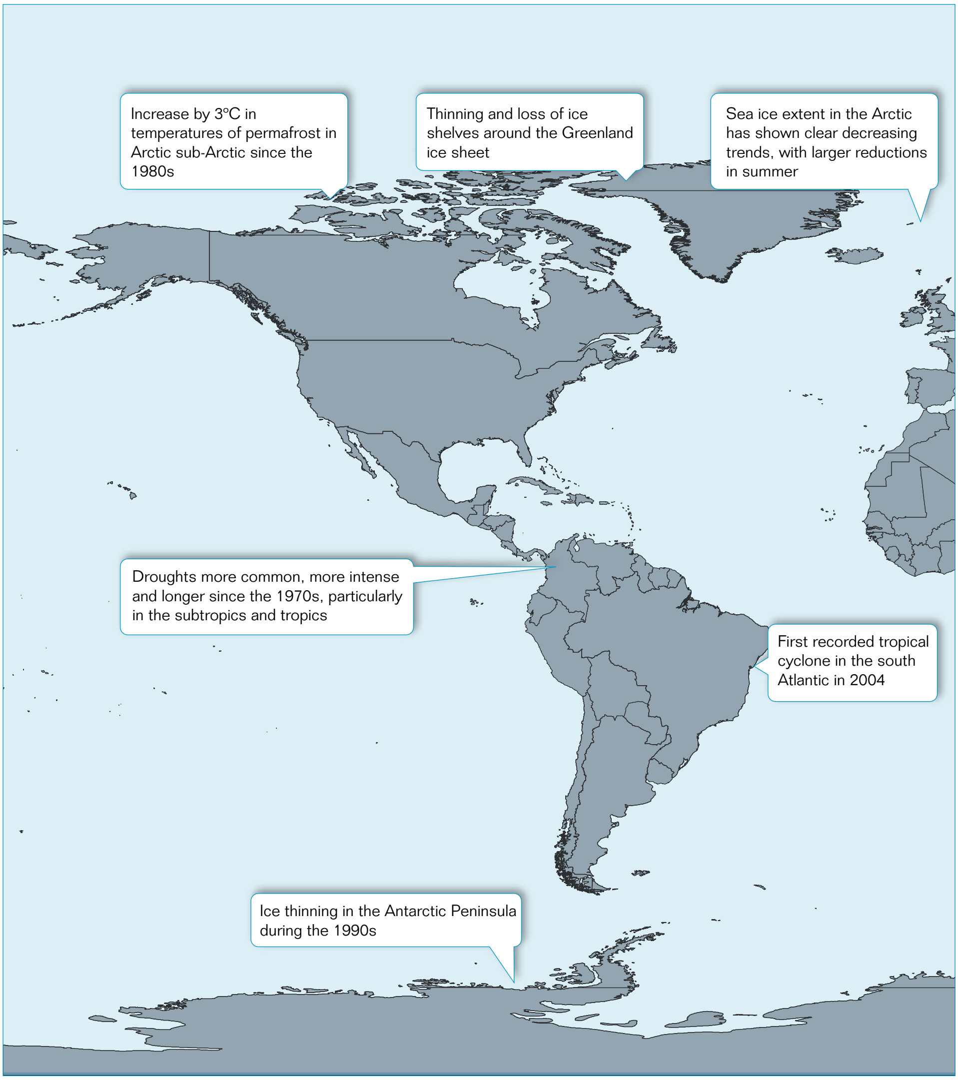
Precipitation

Increases in temperature affect the amount of water vapour that the air can hold and lead to increased evaporation of water from the earth's surface. Together these effects alter the water cycle and influence the amount, frequency, intensity, duration and type of precipitation.

Over oceans and areas where water is abundant, the added heat acts to moisten the air further rather than warm it, which can reduce the increase in air temperature and lead to more precipitation.

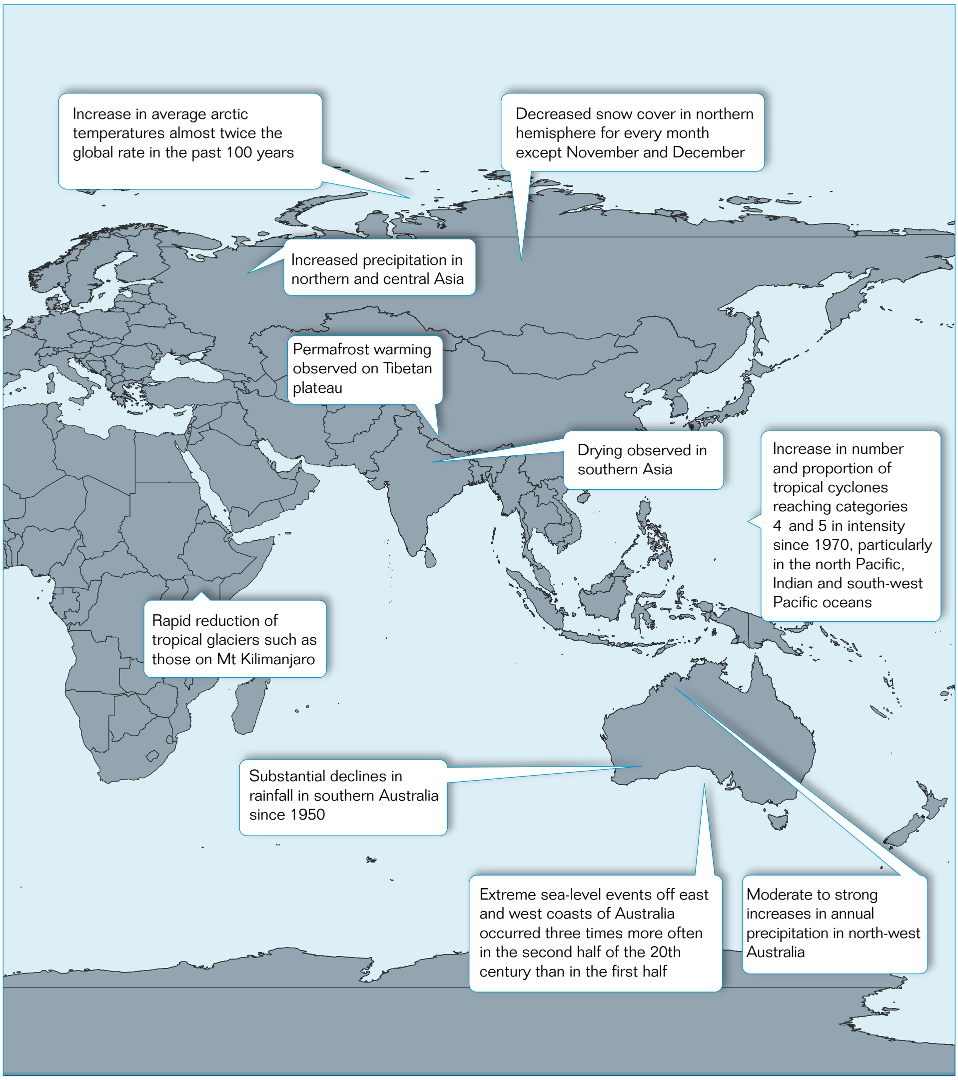
Where the surface is too dry to exchange much water with the atmosphere, increased evaporation can accelerate surface drying without leading to more rainfall. Cloudiness will also fall in the warmer and drier atmosphere, leading to further temperature increases from the higher amount of sunlight reaching the surface (IPCC 2007: 505). These effects can cause an increase in the occurrence and intensity of droughts (IPCC 2007: 262). Local and regional changes in precipitation are highly dependent on climate phenomena such as

Figure 5.3 Selected regional climate change observations



Source: IPCC (2007); Church et al. (2008); CSIRO & BoM (2007).

Figure 5.3 Selected regional climate change observations *(continued)*



the El Niño system, changes in atmospheric circulation and other large-scale patterns of variability (IPCC 2007: 262).

There is high variability in precipitation over time and space, and some pronounced long-term trends in regional precipitation have been observed. Between 1900 and 2005, annual precipitation increased in central and eastern North America, northern Europe, northern and central Asia and south-eastern South America (IPCC 2007: 258). Decreases in annual precipitation have been observed in parts of Africa, southern Asia and southern Australia (IPCC 2007: 256).

In addition to changes in mean precipitation, studies of certain regions show an increase in heavy rainfall events over the last 50 years, and some increases in flooding, even in areas that have experienced an overall decrease in precipitation (IPCC 2007: 316).

Ice caps, ice sheets, glaciers and frozen ground

About 75 per cent of the fresh water on Earth is stored in ice caps, ice sheets, glaciers and frozen ground, collectively known as the cryosphere. At a regional scale, variations in snowfall, snowmelt and glaciers play a crucial role in the availability of fresh water

Ice and snow have a significant influence on local air temperature because they reflect about 90 per cent of the sunlight that reaches them, while oceans and forested lands reflect about 10 per cent (IPCC 2007: 43).

Frozen ground is the single largest component of the cryosphere by area, and is present on a seasonal and permanent basis at both high altitudes and high latitudes (around the poles). Thawing of permanently frozen ground can lead to changes in the stability of the soil and in water supply, with subsequent impacts on ecosystems and infrastructure (IPCC 2007: 369).

Extensive changes to ice and frozen ground have been observed in the last 50 years, some at a rate that is dramatic and unexpected. Arctic sea ice coverage has shown a consistent decline since 1978. The average sea ice extent for the month of September 2007 was 23 per cent lower than the previous record set in 2005 (NSIDC 2007).

There has been a reduction in the mass of glaciers and ice caps everywhere, except in parts of Greenland and Antarctica (IPCC 2007: 44).

5.1.4 Changes to extremes

Changes in the intensity and frequency of certain severe weather events have been observed. Observed changes in temperature extremes have been consistent with the general warming trend—cold days, cold nights and frost have been occurring less frequently in the last 50 years, and hot days, hot nights and heat waves have been occurring more frequently (IPCC 2007: 308).

The area affected by droughts has increased in certain regions, largely due to the influence of sea surface temperatures and changes in atmospheric circulation and precipitation (IPCC 2007: 317). Full assessments of changes in droughts are limited by difficulties in the measurement of rainfall and poor data on soil moisture and stream flow (IPCC 2007: 82).

Tropical storm and hurricane frequency, lifetime and intensity vary from year to year and are influenced by the El Niño – Southern Oscillation, which can mask trends associated with general warming. At the global scale, there is a trend towards storms of longer duration and greater intensity, factors that are associated with tropical sea surface temperatures (IPCC 2007: 308).

5.1.5 Human attribution of observed changes

The climate system varies naturally due to external factors such as the sun's output and volcanic eruptions, and internal dynamics such as the El Niño – Southern Oscillation (Chapter 3). Over the longer term, in geological time, there are changes in climate associated with changes in the earth's orbit and the tilt of its axis (Ruddiman 2008).To establish whether human activities are causing the observed changes in climate, it must be established that the changes cannot be explained by these natural factors.

When only natural factors are included in the modelling of 20th century temperature change, the resulting models cannot account for the observed changes in temperature. However, when human influences are included, the models produce results that are similar to the observed temperature changes (IPCC 2007: 703). Using this technique, the influence of human activities on regional temperatures can be established for every continent except Antarctica, for which limited observed data is available.

Modelling has been used to determine human attribution of a range of observed changes in the climate, including the low rainfall in the south-west of Western Australia since the 1970s (CSIRO & BoM 2007), and the reduction in extent of Arctic sea ice (CASPI 2007).

Apart from modelling exercises, there are other gauges of observed change that suggest a human influence on the climate. These include the measurements of higher rates of warming over land than over sea, which would not be associated with El Niño, and the differential warming in the troposphere and stratosphere, which would be unlikely if caused by increased solar radiation, but can be explained by increases in greenhouse gases in the troposphere and the depletion of the ozone layer in the stratosphere (CASPI 2007).

5.2 Understanding climate change projections

How the climate will change in the future depends on a range of natural changes—'forcings'—as well as human activity, and the way the climate responds to these changes. These forcings are difficult to predict, can occur randomly and may interact in a way that amplifies or reduces the effects of another element. The inherent variability and complexity of the climate system is complicated further by the possibility of a non-linear and unpredictable response to levels of greenhouse gases that are well outside the range experienced in recent history.

The most important direct human forcings are greenhouse gas emissions, a process that humans can control through policy and management. Identifying specific pathways of human-induced greenhouse gas emissions—the dominant mechanism for human influence on the climate—simplifies the projection of climate change. But, of course, future changes in climate will be influenced by the natural factors as well.

5.2.1 Responding to climate change now

The human-induced warming, and the associated changes in climate occurring over the next few decades, will largely be the result of our past actions and is fairly insensitive to our current actions.

An exception is if large changes in emissions of sulphate aerosols occur, where warming (decrease) and cooling (increase) can occur within months of a change in emissions.

Models show that the warming out to 2030 is little influenced by greenhouse gas emissions growth in the future (IPCC 2007a: 68), as a result of lags in the climate system. By 2050, however, different trends in emissions have a clear influence on the climate outcomes, and by 2100 the potential differences are substantial.

To estimate the magnitude of climate change in the future it is necessary to make assumptions about the future level of global emissions of greenhouse and other relevant gases.

The Review takes a different approach to the IPCC in terms of scenario development. While the SRES scenarios show a range of possible outcomes for a world with no mitigation, the Review looks at four futures based on different levels of mitigation.

The four emissions cases

Figure 5.4 shows the emissions and concentration pathways for the four emissions cases considered in this chapter:

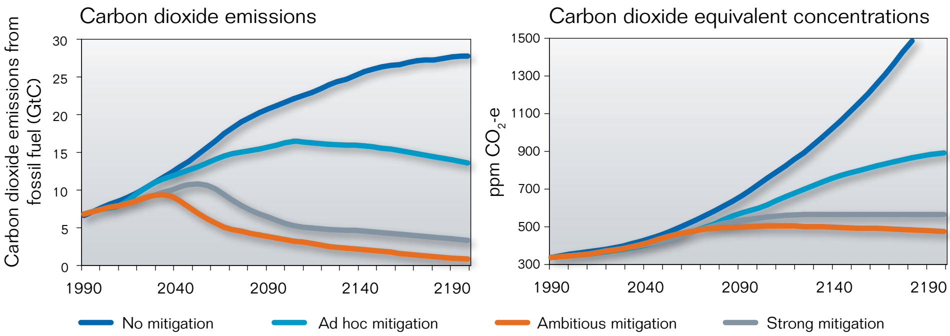
No-mitigation case—A global emissions case with no action to mitigate climate change has been developed as part of this Review. Details of the Garnaut–Treasury reference case are provided in Chapter 4. This emissions case recognises recent high trends in emissions of carbon dioxide and other greenhouse gases; these continue to increase throughout the 21st century.

Ad hoc mitigation case—As concerns rise about climate change, increased mitigation action is likely to occur, but might not be at the scale or speed required to achieve stabilisation, even at a moderate target. The Review therefore models an 'intermediate' emissions case. Current commitments suggest that high emissions growth will continue early in the century, but as developing countries accept mitigation targets, emissions will peak and then decline very gradually.

Strong global mitigation case—In the context of current international discussions, a target is considered that restricts greenhouse gas concentrations to 550 ppm CO_2-e. Emissions peak before 2030 and decline steadily through the remainder of the century.

Ambitious mitigation case—An ambitious target involving emissions reductions that lead to a stabilisation concentration of 450 ppm CO_2-e is considered, with an overshoot to 500 ppm CO_2-e. Carbon dioxide emissions peak before 2020 and decline steadily throughout the century.

Figure 5.4 Carbon dioxide emissions and concentrations of greenhouse gases in the atmosphere for the four emissions cases, 1990–2100



5.2.2 Confidence in the projection of climate change

As discussed in Chapter 3, climate models provide a wide range of estimates of temperature response and changes in climate variables such as rainfall. It is important to understand the uncertainty in the accuracy of model outputs, and how these are reflected in climate change projections.

Confidence in climate models

The ability of climate models to accurately simulate responses in the climate system is dependent on the level of understanding of the processes that govern the climate system, the availability of observed data for various scales of climate response, and the computing power of the model—all of which have improved considerably in recent years (CSIRO & BoM 2007).

Confidence in models comes from their ability to represent patterns in the current climate and past climates, and is generally higher at global and continental scales. For some elements of the climate system, such as surface temperature, there is broad agreement on the pattern of future climate changes. Other elements, such as rainfall, are related to more complex aspects of the climate system, including moisture transport, and are not represented with the same confidence in models.

Using a range of models, the likelihood of a particular outcome can be assessed. However, outcomes at the high or low end of a range of model results may also be plausible, and cannot be excluded from consideration.

There is significant uncertainty associated with the way the atmosphere will respond to a given change in carbon dioxide concentration— the equilibrium climate sensitivity (Chapter 3).

The extent to which the climate warms in response to changes in greenhouse gas concentrations is centrally important to the assessment of projected climate change. Many aspects of projected climate change relate closely to global mean temperature (IPCC 2007: 630). For example, the extent of melting of glaciers and permafrost is ultimately related to the magnitude of temperature increase. However, changes in other dimensions of climate, such as regional variation in rainfall, can not be easily correlated with temperature change; depending on location, the magnitude, spatial pattern and seasonality of rainfall can all change in ways that can not be directly inferred from temperature change. As a general rule, though, the severity of many aspects of climate change are correlated to the magnitude of projected warming.

Confidence in other elements of climate change

To assess the risk of climate change, a good understanding of the different elements that are included or excluded in the model outcomes is necessary, as is the uncertainty associated with these elements based on current knowledge. Elements often are communicated differently to recognise disparities in understanding or certainty, but to gain a comprehensive understanding of potential climate change for a given temperature outcome all these elements should be considered together:

Well-constrained climate outcomes—Some elements of the climate system have a well-established response to increased temperatures or other parameters, and models have a high level of reliability in reflecting the possible outcomes. Examples include the pattern of regional temperature response, sea-level rise from thermal expansion, melting of permafrost and damage to reefs.

Partially constrained climate outcomes—Some elements of the climate system have a relatively well-constrained pattern or direction of change in response to temperature rise, but are known to be poorly represented in models. Some uncertainty is created by disagreement between models. The extent and direction of rainfall change is an example of the latter, although this is becoming well constrained for some parts of Australia.

Poorly constrained climate outcomes—some elements of the climate system have an unknown response to changes in global temperature. An example is the response of the El Niño – Southern Oscillation, where scientists are unsure whether the fluctuations will increase, a permanent El Niño state may form or perhaps decline in influence.

5.2.3 Limitations in the Review's assessment

The uncertainty in projected climate change and the range of model outputs for a given emissions pathway means that there is value in investigating the climate outcomes from a large number of models. The SRES emissions datasets have been publicly available since 1998, and their use as a consistent basis for climate change projections has been extensive. The availability of multiple models allows for a better assessment of the level and sources of uncertainty in climate change projections. This provides more robust results and reduces the influence of individual model bias (IPCC 2007: 754).

An equivalent pool of data is not, however, available for the no-mitigation and mitigation cases being investigated by the Review.

The summary of projected climate change for the four emissions cases in this chapter is based on a range of data from the outcomes of the climate models used in the Review's modelling exercise and interpretation of the 2007 IPCC summary of projected climate change (IPCC 2007), based on the SRES scenarios.

The Review's analysis of the strong and ambitious mitigation cases is still under way. The outcomes will be presented in the supplementary draft and final reports. The emissions profile for the SRES scenario A1B is used a proxy for the ad hoc case. The strong and ambitious global mitigation cases analysed in this draft report were developed using the Simple Model for Climate Policy Assessment (Meinshausen et al. 2006). The global mitigation cases will be updated following more detailed economic modelling for the final report.

The no mitigation case used in this report has been updated to reflect high emissions growth and reductions in aerosols emissions in recent years. The ad hoc, strong and ambitious mitigation cases have not been updated.

5.3 Projected climate change for the no-mitigation and mitigation cases

Quantitative climate change projections for well-constrained elements of the climate system are provided for each emissions case. 'Best-estimate' outcomes are presented along with estimates of the magnitude and possible range of lower-probability outcomes. Severe weather events and changes in variability are considered at a general level.

5.3.1 Changes in temperature

Many of the changes to the climate system are related to changes in global average temperature, and they tend to increase in magnitude and/or intensity as temperature levels rise. As a result, temperature change over time and space is a key indicator of the extent of climate change. This section explores a range of aspects of temperature change under the four emissions cases.

Box 5.2 Temperature reference points

Various reports and studies on mitigation may use different points of comparison for temperature increases. Temperature rise may be framed in terms of the increase from pre-industrial times, or from a given year.

Unless otherwise specified, temperature changes discussed in the Review are expressed as the difference from the period 1980–99, usually expressed as '1990 levels' as per the IPCC Fourth Assessment Report.

Following the same convention, temperatures over the period 1850 to 1899 are often averaged to represent 'pre-industrial levels'. To compare temperature increases from 1990 levels to changes relative to pre-industrial levels, 0.5°C should be added.

Projected changes to the end of the 21st century are generally calculated from the average of 2090–99 levels, but are often expressed as '2100'.

Commited warming

'Committed warming' refers to the future change in global mean temperature from past emissions, even after concentrations are held constant.

The IPCC estimated the warming resulting from atmospheric concentrations of greenhouse gases being kept constant at 2000 levels would result in an increase of 0.6°C by 2100. The increase for each of the next two decades would be 0.1°C from past emissions alone (IPCC 2007: 79).

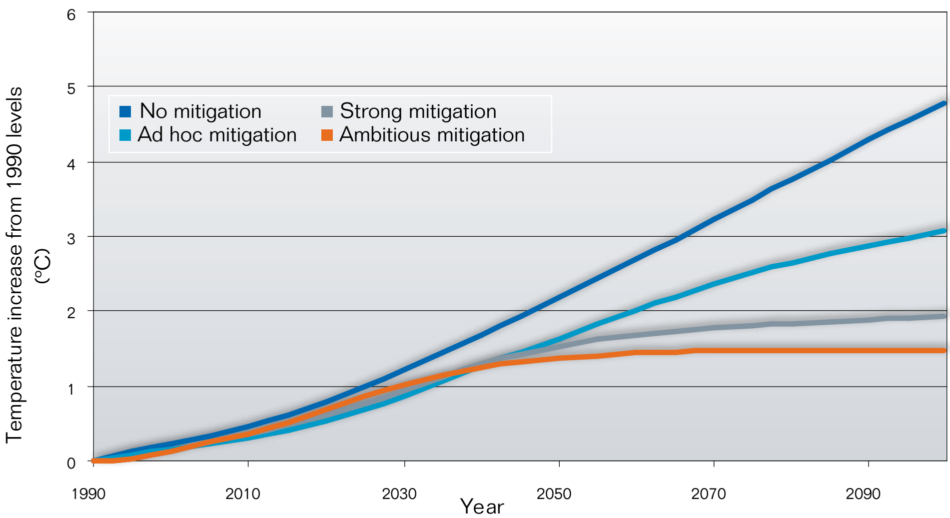
As a result of committed warming, the temperature outcomes for next few decades are minimally affected by the different emissions cases. The average warming for the period 2011 to 2030 for the middle to lower SRES scenarios is in the range 0.64–0.69°C above 1990 levels, with high agreement between models (IPCC 2007: 749).

Global mean temperatures post-2030

Projections of global mean surface air temperature for the 21st century show the increases continuing for all emissions cases. Figure 5.5 shows the projected temperature increases for the four emissions cases for the best-estimate climate sensitivity of 3°C. Temperatures are projected to be slightly higher between 2020 and 2030 under the ambitious global mitigation case than the ad hoc and strong cases as rapid declines in aerosol emissions are expected under strong mitigation which will decrease the cooling influence.

By the end of the century the global average temperature increase under the no-mitigation case is 4.5°C, and still increasing a high rate. The temperature increase under the ad hoc mitigation case is lower, at about 2.8°C and the rate is slowing. The strong and ambitious global mitigation cases reach 1.9°C and 1.5°C respectively, with the rate of increase having fallen to minimal levels in 2100 in both cases.

Figure 5.5 Global average temperature outcomes for four emissions cases with a 'best-estimate' climate sensitivity (3°C)



Note: Temperature increases from 1990 levels are from the MAGICC climate model (Wigley 2003).

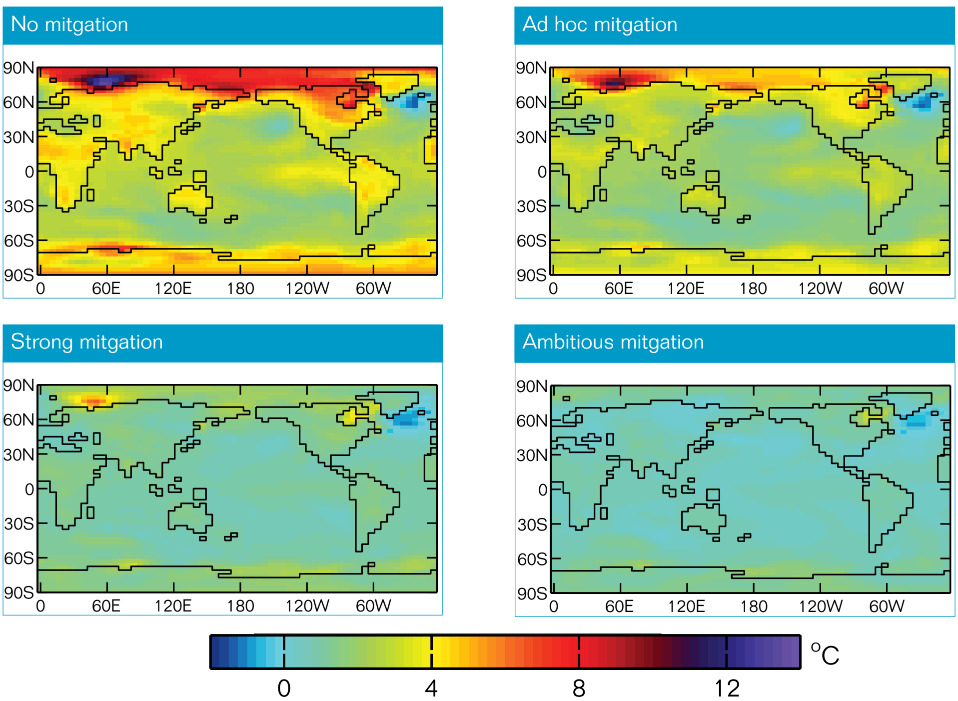
Spatial variation in temperature

Figure 5.6 shows the spatial variation in the simulated temperature changes at the end of the 21st century under the four emissions cases. The greatest warming occurs at the poles and over large land masses, with lesser warming over the oceans. A small region of cooling lies over the north Atlantic ocean.

The strong warming in the polar regions arises from feedbacks caused by changes in the reflection of solar radiation from the loss of ice and snow. Melting ice and snow expose the darker ocean or land surface beneath, which then absorb a greater fraction of incoming solar radiation. In turn, this leads to further warming. By the end of the century in the no-mitigation case, temperatures in parts of the Arctic are more than 10°C above 1990 levels. In the strong and ambitious global mitigation cases, the feedback effects of melting ice are restricted and the temperature response in the Arctic is more subdued.

The north Atlantic region is significantly influenced by oceanic circulation. The Gulf Stream transports warm surface waters northward, warming this region significantly relative to other regions at the same latitude. Climate change is projected to lead to a weakening of the Gulf Stream, resulting in cooler temperatures in the north Atlantic under all emissions cases.

Figure 5.6 Spatial variation in temperature change in 2100 for the four emissions cases



Note: Temperature outcomes are from the CSIRO Mk3L model (Phipps 2006), which demonstrates a lower global average temperature response than the MAGICC model used to calculate the global average temperatures in Figure 5.5. The differences in the response of the two models are discussed in Chapter 9.

Extremes in global mean temperature response

The discussion of climate sensitivity in Chapter 3 outlined the IPCC assessment of a best-estimate climate sensitivity of 3°C, with a likely outcome between 2°C and 4.5°C (IPCC 2007: 12). The lower end of the range of possible outcomes is much better constrained than the upper end—most studies investigating climate sensitivity find a lower 5 per cent limit of between 1°C and 2.2°C, while the upper 95 per cent limit for the same studies ranges from 5°C to greater than 10°C (IPCC 2007: 721).

For the no-mitigation case, the chance of avoiding the 2°C pre-industrial warming threshold, which the European Union has announced as a mitigation goal (1.5 degrees above 1990 levels), is virtually zero. The risk of temperatures above around 6°C ranges from 15 to 40 per cent, according to different distributions of sensitivity.

For the ad hoc and strong emissions cases the chance of avoiding the 2°C threshold is less than 4 per cent and 26 per cent respectively. Only the ambitious global mitigation case has the likelihood of avoiding the 2°C threshold greater than 50 per cent for even one of the selected climate responses.

If a higher temperature response were to occur, the high temperatures evident in the polar regions in the no-mitigation case would be even more extreme. In the mitigation cases, a higher temperature response would lead to positive feedbacks and amplified temperatures in the polar regions.

Temperature outcomes for other mitigation pathways

The strong and ambitious global mitigation cases discussed in this chapter represent a future where the world responds in a coordinated way to a specific target for stabilisation of greenhouse gases in the atmosphere. There are many possibilities for the choice of a global mitigation target, as well as for the pathway to get there (see Chapter 3).

Under the 'likely' range of climate sensitivity, concentrations would need to be stabilised at less than 450 ppm CO_2-e to have at least a 50 per cent chance of keeping long-term warming at below 2°C above pre-industrial levels.

Due to the slow response of the ocean to changes in the energy balance of the climate system, it may be hundreds or even thousands of years before the equilibrium temperature is reached. When considering the impacts of climate change in the future in a policy context, it is relevant as well to consider the transient, or short-term, temperature response. Different models can show a range of short-term temperature outcomes for the same emissions pathway.

The pathway to a given stabilisation target will also be a key factor in the short-term temperature response. As discussed in Chapter 3, to achieve some of the lower concentration targets, an overshoot in concentration may be required, leading to higher temperature responses for a period. This short-term temperature response could lead to greater impacts increasing the risk of reaching key temperature thresholds.

5.3.2 Precipitation

Climate model simulations show that, as temperatures increase, there will be increased precipitation in the tropics and at high latitudes, and decreased precipitation in the subtropics (IPCC 2007: 750). Figure 5.7 shows the percentage change in precipitation in 2100 for the four emissions cases from the average of 1980—99 levels, estimated using a technique based on the outputs of 23 global climate models (Watterson 2008; CSIRO & BoM 2007). The values overlaid by 'stippling' show areas where there is less than 67 per cent agreement on whether the change will be an increase or a decrease.

For the four emissions cases, the pattern of rainfall change in response to temperature generally stays the same, but the change intensifies as temperature increases.

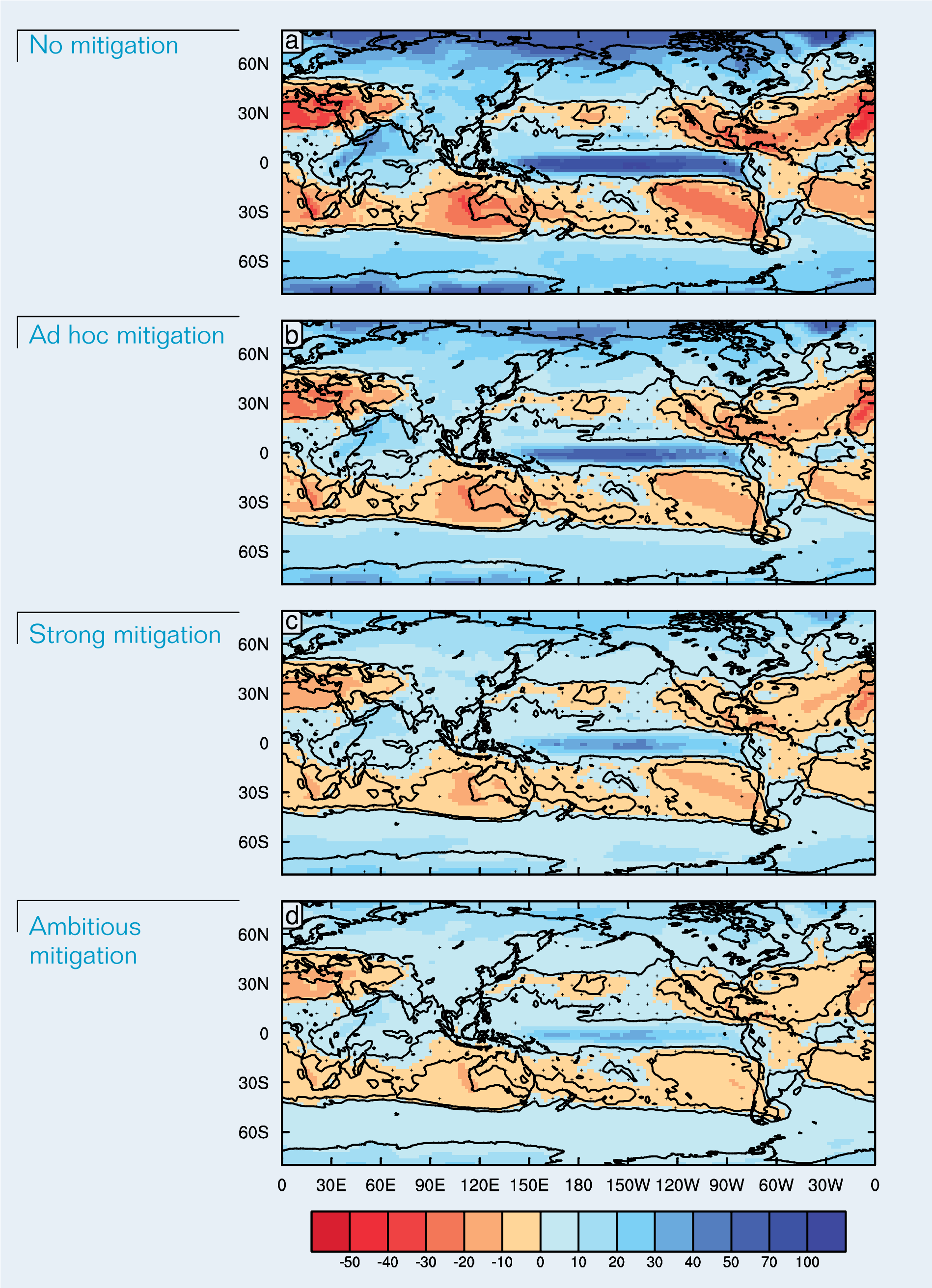
Rainfall is set to increase at high latitudes and over equatorial oceans, where the atmosphere can be rapidly resupplied with moisture after rainfall. In the subtropics, air tends to descend as result of atmospheric circulation patterns, and humidity is relatively low. This process is intensified as the climate warms. Changes in the circulation patterns also push the weather systems that bring rain further towards the poles—the outcome is a decrease in rainfall over many of the subtropical regions. Major regions with substantial decreases in rainfall include Australia, the Mediterranean, Mexico, and north-west and south-west Africa (Watterson 2008).

However, the interactions in the processes that control rainfall in a particular region are complicated, and rainfall changes can vary considerably at the local level. For example, while these projections suggest the likelihood of drying of southern Australia with increases in global average temperature, assessments undertaken at a local scale suggest some possibility of an increase in rainfall. This is discussed in more detail in Chapter 6.

The higher temperatures and lower rainfall in the mid latitudes are expected to lead to an increased risk of drought (IPCC 2007: 782). There is also an increase in the risk of heavy precipitation and flooding, as precipitation will be concentrated into more intense events (IPCC 2007: 782).

Rainfall is expected to increase in the Asian monsoon (although variability is expected to increase season to season), and the southern part of the West African monsoon, and is expected to decrease in Mexico and Central America. Uncertainty about the role of aerosols complicates monsoon projections (IPCC 2007: 750).

Figure 5.7 Percentage changes in precipitation in 2100 for the four emissions cases, based on the mean model outcome



Source: Watterson (2008).

5.3.3 Sea-level rise

Sea-level rise would be greater than was projected by the IPCC if, for any reason, average temperature increases were larger than expected.

Sea-level rise will come from two main sources—thermal expansion and the melting of land-based ice sheets and glaciers. The greater the temperature increase, the greater the increase from thermal expansion and the faster the loss of glacial mass (IPCC 2007: 830). Current estimates show that thermal expansion of the oceans will contribute 70 per cent to 75 per cent of the projected rise. Under the no-mitigation and ad hoc mitigation cases, sea level is expected to continue to rise over the 21st century at a rate that exceeds the observed average rate between 1961 and 2003 (IPCC 2007: 70).

The IPCC estimated sea-level rise in 2100 for a scenario similar to the no-mitigation case at 26–59 cm, and for the ad hoc mitigation case at 21–48 cm (2007: 70). However, melting of some ice sheets on Greenland and the west Antarctic has accelerated in recent decades (IPCC 2007: 44). Observed data suggests that sea-level rise has been at the high end of previous IPCC projections (Rahmstorf et al. 2007).

The level of understanding and uncertainty in the magnitude and timing of contributions to sea level rise from ice melt is low. If the current accelerated rates of ice melt were to increase in the future in proportion to increased globally averaged surface temperatures, the IPCC estimates that it would add between 10 and 20 cm to the upper bound of sea-level rise predicted for the 21st century. A key conclusion of the IPCC sea-level rise projections was that larger values than the upper estimate of 79 cm by 2100 could not be excluded (IPCC 2007:14).

The accelerated response in Greenland may be the result of melt-water from the surface lubricating the movement at the base of the ice sheet and increasing the dynamical flow of solid ice into the sea. The west Antarctic ice sheet is grounded below sea level, which allows warming ocean water to melt the base of the ice sheet making it more unstable (Oppenheimer & Alley 2005).

The sea-level rise projections in the Third and Fourth Assessment Reports of the IPCC in 2001 and 2007 respectively were communicated in a different way in terms of the uncertainty and confidence limits. A key change between the two reports was the revision of the lower estimate of sea-level rise upwards. However, the lower end of the range is still only slightly higher than the sea-level 'committed' rise that would occur if greenhouse gas emissions ceased, and leaves little room for contributions for additional ocean warming and land-ice melt, making such a low outcome unlikely (Rahmstorf 2007; Pew Center 2007).

Ongoing melt of the Greenland and west Antarctic ice sheets

If the Greenland and west Antarctic ice sheets were to melt completely, they would add an estimated 7 m and 6 m to global sea level respectively (IPCC 2007: 752; Oppenheimer & Alley 2005). If a sufficiently warm climate were sustained, the Greenland and west Antarctic ice sheets would be largely eliminated over a long period. The IPCC estimates that the complete melting would take longer than 1000 years (IPCC 2007: 794); Lenton et al. (2008) suggest that a lower limit of 300 years is conceivable if the rapid disappearance of continental ice at the end of the last ice age were to be better simulated in current models.

Current models suggest that once a certain temperature is exceeded, major reduction of the Greenland ice sheet would be irreversible. Even if temperatures were to fall later, the climate of an ice-free Greenland might be too warm for the accumulation of ice (IPCC 2007: 752, 776). Sufficient global temperature rise to initiate ongoing melt of the Greenland ice sheet lies in the range 1.2–3.9°C relative to 1990 (IPCC 2007: 752). Estimates of the warming necessary to melt the west Antarctic ice sheet range from 1°C to 10°C (Oppenheimer & Alley 2005). A simple reading of the scientific literature suggests a high probability that, under business as usual, the point of irreversible commitment to the melting of the Greenland ice sheet would be reached within this century.

Accelerated sea-level rise

While not endorsing outcomes that are not well supported in the published literature, the Review must draw attention to the fact that there is evidence to suggest that future sea-level rise could be much worse.

Sea-level has varied extensively throughout history. Climate records indicate that much faster rates have occurred historically. At the end of the last interglacial when the northern hemisphere ice sheets disintegrated, sea-level rise peaked at a rate of 4 m per year. This indicates that substantially higher rates of sea-level rise than those predicted by the IPCC have occurred historically (Church et al. 2008).

The sea-level rise outcomes of the IPCC (2007) include the effects of thermal expansion of the oceans, and some consideration of ice flow from Greenland and Antarctica. However, they do not show the full effects of ice-sheet flow due to dynamic processes, which are not adequately presented in current models (Oppenheimer & Alley 2005).

Estimating the likelihood of rapid disintegration of ice sheets remains very difficult, but recent evidence and comparison with historical rates suggests it is more likely than previously thought (Hansen 2005; Lenton et al. 2008). If the linear relationship between temperature and sea-level rise observed during the 20th century were to continue, a rise of up to 1.4 m by 2100 for strong warming scenarios could occur (Rahmstorf 2007).

5.3.4 Other climate outcomes

Current limitations in scientific understanding and levels of uncertainty mean that quantifying outcomes under various scenarios is difficult. Box 5.2 summarises the major conclusions relating to the no-mitigation and mitigation cases.

Some climate variables are likely to respond to temperature increase in a nearly linear manner, while change in other variables could occur much faster than the rate of temperature increase. An example of a non-linear relationship is sea-level rise due to the dynamic flow of ice sheets and glaciers, which occurs at an increasing rate as the mass of ice is reduced (IPCC 2007: 70).

5.3.5 Post-2100 outcomes

Beyond 2100, modelling of projected climate change becomes even more uncertain and many emissions pathways and scenarios do not extend into the 22nd century. As part of the Fourth Assessment Report, the IPCC undertook a number of simulations in order to understand the elements of post-2100 climate change better.

If concentrations are stabilised at around 900 ppm, and all other human-induced forcings are also stabilised, current modelling shows that sea-level rise due to thermal expansion in the 22nd century would be similar in magnitude to that of the 21st century, and would continue at a decelerating rate for many centuries. The final magnitude of sea-level rise when equilibrium is reached is estimated at 0.2–0.6 m per degree of temperature increase (IPCC 2007: 752).

If net emissions were reduced to zero in 2100, concentrations could gradually fall over time. Long model runs suggest that temperature and sea level would take more than 1000 years to stabilise, and are projected to remain well above pre-industrial levels even after 3000 years (IPCC 2007: 752).

5.4 Assessing the extremes

The no-mitigation case could generate a greater risk of potentially severe and irreversible impacts on the world's climate, environment and people by 2100 than has been suggested by the focus on 'most likely' or mean outcomes.

5.4.1 Extreme climate outcomes

Extreme climate responses are not always considered or communicated in the assessment of climate change impacts due to uncertainty and lack of understanding about their magnitude and timing.

This section identifies some of the extreme responses within the climate system that could have considerable impact at the subcontinental scale.

Box 5.2 Summary of trends in projected climate change

Temperature extremes

Heatwaves will become more intense, more frequent and last longer as the climate warms. Cold episodes and frost days will decrease (IPCC 2007: 750).

Future increases in temperature extremes generally follow increases in mean (IPCC 2007: 785).

Snow and ice

As the climate warms, snow cover and sea ice extent will decrease. Glaciers and ice caps will lose mass, as summer melting will dominate increased winter precipitation (IPCC 2007: 750).

Snow cover and permafrost area are strongly correlated to temperature, so decreases are expected as warming occurs. In some northern regions where precipitation is expected to increase, snow cover may also increase. This is also true for much of Antarctica.

Some models project that summer sea ice in the Arctic could disappear entirely by 2100 under high-emissions scenarios like the no-mitigation case (IPCC 2007: 750). Comparisons with observed loss in Arctic sea ice suggest that current models underestimate the rate of decline. Between 1953 and 2006, the observed decline in September sea-ice cover is -7.8 ± 0.6 per cent per decade, compared to the multimodel mean trend of -2.5 ± 0.2 per cent per decade (Stroeve et al. 2007).

The extent of sea-ice melting is related to the magnitude of temperature rise, which is amplified in the polar regions due to the warming feedback of melting ice. The small change in global average temperature between the strong and ambitious mitigation pathways could have a relatively large impact on sea-ice extent.

Carbon cycle

As temperatures increase, the capacity of the land and ocean to absorb carbon dioxide will decrease so that a larger fraction of emissions will remain in the atmosphere and cause greater warming (IPCC 2007: 750). The extent of the carbon–climate feedback is dependent on the level of emissions or stabilisation. The higher the temperature increase, the larger the impact on the carbon cycle (IPCC 2007: 750).

Tropical cyclones and storms

Tropical cyclones are likely to increase in intensity and near-storm precipitation. Most models suggest a decrease in the total number of storms. There will be a poleward shift of storm tracks, particularly in the southern hemisphere.

Increased wind speeds will cause more extreme wave heights in these regions (IPCC 2007: 783).

Ocean acidification

As carbon dioxide concentrations increase in the atmosphere, a greater amount is absorbed by the ocean where it reacts with water to create carbonic acid. This increases the acidity of the ocean, which will likely result in carbonate sediments in shallow water dissolving, and may affect marine calcifying organisms.

The level of ocean acidification will depend on the carbon dioxide concentration in the atmosphere. Under the no-mitigation case, carbon dioxide concentrations are more than 1000 ppm in 2100—more than three times pre-industrial concentrations.

Changes to the El Niño – Southern Oscillation

As discussed in Chapter 3, the El Niño – Southern Oscillation ('El Niño' system) is a large-scale pattern of climate variability that leads to climatic effects in both the Pacific region and some other parts of the world (IPCC 2007: 945). Its fluctuations involve a large transfer of heat between the ocean and atmosphere, which has a considerable influence on year-on-year changes in global mean temperature and rainfall patterns.

Palaeoclimatic data suggests that the nature of the El Niño system, and the way it affects the global climate, has changed over time. Some evidence suggests that warmer temperatures in the past were linked to higher El Niño variability, and that the El Niño system may have played an important role in the climatic response to historic changes in radiative forcing (IPCC 2007: 482).

In the 20th century, El Niño system events occurred every three to seven years, but were more intense in the second half of the century (IPCC 2007: 288). There is evidence that this pattern may be significantly different from that exhibited in the 19th century (Steffen et al. 2004).

The far-reaching consequences of the El Niño system, in terms of both its influence on global climate and its consequential impact on human systems, have stimulated intense research into its characteristics. In the last 10 years steady progress has been made in the modelling of El Niño system events, but climate models are still limited in their ability to capture the timescales, amplitude and structure of its variability.

Based on knowledge of the mechanisms behind the El Niño system, as well as historical evidence, it would be expected that changes in ocean temperature and density would change the current pattern of the El Niño system (Lenton et al. 2008). Model outcomes suggest that El Niño system events will continue, but some simulations have shown an increase in its variability, while others exhibit no change or even a decrease.

Based on a survey of available models, the IPCC states that 'there is no consistent indication at this time of discernable changes in projected El Niño – Southern Oscillation amplitude or frequency in the 21st century' (IPCC 2007: 751). However, Lenton et al. (2008) disagree, and based on the available evidence consider there to be 'a significant probability of a future increase in El Niño – Southern Oscillation amplitude', with the potential for the threshold warming to be reached this century. However, the existence and location of any 'threshold' that may result in such a change is highly uncertain.

Climate–carbon feedbacks

As discussed in Chapter 3, there is agreement across climate models that climate change in the future will reduce the efficiency of the oceans and the terrestrial biosphere in absorbing carbon dioxide from the atmosphere. There is large uncertainty regarding the sensitivity of the response. When the impacts of climate change are taken into account in the calculation of carbon dioxide concentrations over time, an additional climate warming of 0.2–1.5°C occurs by 2100 (Friedlingstein et al. 2006).

There are a number of climate–carbon feedback effects that are not well understood, but which could have considerable influences on the temperature response to an increase in carbon dioxide emissions. These include:

- **Release of methane from methane hydrates in the ocean**—Methane hydrates are stored in the seabed along the continental margins in stable form due to the low temperatures and high pressure environment deep in the ocean. It is possible that warming may cause the hydrates to become unstable, leading to the release of methane into the atmosphere (IPCC 2007: 642).
- **Release of methane from melting permafrost**—Methane trapped in frozen soils may be released as temperatures increase and melting occurs.
- **Abrupt changes in the uptake and storage of carbon by terrestrial systems**—The potential for a terrestrial system to change from a sink to a source of carbon dioxide is not well understood, but is beginning to be seriously considered (IPCC 2007: 642). Potential sources could be the increased rate of oxidation of soil carbon and dieback of the Amazon rainforest and high latitude forests in the northern hemisphere.
- **Reduced uptake of CO_2 by oceans.**

All these outcomes are related to the extent of warming and would result in a positive feedback to the climate system, amplifying warming. The thresholds of temperature or emissions that might trigger these outcomes are not well understood, but as the climate warms, the likelihood of the system crossing that threshold increases (IPCC 2007: 642).

5.4.2 High-consequence climate outcomes

Melting of the Himalayan glaciers

After the polar regions, the Himalayas are home to the largest glacial areas. Together, the Himalayan glaciers feed seven of the most important rivers in Asia—the Ganga, Indus, Brahmaputra, Salween, Mekong, Yangtze and Huang Ho.

While localised climate conditions cause different responses, a generalised retreat and reduction in size of glaciers has been observed in the Himalayan glaciers. The trend was strong in the first half of the 20th century, followed by a short period of advance between the 1950s and 1970s. Since the 1980s, however, these glaciers have begun retreating at rates beyond the range of pre-industrial variability. They are receding faster than any other glaciers around the world, and current estimates project that they may disappear altogether by 2035 (WWF Nepal Program 2005).

Unlike many glacial systems, the Himalayan glaciers rely on cool summer temperatures and summer monsoons to accumulate mass in the summer. Under increased temperatures, more precipitation falls as rain rather than snow and the rate of melting increases, which combine to create an increased rate of retreat and risk of downstream flooding.

Rivers fed from glaciers are projected to experience increased stream flows over the next few decades as a result of glacial melt, followed by a subsequent decline and greater instability of inflows as glaciers begin to disappear altogether, leaving only seasonal precipitation to feed rivers (WWF Nepal Program 2005).

Glacial retreat can also result in catastrophic discharges of water from meltwater lakes, known as glacial lake outburst floods, which can cause considerable destruction and flooding downstream.

Failure of the Indian monsoon

The Indian monsoon has been remarkably stable for the last hundred years. The monsoon is central to south Asia's economy and social structure (Challinor et al. 2006). Any change in the monsoon, in timing or intensity, is likely to have significant consequences for the region.

There is limited scientific understanding of the processes underpinning the development of the Indian monsoon (Challinor et al. 2006). The monsoon is the result of the complex interactions among the ocean, atmosphere, land surface, terrestrial biosphere and mountains.

Central to projections of how the Indian monsoon may change with a changing climate is an understanding of the response of El Niño – Southern Oscillation, which is highly uncertain. Some projections indicate a reduction in the frequency of rainfall events associated with the monsoon but an increase in their intensity. The monsoon also exhibits variations within seasons that lead to severe weather events with potentially large consequences. The ability of current climate models to predict these seasonal cycles is limited, but changes in the intensity, duration and frequency of these cycles may constitute the most profound effects of climate change on the monsoon system (Challinor et al. 2006).

Destruction of coral reefs

Coral reefs are highly sensitive to changes in the temperature and acidity of the ocean. As carbon dioxide concentrations increase, a greater amount is absorbed by the ocean where it reacts with the water to create carbonic acid. Higher ocean acidity reduces the availability of calcium carbonate for reef-building corals to create their hard skeletons. The concentration of calcium carbonate in the ocean is a key factor in the current distribution of reef ecosystems.

Long-term records show that sea temperature and acidity are higher than at any other time in the last 420 000 years. The rates of change of these factors in the last hundred years are also two to three times higher than those inferred from records from the same historical period, with the exception of some extremely rare short-lived spikes (Hoegh-Guldberg et al. 2007).

Reef-building corals have already been pushed to their thermal limits by increases in temperature in tropical and subtropical waters over the past 50 years. Many species also have a limited capacity to adapt quickly to environmental change, so the rate at which these changes occur is critical to the level of impact (Hoegh-Guldberg et al. 2007). In combination with other stressors such as excessive fishing and declining coastal water quality, increases in acidity and temperature can push reefs from a coral- to algae-dominated state. If the reef ecosystem is pushed far enough, a tipping point is likely to be exceeded (Hoegh-Guldberg et al. 2007).

Calcium carbonate saturation levels associated with existing coral reefs decrease dramatically under small increases in carbon dioxide concentrations.

Areas with saturation levels suitable for reef development will decrease as ocean acidity increases. The Great Barrier Reef is particularly vulnerable as it is located in an area of ocean with a relatively low concentration of calcium and carbonate ions.

At a carbon dioxide concentration of 450 ppm, the diversity of corals on reefs will decline under the combined affects of elevated temperature and ocean acidity. Atmospheric carbon dioxide concentrations as low as 500 ppm will result in coral communities that no longer produce calcium carbonate to be able to maintain coral reef structures.

Risk of species extinction

The patterns of temperature and precipitation in the current climate are key determinants in the core habitat of a species. These affect the abundance and distribution of species.

Recent research has shown that significant changes in ecosystems are occurring on all continents and in most oceans, and that anthropogenic climate change is having a significant impact on these systems globally and on some continents (Rosenzweig et al. 2008). In Australia these climate-related changes are currently overshadowed as a driver of biodiversity loss by a wide range of existing stressors, the most important of which are landscape modification, fragmentation by land clearance and the introduction of invasive species (Lindenmayer 2007).

However, projected climate change under high-emissions scenarios are expected to exacerbate the effects of existing stressors and lead to even further loss of biodiversity (Steffen et al. in press). Species respond individually to climate change, leading to the formation of novel ecosystems that currently do not exist. The projected rate of climate change will be beyond the capability of many organisms to adapt. A further loss of species is likely, particularly if they are already threatened or endangered (Jones & Preston 2006).

Changes in biodiversity resulting from projected climate change would be an irreversible consequence. Recently there has been increased recognition of the so-called ecosystem services that biodiversity provides.

Industries such as forestry, agriculture and tourism that rely directly on ecosystem services are most exposed to risks linked to declines in biodiversity as a result of climate change (UNEP FI 2008). Ultimately all human beings, even those in highly urbanised areas, are completely dependent on a wide range of ecosystem services for their well-being and even their existence (MEA 2005).

5.4.3 Assessing the likelihood of extreme climate responses

For many extreme climate responses and high-consequence outcomes there is considerable uncertainty around the threshold or tipping point at which an abrupt or ongoing change will occur. With each increment of temperature rise, the likelihood of such an event or outcome increases.

Decision making is aided by the best possible understanding of potential impacts and consequences, and in the case of climate change this is most appropriately provided by the experts in those fields. Where there is insufficient data or an inability to model these processes, it is becoming increasingly recognised that expert judgment—unverified by data—can play a valuable role in informing climate policy decisions (2008).

Table 5.1 and Figure 5.8 summarise the outcomes of a range of studies (Jones & Preston 2006; Warren 2006; Lenton et al. 2008). For the percentage of species at risk of extinction, mortality in coral reefs and irreversible melt of the Greenland ice sheet, the assessment involved the translation of a wide range of results from the literature into a ‘damage function’, which relates the magnitude of loss, or the likelihood of occurrence to global average temperature (Jones & Preston 2006). For the accelerated melt of the west Antarctic ice sheet, changes to the variability of the El Niño – Southern Oscillation and impacts on terrestrial sinks, an approach is taken that identifies a range of temperatures that are likely to include the tipping point or threshold at which these events would occur under the current understanding, based on a critical review of the literature and a survey of experts (Lenton et al. 2008; Warren 2006).

Assessment of these outcomes is complicated by the uncertainty in the temperature response. Table 5.1 shows the potential impacts for the range of best-estimate temperature outcomes for each of the four emissions cases studied. The climate sensitivity studies also suggest that much higher outcomes are possible by the end of the century, even if they have a much lower probability of occurring. Figure 5.8 shows the likelihood of given temperatures being exceeded by 2100 for the four emissions cases, alongside the likelihood of outcomes and potential threshold ranges for some high-consequence and extreme climate responses. It shows that for the higher sensitivity outcomes the damage is considerable and the likelihood almost certain for the climate responses considered.

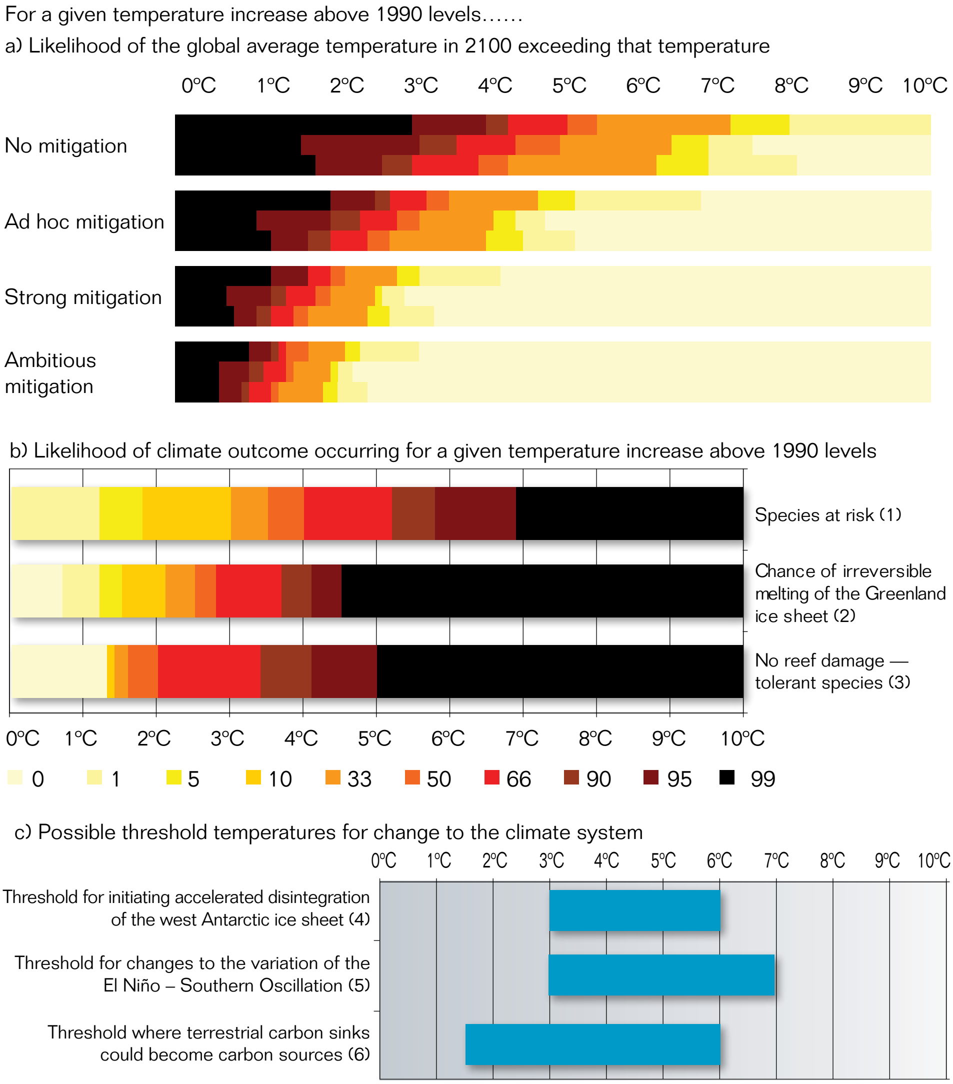
The climate outcomes discussed in this section are sometimes referred to in the literature as 'high-consequence, low-probability events' under human-induced climate change. This assessment shows that these events are of high consequence, but not always of low probability.

Table 5.1 Summary of a selection of extreme climate responses, high-consequence outcomes and ranges in which tipping points may occur under median temperature outcomes for the four emissions cases by 2100

Extreme climate response or impact	Ambitious mitigation	Strong mitigation	Ad hoc mitigation	No mitigation
Range of best-estimate outcomes	**1.3–1.8°C**	**1.8–2.3°C**	**2.9–3.7°C**	**4.5–5.7°C**
a) Percentage of species at risk of extinction	5–10%	10–17%	30–55%	77–94%
b) Likelihood of initiating irreversible melt of the Greenland ice sheet	6–19%	19–40%	67–89%	98–100%
c) Percentage of mortality in tolerant coral species	0–56%	56–73%	84–92%	97–100%
Estimated lower threshold exceeded?				
d) Threshold for initiating accelerated disintegration of the West Antarctic ice sheet	No	No	Possibly	Yes
e) Threshold for changes to the variation of El Niño system	No	No	Possibly	Yes
f) Threshold where terrestrial sinks could become carbon sources	Yes	Yes	Yes	Yes

Note: The probabilities given for the events above are based on a combination of data available in the literature and expert judgment. For a) – c) a 'best fit' damage function has been developed that links the outcomes to global temperature rise (Jones & Preston 2006). The definition of lower thresholds is based on values from the literature and expert elicitation (Lenton et al. 2008 Warren 2006). Further detail is provided in the notes to Figure 5.8.

Figure 5.8 Likelihoods and temperature thresholds for extreme climate outcomes



Notes:

(1) The percentage of all species ‘committed to extinction’ due to shifts in habitat caused by temperature and climate changes, from sample regions covering 20 per cent of the earth’s land surface. The upper limit (>3.5°C) is based on less comprehensive datasets and is therefore more uncertain (Jones & Preston 2006).

(2) Cumulative probability based on four estimates on the threshold for collapse of the Greenland ice sheet from the literature (Jones & Preston 2006).

(3) Percentage of reef area in which there is widespread mortality in slow-growing, tolerant reef species on a frequency of less than 25 years, based on a range of studies from the literature (Jones & Preston 2006).

(4) A range in which the threshold for initiating accelerated disintegration of the West Antarctic ice sheet is expected to occur. The outcomes combine a literature review and expert judgment (Lenton et al. 2008).

(5) A range in which the threshold for changes to the variation of El Niño system is expected to occur. The outcomes combine a literature review and expert judgment (Lenton et al. (2008).

(6) A range in which the threshold where terrestrial sinks could be damaged to the extent that they become carbon sources is expected to occur. This includes a combination of outcomes from Lenton et al. (2008) considering the threshold for extensive damage to the Amazon rainforest boreal forest systems, and Warren (2006) relating to desertification leading to widespread loss of forests and grasslands.

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6 THE AUSTRALIAN CONTEXT TO CLIMATE CHANGE

Key points

Australia's dry and variable climate has been a challenge for the continent's inhabitants since human settlement.

Temperatures in Australia rose slightly more than the global average in the second half of the 20th century. Streamflow has reduced significantly in the water catchment areas of the southern regions of Australia. Some of these changes are attributed by the mainstream science to human-induced global warming.

Effects of future warming on rainfall patterns are difficult to predict because of interactions with complex regional climate systems. Average expectations are for significant drying in southern Australia, with risk of much greater drying. The mainstream Australian science estimates that there may be a 10 per cent chance of a small increase in average rainfall, accompanied by much higher temperatures and greater variability in weather patterns.

Australia is a vast continent that is accustomed to regional and seasonal climate variability. It has a wide range of ecosystems within its borders, from tropical to alpine, and Mediterranean to arid desert. There are multiple influences on Australia's climate, ranging from the global, the regional, such as the El Niño – Southern Oscillation, to the local, such as the Great Dividing Range. Understanding the Australian climate is a complicated task.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology (2007) have undertaken major work projecting Australia's future climate. The Review has commissioned the CSIRO to extend its projections further for a number of variables out to 2100 on the basis of the Review's projections of emissions under no mitigation, ad hoc mitigation, and the specified global mitigation cases.

6.1 Attributing observed and projected climate change to humans

Changes in climate variables that exhibit only a small range of natural variability, such as global mean temperature, are attributed to human factors with some confidence, as small deviations can be significant. Changes in climate variables such as rainfall, which can exhibit high interannual and interseasonal variability, are much harder to attribute to climate change. It is difficult to distinguish the human-induced element from natural variability. Climate variables that manifest themselves over longer scales, such as decades or centuries, are harder still to attribute to human activity (CSIRO & BoM 2007).

Single events, such as an intense tropical cyclone or an intense or long-lived heatwave, cannot be directly attributable to climate change. Climate change may, however, affect the factors that lead to such events and make certain events, like the heatwave that occurred in Adelaide during the summer of 2007–08, much more likely (CSIRO & BoM 2007). In this sense, global warming can make events like Adelaide's heatwave or the prolonged dry conditions seen in Southern Australia in recent years, seem less extraordinary (Power & Nicholls 2007).

Despite these caveats, some changes in the Australian climate system have been attributed to human-induced climate change. Examples include the increase in average temperatures since the middle of the 20th century, the reduction in rainfall in south-west Western Australia, and the decline in snow cover (CSIRO & BoM 2007; Cai & Cowan 2006).

Rainfall declines in parts of the country, such as south-east Australia, have not been definitively attributed to climate change. By contrast, the higher temperatures that have accompanied and exacerbated the drought conditions have been so attributed (see section 6.2.2).

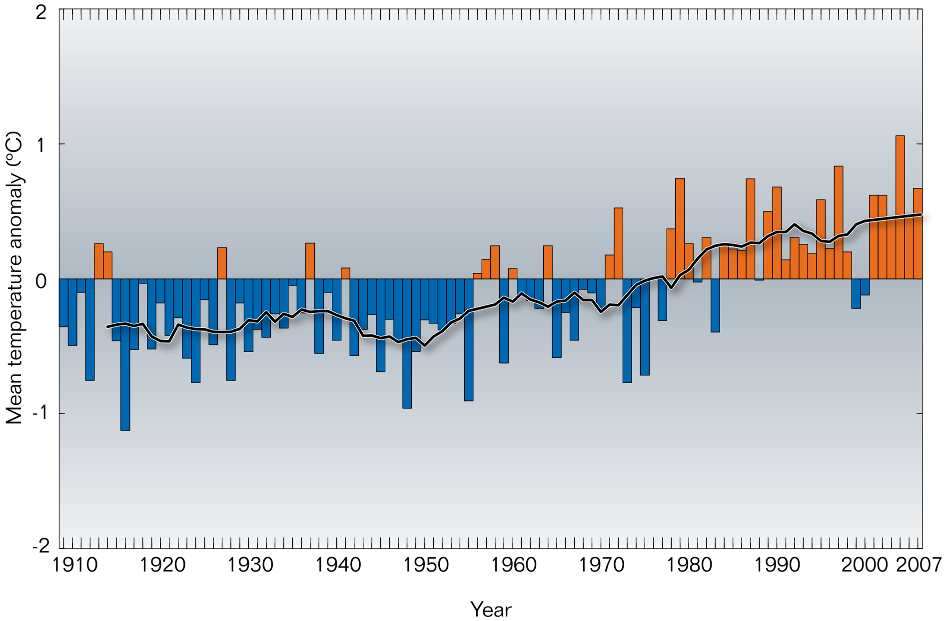
6.2 Historical climate change in Australia

Observations over the last century, and the last 50 years in particular, have shown marked changes in a number of key climate variables.

6.2.1 Temperature

Annual mean temperature in Australia has increased by 0.9°C since 1910 (CSIRO & BoM 2007). Figure 6.1 shows Australian annual mean temperature anomalies from 1900 to 2007.

Figure 6.1 Australian annual mean temperature anomalies, 1900–2007



Note: The data shows temperature difference from the 1961–90 mean. The black line shows the 10-year trailing average.
Source: Bureau of Meteorology.

The warming tendency since the middle of the 20th century has not been uniform across the country. The greatest warming has occurred in central Australia (Murphy & Timbal 2008). In south-eastern Australia, mean maximum temperatures have increased. As a result, droughts have become hotter (Nicholls 2004).

Ocean temperature has changed at a slower pace, due to the ocean's large heat content and enhanced evaporative cooling. Nevertheless, substantial warming has occurred in the three oceans surrounding Australia. The Indian Ocean is warming faster than all other oceans with significant warming off the coast of Western Australia (CSIRO & BoM 2007).

6.2.2 Rainfall

There has been a major change in rainfall patterns since the 1950s, with large geographic variation. Across New South Wales and Queensland, the difference partly reflects a wet period around the 1950s. North-west Australia has seen a significant increase, whereas most of the eastern seaboard and south-west Australia have seen a significant decrease in annual rainfall (CSIRO & BoM 2007). Rainfall changes over the longer period from 1900 to 2007 are generally positive and are largest in the north-west. Drying tendencies over this longer period are evident in south-west Australia, some other parts of southern Australia, including much of Tasmania, and over much of north-east Australia.[1]

Change can occur to both the mean and distribution of variables (Chapter 3). In Australia, the rate of change in the frequency and intensity of rainfall and temperature extremes is greater than the rate of change for the equivalent means (Alexander et al. 2007). For example, maximum temperatures are increasing at a greater rate than mean temperature.

The attribution of changes in rainfall patterns in Australia to climate change is difficult due to naturally high interannual variability. Attribution has been possible in the south-west of Western Australia, where up to 50 per cent of the rainfall decline has been attributed to human-induced climate change (Cai & Cowan 2006). This rainfall decline has been observed since the 1970s, and as such has been the subject of research over many years. The rainfall decline observed in the 1990s in south-east Australia shares many characteristics with the decline in the south-west, but has only recently become the subject of extensive research (CSIRO & BoM 2007). The factors affecting rainfall decline in the south-east appear more complex, however, as this region is affected to a greater extent by major systems such as the El Niño – Southern Oscillation and the subtropical ridge (Murphy & Timbal 2008). This is discussed further in Box 6.1.

Rainfall can be affected by anthropogenic emissions other than greenhouse gases. It has been suggested that the increased rainfall in the north-west of Australia could be affected by aerosols drifting south from Asia. Aerosols can create a localised cooling effect, which in turn affects convection and rainfall patterns, often at long distances (Rostatyn et al. 2007).

Streamflows

A reduction in rainfall results in a proportionately larger fall in streamflows. Generally, a decrease in rainfall can result in a two- to threefold decrease in streamflow (Chiew 2006). In the Murray-Darling Basin, a 10 per cent change in rainfall seems to result in a 35 per cent change in streamflow (Jones et al. 2001).

Low streamflows have been recorded in the rivers supplying most major urban water storage systems over the last decade (Water Services Association of Australia 2007). For Melbourne, Sydney, Brisbane, Adelaide and Canberra,[2] average streamflows over the period 1997–2007 are notably below the long-term average (the period of the long-term average is between 84 and 108 years depending when measurements began). Recent streamflows supplying Canberra are 43 per cent of the long-term average, in Melbourne 65 per cent, Adelaide 62 per cent, Sydney 40 per cent and Brisbane 42 per cent.

The greatest, and earliest, decline in streamflows of rivers supplying major urban water storages has been observed in Perth (Figure 6.2). There has been a marked decline since the 1970s, which has continued and appears to have intensified over the last decade. Annual streamflows over recent years (2001–07) are only 25 per cent of the long-term average up to this observed

Box 6.1 Drought in Australia

Drought can be defined in many ways. The main contributing factors for all definitions, however, are rainfall, temperature and evaporation. Due to the strong connection between anthropogenic emissions and warming in Australia, the CSIRO and the Bureau of Meteorology (2007) conclude that the drought in many parts of the country is linked to, or at least exacerbated by, global warming.

The causes of drought can be many. For example, the drought in south-west Western Australia has been attributed to a combination of natural variability, an increase in greenhouse gas concentrations, and land-use change (Timbal et al. 2006).

In south-east Queensland, the drought appears to have been caused by changes in two key climate variables: the El Niño – Southern Oscillation (see section 6.2.3) and tropical cyclones (Department of Natural Resources and Water 2007). Since 1950, there has been a strong decline in rainfall across eastern Australia and since 1977 there has been an increase in the frequency of El Niño events (Power & Smith 2007). Related to this shift in the system's El Niño behaviour has been a reduction in the region of the number of tropical cyclones, which contribute a large amount to total rainfall.

Since 1997, south-east Australia has recorded a number of changes in relation to rainfall mean (Murphy & Timbal 2008; B. Timbal, pers. comm.):

- From 1997 to 2007 only one year has had rainfall above the 1961–90 annual average.
- Only one autumn from 1990 had rainfall above the 1961–90 autumn average.
- Melbourne streamflows have been below the long-term average every year since 1996 (Timbal & Jones 2008).

Changes in autumn rainfall and temperature are important for a number of reasons. First, April to June is a critical rainfall period for the establishment of crops. Second, while most rainfall in the region falls in winter and spring, autumn rainfall acts as a soil-wetting mechanism affecting streamflows in preceding months. Without this preparation, winter and spring streamflows can be negatively affected, even if rainfall is not (Cai & Cowan 2008a). Finally, it has recently been suggested that increased temperature has a very large impact on streamflow. After accounting for interdependencies, such as the effect of rainfall and clouds on minimum temperatures, Cai and Cowan (2008b) concluded that a 1°C increase in maximum temperature results in a 15 per cent decrease in streamflow in the Murray-Darling Basin.

A similar decline in annual mean rainfall in south-east Australia has occurred once before in historical records. Between 1936 and 1945 mean annual rainfall was 493.8 mm compared with the 1997–2007 mean of 515.1 mm (Murphy & Timbal 2008; B. Timbal, pers. comm.)

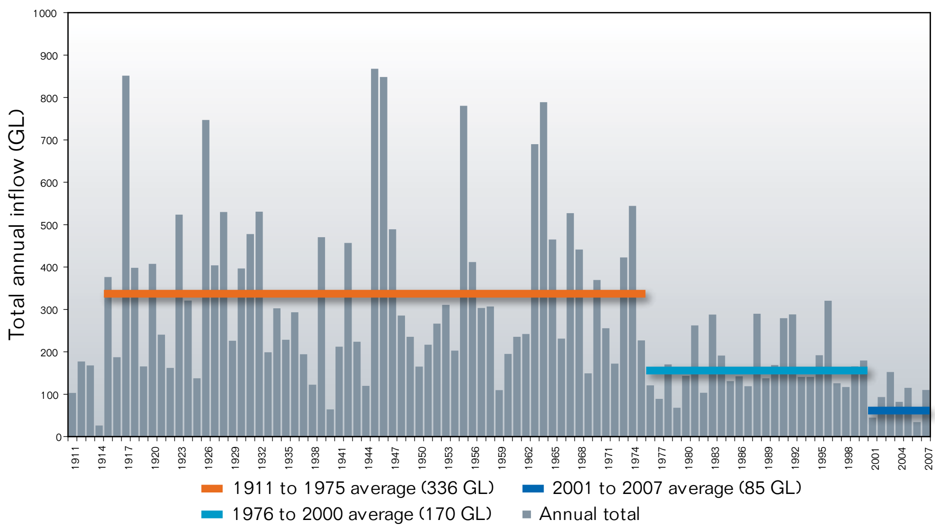
Box 6.1 Drought in Australia *(continued)*

The current drought is marked by an increase in mean maximum temperatures, further affecting evaporation and streamflows and reduced interannual variability.[3]

The decline in autumn rainfall in south-east Australia has strong qualitative similarities with the decline observed in the 1970s in Perth (Murphy & Timbal 2008). However, it has occurred much later. Unlike south-west Western Australia, however, the south-east of Australia is affected by a multitude of climate systems including the El Niño – Southern Oscillation and the Southern Annular Mode, subtropical ridges, and the Indian Ocean Dipole.[4] Although there is currently no consensus on the magnitude of influence of these systems, or on how they will respond to global warming (Murphy & Timbal 2008; Timbal & Murphy 2008; Cai & Cowan 2008a; Hendon et al. 2007), one estimate is that the El Niño system and the Southern Annular Mode account for around 15 per cent of the observed rainfall decline in the south-west and south-east of the country (Hendon et al. 2007).

decline. The decline in rainfall in the region, which occurred at approximately the same time, has been partly attributed to human-induced climage change (Cai & Cowan 2006).

Figure 6.2 Annual streamflow into Perth's dams



Note: Values represent totals for May–April.

Source: Western Australia Water Corporation.

6.2.3 El Niño – Southern Oscillation and the Southern Annular Mode

El Niño – Southern Oscillation

The El Niño – Southern Oscillation is a naturally occurring phenomenon that temporarily disrupts climatic patterns in many countries in the Pacific and Asia, including Australia (Power et al. 2006; Ropelewski & Halpert 1984; Nicholls 1992; Allan et al. 1996). It is often monitored using the Southern Oscillation Index, which is a measure of the difference in mean sea-level pressure across the Pacific Ocean, between Darwin and Tahiti. A positive sustained index is associated with stronger trade winds, a cooler than normal eastern equatorial Pacific Ocean and warmer sea temperatures in the north of Australia. In Australia, it is associated with increased rainfall, flooding and decreased temperatures (Power et al. 1998). This is known as a La Niña episode. A negative index is associated with warmer than normal sea surface temperatures in the central to eastern equatorial Pacific Ocean, weaker trade winds, and a reduction in rainfall in eastern and northern Australia. This is known as an El Niño episode (BoM 2005; Power & Smith 2007).

Many major Australian droughts are associated with an El Niño event, though not all El Niño events trigger a drought. The effect of the El Niño – Southern Oscillation on climate varies across the country. South-west Western Australia, the west coast of Tasmania and coastal New South Wales are less affected than inland eastern Australia (BoM 2005).

A La Niña episode does not produce an exactly opposite effect to that of an El Niño and the pattern of influence is also different (Power et al. 2006). For example, parts of northern and central Australia are more affected by La Niña than El Niño.

The impact of the El Niño – Southern Oscillation on Australia also varies substantially from decade to decade and generation to generation. In fact the 1977–2006 average value of the Southern Oscillation Index was the lowest 30-year value on record. Moreover, the trend over this period was statistically significant at the 95 per cent level. This record-low value primarily arose from record high values in Darwin air pressure, and the changes coincided with very weak trade winds. This period also saw a record high number of El Niño events and a corresponding record low number of rain-bearing La Niña events, making it the most El Niño-dominated period on record (Power & Smith 2007).

The extent to which this decline in the Southern Oscillation Index is influenced by global warming is unknown. Nevertheless some climate models exhibit weakened trade winds in response to global warming (Vecchi et al. 2006), and so global warming might also be contributing to some of the observed changes evident in and around the tropical Pacific (Power & Smith 2007).

The relationship between the Southern Oscillation Index and temperature and rainfall in Australia has also changed over time: both temperature and rainfall values for the period 1973–2005 tended to be higher for any given value of the index than for the preceding period (1910–1972) (Nicholls et al. 1996; Power et al. 1998; CSIRO & BoM 2007).

Southern Annular Mode

Another dominant mode of variability at high southern latitudes is the Southern Annular Mode. When this mode is in its positive phase, unusually high pressure is observed over Antarctica and unusually low pressure around 40–55° South (CSIRO & BoM 2007).

Both the Southern Annular Mode and El Niño – Southern Oscillation are estimated to drive approximately 15 per cent of the variability in spring and summer rainfall in south-east Australia (CSIRO & BoM 2007).

Over recent decades, the Southern Annular Mode has spent increasingly more time in its positive phase (CSIRO & BoM 2007). There is an association between this positive phase and significant winter rainfall reduction in southern Australia as well as significant rainfall increases in the Murray-Darling Basin in summer (Hendon et al. 2007).

This shift has led to a decrease in the potential for storm formation over southern Australia. In south-west Australia, a reduction in winter rainfall is associated with a decrease in the number of rain-bearing synoptic systems and a deflection southward of some storms (CSIRO & BoM 2007).

6.2.4 Other climate variables

Cyclones and storms

It is difficult to determine trends in the frequency and intensity of tropical cyclones in the Australian region due to inherent multidecadal variability in tropical cyclone frequencies and intensities, and the varying quality of historical records (CSIRO & BoM 2007). Similarly, hailstorms are highly sensitive to small-scale variations in meteorological and oceanographic conditions as well as geographic features. Furthermore, accurate and consistent data collection methods, such as digital and microwave satellite imagery and comprehensive storm spotter networks, have been continually evolving, and hence comprehensive and homogeneous datasets are not yet of sufficient length for rigorous climate change analyses. As such, it is difficult to draw definitive conclusions on observed changes in hailstorm and tropical cyclones that can be attributed to climate change from the current historical datasets (B. Buckley, pers. comm.).

Limited observations have suggested that there was a substantial increase in tropical cyclone numbers on the east coast since the 1950s, followed by a reduction since the 1970s. This reduction appears to be linked to an increasing number of El Niño events since there tend to be fewer tropical cyclones in Australia during El Niño events (CSIRO & BoM 2007). On the west coast, there appears to have been an increase in the proportion of severe (category 3 and 4) cyclones (CSIRO & BoM 2007). During the period 1974–88, severe cyclones accounted for 29 per cent of the total. In the period 1989–98 they accounted for 41 per cent.

In general, there are fewer tropical cyclones in Australia during El Niño events than during La Niña (CSIRO & BoM 2007).

Bushfires

During the period 1973–2007, there has been a general increase in the Forest Fire Danger Index across the east and south-east of the country. A recent review of 23 measuring locations over this period analysed the three years with the highest index (Lucas et al. 2007). Fifty out of 69 of the selected years were after the year 2000, with the increasing trend statistically significant above the 95 per cent level for most inland locations.

Box 6.2 Heatwaves

The number of hot days and warm nights per year has increased since 1955 (CSIRO & BoM 2007) and heatwaves have become increasingly common (Lynch et al. 2008).

In February 2004, for example, maximum temperatures were 5–6°C above average throughout large areas, reaching 7°C above average in parts of New South Wales (National Climate Centre 2004). Adelaide had 17 successive days over 30°C (the previous record was 14 days). Sydney had 10 successive nights over 22°C (the previous record was six). Around two-thirds of the continent recorded maximum temperatures over 39°C and temperatures peaked at 48.5°C in western New South Wales (Lynch et al. 2008).

In May 2007, high mean temperatures were observed in large parts of eastern Australia and records were set over most of Victoria and Tasmania, most of New South Wales, parts of Southern Australia and most of Queensland. January to May 2007, in south-east Australia, was the warmest on record at 0.3–0.5°C higher than the previous record period (National Climate Centre 2007).

In March 2008, Adelaide had 15 consecutive days 35°C or above and 13 consecutive days of 37.8°C or above. Hobart matched its previous record high temperature of 37.3°C and Melbourne recorded a record high overnight minimum of 26.9°C (National Climate Centre 2008).

6.3 Projected climate change in Australia

Climate projections are based on emissions cases or scenarios. In assessing projections of climate change in Australia, the Review used a combination of the IPCC SRES scenarios, as used by the CSIRO and BoM (2007), and emissions cases based on strong and ambitious global mitigation. Emissions scenarios are based on, necessarily, simplified global models and the actual outcome is unlikely to exactly match a predicted scenario or case. There is significant uncertainty in the timing of particular temperature increases, as discussed in Chapter 3.

As discussed in Chapter 5, projections of global mean temperature across different emissions scenarios show little variation until the decade of the 2030s. Australian mean temperature responds in a similar fashion. After this point, projections of climate variables are increasingly dependent on emissions pathways.

The future climate is a function of both human-induced climate change projections and natural climate variability about these projections. In some decades the natural variability will reinforce the climate change signal, while in other decades it will offset the signal to some degree.

6.3.1 Temperature

Annual mean temperatures in Australia are expected to rise in parallel with rises in global mean temperature. Significant regional variation, however, is projected across Australia. In general, the north-west is expected to warm more quickly than the rest of the country.

By 2030, annual temperature over Australia will be around 1°C above 1990 levels (CSIRO & BoM 2007).[5] The range of uncertainty (10th to 90th percentiles) produces a national increase of between 0.4°C and 1.8°C for 2030. Coastal areas will experience slightly less warming in the range 0.7–0.9°C, whereas inland Australia will experience greater warming in the range 1.0–1.2°C.

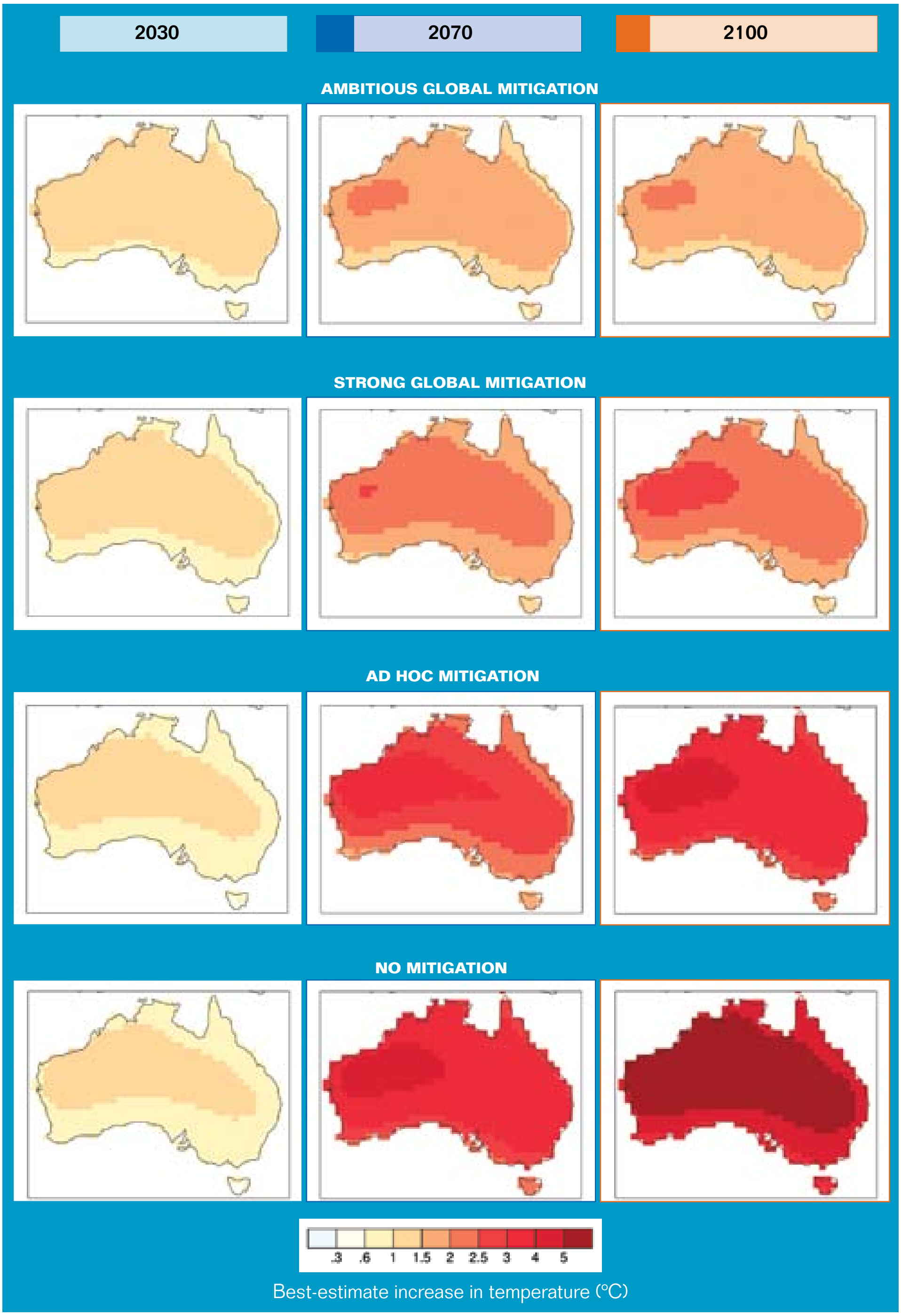
From 2030 to the end of the century there are marked differences between cases, as shown in Figure 6.3.

At both the 10th and 90th percentile outcomes there are noticeable temperature increases across the country. The 90th percentile of outcomes in a no-mitigation case includes an increase of more than 7°C in some areas. The 10th percentile of outcomes shows an increase of more than 3°C for most of the country, increasing to 4.85°C over an extensive area in north-west Australia.

6.3.2 Rainfall

The relationship between local precipitation and atmospheric temperature is complex. Local rainfall patterns are highly sensitive to the amount of water available for evaporation, the local topography and land cover, and atmospheric and ocean circulation patterns. At the global level a decrease in precipitation is indicated as the ‘best estimate’ outcome for Australia (see Chapter 5). However, because of the localised nature of influences on precipitation, there is considerable regional variation in precipitation change within Australia, so that some areas are expected to experience an increase in rainfall. The complexities also lead to disagreement between climate models regarding the potential extent, and even direction, of the change.

Figure 6.3 Best estimate (50th percentile) of Australian annual temperature change at 2030, 2070 and 2100 under four emissions cases



Notes: Four cases are shown: ambitious global mitigation (450 ppm stabilisation), strong global mitigation (550 ppm stabilisation), ad hoc mitigation (based on the SRES A1B scenario), no mitigation (based on the SRES A1FI scenario). Values greater than or equal to 5 are represented with the same colour.

Source: CSIRO.

Best-estimate annual average change in rainfall

Table 6.1 shows the best-estimate (50th percentile) annual average rainfall outcomes for Australia in a no-mitigation case in 2030, 2070 and 2100.[6] The best-estimate outcomes of change in annual average rainfall in 2030 are minimally different between the different emissions cases due to climate change commitments (Chapter 5), but later in the century the rainfall outcomes are more dependent on the level of mitigation action. The changes under the ad hoc and strong and ambitious global mitigation cases follow the same patterns of change but the reductions are considerably more subdued. The extent of rainfall change under the ambitious mitigation case in 2100 is less than that experienced under the no-mitigation case in 2070.

Table 6.1 Projected changes to state-wide average rainfall, best-estimate outcome in a no-mitigation case (per cent change relative to 1990)

	NSW	Vic.	Qld	SA	WA	Tas.	NT	ACT
2030	-2.5	-3.5	-2.4	-4.2	-4.1	-1.4	-2.5	-2.8
2070	-9.3	-12.9	-8.6	-15.5	-14.9	-5.1	-9.0	-10.3
2100	-13.7	-19.0	-12.7	-22.8	-21.9	-7.6	-13.3	-15.2

Source: CSIRO.

The 'dry' and 'wet' ends of precipitation projections

The best-estimate outcomes do not reflect the extent of the uncertainty in potential rainfall outcomes for Australia under climate change. Rainfall projections are highly sensitive to small changes in model assumptions and inputs, and the range of precipitation outcomes predicted by various climate models for Australia is large.

Table 6.2 shows the average annual changes for rainfall in Australia for the no mitigation case for 'dry' (10th percentile) and 'wet' (90th percentile) end of projections in 2030, 2070 and 2100.

Table 6.2 Projected changes to state-wide average rainfall, 'dry' and 'wet' outcomes in a no-mitigation case (per cent change relative to 1990)

Dry outcome (10th percentile)

	NSW	Vic.	Qld	SA	WA	Tas.	NT	ACT
2030	-10.1	-8.3	-11.5	-13.1	-12.7	-5.2	-11.4	-8.2
2070	-37.0	-30.3	-42.0	-48.0	-46.5	-19.2	-41.8	-30.1
2100	-54.6	-44.7	-61.8	-70.8	-68.5	-28.3	-61.6	-44.4

Wet outcome (90th percentile)

	NSW	Vic.	Qld	SA	WA	Tas.	NT	ACT
2030	4.2	0.9	6.0	4.0	4.2	2.6	6.0	2.0
2070	15.5	3.4	22.0	14.8	15.5	9.5	22.0	7.4
2100	22.8	5.1	32.5	21.9	22.8	14.0	32.4	10.9

Source: CSIRO. The methodology for the preparation of these distributions is described in CSIRO & BoM (2007).

The uncertainty in projections of change in annual Australian rainfall has been taken into consideration in the determination of impacts in Chapter 7.

Temporal variation in rainfall

Changes in annual rainfall often mask significant inter-seasonal variation. Similarly, mean annual rainfall may mask changes in rainfall patterns, rainfall intensity and the number of rain events. For example, it is possible for mean annual rainfall to remain the same, while rain intensity increases and the number of rain days decreases.

In summer and autumn, decreases are more limited and some areas experience slight increases. Larger decreases in rainfall are experienced in winter and spring (CSIRO & BoM 2007).

As well as changes to annual average rainfall, the character of daily rainfall may change. There is expected to be an increase in the intensity of rainfall events in some areas, and the number of days without rainfall are also expected to increase. This suggests that the future precipitation regime may have longer dry spells broken by heavier rainfall events (CSIRO & BoM 2007).

Consideration of a progressive change in annual average rainfall does not reflect the considerable interannual and decadal variation in Australian rainfall. In terms of precipitation, observed decadal variability in the 20th century and models run with a 'no climate change assumption' show natural variability in rainfall of between 10 and 20 per cent (CSIRO & BoM 2007). Natural variability may therefore mask, or enhance, changes due to high concentrations of greenhouse gases.

Variation in the intensity and temporal pattern of daily rainfall, differences in seasonal change, and the influence of natural decadal variability could have considerable impact on sectors such as agriculture and infrastructure.

6.3.3 El Niño – Southern Oscillation and the Southern Annular Mode

There is no consensus among models as to how climate change will affect the El Niño – Southern Oscillation (see IPCC 2007: 779–80; CSIRO & BoM 2007; Lenton et al. 2008)—in some models it intensifies, while in other models it weakens.

The Southern Annular Mode is likely to shift towards its positive phase, which will result in weaker westerly winds in southern Australia and stronger westerly winds at higher latitudes. Such a movement would be associated with lower rainfall.

6.3.4 Other climate variables

Cyclones and storms

As stated above, tropical cyclone frequency and intensity display high variability across seasonal, annual, decadal and multi-decadal timescales (CSIRO & BoM 2007). The El Niño – Southern Oscillation also has a strong effect on tropical cyclone numbers (Abbs et al. 2006). As it is as yet unknown what effect climate change will have on the El Niño – Southern Oscillation, it is difficult to project changes in the frequency and intensity of tropical cyclones.

Studies suggest that the frequency of east coast cyclones will either remain the same or decrease by up to 44 per cent (see CSIRO & BoM 2007). Abbs et al. (2006) estimate that category 3–5 storms will increase in intensity by 60 per cent for 2030 and 140 per cent in 2070.

Projections also indicate that the regions of east Australian cyclone genesis could shift southward by 2° (approximately 200 km) by 2050 (Leslie et al. 2007), while the average decay location could be up to 300 km south of the current location (Abbs et al. in CSIRO & BoM 2007). Models also estimate that the number of strong cyclones reaching the Australian coastline will increase, and 'super cyclones', with an intensity hitherto unrecorded on the Australian east coast, may develop over the next 50 years (Leslie et al. 2007).

Future projections indicate an increase in the intensity and frequency of hailstorms in the Sydney basin region with only a 1–2°C rise in temperature (Leslie et al. 2008).

Heatwaves

There is projected to be a strong increase in the frequency of hot days and warm nights. The current projected number of days per year above 35°C for 2030, 2070, and 2100 in all capital cities is displayed in Table 6.3.

Most notable is the marked increase of hot days in Darwin. Under a no-mitigation case, there are 221 days over 35°C in 2070. By 2100, this increases to 312—or less than eight weeks in the year with days under 35°C.

Table 6.3 Projected increases in days over 35°C for all capital cities under a no-mitigation case

	Current	2030	2070	2100
Melbourne	9	12	21	27
Sydney	3.3	4.4	9	14
Brisbane	0.9	1.7	8	21
Adelaide	17	22	34	44
Perth	27	35	56	72
Canberra	5	8	21	32
Darwin	9	36	221	312
Hobart	1.4	1.7	2.5	3.4

Source: CSIRO.

Bushfires

The most recent projections of fire weather in a study by Lucas et al. (2007) suggest that fire seasons will start earlier, end slightly later, and generally be more intense in their duration. This effect increases over time, but should be directly observable by 2020.

Table 6.4 shows projections of the percentage increase in the number of days with very high and extreme fire weather.[7]

Table 6.4 Projected increases in the number of days with very high and extreme fire weather for selected increases in global mean temperature

	Approximate year		
	2013	2034	2067
Very high	+2–13	+10–30	+20–100
Extreme	+5–25	+15–65	+100–300

Note: This study was based on scenarios producing 0.4ºC, 1.ºC and 2.9ºC temperature increases, which equate to the years in this table under a no-mitigation case.

Source: Lucas et al. (2007).

The Lucas study defined two new categories of fire weather: 'very extreme' and 'catastrophic'.[8] Of the 26 sites used in the study, only 12 have recorded catastrophic fire danger days since 1973. At a 0.4°C increase in temperature there is little or no change in the number of catastrophic fire weather days. At a 1.0°C increase, catastrophic days are occurring at 20 sites. For half of these sites, the return period is around 16 years or less. At a 2.9°C increase, 22 sites record catastrophic days. Nineteen of these have a return period of around eight years or less. Seven sites have return periods of three years or less.

Notes

1 See <www.bom.gov.au/climate/> for further details.

2 Hobart has not been included as normally only 40 per cent of supply is taken from storage facilities with the remainder being extracted from the Derwent River, whose catchment area is approximately 20 per cent of the area of the state. During scarce periods, larger quantities are drawn from the Derwent River, though on average this represents less than 1 per cent of the total streamflow. Darwin has not been included as streamflows in its catchment areas have been largely unaffected over the last decade (R. Young, pers. comm.).

3 The standard deviation for annual rainfall for the period 1936–45 was 105.5 mm, compared with 85.8 mm for the current drought (Murphy & Timbal 2007; B. Timbal, pers. comm.).

4 While geographically distant, Indian Ocean sea surface temperatures have been shown to be associated with south-eastern Australian rainfall (Murphy & Timbal 2008; Cai & Cowan 2008a).

5 All temperature increases are from a 1990 baseline.

6 Changes in precipitation are reported as percentage changes from a 1990 baseline.

7 'Very high' fire weather has a Forest Fire Danger Index (FFDI) of 25–50 and 'extreme' fire weather has an FFDI of 50+. Suppression of fires during 'extreme' fire weather is "virtually impossible on any part of the fire line due to the potential for extreme and sudden changes in fire behaviour. Any suppression actions such as burning out will only increase fire behaviour and the area burnt" (Vercoe in Lucas et al. 2007).

8 'Very extreme' fire weather has an FFDI of 75–100 and 'catastrophic' fire weather has an FFDI of over 100 (Lucas et al.).

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7 IMPACTS OF CLIMATE CHANGE ON AUSTRALIA

Key points

This chapter provides a taste of conclusions from detailed studies of Australian impacts. These studies are available in full on the Review's website.

Growth in emissions is expected to have a severe and costly impact on agriculture, infrastructure, biodiversity and ecosystems in Australia.

There will also be flow-on effects from the adverse impact of climate change on Australia's neighbours.

These impacts would be significantly reduced with ambitious global mitigation.

The hot and dry ends of the probability distributions, with 10 per cent chance of realisation, would be profoundly disruptive.

This chapter considers the impacts of climate change on Australia in six key sectors and areas, chosen either because they make a large economic contribution to Australia, or because the impacts on market or non-market values are expected to be severe. These areas, sectors and subsectors are presented in Table 7.1.

The Review considers both the direct impacts (section 7.3) and indirect impacts (section 7.4) of climate change on Australia. 'Direct' refers to those impacts that are experienced within Australia's land and maritime boundaries. 'Indirect' refers to impacts experienced in other countries, such as those within the Asia–Pacific region, with consequences for Australia. We focus first on the medians of the probability distributions of the impacts identified by the main climate models. For some sectors we supplement the middle-of-the-road assessment with analysis of the higher ends of the probability distribution of impacts. We take the standard IPCC projections and those based on them for cases that correspond most closely to those we expect from no mitigation or from effective global mitigation policies. We do not examine the more serious implications of climatic tipping points, due to the high degree of uncertainty associated with these and the limited time available to the Review to explore the breadth of potential impacts.

Two time periods are discussed. We explore how climate change might affect Australia up to 2030. These impacts can be broadly considered as locked in because of our present level of greenhouse gas emissions. The magnitude of these impacts can only be tempered by our level of adaptation effort. We also explore how Australia might be affected by climate change at the close of the century. The magnitude of impacts in 2100 will be determined by the ambition and effectiveness of international greenhouse gas mitigation as we move forward, and also by Australia's continued adaptation effort.

The chapter offers an illustrative selection and not a complete assessment of the impacts that are likely to be experienced across Australia. It is meant to provide a flavour of the insights contained in a series of papers commissioned by the Review. The papers are available on the Review website. In addition to the sectors and impacts discussed in this chapter, the commissioned papers cover livestock, horticulture, viticulture and forestry; Australia's World Heritage properties; tourism in south-west Western Australia; Ross River virus; ports; and telecommunications. These are an important part of the base from which the modelling of economic impacts on Australia, reported in Chapter 9, has been developed.

The Review encourages readers to examine the accompanying material. We have drawn on Australia's leading experts in 30 fields of inquiry (listed in Table 7.1) to provide a comprehensive collection of impacts stories. We draw on this material at various times through this draft report and it will be further considered in the final report. The availability of these reports on the Review's website provides a valuable public resource to build understanding of the diversity and magnitude of impacts that could be experienced across Australia.

This chapter and the commissioned reports form the foundation of the CGE modelling referred to in chapters 9 and 10. The CGE modelling will illustrate how the impacts flow through the whole of the Australian economy (final report).

The exploration of impacts also enables the Review to demonstrate the importance of both international greenhouse gas mitigation and national adaptation. This chapter makes the case that certain sectors and areas will be severely affected by a business-as-usual treatment of climate change, and that only through globally coordinated greenhouse gas mitigation do we leave open the opportunity to maintain many things that we value.

This chapter further demonstrates that in some cases it will be near impossible to avoid some level of climate change impact. It is possible that we will not avoid large and costly impacts. Where this is the case adaptation to the arising impacts will be required. The necessary response to the climate change impacts discussed in this chapter will be discussed in the adaptation chapters of the final report.

Further details on potential impacts can also be found in various synthesis reports (IPCC 2007; CSIRO & BoM 2007; PMSEIC 2007; ed. Pittock 2003; Preston & Jones 2006).

Table 7.1 Sectors and areas considered in this chapter

Sector or area	Discussed in this chapter	Modelled by the Review
Resource-based industries and communities		
Subsector or area		
Dryland cropping	Yes – wheat	Yes
Irrigated cropping	Yes – in the Murray Darling Basin	Yes – nationally
Livestock carrying capacity	No	Yes
Fisheries and aquaculture	No	No
Forestry	No	No
Mining	No	No
Horticulture	No	No
Viticulture and the wine industry	No	No
Australia's World Heritage properties	No	No
Alpine zone of south-east Australia	Yes	No
South-west Western Australia	No	No
Great Barrier Reef	Yes	No
Critical infrastructure		
Subsector or area		
Buildings in coastal settlements	Yes	Yes
Urban water supply	Yes	Yes
Electricity transmission and distribution network	No	Yes
Port operations	No	Yes
Roads and bridges	No	No
Telecommunications	No	No
Cyclone impacts on dwellings	No	Yes
Human health		
Subsector or area		
Temperature-related death and serious illness	Yes – death	Yes
Ross River virus	No	No
Dengue virus	Yes	Yes
Bacterial gastroenteritis	No	Yes
Health of remote northern Australian Indigenous communities	No	No
Rural mental health	No	No

Table 7.1 Sectors and areas considered in this chapter *(continued)*

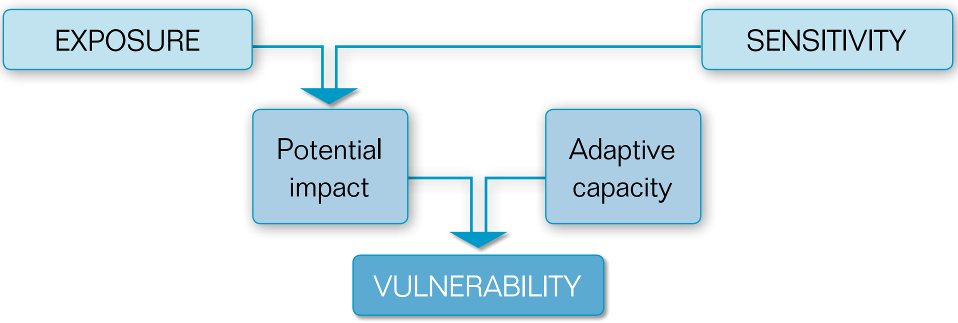
Sector or area	Discussed in this chapter	Modelled by the Review
Ecosystems and biodiversity		
Subsector or area		
Considers a range of ecosystems and impacts on plants and animals	Yes	No
Changes in demand and terms of trade	Yes	Yes
Geopolitical stability		
Subsector or area		
Geopolitical instability in the Asia–Pacific region and the subsequent aid and national security response from Australia	Yes	No
Catastrophic events as affect Australia		
	Yes	No
Severe weather events in Australia		
	Yes	No

7.1 Understanding Australia's vulnerability to climate change

The effect of climate change on the Australian population and our natural assets will depend on our *exposure* to changes in the climate system (as discussed in Chapter 3), our *sensitivity* to those exposures and whether we have the capacity to adapt to the changes to which we are sensitive. This concept, which constitutes our *vulnerability* to climate change, is illustrated in Figure 7.1.

Australia's level of exposure and sensitivity to the impacts of climate change are high. The extent to which these impacts are realised will depend on the success and timing of global greenhouse gas mitigation and on national adaptation efforts.

Figure 7.1 Vulnerability and its components



As a nation, Australia has a high level of capacity to plan for and respond to the impacts of climate change—that is, its adaptation potential is high. Australia has a well-developed and flexible economy with high per capita income, advanced scientific and technological knowledge, low population densities, strong emergency management capabilities, and abundant natural resources.

Several chapters in the final report will focus on Australia's adaptation challenge. This chapter focuses on Australia's exposure and sensitivity to climate change.

Unless otherwise stated, the consideration of impacts in this chapter assumes adaptation at the level of an individual or firm (autonomous adaptation), rather than economy-wide. Autonomous adaptation is likely to occur gradually, as impacts are felt but require little policy intervention.

7.2 Implications of the no-mitigation case for Australia

If global development were to continue along a no-mitigation path, the mainstream science tells us that the impacts of climate change on Australia are likely to be severe.

For the next two decades or so, the impacts of climate change are likely to be dominated by stressed urban water supply and the effects of changes in temperature and water availability on agriculture. Already all major cities and many regional centres are feeling the strain of declining rainfall and runoff into streams. Some cities are commencing the development of high-cost infrastructure for alternative water sources. In a no-mitigation case, the development of this infrastructure is likely to be a necessity.

By mid century the no-mitigation case is likely to lead to major declines in agricultural production across much of the country. Irrigated agriculture in the Murray-Darling Basin is likely to lose half of its annual output. This would lead to changes in our capacity to export food and a growing reliance on food imports, with associated shifts from export parity to import parity pricing.

A no-mitigation case is likely also to see the mid century effective destruction of the Great Barrier Reef. The three-dimensional coral of the reef is likely to disappear. This will have serious ramifications for marine biodiversity and the tourism and associated service industries reliant on the reef.

By the close of the century, the impacts of a no-mitigation case, at the median of the probability distributions of mainstream science's assessment of the range of possible impacts, are profound. The increased frequency of drought, combined with decreased median rainfall and a nearly complete absence of runoff in the Murray-Darling Basin, is likely to have ended irrigated agriculture for this region, and depopulation will be under way.

The increased incidence of heatwaves and hot days is likely to lead to about 4000 more deaths across Queensland annually. The rise in temperatures is likely to have caused the end of snow-based tourism.

Much coastal infrastructure along the early 21st century lines of settlement is likely to be at high risk of damage from storms and flooding.

Key Australian export markets are projected to have significantly lower economic activity as a result of climate change. This is likely to feed back into significantly lower Australian export prices and terms of trade. As fragile states in our Asia–Pacific neighbourhood are further weakened by the effects of climate change in a no-mitigation case, we can expect the Australian Defence Force and Australian Federal Police to be more heavily committed in support of peacekeeping operations.

Australians will be substantially wealthier in 2100 in terms of access to goods and services, despite any setbacks from climate change. They are likely to be substantially poorer in terms of environmental amenity of various kinds. Australians over a century of change will have demonstrated the capacity to adapt in various ways. In some regions, retreat will have been the only viable strategy.

If the world were to have agreed and implemented global mitigation so that greenhouse gas concentrations were stabilised at 450 ppm or even 550 ppm carbon dioxide equivalent (CO_2-e), then the story of risks of impacts for Australia could be radically different. The differences are summarised in Table 7.2, again in terms of the median of the probability distributions emerging from the assessments of contemporary mainstream science. For some sectors, the difference between the median of the distributions at 550 ppm to 450 ppm CO_2-e is material.

Table 7.2 Differences between probable unmitigated and mitigated futures at 2100

Sector	No mitigation	Mitigation	
		550 ppm CO_2-e	450 ppm CO_2-e
Irrigated agriculture in the Murray-Darling Basin	92% decline in irrigated agricultural production in the Basin, affecting dairy, fruit, vegetables, grains.	20% decline in irrigated agricultural production in the Basin.	6% decline in irrigated agricultural production in the Basin.
Natural resource–based tourism (Great Barrier Reef and Alpine areas)	Catastrophic destruction of the Great Barrier Reef. Reef no longer dominated by corals.	Disappearance of reef as we know it, with high impact to reef-based tourism. Three-dimensional structure of the corals largely gone and system dominated by fleshy seaweed and soft corals.	Mass bleaching of the coral reef twice as common as today.
	Snow-based tourism in Australia is likely to have disappeared. Alpine flora and fauna highly vulnerable because of retreat of snowline.	Moderate increase in artificial snowmaking.	
Water supply infrastructure	Up to 35% increase in the cost of supplying urban water, due largely to extensive supplementation of urban water systems with alternative water sources.	Up to 5% increase in the cost of supplying urban water. Low-level supplementation with alternative water sources.	Up to 4% increase in the cost of supplying urban water. Low-level supplementation with alternative water sources.
Buildings in coastal settlements	Significant risk to coastal buildings from storm events and sea-level rise, leading to localised coastal and flash flooding and extreme wind damage.	Significantly less storm energy in the climate system and in turn reduced risk to coastal buildings from storm damage.	Substantially less storm energy in the climate system and in turn greatly reduced risk to coastal buildings from storm damage.
Temperature-related death	Over 4000 additional heat-related deaths in Queensland each year. A 'bad-end story' (10% chance) would lead to more than 9500 additional heat-related deaths in Queensland each year.	Fewer than 80 additional heat-related deaths in Queensland each year.	Fewer deaths in Queensland than at present because of slight warming leading to decline in cold-related deaths.

Table 7.2 Differences between probable unmitigated and mitigated futures at 2100 *(continued)*

Sector	No mitigation	Mitigated 550 ppm CO_2-e	Mitigated 450 ppm CO_2-e
Dengue virus	5.5 million Australians exposed to Dengue virus.	720 000 Australians exposed to Dengue virus.	
Geopolitical stability in the Asia–Pacific region	Sea-level rise beginning to cause major dislocation in coastal megacities of south Asia, south-east Asia and China and displacement of people in islands adjacent to Australia.	Substantially lower sea-level rise anticipated and in turn greatly reduced risk to low-lying populations.	

Note: The assessment of impacts in this table does not build in centrally coordinated adaptation. The median of the probability distribution is used for the scenarios considered.

7.3 Direct impacts of climate change on Australia

7.3.1 Resource-based industries and communities

Climate variability has long posed a challenge to Australian communities and industries that rely on access to or use of natural resources. This challenge is now compounded by risks of human-induced climate change. Australia's forestry, mining, horticulture and natural resource–based tourism are actively exploring the implications of climate change on their operations.

In this section the Review presents the impacts of climate change on:

- agriculture (irrigated agriculture in the Murray-Darling Basin and dryland cropping)
- natural resource–based tourism.

Agriculture

Climate change is likely to affect agricultural production through changes that include changes in water availability, water quality and temperatures. Crop production is likely to be affected directly by changes in average rainfall and temperatures, and by changes in distribution of rainfall during the year. The productivity of livestock industries will be influenced by the changes in the quantity and quality of available pasture, as well as by the direct effects of temperature changes, and the increased likelihood of greater extreme temperatures inducing heat stress in livestock (Adams et al. 1999).

Some impacts are potentially positive. Increases in carbon dioxide concentration will have positive carbon fertilisation effects by increasing the rate of photosynthesis in some plants where there is adequate moisture to support it (Steffen & Canadell 2005). There is some trade-off: higher concentrations of carbon dioxide could also reduce crop quality, by lowering the content of protein and trace elements (European Environment Agency 2004). The positive impacts of carbon fertilisation are likely to be restricted by higher temperatures and lower rainfall, which are both expected to become more important through the 21st century. A 10 per cent reduction in rainfall would be likely to remove the carbon dioxide benefit (Howden et al. 1999; Crimp et al. 2002).

Severe weather events such as bushfire and flooding are likely to reduce agricultural production by decreasing crop yields and increasing stock losses (Ecofys BV 2006). Changes in temperatures are also projected to alter the incidence and occurrence of pests and diseases. For example, Queensland fruit fly is expected to spread southwards in response to future higher temperatures, reducing yields and increasing costs to the Australian agriculture sector (ABARE 2007).

Irrigated agriculture in the Murray-Darling Basin

The Murray-Darling Basin covers over one million square kilometres of south-eastern Australia. Water flows from inside the Great Dividing Range from Queensland, New South Wales, the Australian Capital Territory and Victoria, eventually draining into the Southern Ocean in South Australia.

The Basin produces more than 40 per cent of Australia's total gross value of agricultural production, utilises over three-quarters of the total irrigated land in Australia, and consumes 70 per cent of Australia's irrigation water (ABS 2007a).

The Review considered the impacts of climate change on several different irrigated production groups: beef and sheep products, dairy, other livestock, broad-acre (cotton, rice and other grains), and other agriculture (grapes, stone fruit and vegetables).

A crucial feature of the analysis is that inflows to river systems vary much more than precipitation, and particularly rainfall. This is because inflows are a residual variable, consisting of water flows that are not lost to evapo-transpiration, or absorbed by the soil. Jones et al. (2001) indicate that a 10 per cent reduction in precipitation will generate a reduction in inflows of at least 35 per cent. Similarly a 10 per cent increase in evaporation will reduce inflows by around 8 per cent. Thus, quite modest changes in precipitation and evaporation could reduce inflows substantially. For the Review modelling, the reductions in runoff were capped at 84 per cent based on advice from R. Jones (2008, pers. comm.).

In aggregating our findings across all production groups the Review found big differences between the implications of a no-mitigation case and one of global mitigation. The differences between runoff levels and consequently economic activity within the Basin have large implications for the viability of many aspects of life in the Murray-Darling. The change in economic value of production in the Murray-Darling Basin from a world with no human-induced climate change through to 2100 is presented in Table 7.3.

Table 7.3 Decline in value of irrigated agricultural production in the Murray-Darling Basin out to 2100 from a world with no human-induced climate change

	No-mitigation case	Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100	Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100	Hot, dry extreme case (the 'bad-end story')
Year	Decline in economic value of production (%)			
2030	12	3	3	44
2050	49	6	6	72
2100	92	20	6	97

Note: Moving from left to right, the first three cases are 'best estimate' cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see 7A for a description of each case). The fourth case is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).

In an unmitigated case, irrigation will continue in the Basin in the immediate term. Later in the century, decreasing runoff and increased variation in runoff are likely to limit the Basin's ability to recharge storages. By 2030 economic production falls by 12 per cent. By 2050 this loss increases to 49 per cent and, by 2100, 92 per cent has been lost due to climate change. Beyond 2050 fundamental restructuring of the irrigated agriculture industry will be required.

If the world were to achieve ambitious stabilisation of greenhouse gas concentrations to 450 ppm CO_2-e by 2100, it is very likely that producers would be able to adjust their production systems with greater efficiency and technological improvement (not modelled) to adapt with little cost to overall economic output from the Basin under this scenario. By 2030 economic production falls by 3 per cent. By 2050, this loss increases to 6 per cent. By 2100, 20 per cent has been lost due to climate change.

While the differences between economic output in the 450 and 550 ppm CO_2-e mitigation cases are not substantial until the end of the century, the additional considerations of environmental flows and water quality in the Basin create a presumption that there is greater value in ambitious global mitigation.

In the 10th percentile hot, dry case, by 2050 the rivers in the Basin would barely be flowing. This would be well outside of the range of natural variation observed in the historical record. By 2070 all except one catchment would be operating on the maximum possible reduction on which the model has been allowed to run (84 per cent decline in runoff from baseline). By 2030 economic production falls by 44 per cent. By 2050, 72 per cent of production has been lost. By 2100, 97 per cent has been lost. Only opportunistic upstream production might persist in 2100.

Box 7.1 Is there potential for a positive irrigation story? The possibility of a wetter Murray-Darling Basin

Mainstream contemporary science says that there is a 10 per cent chance of Australia becoming wetter under a no-mitigation case. This would be associated with a significant increase in rainfall in the northern part of the Murray-Darling Basin by 2050 (that is, a 20–30 per cent increase). The increased water supply flowing south would support greater flexibility in commodity choices.

Under a warm, wet no-mitigation case the average value of irrigated agriculture in the Murray-Darling Basin would increase from a world with no human-induced climate change by less than 1 per cent over the century.

Dryland cropping: wheat

Wheat is the major crop in Australia in terms of value ($5.2 billion in 2005–06), volume (25 Mt in 2005–06) and area (12.5 Mha in 2005–06) (ABARE 2008). On average, over the past 10 years to 2005–06, about 80 per cent of the Australian wheat harvest has been exported, worth on average about $3.2 billion a year (ABARE 2008). Yields are generally low due to low rainfall, high evaporative demand and low soil fertility and can vary by as much as 60 per cent in response to climate variability (Howden & Crimp 2005). Thus the Australian wheat industry is highly sensitive to climatic influences.

The value of wheat is based on both quantity and quality (protein content), which determines market price and end use. A range of studies indicate that grain protein contents are likely to fall in response to combined climate and carbon dioxide changes. There could be protein losses of 4–14 per cent (Howden et al. 2001), which would significantly downgrade prices unless fertiliser application or pasture rotations were incorporated to reduce the effect (Crimp et al. 2008). Increases in heat shock also may reduce grain quality by affecting dough-making qualities (Crimp et al. 2008).

The Review considered 10 study sites to understand the difference in magnitude of impacts on wheat yield between a no-mitigation case and one of global mitigation. The results are presented in Table 7.4.

As Table 7.4 shows, there are markedly different yield impacts between regions and also between the no-mitigation case and the global mitigation cases.

Table 7.4 Percentage cumulative yield change from 1990 for Australian wheat under four climate cases

	No-mitigation case		Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100		Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100		Hot, dry extreme case (the 'bad-end story')	
	Cumulative yield change (%)							
	2030	2100	2030	2100	2030	2100	2030	2100
Dalby, Qld	8.2	-18.5	4.8	-1.0	1.6	-3.7	-6.6	-100.0
Emerald, Qld	7.2	-10.1	4.4	0.0	1.8	-2.5	-7.6	-100.0
Coolamon, NSW	11.6	1.9	9.9	12.3	8.2	7.4	1.2	-100.0
Dubbo, NSW	8.1	-5.9	6.1	6.7	4.0	2.3	-2.4	-100.0
Geraldton, WA	12.5	22.4	9.7	5.6	6.9	2.6	9.5	-16.9
Birchip, Vic.	14.8	-24.1	10.7	1.5	6.8	-0.3	-0.7	-100.0
Katanning, WA	15.6	16.8	14.8	18.9	13.9	14.6	-15.7	-18.7
Minnipa, SA	0.8	-23.9	-3.4	-15.3	-7.4	-15.7	-13.8	-82.0
Moree, NSW	20.6	10.9	17.7	14.1	14.8	10.8	6.4	-79.2
Wongan Hills, WA	16.1	-21.8	13.0	5.5	10.0	4.4	5.5	-100.0

Note: Moving from left to right, the first three cases are 'best estimate' cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see 7A for a description of each case). The fourth case is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).

Under the no-mitigation case and through adaptive management much of Australia could experience an increase in wheat production by 2030. This is attributable to the farm-scale (autonomous) adaptive management considered (that is, moving planting times in response to warming and selection of optimal production cultivars) and increases in growth and water-use efficiency resulting from higher carbon dioxide concentrations. Over time, even with adaptive management considered, a number of regions may experience substantial declines in wheat yield. This is particularly evident later in this century. At this stage the benefits of carbon dioxide fertilisation and adaptive management are likely to have been negated by increasing temperatures and declining available water.

In some Western Australian sites (that is, Geraldton and Katanning) the rainfall changes associated with the no-mitigation case serve to improve yields. This unexpected result arises as sub-soil constraints to growth e.g. salinity is reduced in response to less annual rainfall. This beneficial impact is only simulated for modest rainfall declines (that is, less than 30 per cent of the long-term annual mean) with yields negatively affected with larger declines.

Under the global mitigation cases, the carbon dioxide fertilisation effect is less marked and yield increases are lower than for the no-mitigation case. However, by 2100 for those regions that under the no-mitigation case were facing large declines in yield, this impact is reduced substantially with global mitigation.

The hot, dry extreme case has devastating consequences for the Australian wheat industry, leading to complete abandonment of production for most regions.

In interpreting these findings it should be noted that the cases above use *average* change in temperature and rainfall, and therefore available runoff, as the key variables. The approach implicitly assumes that there is *no change* in either the frequency or intensity of El Niño/La Niña events with climate change. There is concern in mainstream science, however, that El Niño frequencies may increase, thus changing the proportion of good and bad years. This may cause the net impact on wheat to be different from the average change in rainfall (Crimp et al. 2008). A world of climate change would be associated with less predictability of rainfall, generating large problems for management of farm systems to make optimal use of available water resources.

Natural resource–based tourism

The Australian tourism industry generated value added of $37.6 billion per annum or 3.7 per cent of GDP for 2006–07 (ABS 2008a). International tourism generated $21 billion of export income in 2005–06, or 10.5 per cent of total exports (ABS 2008b).

In 2006–07, 482 000 people were employed in the tourism industry, or 4.7 per cent of total employment (ABS 2007a). Tourism is often the major non-agricultural source of livelihoods in rural and regional areas, and is the major industry in some regions.

Australia's natural landscapes are important to the Australian tourism industry. The Great Barrier Reef and rainforests of tropical north Queensland, Kakadu, the deserts of Central Australia, the coastal environs of south-west Western Australia and the alpine regions of New South Wales and Victoria are leading examples of tourist attractions defined by features of the natural environment.

Each of these attractions, and many that are less well known, would be significantly affected in a future of unmitigated climate change. Climate change would lead to loss of attractions; loss of quality of attractions; increased cost of adaptation; increased cost for repair, maintenance and replacement of tourism capital; and increased cost for developing alternative attractions (Sustainable Tourism Cooperative Research Centre 2007).

Some tourist destinations may benefit from drier and warmer conditions—perhaps beach-based activities, viewing of wildlife, trekking, camping, climbing and fishing outside the hottest times of the year. However, greater risks to tourism are likely from increases in hazards such as flooding, storm surges, heatwaves, cyclones, fires and droughts.

In a study by Hoegh-Guldberg (2008), 77 Australian tourism regions were assessed for prospective risk of climate change. Among the 77 tourism regions, the following three were identified as the most threatened:

- **Tropical north Queensland**, the hub of Great Barrier Reef tourism, contains the coral reef, severely threatened rainforest areas, beaches in danger of inundation and increasing storm damage (see also Box 7.4). There are threats to tourism from increased incidence of bushfires and increased ultraviolet radiation. The threats to the region are exacerbated by a high reliance on international holiday tourism, which could be relatively easily diverted elsewhere.
- **South-west Western Australia** is the scene of Australia's only internationally recognised biodiversity hotspot, one of only 34 in the world. It has high risk ratings based on the greatest diversity of vulnerable native flora, a vulnerable wine industry and, together with the Murray-Darling Basin, the greatest salinity problem in the country. It attracts a large number of holiday tourists, but few are international visitors.
- In the **Top End** of the Northern Territory, national parks and wetlands are at risk, and tourism is threatened by increased ultraviolet radiation and increased exposure to disease. This area also attracts many holiday tourists; more than one-fifth of bed nights represent inbound holiday visitors.

The same study offers the following observations on state-by-state threats:

- Queensland is most at risk from climate change in terms of absolute number of tourist nights, especially the tropical north. The Gold and Sunshine coasts may retain some relative advantages despite the risk of sea-level rise, storm surges and rising summer temperatures.
- Western Australia has the largest number of regions at relatively high risk.
- New South Wales is rated at moderate risk (except its northern regions), and the southern states of Victoria, South Australia and Tasmania at least risk overall. This does not mean that these states or individual regions within them are without risk. For example, the Victorian Alpine region (see Box 7.2) would be heavily affected.

Australia is likely to be greatly diminished as an international tourist destination by climate change.

Domestically, the loss of tourism income from one region, such as the Great Barrier Reef, does not necessarily equate with overall loss of tourism income for Australia. Some of the tourism expenditure will be diverted to other Australian regions.

Box 7.2 Alpine tourism in south-east Australia

The alpine resorts in Australia are located in areas of great environmental sensitivity and are at severe risk from climate change. The total alpine environment in Australia is small: approximately 0.2 per cent of the total land mass, with alpine areas restricted to New South Wales, Victoria and Tasmania.

The alpine resorts across New South Wales, Victoria and Tasmania generate 2 per cent of total Australian tourist activity (National Institute of Economic and Industry Research 2006). The industry is characterised by many small businesses, a large proportion of which only operate during the snow sports season, a period of around four months.

In the alpine regions of south-east Australia natural snow conditions over the past 35 years have been in slow but steady decline, with increased maximum and minimum temperatures across many locations (Hennessy et al. 2003). This has created greater reliance by the ski industry on the production of artificial snow to service tourism demand (for snow depths and season length). There have also been implications for sensitive alpine flora and fauna due to changing snow conditions (see discussion in section 7.3.4).

The no-mitigation case would see the average snow season contract by between 85 to 96 per cent by 2050 (Hennessy et al. 2003) and to disappear before the end of the century. Conversely, if the international community were to achieve stabilisation of 450 ppm CO_2-e by 2100, snow depths and coverage would fall only marginally. In this latter case, it is likely that alpine resorts could continue their current operations with minimal technological adaptation. Stabilisation at 550 ppm CO_2-e by 2100 would be likely to result in maintenance of snow depth and coverage at higher elevations. However, the alpine areas located at lower elevations would experience a loss of snow coverage as the snow line moves to higher ground.

As many as a third of all visitors to the alpine region visit outside the traditional snow season, to enjoy the unique flora and fauna, as well as recreational activities such as hiking, camping and fishing. However, summer recreational activities are also at increasing risk of bushfires and storm and wind events.

7.3.2 Critical infrastructure

Climate change will have wide-ranging and significant impacts on the infrastructure critical to the operation of settlements and industry across Australia. This will occur through changes in the average climate and changes in the frequency and intensity of extreme events.

Buildings and infrastructure being constructed now have projected functional lives of many decades and longer. Therefore, an understanding of the anticipated impacts from climate change over the course of the century is helpful to inform construction decisions being made now, and to avoid increased future operation and maintenance costs or the early retirement of infrastructure.

This section presents the impacts of climate change on two key forms of infrastructure:

- water supply infrastructure in major cities
- buildings in coastal settlements.

The Review offers a broad commentary on the magnitude of impacts in a no-mitigation case compared to a future with global mitigation.

Water supply infrastructure in major cities

Nearly all major Australian cities are already experiencing the effects of reductions in rainfall on water supplies. All capital cities except Darwin and Hobart are now relying on severe restrictions on water use. Some regional cities are facing sharply diminished supply and extreme restrictions (Marsden Jacob Associates 2006).

Under a no-mitigation case, with outcomes near the median of the probability distributions generated by mainstream Australian science, most major population centres across the country will be required to substantially supplement their water supply system with alternative water sources through the 21st century. As shown in Table 7.5, there will be differing impacts across the states and territories, with Western Australia and South Australia the most severely affected by climate change–induced water scarcity. The development of alternative water sources for Perth and Adelaide will require a significant response in the short term.

In a case of global mitigation, the reduced level of temperature increase relative to the no-mitigation case has the effect of lessening the changes in rainfall and evaporative demand, and therefore creating less stress on water supply. However, a low level of additional supplementation would still be required across most major centres.

Buildings in coastal settlements

More than 80 per cent of the Australian population lives within the coastal zone, that is, within 50 kilometres of the coastline. In recent years coastal regions have experienced significant growth and are projected to continue to show the most rapid population growth (IPCC 2007).

In a no-mitigation case, the impacts of climate change are likely to be substantial. This can be seen in Table 7.6.

The increased magnitude of storm events and sea-level rise under a no-mitigation case are likely to exert significant pressure on coastal infrastructure in the form of storm damage, inundation and localised flash flooding. This would cause immediate damage to assets, particularly building contents, and accelerate the degradation of buildings.

Table 7.5 Magnitude of impacts to water supply infrastructure in major cities under four climate cases

	No-mitigation case		Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100		Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100		Hot, dry extreme case (the 'bad-end story')	
Region	2030	2100	2030	2100	2030	2100	2030	2100
ACT	M	E	M	L	M	L	H	E
NSW	H	E	H	L	H	L	H	E
NT	L	H	L	N	N	N	L	E
Qld	H	E	H	L	H	L	H	E
SA	E	E	E	M	E	M	E	E
Tas.	N	M	N	N	N	N	N	E
Vic.	H	E	H	M	H	L	H	E
WA	E	E	E	M	E	M	E	E

Magnitude of net impact	
N	Neutral
L	Low
M	Moderate
H	High
E	Extreme

Note: Moving from left to right, the first three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see 7A for description of each case). The fourth case is an illustrative 'bad-end' story that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).
A description of each level of impact is provided in 7B.

Changes in temperature, and extreme rainfall and wind, may also accelerate degradation of materials, structures and foundations of buildings, thereby reducing the life expectancy of buildings and increasing their maintenance costs. Low soil moisture before severe rainfall events would increase the impact and magnitude of flooding. In between flooding episodes the low levels of soil moisture would lead to increased ground movement and generate degradation in building foundations.

In the medium term (2030 to 2070) the cost of climate change for coastal settlements would mainly arise from repair and increased maintenance, clean up and emergency response. Later in the century costs for preventive activity are likely to be higher. There will be large costs associated with altered building design, higher sea-wall protection and higher capital expenditure for improved drainage.

Changes to building design are expected to improve the resilience of buildings in the latter part of the century as stock is renewed or replaced. However, even with improved standards, the magnitude of climate change leading up to 2100 under a no-mitigation case is expected to generate high impacts.

In a future with global mitigation, the reduced level of temperature increase relative to the no-mitigation case would lessen the magnitude of temperature-driven storm energy in the Australian climate system, and impacts from storm surge, extreme rainfall and flash flooding. As shown in Table 7.6, overall impacts to buildings in coastal settlements would be substantially lower under the global mitigation cases.

Table 7.6 Magnitude of impacts on buildings in coastal settlements under four climate cases

	No-mitigation case		Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100		Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100		Hot, dry extreme case (the 'bad-end' story)	
Region	2030	2100	2030	2100	2030	2100	2030	2100
NSW	M	H	M	M	M	M	M	E
NT	L	M	L	M	L	L	L	H
Qld	M	E	M	M	M	M	M	E
SA	L	H	L	M	L	L	L	H
Tas.	L	M	L	M	L	N	L	M
Vic.	M	H	M	M	M	L	M	H
WA	L	M	L	M	L	L	L	H

	Magnitude of net impact
N	Neutral
L	Low
M	Moderate
H	High
E	Extreme

Note: Moving from left to right, the first three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see 7A for a description of each case). The fourth case is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme). The Australian Capital Territory is not included in this assessment as it does not have any coastline.
A description of each level of impact is provided in 7B.

7.3.3 Human health

Climate change is likely to affect the health of Australians over this century in many ways. Some impacts will become evident before others. Some, such as heatwaves, would operate directly. Others would occur indirectly through disturbances of natural ecological systems, such as mosquito population range and activity.

Most health impacts will impinge unevenly across regions, communities and demographic subgroups, reflecting differences in location, socioeconomic circumstances, preparedness, infrastructure and institutional resources, and local preventive (or adaptive) strategies. The adverse health impacts of climate change will be greatest among people on lower incomes, the elderly and the sick. People who lack access to good and well-equipped housing will be at a disadvantage.

The main health risks in Australia include:

- impacts of severe weather events (floods, storms, cyclones, bushfires, and so on)
- impacts of temperature extremes, including heatwaves
- vector-borne infectious diseases (for example, dengue virus and Ross River virus)
- food-borne infectious diseases (including those due to *Salmonella* and *Campylobacter*)
- water-borne infectious diseases and health risks from poor water quality
- diminished food production: yields, costs/affordability, nutritional consequences
- increases in air pollution (for example, from bushfire smoke)
- changes in production of aeroallergens (spores, pollens), potentially exacerbating asthma and other allergic respiratory diseases
- mental health consequences of social, economic and demographic dislocation (for example, in parts of rural Australia, and through disruptions to traditional ways of living in remote Indigenous communities)
- emotional stresses and mental health problems in children, in response to perceptions/fears of climate change and to family stresses (for example, impaired rural livelihoods).

Temperature-related death

Exposure to prolonged ambient heat promotes various physiological changes, including cramping, heart attack and stroke. People most likely to be affected are those with chronic disease (such as cardiovascular disease or type 2 diabetes). These tend to be older people.

The effects of climate change on temperature-related mortality and morbidity are highly variable over place and time. Temperature-related deaths and hospitalisations may fall at some places and times (due to fewer cold-related deaths) in some parts of Australia, but increase in others. Table 7.7 illustrates the change in the number of temperature-related deaths in Australia over time under four different climate change cases.

As shown in Table 7.7, in Australia as a whole and across all cases, small declines in total annual temperature-related deaths are expected in the first half of the century due to decreased cold-related sickness and death. The winter peak in deaths is likely to be overtaken by heat-related deaths in nearly all cities by mid century (McMichael et al. 2003).

For the no-mitigation case there is a large national increase in temperature-related deaths in the second half of the century. Much of the increase is attributable to expected deaths in Queensland and the Northern Territory. The large increases in deaths between 2030 and 2100 are avoided under the global mitigation cases.

The hot, dry extreme case would lead to twice as many temperature-related deaths annually when compared to the baseline. In Victoria, Tasmania and New South Wales, even under the hot, dry extreme case, temperature-related deaths are reduced relative to the baseline because those populations are more susceptible to cold than to heat (K. Dear 2008, pers. comm.).

Dengue virus

The dengue virus is not endemic to Australia. All outbreaks begin from an infected person who has travelled here from another country.

Epidemics of dengue appear to have recently become more regular in north Queensland, where five major epidemics (three affecting the Torres Strait) and many smaller epidemics occurred between 1992 and 2004. In contrast, the five previous epidemics occurred over 90 years (McBride 2005). Increasing international travel to north Queensland and the global amplification in dengue activity have been proposed as the main reasons for this rise.

Table 7.8 shows the estimated change from 2000 in the number and percentage of Australians exposed to dengue virus for a no-mitigation case and for global mitigation cases.

Table 7.7 Change in likely temperature-related deaths due to climate change

Region	Baseline – a world with no human-induced climate change		No-mitigation case		Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100		Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100		Hot, dry extreme case (the 'bad-end story')	
	Number of temperature-related deaths									
	2030	2100	2030	2100	2030	2100	2030	2100	2030	2100
ACT	300	333	280	250	278	285	276	295	275	262
NSW	2 552	2 754	2 316	1 906	2 290	2 224	2 268	2 334	2 255	2 040
NT	63	61	63	407	63	93	64	76	64	768
Qld	1 399	1 747	1 276	5 878	1 274	1 825	1 278	1 664	1 286	11 322
SA	806	811	770	704	766	735	762	750	758	740
Tas.	390	375	360	240	357	313	354	327	352	211
Vic.	1 788	1 966	1 632	1 164	1 614	1 586	1 599	1 673	1 589	1 012
WA	419	515	418	685	419	529	419	519	420	835
Australia	7 717	8 562	7 155	11 234	7 061	7 590	7 020	7 638	6 999	17 190

Note: Moving from left to right, in the baseline case any increase in number of deaths shown is due to the expanding and ageing of the population. The next three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see 7A for a description of each case). The final case (right-hand side) is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).

Table 7.8 Estimated change since 2000 in people exposed to dengue virus in Australia

	No-mitigation case	Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100	Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100	Warm, wet extreme case (the 'bad-end story')
Year	**Number of people exposed**			
2000	310 159	310 159	310 159	310 159
2030	539 819	539 819	539 819	539 819
2100	5 522 133	721 819	721 819	7 930 027

Note: The first three cases (left to right) are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see 7A for a description of each case). The final case (right-hand side) is an illustrative 'bad-end story' that uses the 90th percentile rainfall and relative humidity and 50th percentile temperature for Australia (a warm, wet extreme).

Under the no-mitigation case the geographic region suitable for the transmission of dengue is expected to move south along the east coast from its current position in the far north (Cairns region). Under this case the climate becomes suitable for dengue transmission in Mackay by 2050, Brisbane by 2075 and northern New South Wales by 2095. Substantial control measures by public health authorities will be needed to respond to this extended range to avert more frequent and larger epidemics. The global mitigation cases show far less expansion of areas suitable for dengue transmission.

Given the uncertainty in projections for precipitation, the Review explored the 10th percentile wetter case. For the dengue virus this case leads to a far more hospitable environment for mosquito survival. By 2100 under this warm, wet case nearly eight million Australians would be exposed to the dengue virus.

7.3.4 Ecosystems and biodiversity

Natural biological systems in Australia have been dramatically altered by human actions. The added stressors from climate change would exacerbate existing environmental problems, such as widespread loss of native vegetation, overharvesting of water and reduction of water quality, isolation of habitats and ecosystems, and the influence of introduced pest plant and animal species.

The impacts of climate change on Australia's biodiversity and ecosystems will be uneven. Some species can tolerate the changes where they are or adapt to change. Other species will move to more suitable habitat if possible. Some species may dwindle in numbers in situ, threatening their viability as a species and ultimately leading to extinction.

For biological systems, climate change will affect:

- physiology (individual organisms)
- timing of life cycles (phenology)
- population processes, such as birth and death rates
- shifts and changes in distribution (dispersal and shifts in geographic range)
- potential for adaptation (rapid evolutionary change).

These effects on individual organisms and populations cascade into changes in interactions among species. Changes in interactions further heighten extinction rates and shifts in geographic range. The ultimate outcomes are expected to be declines in biodiversity favouring weed and pest species (a few native, most introduced) at the expense of the rich variety that has occurred naturally across Australia.

Many plant and animal species depend on the wide dispersal of individuals for both demographic processes and interchange of genes to avoid inbreeding effects. Over large areas and long periods, many species will respond (and have already responded) to climate change by moving, resulting in geographic range shifts. However, some species will not be able to migrate or adapt to climate change because they lack a suitable habitat into which to move, have limited or impeded mobility or do not possess sufficient and necessary genetic diversity to adapt. For these species, their geographic ranges would contract, heightening the risk of extinction.

Australia's high-altitude species are at risk. These species are already at their range limits due to the low relief of Australia's mountains, and lack suitable habitat to which to migrate. For example, a 1°C temperature rise, anticipated in about 2030 for south-eastern Australia under all four cases, will eliminate 100 per cent of the habitat of the mountain pygmy possum (*Burramys parvus*). This species cannot move to higher mountains because there are no such mountains, and will not be able to stay where it is because it does not have the capacity to adapt to warmer temperatures. The potential for extinction is high.

The wet tropics of far north Queensland are also likely to face high levels of extinction. It is estimated that a 1°C rise in temperature, anticipated before 2030 under all four cases, could result in a 50 per cent decrease in the area of highland rainforests (Hilbert et al. 2001). A 2°C rise in average temperatures (anticipated about 2050 for the no-mitigation case, 2070 for 550 ppm CO_2-e, and after 2100 for 450 ppm CO_2-e) would force all endemic Australian tropical rainforest vertebrates to extinction (Australian Centre for Biodiversity 2008).

Sea-level rise would have implications for coastal freshwater wetlands that may become inundated and saline. A well-documented example is the World Heritage and Ramsar Convention–recognised wetlands of Kakadu National Park in the Northern Territory. The wetland system at Kakadu depends on a finely balanced interaction between freshwater and marine environments. In places, the natural levees that act as a barrier between Kakadu's freshwater and saltwater systems are only 20 cm high. Sea-level rises of another 59 cm (thermal expansion only) by 2100 would adversely affect 90 per cent of the Kakadu wetland system. Rising sea levels will erode the levees from the seaward side and make the freshwater sections vulnerable to storm surges. The area supports more than 60 species of water birds, which congregate around freshwater pools in the wetlands. The coastal wetlands are important nursery areas for barramundi, prawns and mud crabs, and are key breeding habitats for crocodiles, turtles, crayfish, water snakes and frogs. Fundamental changes in the ecological function of the national park will place severe pressure on many species of plants and animals.

Increased warming of Australia's oceans has pushed coral reefs above their thermal tolerance. This has resulted in episodes of mass coral bleaching (see Box 7.3).

Box 7.3 Climate change and the Great Barrier Reef

The Great Barrier Reef is the world's most spectacular coral reef ecosystem. Lining almost 2100 kilometres of the Australian coastline, the Reef is the largest continuous coral reef ecosystem in the world. It is home to a wide variety of marine organisms including six species of marine turtles, 24 species of seabirds, more than 30 species of marine mammals, 350 coral species, 4000 species of molluscs and 1500 fish species. The total number of species is in the hundreds of thousands. New species are described each year, and some estimates suggest that we may be familiar with less than 50 per cent of the total number of species that live within this ecosystem.

In addition to housing a significant part of the ocean's biodiversity, coral reefs provide a barrier that protects mangrove and sea grass ecosystems, which in turn provide habitat for a large number of fisheries species. This protection is also important to the human infrastructure that lines the coast.

The Great Barrier Reef is threatened by increased nutrients and sediments from land-based agriculture, coastal degradation, pollution and fishing pressure. Climate change is an additional and significant stressor.

The IPCC recognises coral reefs globally as highly threatened by rapid human-induced climate change (IPCC 2007).

The Great Barrier Reef waters are 0.4°C warmer than they were 30 years ago (Lough 2007). Increasing atmospheric carbon dioxide has also resulted in 0.1 pH decrease (that is, the ocean has become more acidic).

These changes have already had major impacts. Short periods of warm sea temperature have pushed corals and the organisms that support their development above their thermal tolerance. This has resulted in episodes of mass coral bleaching that have increased in frequency and intensity since they were first reported in the scientific literature in 1979 (see Brown 1997; Hoegh-Guldberg 1999; Hoegh-Guldberg et al. 2007).

The Great Barrier Reef has been affected by coral bleaching as a result of heat stress six times over the past 25 years. Recent episodes have been the most intense and widespread. In the most severe episode to date, in 2002, more than 60 per cent of the reefs within the Great Barrier Reef Marine Park were affected by coral bleaching, with 5–10 per cent of the affected corals dying.

Consideration has recently been given to how reef systems will change in response to changes in atmospheric greenhouse gas composition. If atmospheric carbon dioxide levels stabilise at 420 ppm and the sea temperatures of the Great Barrier Reef increase by 0.55°C, mass bleaching events will be twice as common as they are at present.

Box 7.3 Climate change and the Great Barrier Reef *(continued)*

If atmospheric carbon dioxide concentrations increase beyond 450 ppm, together with a global temperature rise of 1°C, a major decline in reef-building corals is expected. Under these conditions, reef-building corals would be unable to keep pace with the rate of physical and biological erosion, and coral reefs would slowly shift towards non-carbonate reef ecosystems. Reef ecosystems at this point would resemble a mixed assemblage of fleshy seaweed, soft corals and other non-calcifying organisms, with reef-building corals being much less abundant, even rare. As a result, the three-dimensional structure of coral reefs would slowly crumble and disappear.

Depending on the influence of other factors such as the intensity of storms, this process may happen either slowly or rapidly. Significantly, this has happened relatively quickly (over an estimated 30 to 50 years) on some inshore Great Barrier Reef sites.

A carbon dioxide concentration of 500 ppm or beyond, and likely associated temperature change, would be catastrophic for the majority of coral reefs across the planet. Under these conditions the three-dimensional structure of the Great Barrier Reef would be expected to deteriorate and would no longer be dominated by corals or many of the organisms that we recognise today. This would have serious ramifications for marine biodiversity and ecological function, coastal protection and the tourism and associated service industries reliant on the reefs.

(Hoegh-Guldberg & Hoegh-Guldberg 2008)

The disruption of ecosystems, species populations and assemblages will also affect ecosystem services—the transformation of a set of natural assets (soil, plants and animals, air and water) into things that we value. These include clean air, clean water and fertile soil, all of which contribute directly to human health and wellbeing. Often the productivity of our natural resource–based industries such as agriculture and tourism depends on them.

The vast majority of ecosystem services are far too complex to implement by engineering, even with the most advanced technologies. Their benefits are poorly understood but seem to be large. Human-induced environmental change has already disrupted ecosystem processes. Climate change will further degrade the services provided. The complex biotic machinery that provides ecosystem services is being disrupted and degraded. The consequences are impossible to predict accurately.

7.4 Indirect impacts of climate change on Australia

Australia will be affected indirectly by climate change as experienced by other countries.

This section discusses two areas of indirect impact:

- implications of changes in demand for Australian export products and the prices received for Australian goods on the world market
- implications for Australia of geopolitical instability in its Asian and south-west Pacific neighbourhood.

7.4.1 International trade impacts for Australia

Climate change is likely to affect economic activity in other countries. It will therefore affect the supply of imports to Australia and demand for Australian exports and consequently Australia's terms of trade (the ratio of Australian export and import prices). Australia is projected to be the developed economy whose terms of trade are most adversely affected by climate change (Chapter 9).

The key Australian export markets in China, India, Indonesia and elsewhere in Asia are projected to have significantly lower economic activity as a result of climate change.

A slowdown in global economic activity in other countries would be associated with a decline in international demand for Australia's mineral and energy resources and agricultural products.

The decline in Australia's overall terms of trade as a result of climate change damages will be driven primarily by falls in the prices received for coal, other minerals and agricultural products. These commodities are projected to account for over 60 per cent of the value of Australia's exports in 2100.[1]

7.4.2 Geopolitical stability in Asia and the Pacific region

Weather extremes and large fluctuations in rainfall and temperatures have the capacity to refashion Asia's productive landscape and exacerbate food, water and energy scarcities in Asia and the south-west Pacific. Australia's immediate neighbours are vulnerable developing countries with limited capacity to adapt to climate change.

Climate change outcomes such as reduced food production, water scarcity and increased disease, while immensely important in themselves, also have the potential for destabilisation of domestic and international political systems in parts of Asia and the south-west Pacific.

Should climate change coincide with other transnational challenges to security, such as terrorism or pandemic diseases, or add to pre-existing ethnic and social tensions, the impact will be magnified.

The problems of its neighbours can quickly become Australia's, as recent history attests. Over the past decade, Australia has intervened at large cost in Bougainville, Solomon Islands and Timor-Leste in response to political and humanitarian crises. Responding to the regional impacts of climate change will require cooperative regional solutions and Australian participation.

Food security

Climate change is likely to affect food production in the Asia–Pacific region for five main reasons:

- Increased temperatures could reduce crop yields by shortening growing seasons and accelerating grain sterility in crops.
- Marine ecosystems could experience major migratory changes in fish stocks and mortality events in response to rising temperatures. Fish is the primary source of protein for more than one billion people in Asia.
- Shifts in rainfall patterns could accelerate erosion and desertification and reduce crop and livestock yields (see Box 7.4).
- Rising sea levels could inundate and make unusable fertile coastal land.
- An increase in the intensity or frequency of extreme weather events will disrupt agriculture.

Box 7.4 Asian food security and the south Asian monsoon

Much of Southeast Asia's water supply is dependent on the monsoons. Climate change may affect the nature of the south Asian monsoon (see Chapter 5). Shifts in monsoon-driven rainfall patterns and a reduction in water available for irrigation will have a serious effect on crop yields.

Asia is more dependent on irrigation than any other region of the world for growing rice and other cereals. Although less important than it once was, rice is still a vital food staple, providing 60 per cent of the carbohydrate and second-class protein consumed by Asians (Dupont 2001). If rice paddies and croplands dry out, the carrying capacity of large parts of Asia will diminish and some countries may be unable to sustain their populations without importing large quantities of food, which may be simply unaffordable for poorer nations.

The Consultative Group on International Agricultural Research (2002) has predicted that food production in Asia will decrease by as much as 20 per cent due to climate change. These forecasts are in line with IPCC projections showing significant reductions in crop yield (5–30 per cent compared with 1990) affecting more than one billion people in Asia by 2050 (Parry et al. 2004, cited in IPCC 2007).

Poorer countries with predominantly rural economies and low levels of agricultural diversification will be at most risk. They have little flexibility to buffer potentially large shifts in their production bases. Higher worldwide food prices associated with climate change, its mitigation and other factors will diminish the opportunity to seek food security from international trade—compounding biophysical constraints on production and negatively affecting both rural and urban poor (Consultative Group on International Agricultural Research 2002).

In these circumstances, it is likely that price volatility on world markets will increase, especially at times of pressure on global food supplies. Freer and more deeply integrated international markets for agricultural products would be a helpful adaptive response (this issue will be addressed in the adaptation chapters in the final report).

Water scarcity

Water flows to densely populated parts of Asia could be affected by factors in addition to disruption of the south Asian monsoon. The melting of the Himalayan glaciated regions could destabilise flows in the large rivers of south and south-east Asia and China (see Box 7.5). Water shortages, intensified by human-induced climate change, would aggravate social and political tensions and add to the internal security challenges faced by the Asia–Pacific region's developing states.

Box 7.5 The security challenge created by the melting of the Himalayan and Tibetan glaciers

The melting of the Tibetan and Himalayan glaciers (see section 5.4.2) illustrates the complex nexus of climate change, economic security and geopolitics.

Many hundreds of millions of people are dependent on the flow of these rivers for most of their food and water needs, as well as transportation and energy from hydroelectricity. Initially, flows may increase, as glacial run-off accelerates, causing extensive flooding. Within a few decades, however, water levels are expected to decline, jeopardising food production and causing widespread water and power shortages.

As water availability in China has decreased because of rising demand and diminishing fresh water reserves, China has increased its efforts to redirect the southward flow of rivers from the water-rich Tibetan high plateau to water-deficient areas of northern China. The problem is that rivers like the Mekong, Ganges, Brahmaputra and Salween flow through several states. China's efforts to rectify its own emerging water and energy problems indirectly threaten the livelihoods of millions of people in downstream, riparian states. Chinese dams on the Mekong are already reducing flows to Myanmar, Thailand, Laos, Cambodia and Vietnam. India is concerned about Chinese plans to channel the waters of the Brahmaputra to the over-used Yellow River. Should China go ahead with this ambitious plan, tensions with India and Bangladesh would almost certainly increase (Chellaney 2007).

Any disruption of flows in the Indus would be highly disruptive to Punjabi agriculture on both sides of the India–Pakistan border. It would raise difficult issues in India–Pakistan relations.

Any consequent conflicts between China and India, or India and Pakistan, or between other water-deficient regional states, could have serious implications for Australia, disrupting trade and people flows and increasing strategic competition in Asia.

(Dupont 2008a)

Infectious disease

There are serious security risks from climate change through infectious disease. Temperature is the key factor in the spread of some infectious diseases, especially where mosquitos are a vector as with Ross River virus, malaria and dengue virus. With warming, mosquitos will move into previously inhospitable areas and higher altitudes, and disease transmission seasons may last longer. A study by the World Health Organization (2002) estimated that 154 000 deaths annually were already attributable to the ancillary effects of climate change due mainly to malaria and malnutrition. The study suggests that this number could nearly double by 2020 (World Health Organization 2002).

Health problems can quickly metamorphose into a national security crisis if sufficient numbers of people are affected and there are serious economic and social consequences. However, climate change will not necessarily provide a more favourable environment for the spread of infectious diseases, since transmission rates and lethality are a function of many interrelated social, environmental, demographic and political factors. These include the level of public health, population density, housing conditions, access to clean water and the state of sewage and waste management systems, as well as human behaviour.

Severe weather events

Severe weather events such as cyclones, intense storms and storm surges pose a significant security challenge for the Asia–Pacific region, because of the death and destruction that results and the political, economic and social stresses these events place on even the most developed states. Severe events may call into question the legitimacy or competence of a national government and feed into existing ethnic or inter-communal conflicts.

As an example, the 1998 monsoon season brought with it the worst flood in living memory to Bangladesh, inundating some 65 per cent of the country, devastating its infrastructure and agricultural base and raising fears about Bangladesh's long-term future in a world of higher sea levels and more intense cyclones. More recently the Myanmar cyclone has affected an estimated 2.4 million people (OCHA 2008).

Severe weather events have the potential to generate an increasing number of humanitarian disasters requiring national and international relief. Because it has the resources and skilled personnel to respond quickly and effectively, Australia will be called upon to shoulder the brunt of any increase in emergency and humanitarian operations in its immediate neighbourhood.

Australian defence personnel and police may also be more heavily committed in support of peacekeeping and peace enforcement operations, particularly in the south-west Pacific, should already fragile states be further weakened by the effects of climate change. This will have significant cost and human resource implications. Since 1999, Australian Defence Force regional interventions have cost the federal budget on average over half a billion dollars every year, a figure that could rise significantly in the longer term with climate change (M. Thomson 2008, pers. comm.).

Sea-level rise

In Asia and the Pacific, millions of people are exposed to relatively high levels of risk from flooding because of the density of urban populations and industrial economic activity and the prevalence of high-value agriculture in coastal regions. The vulnerability of coasts varies dramatically for a given amount of sea-level rise. Small rises in mean sea level, when associated with storm surges and major coastal populations, can be devastating.

It is estimated that 105 million people in Asia would be exposed to a one-metre rise in sea level (Anthoff et al. 2006). Most of Asia's densest aggregations of people and productive lands are on coastal deltas, including the cities of Shanghai, Tianjin, Guanzhou, Hong Kong, Tokyo, Jakarta, Manila, Bangkok, Singapore, Ningbo, Mumbai, Kolkata and Dhaka. The areas under greatest threat are the Yellow and Yangtze river deltas in China; Manila Bay in the Philippines; the low-lying coastal fringes of Sumatra, Kalimantan and Java in Indonesia; and the Mekong, Chao Phraya and Irrawaddy deltas in Vietnam, Thailand and Myanmar respectively (Handley 1992; Morgan 1993).

Sea-level rise would have proportionately the most severe consequences for low-lying atoll countries in the Pacific such as Kiribati (population 78 000), the Marshall Islands (population 58 000), Tokelau (population 2000), and Tuvalu (population 9000). These small islands are highly vulnerable to sea-level rise because of their topography, high ratio of coast to land area, relatively dense populations and subsistence economies (Barnett & Adger 2003). Ultimately, human habitation may not be possible on these islands even with moderate climate change. If temperature and sea-level rises are at the high end of the forecasts, then the sea will either eventually submerge the coral atolls or groundwater will become so contaminated by salt water intrusion that agricultural activities will cease (IPCC 2007). Their small populations make them relatively easy to absorb into larger countries, and the international community and the islanders would expect Australia and New Zealand to be the main countries of resettlement.

The numbers of people exposed to small increases in sea level are much larger in Papua New Guinea (the vast wetlands west of Port Moresby to the border, and the densely populated communities in the lower reaches of the Sepik River in the north-east), in coastal and low-lying river areas of Indonesian New Guinea, and in other insular eastern Indonesia. Elementary mapping of the vulnerability of people in these areas to sea-level rise has hardly begun. The tendency for settlement to proceed to the high-tide levels in coastal and river delta areas has meant that small rises in sea level have been associated with saline intrusion into gardens and household water supplies. Village communities have been displaced by destruction of food and water supplies by unexpectedly high king tides. In addition, as Bourke (2008: 53) writes: 'There are about 100 000 people in PNG living on what have been defined as "Small Islands in Peril." These are about 140 islands smaller than 100 km^2 in size and with population densities greater than 100 persons/km^2. It is these people [who are] likely to suffer the most severe consequences of rising sea levels.'

Much of Fiji's productive land and urban areas would also be flooded if the increase is at the upper end of the IPCC forecasts, which would exacerbate ethnic tensions over land (Edwards 1999). Inter-communal strife between Indigenous Kanaks and French settlers in New Caledonia could similarly be inflamed if productive land becomes scarce and the Kanaks cannot sustain their agriculture and lifestyles on their ancestral land (Edwards 1999). For these reasons, climate change has risen to the top of the political agenda in the Pacific and will require an Australian response.

Climate refugees

Ecological stress in the form of naturally occurring droughts, floods and pestilence has been a significant factor in forcing people to migrate since the beginning of recorded history. So has war-related environmental destruction. In the future, however, climate refugees could constitute the fastest-growing proportion of refugees globally, with serious consequences for international security (Dupont 2008).

Climate-induced migration is set to play out in three distinct ways. First, people will move in response to a deteriorating environment, creating new or repetitive patterns of migration, especially in developing states. Second, there will be increasing short-term population dislocations due to particular climate stimuli such as severe cyclones or major flooding. Third, larger-scale population movements are possible. These may build more slowly but will gain momentum as adverse shifts in climate interact with other migration drivers such as political disturbances, military conflict, ecological stress and socio-economic change.

Australia will not be immune from the consequences of climate-induced migration in Asia and the Pacific. Although abrupt climate change that triggers a massive exodus of environmental refugees is unlikely, significant population displacement caused by sea-level rise, declining agricultural production, flooding, severe weather and step changes in the climate system are all distinct possibilities.

If affected states have the time and resources to anticipate and plan for such exigencies, then the security consequences may be small. Still, climate change is set to stretch the limits of adaptability and resilience in some developing states, overwhelming the carrying capacity of the land, disrupting traditional land management systems and making migration an attractive option to preserve quality of life (Edwards 1999). Poorer states could well be overwhelmed by the task confronting them, in which case Australia may experience the ripple effects of climate-induced political disturbances and even violent conflict in the region.

Boundaries and energy

The melting of the Greenland or West Antarctic ice caps and accompanying sea-level rise would throw into question established maritime boundaries and exclusive economic zones, creating tensions at sea that could have an impact on energy supplies and stimulate conflict in Australia's strategic backyard.

One aspect of the inter-relationship between climate change and energy security that has received scant attention is the impact the submergence of small atolls, rocks and low-lying islands due to sea-level rise could have on the exclusive economic zones of maritime states and disputed seabed resources, including oil and gas. This is a critically important issue since small rocks and islets are commonly used to delineate maritime boundaries and to claim vast tracts of ocean which would otherwise fall outside the exclusive economic zones of contiguous states or be designated as high seas. International law currently provides no answer to the question of what would happen to sovereignty and exclusive economic zones if an island, or even country, is submerged. In the event of significant sea level rise, the low water marks from which exclusive economic zones are measured would shift, raising the real possibility of serious new maritime disputes as states argued about the criteria for resetting baselines and redesignating these zones as high seas (Dupont 2008).

Rising sea level could complicate the resolution of disputed sovereignty claims in the Spratly Islands, a group of low-lying atolls in the South China Sea, which sit astride potentially rich deposits of oil and have already been the source of military tension between China, Vietnam and the Philippines. Some of these islands are already partially submerged and the highest, Southwest Cay, is only four metres above sea level (Central Intelligence Agency 2006). Heightened tensions in the South China Sea could precipitate a crisis between Japan and China, the Association of South East Asian Nations (ASEAN) and China, or between rival ASEAN states. This could complicate attempts to reduce and eventually eliminate longstanding territorial and resource disputes at sea.

7.5 Conclusion

The probable impacts of climate change on Australia will be varied and extensive, and will be unevenly spread across the country. For the next two decades or so, the impacts of climate change are likely to be dominated by stressed urban water supply and the effects of changes in temperature and water availability on agriculture.

By mid century a no-mitigation case will likely lead to major declines in agricultural production across much of the country. This will affect our capacity to export food and create a growing reliance on food imports. An unmitigated future is likely to also see the mid century destruction of the Great Barrier Reef.

By the close of the century, the impacts of a no-mitigation case and associated increased incidence of heatwaves will likely lead to about 4000 more deaths across Queensland annually. The rise in temperatures is likely to have caused the end of snow-based tourism. Much coastal infrastructure along the early 21st century lines of settlement is likely to be at high risk of damage from storms and flooding.

Over the course of the century climate change impacts elsewhere in the world will affect Australians, including through diminished opportunities for trade and investment, and demands in peacekeeping and humanitarian aid.

While this chapter's focus has been on the 'average' of possible outcomes, warming will increase the chance of abrupt and large-scale changes, with potential for much greater impacts.

If the world were to have agreed and implemented global mitigation goals so that greenhouse gas concentrations were stabilised at 450 ppm or even 550 ppm carbon dioxide equivalent, and combined with national adaptation, then the story of impacts for Australia could be radically different.

Note

1. From GIAM modelling for the Garnaut Review (see Chapter 9).

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7A Climate cases considered by the Garnaut Review

For the purpose of illustrating how the impacts of climate change might arise out to 2100 the Review considered a sample of climate cases, which present a set that are physically plausible for Australia. The diversity of choice is intended to inform opinions and decisions about the type of future that is acceptable to us as a nation and as part of the international community.

Case	Emissions	Climate sensitivity	Rainfall and relative humidity (surface)	Temperature (surface)	Mean global warming in 2100
Unmitigated 1 (U1) Hot, dry	A1FI path	3°C	10th percentile	90th percentile	~4.5°C
Unmitigated 2 (U2) Best estimate (median)			50th percentile	50th percentile	
Unmitigated 3 (U3) Warm, wet			90th percentile		
Strong mitigation 1 (M1) Dry	CO_2-e stabilised at 550 ppm by 2100 (CO_2 500 ppm)		10th percentile	90th percentile	~2°C
Strong mitigation 2 (M2) Best estimate (median)			50th percentile	50th percentile	
Strong mitigation 3 (M3) Wet			90th percentile		
Ambitious mitigation 4 (M4) Best estimate (median)	CO_2-e stabilised at 450 ppm by 2100 (CO_2 420 ppm)		50th percentile		~1.5°C

Note: For each of the above scenarios global mean temperature is presented from a 1990 baseline. To convert to a pre-industrial baseline add 0.5°C.

7B Infrastructure impacts criteria

The assessment of impacts of climate change on infrastructure is based on determination of net impact to capital expenditure, operational expenditure and productivity. The criteria for this assessment are presented below.

	Magnitude of net impact	Description of impact
N	Neutral	No change in capital expenditure, operational expenditure or productivity.
L	Low	Minor increase in capital expenditure and operational costs but no significant change to cost structure of industry. Minor loss in productivity. For example, minor loss in port productivity due to increased downtime of port operations.
M	Moderate	Moderate increase in capital and operational expenditure with a minor change to cost structure of industry. Moderate loss in productivity. For example, moderate increase in capital and operational expenditure for electricity transmission and distribution due to increased design standards, maintenance regimes and damage from severe weather events.
H	High	Major increase in capital and operational expenditure with a significant change to cost structure of industry. Major loss of productivity. For example, major increase in capital expenditure for increased building design standards for new and existing residential and commercial buildings.
E	Extreme	Extreme increase and major change to cost structure of industry with an extreme increase in operational and maintenance expenditure. Extreme loss of productivity. For example, extreme increase in capital expenditure from significant investment in new water supply infrastructure.

8 AUSTRALIA'S EMISSIONS AND THE ECONOMY

Key points

Australia's per capita emissions are the highest in the OECD and among the highest in the world. Emissions from the energy sector would be the main component of an expected quadrupling of emissions by 2100 without mitigation.

Australia's energy sector emissions grew rapidly between 1990 and 2005. Total emissions growth was moderated, and kept more or less within our Kyoto Protocol target, by a one-off reduction in land clearing.

Relative to other OECD countries, Australia's high emissions are mainly the result of the high emissions intensity of energy use, rather than the high energy intensity of the economy or exceptionally high per capita income.

The high emissions intensity of Australian energy use is mainly the result of our reliance on coal for electricity. This is a recent phenomenon: Australian and OECD average emissions intensity of primary energy supply were similar in 1971.

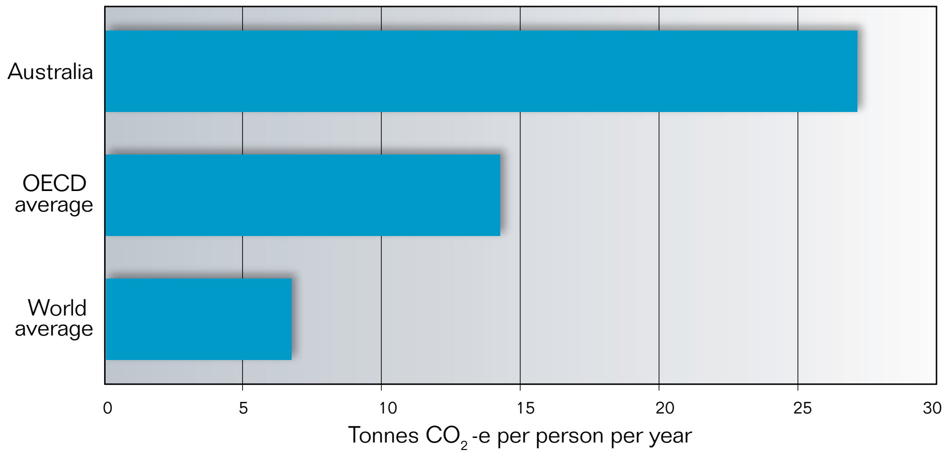
8.1 Australia's emissions profile and international comparisons

In 2005 Australia's net greenhouse gas emissions were 559.0 million tonnes (Mt) carbon dioxide equivalent using Kyoto Protocol accounting provisions (DCC 2008b). From 1990 to 2005, Australia's net emissions increased by 2.2 per cent (11.9 Mt).

Australia's per capita greenhouse gas emissions are the highest of any OECD country and are among the highest in the world. Only five countries in the world rank higher— Bahrain, Bolivia, Brunei, Kuwait and Qatar. In 2005 Australia's per capita emissions were nearly twice the OECD average and more than four times the world average (see Figure 8.1).

For the calculation of per capita greenhouse gas emissions the data sources used for Australia were the Department of Climate Change and the Australian Bureau of Statistics, while the International Energy Agency was the source used for all other countries. Other data sources, such as the United Nations Framework Convention on Climate Change (UNFCCC) and relevant national agencies, exist for emissions by developed countries and there is some variation between emissions estimates by those sources. However, regardless of which of these sources is used for other countries' emissions, Australia's per capita greenhouse gas emissions in 2005 were higher than any other developed country.

Figure 8.1 Per capita greenhouse gas emissions, 2005



Source: DCC (2008b) and IEA (2007a).

8.1.1 Recent growth trends in Australia's emissions

The growth in Australia's emissions profile is dominated by the energy sector. This comprises stationary energy—electricity generation, fuel combustion in the manufacturing industries, metals production, plastics production and construction—and fugitive emissions and transport.

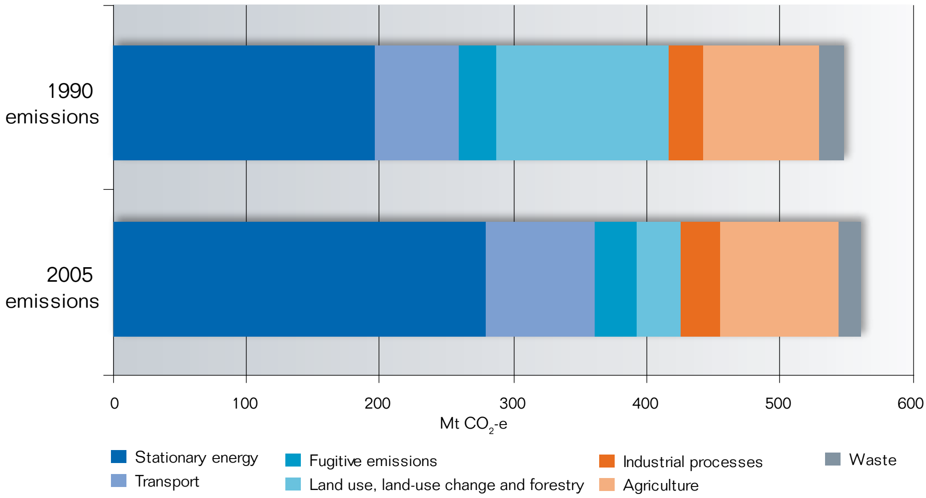
Emissions for 1990 and 2005 by sector are illustrated in Figure 8.2.

Energy sector emissions increased by about 36 per cent between 1990 and 2005. Over the same period there was a substantial reduction (about 74 per cent) in emissions from land use, land-use change and forestry.

Growth in emissions from the stationary energy sector is largely driven by the structure and growth of Australia's economy, the fuel mix used in electricity generation and energy efficiency improvements across the economy.

Emissions arising from land use change depend on the area of forest cover removal, the method of forest conversion and land development. The estimates rely on the amount of carbon sequestered in biomass and soils, which differ by vegetation type, geography and climate (DCC 2008a). Reductions in the rate of forest cover removal since 1990 have been the main source of the reduction in emissions from land use, land-use change and forestry.

Figure 8.2 Greenhouse gas emissions trends by sector, 1990 and 2005

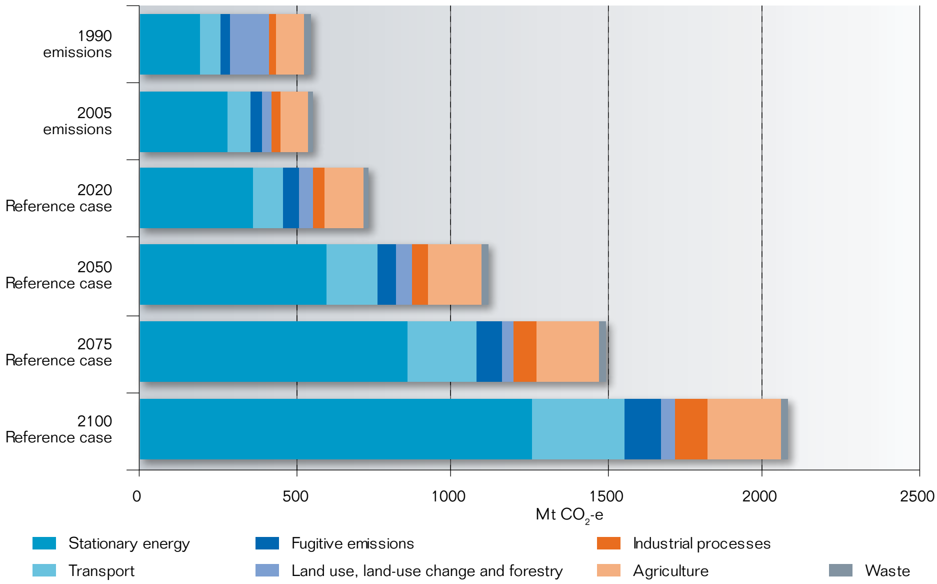


Source: DCC (2008b).

8.1.2 Future emissions growth in Australia

The Review's reference case for emissions growth in the absence of new policy measures and the assumptions underlying the modelling are outlined in Chapter 9. Figure 8.3 presents expectations of future emissions under the Garnaut–Treasury reference case. In the absence of measures to reduce greenhouse gas emissions, energy-related emissions are expected to grow rapidly and to increase their share of the total.

Figure 8.3 Greenhouse gas emissions by sector: 1990, 2005 and reference case scenarios



Note: 1990 and 2005 emissions are from the most recent National Greenhouse Gas Inventory (DCC 2008b). 2020– 2100 projections are from MMRF.

8.1.3 Why are Australia's per capita emissions so high?

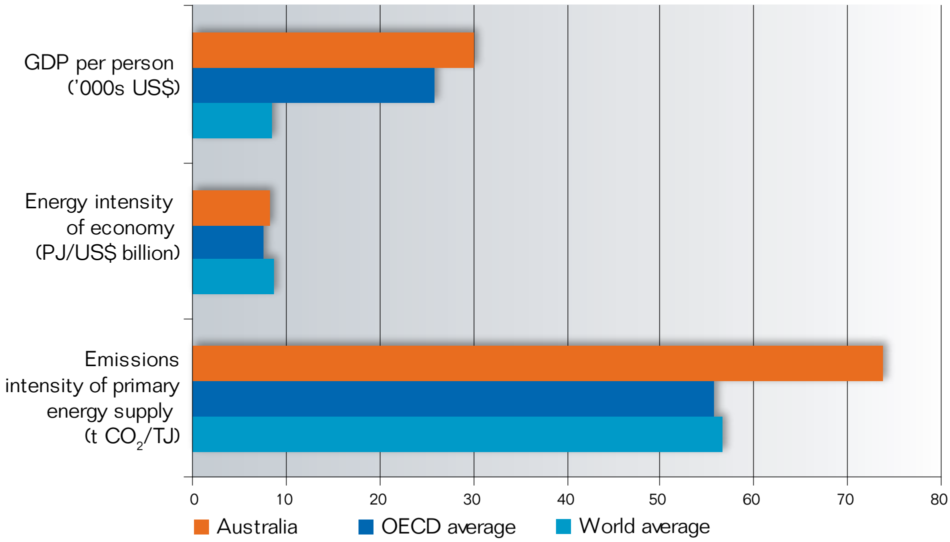
As discussed in Chapter 4, energy-associated per capita emissions are the product of per capita GDP, the energy intensity (of the economy) and emissions intensity (of energy) as follows:

$$CO_2 \text{ per capita} = \text{GDP per capita} \times \text{Energy/GDP} \times CO_2\text{/Energy}$$

The energy intensity of an economy is a measure of the amount of energy used per unit of economic activity generated. The emissions intensity of energy is a measure of the amount of greenhouse gases emitted per unit of energy used.

Figure 8.4 illustrates the factors underlying a country's per capita emissions and compares those factors for Australia, the OECD average and the world average.

Figure 8.4 Factors underlying per capita emissions, 2005



Note: All financial values are measured in 2000 US$ and using purchasing power parities.
Source: IEA (2007a).

8.1.4 Australian incomes relative to those in other developed countries

Australia's GDP per capita in 2005 was about 16 per cent higher than the OECD average (IEA 2007a). While this contributes to Australia's comparatively high per capita greenhouse gas emissions, it does not explain why they are more than twice the OECD average.

In 2005, Australia's per capita GDP in purchasing power parity terms was the 11th highest among OECD countries and moderately above the OECD average.

8.1.5 Relative energy intensity of Australia's economy

Australia's economy is the 8th most energy-intensive among OECD countries. It is about 5 per cent less energy-intensive than the world average and about 8 per cent more energy-intensive than the OECD average.

The aggregate energy intensity of the Australian economy, measured as total primary energy consumption per dollar of GDP, remained broadly stable over the 1970s and 1980s, and then fell by an average of 1.1 per cent a year during the 1990s (Syed et al. 2007).

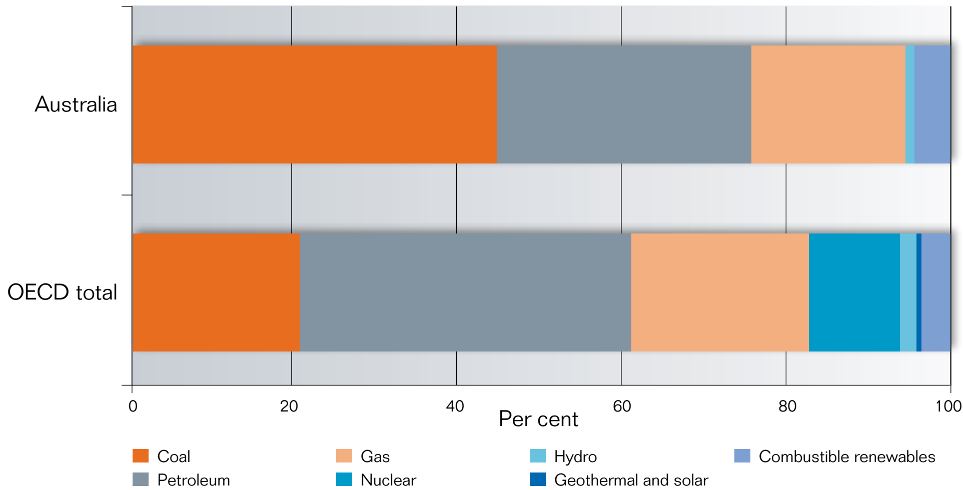
The energy intensity of Australia's economy does not account for our extremely high per capita greenhouse gas emissions.

8.1.6 Why is the emissions intensity of Australia's energy so high?

The emissions intensity of Australia's primary energy supply is the second highest among OECD countries. It is more than 30 per cent higher than both the OECD average and the world average. There are only five countries in the world with a more emissions-intensive energy supply than Australia's—Bosnia Herzegovina, the Democratic People's Republic of Korea, Estonia, Mongolia and Poland.

Fossil fuels play a dominant role in Australia's primary energy consumption. More than 40 per cent of Australia's total primary energy supply is derived from coal. This is a much higher proportion than in other OECD, countries as illustrated in Figure 8.5.

Figure 8.5 Fuel mix contributing to total primary energy supply, 2005

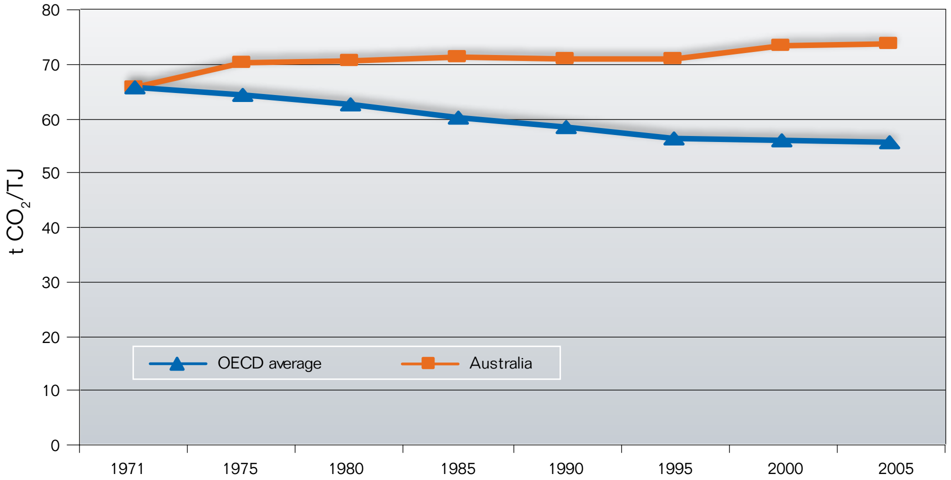


Source: IEA (2007b).

The exceptional emissions intensity of Australia's primary energy supply has only emerged in recent decades. Figure 8.6 shows the trends in Australia's average emissions intensity of primary energy supply compared with those in all OECD countries. The Australian average was similar to that of the OECD in 1991.

The increasing emissions intensity of Australia's primary energy supply is largely due to its increasing reliance on coal for electricity generation, at a time when other developed countries have shifted significantly to lower-emissions sources. In 2005–06, 54 per cent of electricity was generated from black coal, 21 per cent from brown coal, 15 per cent from natural gas, 2 per cent from oil and 8 per cent from renewable sources (Syed et al. 2007).

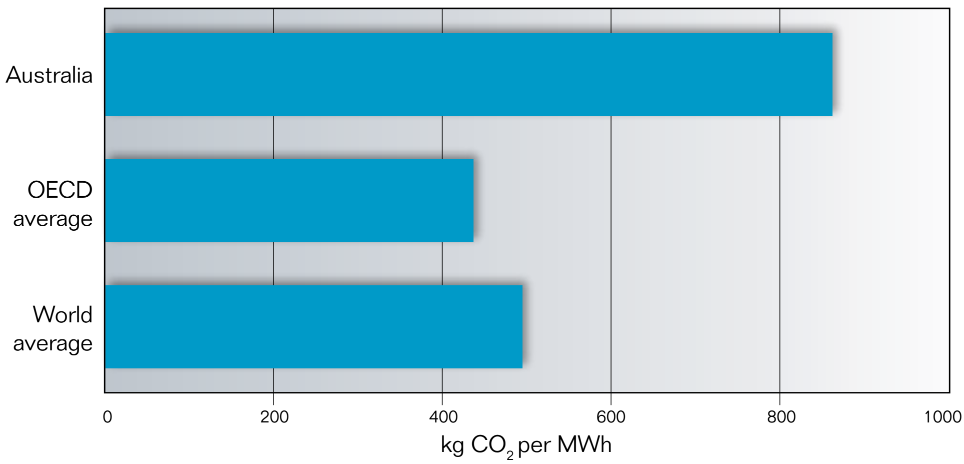
Figure 8.6 Trends in average emissions intensity of primary energy supply, Australia and OECD



Source: IEA (2007a).

The carbon dioxide emissions intensity of Australia's electricity supply is the highest of any OECD country. It is 98 per cent higher than the OECD average, and 74 per cent higher than the world average (see Figure 8.7). There are only eight countries in the world with an electricity system that is more emissions-intensive than Australia's. Those countries are Bahrain, Botswana, Cambodia, Cuba, India, Kazakhstan, Libya and Malta.

Figure 8.7 Carbon dioxide emissions intensity of electricity production, 2005



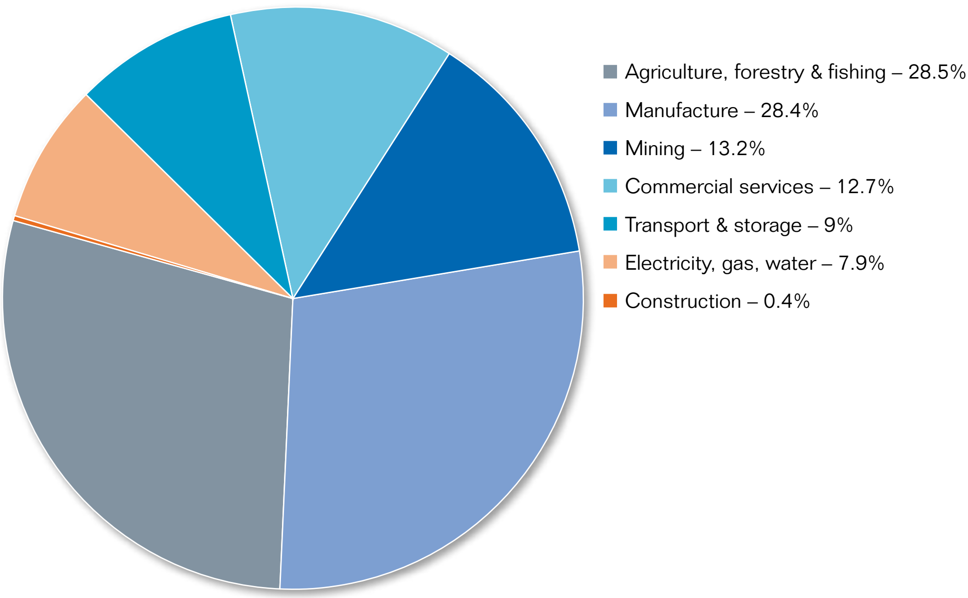
Source: IEA (2007a).

8.2 Emissions profiles of Australian industries

8.2.1 How do Australian industries contribute to emissions and GDP?

Figure 8.8 shows the total emissions attributable to each Australian industry, derived by summing a sector's direct emissions, and the indirect emissions attributable to its electricity consumption. Emissions due to transport have not been attributed in the same way, due to lack of suitable data. Industry accounts for about 81 per cent of Australia's total emissions, with the remainder attributable to the residential sector. The agriculture, mining and manufacturing industries are responsible for large amounts of greenhouse gas emissions relative to their shares of GDP.

Figure 8.8 Emissions attributable to Australian industry by sector, 2005



Source: DCC (2008b) and ABS (2007).

8.2.2 Which industries would be most affected by a price on emissions?

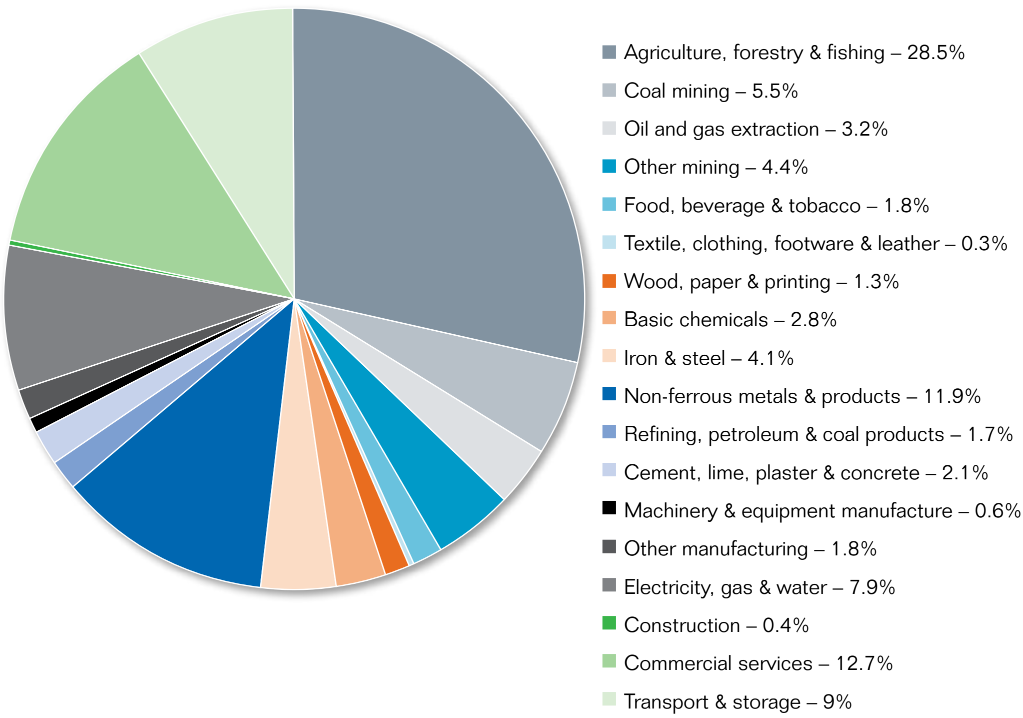
The industries whose competitiveness is most likely to be adversely affected by a price on greenhouse gas emissions are those that are exposed to international trade and that have either a high degree of energy intensity or a high level of direct greenhouse gas emissions.

The Review sought to identify the industries that might be most affected in their international competitiveness by a price on greenhouse gas emissions. It considered data on trade, direct emissions, and indirect emissions attributable to electricity consumption. It used the 1993 Australian and New Zealand Standard Industrial Classification (ANZSIC) as a guide to industry classification, and selected the following industries for analysis of the impact of an emissions price on international competitiveness:

- agriculture, forestry and fishing
- coal mining
- oil and gas extraction (including liquefied natural gas (LNG) production)
- mining (non-energy)
- food, beverage and tobacco manufacturing
- textile, clothing, footwear and leather manufacturing
- pulp, paper and printing
- petroleum refining
- petroleum and coal products
- basic chemicals
- cement, lime, plaster and concrete
- iron and steel
- basic non-ferrous metals and products (including aluminium production)
- machinery and equipment manufacturing.

The contribution of the sum of direct and indirect emissions for each of these sectors as a proportion of total emissions attributable to industry is illustrated in Figure 8.9.

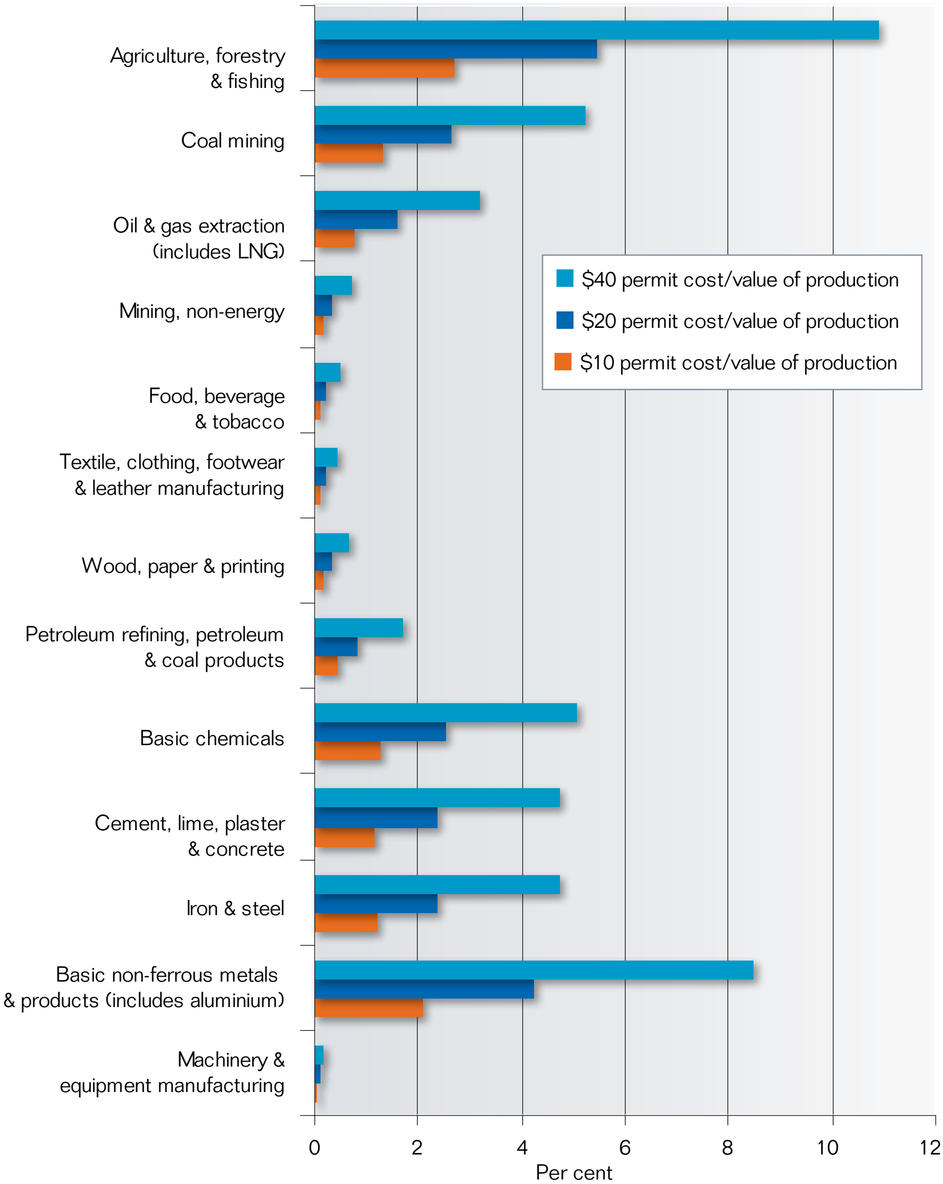
Figure 8.9 Emissions attributable to Australian industry by sector, with the manufacturing sector disaggregated, 2005



Source: DCC (2008b) and ABS (2007).

In order to gauge the potential impact of a price being placed on greenhouse gas emissions, the Review examined the effect of a permit price of $10, $20 and $40 per tonne of carbon dioxide equivalent and assumed that there would be 100 per cent pass-through of emissions costs to energy consumers. The latter is a worst-case scenario from the perspective of energy-intensive industries. If this were too high, the analysis that follows would overestimate the additional costs accruing to energy-intensive industries as a result of a price being placed on emissions.

Figure 8.10 Ratio of permit costs to value of production, 2005



Note: Production is largely composed of sales revenue but also includes production for own final use.
Source: DCC (2008b) and ABS (2008).

Under these assumptions, the ratio of greenhouse gas emission costs to the value of production is as shown in Figure 8.10.

Recent and projected increases in commodity prices reduce the ratio of greenhouse gas emissions to the value of production. For example, it is estimated that projected 2008–09 increases in the price for coal exports would reduce the ratio of greenhouse gas emissions costs to the value of production for coal mining to about one-third of that shown in figure 8.10.

8.2.3 Does our industry emissions profile make Australia a special case?

For the OECD countries considered—those that are parties to Annex I of the UNFCCC—the direct and indirect emissions attributable to the agriculture, mining and manufacturing industries were calculated. These are the main emissions-intensive, trade-exposed sectors.

The emissions attributable to the mining and manufacturing industries accounted for about 34 per cent of Australia's total greenhouse gas emissions in 2005. This was the 10th highest proportion among the OECD countries considered. Across all the OECD countries considered, 33 per cent of greenhouse gas emissions were attributable to the mining and manufacturing industries (see Figure 8.12).

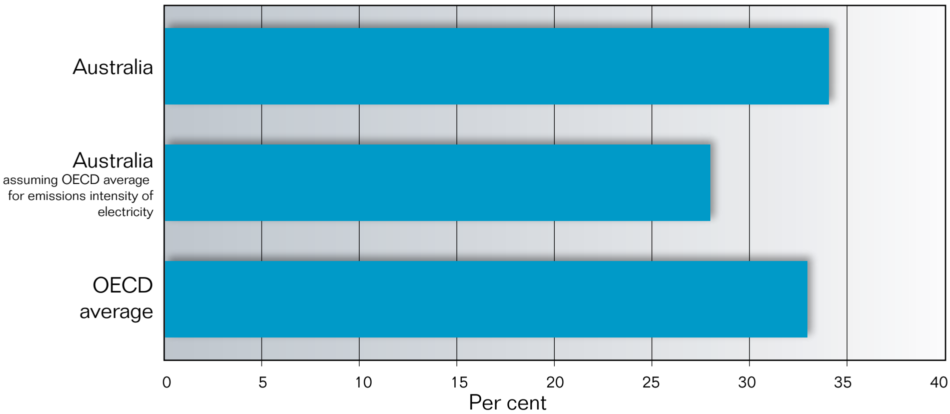
The emissions attributable to the agriculture, mining and manufacturing industries accounted for about 57 per cent of Australia's total greenhouse gas emissions in 2005. This was the fourth-highest proportion among the OECD countries, exceeded only by Finland, Norway and New Zealand. Across all the OECD countries, 42 per cent of greenhouse gas emissions were attributable to the agriculture, mining and manufacturing industries.

The proportion of total emissions attributable to Australia's mining and manufacturing industries (34 per cent) is not high in comparison with the average of the OECD countries considered (33 per cent). If the emissions intensity of Australia's electricity supply were reduced to the OECD average then only about 28 per cent of Australia's total emissions in 2005 would have been attributable to the mining and manufacturing industries.

The unusually large agricultural sector contributes exceptionally to Australia's unusually high emissions profile. The mining and manufacturing sectors contribute high levels of emissions per capita, but no more than the rest of the economy

It is the emissions intensity of Australian energy supply, more than the industrial structure of the Australian economy that accounts for the fact that the proportion of emissions attributable to the mining and manufacturing industries in Australia is above average in comparison with that of other OECD countries.

Figure 8.11 Direct and indirect emissions attributable to the mining and manufacturing industries as a proportion of total emissions, Australia and OECD, 2005



Source: IEA (2007b) and UNFCCC (2008).

Conclusions

There are several sectors of Australian industry that are responsible for a relatively large amount of greenhouse gases in proportion to their contribution to economic activity—notably aluminium production and some forms of agriculture.

Overall, the contribution of the agriculture sector to Australia's greenhouse gas emissions is relatively large. The contribution by our manufacturing and mining sectors is in line with the OECD average.

Australia's high level of per capita greenhouse gas emissions is not due to an unusually large contribution by energy-intensive industries nor is it due to relatively inefficient use of energy. It is largely due to the emissions intensity of energy used in Australia and our reliance upon coal as a source of primary energy.

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9 THE MODELLED ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IN AUSTRALIA

Key points

The joint Garnaut–Treasury reference case suggests that, in the absence of climate change or costs from its mitigation, from 2005 to 2100, the Australian population will more than double to nearly 47 million, per capita output will almost quadruple, and economic output will expand by over 700 per cent.

Over the same period, the reference case sees global population increasing by about 40 per cent and stabilising, and then starting to decline late in the second half of the century. Global output increases by about 15 times, mostly in the developing world, led by the large Asian developing economies—China, India and Indonesia.

The median temperature and rainfall outcomes for Australia from climate change with unmitigated growth in global emissions—particularly from impacts on infrastructure, agriculture and international terms of trade—may see GDP fall from the reference case by around 4.8 per cent, household consumption by 5.4 per cent and real wages by 7.8 per cent by 2100.

This would represent significant reduction of economic growth and welfare from what it would have been in the absence of climate change.

These are not the total costs of climate change. Nor can these costs be avoided entirely by mitigation.

This chapter draws on the scientific evidence presented in earlier chapters on the relationship between global warming, climate change and climate change impacts, to assess the economic effects of climate change on primary production, human health, infrastructure, international trade and tropical cyclones.

To understand the potential economic implications of climate change for Australia, appropriate scientific and economic frameworks must be combined to estimate impacts at the regional level. This is not a trivial task. As discussed in chapters 3 and 5, there is uncertainty in many aspects of climate change science at the climate system, biophysical and impact assessment levels. These compounding sources of uncertainty mean that quantifying the economic impacts of climate change is a difficult, and at times speculative, task.

As a result of such uncertainty, and the complexities and limitations associated with economic modelling frameworks and assumptions over very long timeframes, the economic modelling presented in this chapter should be interpreted as indicative and broadly illustrative of the direction of change and magnitude of costs from climate change. As cautioned in the Stern Review (2007: 161), 'modelling the overall impact of climate change is a formidable challenge, demanding caution in interpreting results'. The Review reiterates this warning.

Such warnings must also be heeded when using climate change impact modelling as a basis for a cost–benefit evaluation of policy on climate change mitigation. The costs of climate change mitigation come earlier and are better known than the costs of climate change.

Chapter 2 noted that while economic modelling can provide a valuable tool to evaluate the potential economic consequences of climate change, it should not be used in isolation, or without regard to other potentially significant market and non-market impacts that are not amenable to quanitification through economic models. Chapter 10 discusses the extent of these impacts and their potential economic consequences.

In undertaking the pioneering economic analysis presented in this chapter, the Review has combined a range of expert views and modelling frameworks, some highlights of which were presented in Chapter 7. This is a first step towards a comprehensive framework for analysing the economic impacts of climate change for the Australian economy. The Review looks forward to further empirical work and refinement by others improving the estimates provided in this chapter.

The modelling presented in this chapter assesses the economic impacts of climate change as they occur under median or best-estimate[1] climate change outcomes over the current century. Impacts are estimated with consideration to their market effects on economic sectors such as agriculture, electricity and residential dwellings. The assessment precludes the assessment of non-market effects, such as the impacts of climate change on biodiversity and ecosystems and some aspects of human health. Section 6.3 and chapters 2 and 10 discuss the implications associated with excluding non-market effects from an economic evaluation of climate change.

The remainder of this chapter describes the results, assumptions and methodology underpinning the economic modelling. Detailed discussion of the full modelling results, modelling frameworks and methodologies will be provided in the supplementary draft and final reports.

9.1 Capturing the impacts of climate change through economic modelling

There are a number of types of mechanisms and models through which economic modelling of climate change could be undertaken. These include integrated assessment modelling, partial equilibrium modelling, and computable general equilibrium modelling, all of which have strengths and weaknesses.

Integrated assessment modelling incorporates socio-economic and biophysical assessments of climate change at the global and broad country level by capturing the feedback between economic and scientific systems. Such modelling usually involves broad assumptions at a high level of spatial and sectoral aggregation. The global and sectorally aggregated nature of most integrated assessment modelling makes its use inadequate for a detailed Australian industry and regional analysis.

Partial equilibrium modelling allows detailed industry specific economic evaluation. However, partial equilibrium models are not linked into the broader economy and therefore do not consider the feedback from changes in prices and opportunity costs from outside the specific industry. They are therefore inadequate when considering the economy-wide implications of climate change, but can be valuable as a complement to economy-wide modelling.

Computable general equilibrium (CGE) modelling is capable of capturing the economy-wide inter-sectoral reallocation of resources that may result from climate change. This type of modelling is useful when direct change or impacts, at either the specific industry or regional level, are expected to have economy-wide implications.

Climate change impacts will have diverse effects on a range of industries and sectors of the economy. Within this context, CGE modelling is considered the most useful and appropriate framework currently available to undertake a comprehensive assessment of the economic costs of climate change in Australia. Of these models, the Monash Multi Regional Forecasting Model, described in section 9.2.3, has advantages because of its capabilities for environmental analysis as well as its rich sectoral and regional detail.

To date, no comprehensive modelling of climate change using a CGE model has been undertaken at the Australian economy level. At the international level, there are few CGE studies that map physical effects of climate change to economic effects in a systematic or comprehensive way (see Box 9.1).

The modelling undertaken by the Review accounts for a broad range of detailed climate change impacts as they affect various sectors simultaneously over the next century. This analysis allows a dynamic assessment of a set of unmitigated and mitigated climate change scenarios, and provides regional and sectoral detail of the Australian economy. The analysis also allows for the effects of climate change internationally, and its indirect impact on Australia's international trade, by linking to a global CGE model.

Box 9.1 Modelling of climate change impacts using CGE modelling

There are few published examples of Australian studies using CGE models that examine the economic impacts of climate change. One recent study is the Australian Bureau of Agricultural and Resource Economics' assessment of the impacts of climate change on dryland broad-acre agriculture (wheat, beef, sheep meat and wool) (Heyhoe et al. 2007). This analysis considers high and low rainfall outcomes based on a given global (and local) temperature change to 2030. The assessment analyses gross regional product using the AusRegion model.

Numerous international studies have attempted to evaluate the economic effects of climate change using general equilibrium models. However, few studies have comprehensively assessed the impacts of climate change over multiple sectors simultaneously over time in a dynamic CGE framework.

Moreover, the international studies that analyse the economic effects of climate change in a regionally disaggregated way rarely identify effects on the Australian economy separately. More often, Australia is included in a regional group.

In a series of papers undertaken in association with the Fondazione ENI Enrico Mattei and Robert Roson of the Ca' Foscari University, the effects of climate change have been analysed separately for several dimensions of the global economy. These include tourism (Berrittella et al. 2006), coastal erosion (Bosello et al. 2007) and human health (Bosello et al. 2006), each of which uses a comparative static framework. The shocks applied are based on climate change impacts taken from the FUND integrated assessment model. There are no complete time paths for the global economy, either with or without climate change effects.

More recently, the Fondazione ENI Enrico Mattei has described a new dynamic version of its model (Eboli et al. 2008) that focuses on the global effects of climate change to 2050. Impacts are considered for agricultural production, energy demand, human health, sea-level rise and tourism. Climate change shocks are adapted from those previously used in static CGE models. For example, agriculture impact estimates are based on Tol (2002).

To the best of the Review's knowledge, only a handful of studies focused in detail on the impacts of climate change for single countries and for the impacts to multiple sectors over time (for example, Jorgenson et al. 2004; Carraro & Sgobbi 2008). These studies most closely reflect the approach being undertaken by the Review.

Box 9.1 Modelling of climate change impacts using CGE modelling *(continued)*

The Jorgensen study focuses on the impacts of climate change on the US economy to 2100. Impacts are considered for crop and livestock agriculture, forestry, fishing, the provision of heating and cooling, water supply, human health (mortality and morbidity) and protection of property and assets from sea level rise. The study attempts to consider uncertainties in climate change and economic outcomes by considering three levels of climate change (low, central and high) in combination with two sets of market outcomes (optimistic and pessimistic). Uncertainty in precipitation is considered by combining high temperature outcomes with lower precipitation ('high and drier') and low temperature outcomes combined with higher precipitation ('low and wetter'). The effects of climate change on agriculture were found to dominate the market impacts in the analysis.

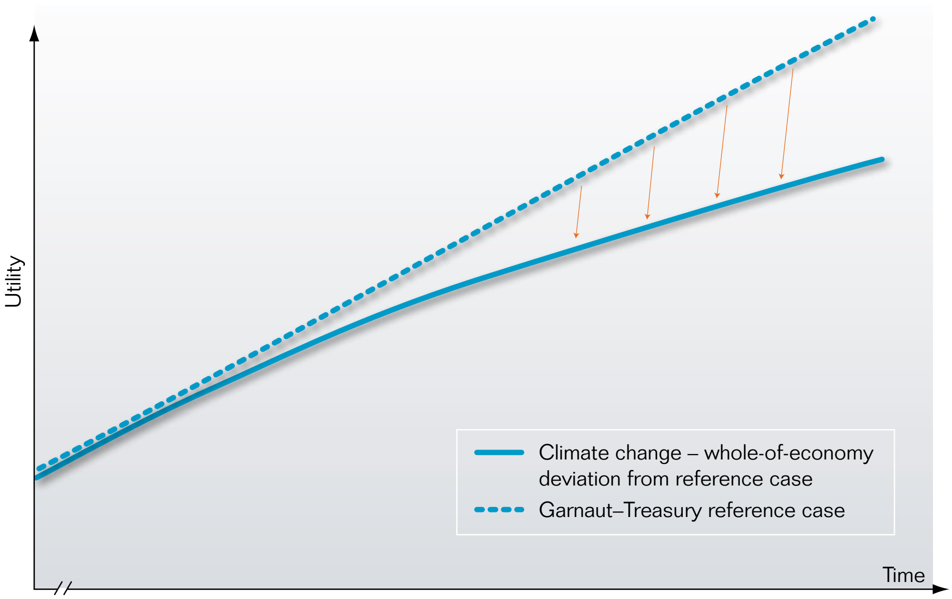
9.2 Representing climate change impacts in economy-wide analyses

The Review undertook a series of modelling tasks to illustrate the potential economic costs of climate change to the Australian economy. The first of these tasks involved the development of a hypothetical future or 'reference' case. This reference case projects the evolution of the global and Australian economies and associated greenhouse gas emissions to the end of the current century in the complete absence of climate change. The Garnaut–Treasury reference case was developed jointly by the Australian Treasury, the Centre of Policy Studies at Monash University and the Review, and drew on a wide range of external expertise. A summary of the Australian component of the reference case is provided in section 9.2.6. Chapter 4 discussed the global aspects of the reference case. Further details will be provided in the supplementary draft report.

To determine the economic consequences of climate change, various direct impacts or 'shocks' to sectors are imposed onto the reference case. These shocks cause the path of economic growth to deviate from the reference case (Figure 9.1) and represent the economic costs of climate change.

To determine these shocks, the Review worked with a range of expert groups who undertook sector-specific analyses of climate change impacts. The sectors and areas of impact considered as part of the modelling are discussed in section 9.2.2.

Figure 9.1 The costs of climate change: representing economic growth and climate change



9.2.1 Alternative scenarios to represent unmitigated and mitigated climate change

In order to determine the economic impacts of unmitigated and mitigated climate change, the Review formed a judgment about the emissions scenarios (and consequently the resulting temperature and climate changes) that may occur under unmitigated and mitigated climate change. In order to be able to begin, and complete, work on the Australian impacts of climate change within the time frames of the Review, this judgment was required well in advance of the economic analysis and modelling that underpins the reference case. The Review chose from the IPCC's *Special Report on Emissions Scenarios* (2000) the scenario that most closely reflected the Review's view of global emissions growth over the next century—the one with the highest emissions outcome, known as the A1FI—and hence the likely climate outcomes.

Section 4.5 illustrates the similarities in global emissions growth of the A1FI emissions scenario with the Review's ideas of a likely reference case emissions profile, the Garnaut–Treasury reference case. This global scenario is consistent with the reference case introduced above and discussed further in section 9.2.6, and was the basis for the no-mitigation case discussed in Chapter 5.

The choice of climate change scenarios

To determine the Australian impacts of climate change, the Review considered three median (or best-estimate) climate change outcomes: one representing an unmitigated scenario consistent with an A1FI emissions path, and two representing emissions stabilisation scenarios of 450 ppm and 550 ppm (the strong and ambitious global mitigation cases discussed in Chapter 5).

'Median' in this context refers to the median change in local average rainfall (50th percentile rainfall) and median local average temperature (50th percentile temperature) responses to a given global average temperature rise. A range of changes to climate variables is possible at the local scale—these are provided by climate models. Here we apply the likelihoods developed by the CSIRO and the Bureau of Meterology.[2] These three scenarios are represented in Table 9.1. The temperatures represented in Table 9.1 are relative to 1990 levels. As such, approximately 0.5°C should be added for these temperatures to be relative to pre-industrial times.

The results presented in this chapter relate only to the median unmitigated scenario in Table 9.1. Modelling associated with the mitigated climate change scenarios will be provided in the supplementary draft report.

Again, there are many and compounding sources of uncertainty associated with greenhouse gas emissions, global warming and climate change, and the timing and extent of impacts from each degree of warming. The cumulative nature of these uncertainties (see Figure 3.9), means that the range of possible climate change impacts on any one of the Review's choices on unmitigated and mitigated global emissions paths can be considerable.

To represent some of these uncertainties and ranges, the Review modelled an additional unmitigated scenario. All the modelled scenarios used by the Review to assess domestic impacts assume a climate sensitivity of 3°C.[3] However, uncertainty about how the Australian climate will respond to increased global average temperatures is incorporated by considering a 'dry' local rainfall sensitivity (relative to the median rainfall estimate), combined with a 'hot' local temperature sensitivity (relative to the median temperature estimate). The results for this 'hot and dry' rainfall scenario are discussed in detail in Chapter 10. The more complex climate model used to assess the international impacts has an intrinsic climate sensitivity that is somewhat less than 3.0°C.

Table 9.1 Physical climate scenarios

Scenario	Global data (2100)		Australian percentiles		Comment
	Mean temperature	CO_2 concentration (ppm)	Temperature and evaporation	Rainfall and humidity	
Unmitigated					
Median	4.5°C	976	50th	50th	Global data based on A1FI scenario using MAGICC climate model
Mitigated*					
550 ppm	2.0°C	470	50th	50th	Global stabilisation profiles created using the SIMCAP model, temperature outcomes from MAGICC
450 ppm	1.5°C	408	50th	50th	

* For the calculation of climate change impacts for the mitigated scenarios, emissions pathways and temperature outcomes were developed using the Simple Model for Climate Policy (SIMCAP) assessment, version: beta 1.0.2 (February 2006) developed by Meinshausen et al. (2006) and available at <www.simcap.org>. Climate change outcomes resulting from these emissions pathways were calculated using MAGICC version 4.1 (Wigley 2003). The local temperature and rainfall responses, by state and territory, associated with the median and dry scenarios are provided in Chapter 6.

9.2.2 Selection of key climate change impacts for use in the economic modelling

The diversity of climate change impacts on Australia makes quantifying the impacts of climate change to a level sufficient to determine economic impacts challenging and time-consuming. As a result, only a subset of impacts was included in the economic modelling exercise. This subset was selected based on the availability of data that was defined sufficiently clearly for the modelling exercise, as well as the Review's consideration of the potential scale of economic impacts on key sectors of the economy.

The key areas of impact and their subcomponents are:

Primary production		
• cropping (dryland and irrigated)	• livestock (dairy, sheep, cattle)	
Human health		
• heat stress (deaths and hospitalisations)	• vector-borne dengue viruses	• bacterial gastroenteritis
Critical infrastructure (human settlements)		
• water supply infrastructure in major cities	• electricity transmission and distribution networks	• buildings in coastal settlements
• ports operations and maintenance		
Tropical cyclones		
• impacts on residential dwellings		
International trade		

Effects on ecosystems and biodiversity; the fiscal demands on Australia that may arise from geopolitical instability in the Asia–Pacific region; effects on forestry; effects on tourism due to the reduction in environmental amenity;[4] effects on other services industries; and some effects on manufacturing[5] are among the exclusions.

Even within the key areas of impact considered, the Review was not able to capture all of the full market impacts of climate change. Due to the complexity of the modelling task, general uncertainty, and significant data limitations, it was not feasible to include all climate change impacts. For example, human health includes impacts of heat-related stress and dengue virus, but does not include the impacts of some other health issues that are likely to be affected by climate change, such as Ross River virus and mental health issues in drought-affected farming communities. As another example, the effects of increased variability and reduced predictability of rainfall may be as important for agriculture as reduced average rainfall, but these could not be taken into account.

Chapter 10 discusses the implications of excluding potentially large areas of climate change impacts from the economic analysis. It attempts to quantify the proportion of market impacts that have been captured as part of the analysis in this chapter and provides a judgment as to the size of impacts in excluded sectors.

While acknowledging the partial nature of this approach, the Review considers it a necessary and important first step in developing a deeper understanding of the costs and benefits of Australia participating in a global effort to stabilise global greenhouse gas concentrations.

9.2.3 Translating climate change impacts into economic impacts

There is currently no single model that can capture the global, national, regional and sectoral detail that was necessary for the Review's approach to modelling climate change. As a result, the Review has drawn on a number of economic models to determine the costs of climate change to the Australia economy.

The key economic model used to determine the economy-wide costs of climate change for Australia was the Monash Multi Regional Forecasting (MMRF) model (Box 9.2). The MMRF framework was supported by a series of scientific and economic models used to determine impacts in particular sectors. Detailed sector-specific modelling was undertaken for the reference case and its impact analysis. Figure 9.2 illustrates the modelling frameworks used as part of the MMRF analysis.[6]

The direct Australian impacts of climate change for both unmitigated and mitigated climate change were estimated outside the MMRF model and then incorporated as a series of shocks to economic variables in the reference case. The environmental changes likely to occur under the different climate scenarios described in section 9.2.1 were translated into direct economic impacts that could be used in the model.

Box 9.2 The Monash Multi Regional Forecasting (MMRF) model

The Monash Multi Regional Forecasting (MMRF) model is a multisector dynamic model of the Australian economy covering all states and territories. It models each region as an economy in its own right, with region-specific prices, consumers, and industries. As a dynamic model, MMRF can produce sequences of annual solutions connected by dynamic relationships.

The main features of the model include:

- Cost-minimising behaviour by firms and households—firms maximise profits and consumers maximise utility by purchasing inputs from the cheapest source; and by purchasing the bundle of goods that best meets their needs. For basic necessities, consumption is relatively insensitive to price changes. For luxuries, households substitute between goods based on their relative price.
- Substitution between factors of production—firms are assumed to minimise costs by substituting between labour, capital and land.
- Weak price-driven substitution between commodities in the production decision of firms. Firms are assumed to respond to large increases in the prices of inputs by undertaking technological innovation that reduces their reliance on the good in question.

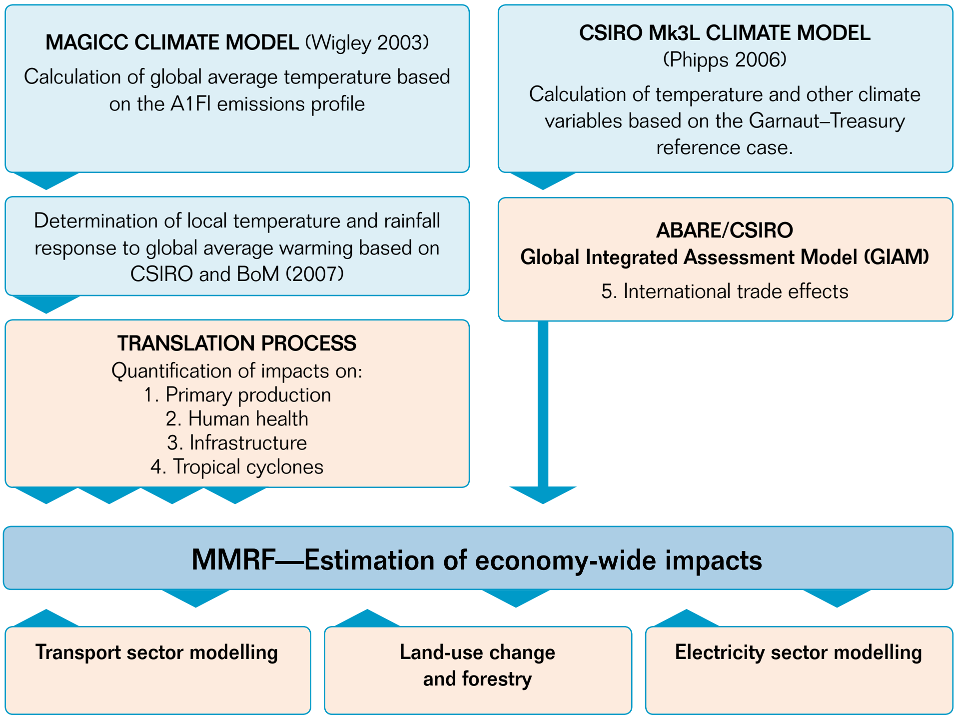
Box 9.2 The Monash Multi Regional Forecasting (MMRF) model *(continued)*

The model also includes enhanced capabilities for environmental analysis, such as:

- an energy and greenhouse gas emissions accounting module, which accounts explicitly for each of the 58 industries and eight regions recognised in the model and splits the commodity petroleum and coal products into five commodities—petrol, diesel, LPG, aviation fuel and all other coal products—produced by the petroleum and coal products industry
- model structure that allow for inter-fuel substitution in electricity generation and private road transport by region
- detailed treatment of renewable generation
- explicit modelling of the national electricity market
- special treatment of energy substitution in residential demand through the creation of energy-related service industries.

The general structure of the MMRF model is described in Adams (2007).

Figure 9.2 The Review's modelling framework



9.2.4 Dealing with adaptation

In the analysis of economic effects of climate change, a critical component is the assessment of the adaptive capacity and responses of economic agents to climate change. While ignoring such responses would overestimate the impacts of climate change, adaptation itself is not cost free.

Where the impacts avoided are non-market, adaptation will increase the market costs of climate change. For example, one of the likely adaptive responses to climate change will be to construct houses that are better able to cope with heat extremes. These modifications are likely to increase the cost of housing construction and hence increase the market costs of climate change. As a result, while market costs (construction costs) increase, non-market costs are avoided (discomfort from hot houses).

The Review has given careful consideration to the adaptive responses of economic agents for each of the key areas of impact analysed. However, quantifying such responses over very long time frames and under conditions of considerable uncertainty is a difficult task, often requiring the exercise of judgment.

The adaptive responses assumed are generally considered to occur in the absence of the introduction by government of significant adaptation policies. In some cases, however, the extension of traditional government roles into new areas has been assumed. Examples include development and enforcement of new building design standards, expenditure on public health, and participation in the breeding of new plant varieties and the dissemination of its results.

Agriculture

There are a number of adaptation responses that are inherent in the estimated direct impacts on agriculture.

For dryland cropping, it is assumed that wheat producers are able to minimise the costs of climate change by changing planting times and optimising cultivar choice. Climate change, while reducing water availability, also reduces frosts, thereby allowing planting in the wetter winter months. While it is also possible that this will reduce the planting windows for other complementary crops such as oats and barley, this possibility was not considered in the modelling.

Dairy producers are assumed to adapt to reductions in water availability by (1) switching away from irrigated and pasture fed cattle towards more intensive, grain-fed, production methods, or (2) returning to a form of dryland dairy farming (with supplementary feedstock) that was common in the first half of the last century.

Land-use change among agricultural producers is also a feature of the modelling. Scarce land resources are assumed to flow to the areas of highest return. For example, irrigation land that is no longer viable due to water scarcity can be converted to other uses, such that farmers maximise returns from land.

Infrastructure

The infrastructure analysis includes some broad assumptions regarding new planning and engineering standards to increase the resilience of buildings, port and water supply infrastructure, and electricity transmission and distribution networks.

For buildings, changes to building design (insulation and double glazing) have been included. The degree to which these standards are taken up over time depends on the replacement timelines for existing buildings and the degree of temperature changes and other climate outcomes over the period to 2100.

Expert opinion suggests that climate change will force more port closures and downtime from an increase in severe weather events. In order to cope with this change, the modelling assumes that average throughput can be maintained over time, but that larger ships and ports will be required to achieve this.

Climate change is likely to reduce the water available from traditional sources (such as dams and aquifers) for urban users. In order to cope with this change, alternative supply options, such as desalination and water recycling, have been included in the modelling. The costs and increased energy demand associated with desalination and water recycling have been included.

For electricity transmission and distribution network infrastructure, assumptions regarding investment in new capital and improved design standards have been incorporated. Examples include shifts toward below-ground transmission and distribution infrastructure to cope with an increase in severe weather events. All new greenfield urban developments are expected to be less vulnerable to severe events as a result of an immediate shift to underground distribution networks.

Health

Impacts from health are assumed to be reduced by undertaking preventive measures. While these preventive measures require government outlays, they prevent widespread outbreaks of diseases such as dengue virus and bacterial gastroenteritis.

While the Review was able to consider preventive measures, it was not able to develop an opinion on future medical advances that might further reduce the economic costs of diseases likely to be more prevalent as a result of climate change. For example, it is possible that a cure for dengue virus would reduce the time that patients take to recover, and hence reduce the time workers need to be away from their jobs.

The analysis also includes an assumption that the population will acclimatise, at least partially, to higher temperatures. This assumption builds in a limit to the range in which the human body is able to physically cope with extreme temperature. This means that temperature changes are still assumed to have some adverse impacts on the productivity of outdoor workers.

Adaptation in MMRF

As described in Box 9.2, MMRF has a number of features that allow agents in the model to adapt to economic impacts. The net effect of these features is that they reduce the costs that would otherwise be incurred by the economy as a result of the direct impacts from climate change.

For example, the economic loss from a reduction in productivity in a single industry can be minimised by agents switching purchasing decisions towards substitutes that are not as heavily affected. Where demand is relatively price insensitive, for example where a good is a required input to the production of another firm, or is a basic consumer good, firms are able to substitute between factors, or become more factor-intensive in order to meet demand. However, this adaptation comes at a cost—in this case, higher costs from the use of additional inputs.

9.2.5 Limitations to the analysis

The many and compounding sources of uncertainty associated with climate change science and impacts analysis, as well as the uncertainties inherent in undertaking economic modelling over very long time periods, mean there are significant limitations to the analysis.

Incorporating the breadth of economic impacts of climate change

The nature of the modelling undertaken by the Review does not allow for feedback of impacts from climate change in an internally consistent or integrated way. The domestic economic modelling framework is a traditional market model. It does not explicitly account for feedback from environmental changes to changes in economic factors or activity. As a result, the analysis is limited to the five key areas of climate change impact, and their economic effects, that could be determined outside the model and manually imposed as a shock.

The specified climate change impacts have been incorporated in a detailed and comprehensive way. This allows a much more robust assessment of the individual climate change impacts than would be possible using an integrated assessment model. It also illustrates and tests a methodology that can be taken further in subsequent work.

While many of the impacts of climate change have been excluded from the analysis, the Review is of the opinion it has captured a sizeable proportion of the 'median' impacts that are manifested through market processes (see Chapter 2).

Market versus non-market impacts

Non-market services are not traded in conventional markets but have considerable value to many Australians. This means that traditional market models, such as MMRF, cannot capture their effect.

For example, one of the possible impacts of climate change could be an increase in mortality. This is likely to have both market and non-market consequences. The loss of life or quality of life is a non-market impact and cannot be captured in a CGE framework. The market impacts, on the other hand, may include a reduction in the labour force, a reduction in labour productivity and/or an increase in the requirements for health services. It is these market impacts that are captured in a CGE framework.

Chapter 10 discusses the wider context of costs of climate change within which the contents of this chapter should be seen.

Treatment of uncertainty and risk

The cumulative nature of the uncertainties associated with climate change science and impacts anlaysis means that the range of possible outcomes from any one of the Review's choices on unmitigated and mitigated global emissions paths can be considerable.

Given the detailed sectoral and regional focus of the Review's economic modelling, and the modelling frameworks used, it was not possible for the Review to model climate change impacts probabilistically to account for the large range of possible outcomes.

In further development of this work, it would be desirable to undertake sensitivity analysis on each of the key areas of uncertainty, potentially with reference to higher and lower areas of the probability distributions. Given the non-integrated nature of the MMRF modelling framework, and the manual linking and estimation required for each of five key areas of impact being considered, this will be a significant task. Attempting to model the large range of outcomes for each variable in the chain of events from emissions to economic impacts would be an extraordinary task in a modelling framework such as MMRF. The number of simulations required to deal with the range of uncertainties would be immense.

In dealing with the sources of uncertainty, the Review's general approach was to choose a best-estimate for each of the decision parameters required. This best estimate was generally determined by reference to the 'middle' or central outcome of the range of possible outcomes.

For example, in relation to global average temperature change, the best estimate of 3°C climate sensitivity was used for the domestic impacts analysis. However, the temperature response may very well be higher or lower. While unlikely to be less than 1.5°C, values substantially higher than 4.5°C cannot be excluded (see Chapter 3).

The climate change response to temperature increase is also highly uncertain for a number of climate variables, as discussed in Chapter 5. For Australia, variability is particularly pronounced for rainfall. The Review has chosen to deal with the uncertainty in how the Australian climate will respond to increased global average temperatures by considering an additional 'dry' rainfall sensitivity. Results and discussion of the dry scenario are provided in Chapter 10.

These examples are only a subset of the many sources of uncertainty relating to climate change and climate change impacts. As noted above, and discussed in Chapter 3, there were many matters on which the Review was required to make decisions.

The Review is acutely aware of the limitations associated with its approach to dealing with uncertainty. It acknowledges that a best-estimate approach to the selection of key parameters will preclude analysis of low probability but high damage outcomes. It is these outcomes that are likely to pose risk of catastrophic damages from climate change and which should feature prominently in an overall assessment of the costs and benefits of climate change mitigation (see Chapter 2).

However, given the computational requirements of MMRF and the manual quantification of climate change impacts required for each of the key areas of impact, multiplied by the number of scenarios being considered, the chosen approach was the most appropriate in the time available for the Review. In addition, this approach does not preclude a detailed external assessment of the potential impacts of low probability but high impact events, and other extreme outcomes and responses, as a complement to the assessment of the economic impacts of climate change taken in this chapter.

Uncertainty in modelling over long time frames

The long time frames and large structural shifts involved in climate change analysis present considerable challenges for modelling. For example, very large productivity changes under more extreme climate scenarios, such as the dry unmitigated scenario, introduce a significant degree of uncertainty about the way the economy is likely to respond. Most economists think about changes at the margins. Economic models, on the whole, reflect this. Climate change is likely to introduce large changes to productivity in key sectors (Cline 2007) and hence result in significant changes to production technologies, prices and consumer behaviour.

Like most economic models, the assumed behavioural responses in MMRF are determined by parameters and data that have been derived from recent history. These responses will not necessarily still hold far into the future, or for change that is outside of recent experience. For this reason, the results for the latter half of the century, particularly for the more extreme climate scenario discussed in Chapter 10, should be treated with caution.

This limitation is an important one given that increased risks and potential impacts of unmitigated climate change are likely to be felt most severely in the second half of this century, and into the next, if left unmanaged.

Linking of global climate change impacts

For technical reasons, it was necessary for the Review to use different global average temperature changes for the assessment of domestic climate change impacts than for the assessment of international climate change impacts.

As shown in Table 9.1, domestic climate change impacts were derived from global average temperature changes estimated from the A1F1 global emissions profile and the MAGICC climate model. The international impacts were derived from global temperature changes estimated from the newly developed Garnaut–Treasury global emissions profile and the CSIRO Mk3L climate model (Phipps 2006). This has resulted in some differences in global average temperatures used for the domestic and global modelling exercises.[7]

These differences could not be avoided in the time frames available for the Review. As noted in section 9.2.1, in order to begin detailed work on quantifying the direct Australian impacts of climate change for the range of sectors and areas of impact considered, an assessment of global emissions from a business-as-usual reference case was required well in advance of the completion of the newly constructed Garnaut–Treasury global reference case. The requirements of the global model (GIAM) also necessitated a more complex model to provide regional analysis of temperature changes.

9.2.6 What would the Australian economy look like in the absence of climate change?

Climate change operates over very long time frames, with significant time lags between greenhouse gas emissions and resulting impacts. As a result, quantitative analysis of climate change impacts must take a long-term view.

The reference case projects the evolution of the global and Australian economy, and associated greenhouse gas emissions, to the end of the current century. This was a challenging exercise, requiring assumptions for a wide range of economic, social and environmental variables that can change in unpredictable ways. As the time frame expands, assumptions necessarily become more speculative.

The assumptions used draw on an extensive analysis of the historical structure, performance and evolution of the global and Australian economies. Future projections are based primarily on a continuation of historical trends, adjusted in the light of broadly accepted views on likely future behavioural shifts, for instance declining fertility rates and a gradual increase in consumer preferences for services as per capita incomes continue to rise.

The reference case presents a 'world without climate change', and so provides the starting point from which the impacts of climate change can be measured. The future structure of the economy is a crucial determinant of cost estimates—for example, a change to an industry that contributes 5 per cent to GDP will have a larger impact than the same proportionate change to an industry that only contributes 1 per cent.

The socio-economic storyline

Real economic output (real GDP) is determined by three components: population, participation and productivity (the '3Ps'). The pattern and rate of GDP growth is therefore a function of the assumptions regarding movements in population; changes in participation rates; and the growth of productivity. Trends in these variables differ across geographic regions and industry sectors.

The reference case describes a world of strong economic growth and continued improvement in technology and resource use efficiency. Global population peaks in the second half of the century, and the productivity gap between countries narrows, reducing regional differences in per capita income.

Over the century to 2100, global population is assumed to follow United Nations projections, increasing by about 40 per cent from 6.5 billion in 2005 to around 9.3 billion people at the end of the century (Chapter 4). The majority of this population growth occurs in south Asia, the Middle East and Central Asia, Africa and South America.

Over the same period, Australia's population is projected to more than double, rising from just over 20 million in 2005 to nearly 47 million by 2100. Population growth moderates in the second half of the century due to declining fertility rates. Queensland, Western Australia and the Northern Territory have rising shares of the national population, while South Australia, Tasmania and the Australian Capital Territory have falling national shares. Population shares for New South Wales and Victoria remain stable.

Productivity growth is the primary driver of the global economy, with per capita GDP projected to increase by more than 900 per cent over the coming century, compared to a 380 per cent increase over the 20th century (Chapter 4). Overall, the global economy is projected to be roughly 15 times larger in 2100 than in 2005.

Productivity growth rates vary across countries, reflecting their different stages of development and an expectation of conditional convergence in productivity levels. Existing differences in productivity levels narrow over the century. Developed countries all improve their productivity at around the same rate, while developing countries accelerate towards the productivity levels of developed countries. This acceleration occurs for all developing countries, but the rate of acceleration in the nearer term takes into account each country's recent growth performance.

In the near term, China continues to experience strong productivity growth. China's per capita GDP will reach 2005 US levels by mid century. By the end of the century, average Chinese productivity levels and living standards are approaching the range of developed countries, although they remain significantly below US levels in 2100.

For Australia, the combination of population, participation and productivity growth results in Australia's GDP level experiencing an increase of around 200 per cent between 2005 and 2050, and over 700 per cent increase to 2100. Australian GDP grows at an average annual rate of 2.3 per cent over the century. This comprises average growth in the labour supply of 0.8 per cent a year and aggregate labour productivity growth of 1.5 per cent per annum.

Sectoral trends in the global and Australian economy are driven by both supply- and demand-side factors.

On the supply side, industry sectors are assumed to have different rates of productivity growth. The sectoral differences assumed in the reference case are based on historical patterns, where some industries show considerably higher average growth rates than others. For instance, in Australia the communications industry is expected to grow at almost double the average rate, while productivity in service sectors such as public administration grows much more slowly. Over time the industry productivity growth assumptions are assumed to converge, reflecting uncertainty around how persistent historical differences will be over the century. Similar assumptions are made to the sectoral productivity of all countries based on their own historical patterns.

As a small open economy, Australia is strongly affected by global economic forces.

Rising per capita incomes in developing countries are expected to result in more of the world's population spending a larger share of their income on more energy-intensive goods and higher-value food. These forces will create strong demand for Australia's commodity exports and result in substantial changes in our pattern of trade with other nations.

China, India and Indonesia are our first, second and third largest export markets by 2100. The proportion of Australia's exports going to these three countries increases from 14 per cent in 2005 to more than 40 per cent in 2100.

Australia's terms of trade are expected to benefit from the pattern of global growth. Projecting movements in Australia's terms of trade is somewhat complicated due to the recent strong growth in export prices reflecting the surge in global demand for commodities. However, over the coming decade Australia's terms of trade are expected to fall as commodity producers around the world increase the supply of resources in response to the recent demand surge. Beyond 2020, Australia's terms of trade are expected to gradually improve as export prices return to an upward trend and import prices remain modest reflecting the likely pattern of global productivity growth. By the end of the century Australia's terms of trade remain below the level reached in recent years, and are around 13 per cent higher than in 2005.

Australian real household income is expected to grow more strongly than GDP over the century, reflecting the influence of the terms of trade. As Australia's per capita income rises we expect to see a continuation of the historical shift in household preferences towards services. In addition, the government services industry is expected to grow faster than average, in part due to the ageing of Australia's population.

The divergent industrial productivity trends combined with these two key demand–side influences, shifting household demand preferences and global demand for Australian exports, combine to influence industrial shares in the economy.

Services are expected to represent a growing share of the Australian economy, while the manufacturing sector continues its historical decline. Services are projected to increase by 2.5 per cent per annum over the century. Strong productivity growth in global manufacturing, combined with a rising nominal exchange rate reflecting the terms of trade, will result in a loss of competitiveness for the Australian manufacturing sector. The manufacturing sector as a whole is expected to grow by 1.1 per cent per annum over the century.

The mining sector in the near term benefits from the current surge in world demand for commodities. However, as resource constraints start to affect underlying productivity in the later half of the century, the mining sector is expected to experience more modest growth. On average over the century the mining sector is expected to grow by slightly less than aggregate GDP growth. The agricultural sector is expected to grow more slowly, at around 1.5 per cent per annum over the century, largely reflecting constraints on land.

Greenhouse gas emissions

The strong productivity and population growth story outlined above, combined with the changing structural mix of the economy, result in Australia's greenhouse gas emissions nearly doubling between 2005 and 2050, and nearly doubling again by the end of the century. Emissions are projected to grow more slowly than economic activity, resulting in a significant decline in the emissions-intensity of GDP from 0.6 kg CO_2-e/$ in 2005 to 0.3 kg CO_2-e/$ in 2100.

Emissions growth is in large part due to the combination of rising energy consumption and continued reliance on emissions-intensive fossil fuels. The largest contribution to the growth in Australia's emissions comes from the stationary energy sector: its emissions are projected to increase by 350 per cent to over 1200 Mt CO_2-e in 2100; which comprises around 60 per cent of projected national emissions. Transport emissions maintain a stable share of national emissions, at around 14 per cent, with strong growth in air transport emissions being offset by more modest growth in passenger transport emissions.

9.2.7 The economic costs of climate change: unmitigated climate change

The results presented in this section and throughout the remainder of this chapter, provide an indication of the economic consequences of climate change associated with the first category of climate change costs—measured market impacts of climate change (Chapter 2). Chapter 10 provides an assessment and some preliminary quantification of the additional three categories of costs associated with climate change: (1) unmeasured market impacts, (2) the insurance value of mitigation, and (3) non-market impacts that Australians value.

The results presented in this section are for the median scenario for climate damages discussed in section 9.2.1. These damages represent the Review's best estimate of those that would occur under a best-estimate unmitigated climate change scenario for Australia. As noted previously, the future climate changes that would result from global warming are highly uncertain. It is possible that the impact could either be much less or much worse than described in this section. The results presented in this section are generally presented as deviations from a reference case without climate change. For this reason, a 5 per cent reduction in GDP by 2100, should be interpreted as meaning that GDP is projected to be 5 per cent lower than it would otherwise have been in 2100.

Finally, caution should be used in interpreting GDP as a measure of economic welfare. Economic welfare is derived from consumption. While an important determinant of welfare, GDP is a measure of production. For this reason, household consumption[8] is the most appropriate indicator of welfare produced indicator by the modelling.

Macroeconomic implications of climate change for Australia

Under the median unmitigated scenario (Figure 9.3), by 2025, GDP is projected to decline by almost 1 per cent relative to the reference case without climate change. The direct effect of climate changes as well as expenditure on adaptation measures to minimise future impacts contribute to the reduction.

By 2050, the level of GDP is projected to fall by almost 2 per cent, relative to the reference case without climate change. By 2100, this loss reaches 4.8 per cent. This implies that economic output is projected to grow by 8.1 times compared with 8.6 times in the reference case without climate change. The loss equates to GDP being around $425 billion (2005–06 dollars) lower in the year 2100, relative to a reference case without climate change.

Real household incomes are likely to be reduced substantially by climate change. Declines in wages (and other income), coupled with higher consumer prices, work to reduce household consumption by around 5.4 per cent or $275 billion (2005–06 dollars) by 2100. This represents a loss of consumption equivalent to almost $5700 per person in 2100.

Figure 9.3 Changes to select macroeconomic variables, median unmitigated climate scenario, 2005–2100

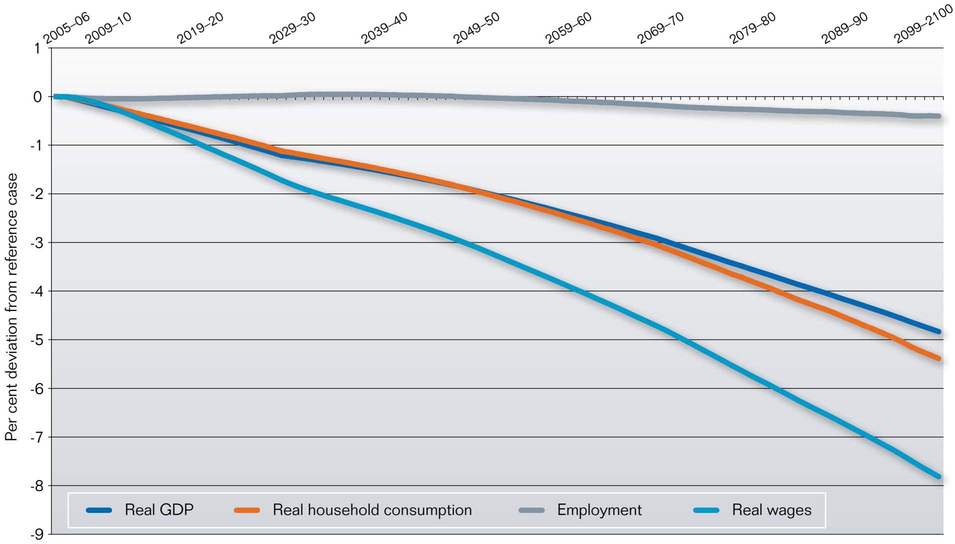


Table 9.2 shows projections for key macroeconomic variables for the median unmitigated climate scenario. It shows that the gap between the deviation in household consumption and GDP is widening through time. This is a result of the projected fall in Australia's terms of trade relative to the reference case.[9] A lower terms of trade ratio implies that a greater volume of exports are now required to pay for the same volume of imports. Household consumption is import intensive, which tends to reduce consumption levels relative to GDP.[10]

Table 9.2 Projected macroeconomic effects of climate change, median unmitigated climate scenario (per cent deviation from reference case)

Variable	2020	2050	2100
Real GDP	-0.7	-1.9	-4.8
Real gross national expenditure	-0.6	-1.9	-5.3
Real household consumption	-0.6	-1.9	-5.4
Export volumes	-0.7	-1.7	-2.0
Import volumes	-0.2	-0.8	-2.3
Terms of trade	0.1	0.1	-1.8
Real wages	-0.9	-3.0	-7.8

Changes in labour demand are captured in large changes to wages, rather than unemployment. Unmitigated climate change causes real wages to be 7.8 per cent lower than they would otherwise have been.

In interpreting these results it is important to recognise that the modelling has not been able to capture the impacts of increased climate variability. For example, although climate change is likely to result in more drought periods and an increase in the intensity of tropical cyclones, the Review is unable to predict when these events might occur. For this reason, the shocks that feed into the Review's modelling work have been averaged across time. This averaging means that the Review is unlikely to capture the short-run implications of climate-related shocks.

Short-run variability is likely to result in significant employment effects. For example, it is possible that a combination of effects could push Australia's economy into periods of recession. Unemployment is likely to increase during the recession period, and then slowly decline as the economy heads back into full employment. However, it is possible that the effects could take some time to wash through the economy. For example, recent history has shown that hysteresis effects can work to keep unemployment at high levels for reasonably long time periods. Associated effects may cause recession to lower average growth rates than have been modelled here.

Consequences for households

Climate change will have significant negative effects on households. These are likely to be differentiated across different household types. Low-income households are likely to be most negatively affected.

As shown in Table 9.2, household consumption falls by a higher proportion than GDP. As stated above, the reason for this lost purchasing power is a fall in Australia's terms of trade relative to the reference case.

At the same time, the decline in economic activity reduces the demand for labour. In order to maintain employment levels near to their long-run equilibrium, wages must fall relative to the reference case. The combined effects of lower economic growth (and hence reduced demand for labour) and higher consumer prices cause real wages to fall substantially (7.8 per cent by 2100).

The net effect of these changes is that household consumption falls by a higher proportion than GDP. Household consumption falls by 0.6, 1.9 and 5.4 per cent by 2020, 2050 and 2100 respectively, relative to a reference case without climate change.

Climate change will have disproportionate effects on food and dwelling prices. These commodities are non-discretionary goods. Lower-income families and households, who spend a high proportion of their income on these goods, are likely to be more adversely affected than others.

Climate change is likely to have adverse effects on agricultural production in Australia. Higher temperatures and especially reduced rainfall will make it increasingly difficult for Australian farms to maintain production at levels sufficient to meet foreign and domestic demand. In order to cope with water shortages, farmers require higher levels of capital and labour inputs. Additionally, increased climate variability causes farm production to become less reliable. These factors impose significant additional costs on farms and cause the cost of food to increase substantially. Relative to the general price of goods in the economy, the cost of food is projected to rise by just over 10 per cent by 2100.

Climate change will also have large impacts on the dwellings sector. The need for more stringent building codes, accelerated degradation of building materials and impacts from cyclones will impose significant costs on consumers. The modelling undertaken by the Review shows that, relative to the general price of goods in the economy, the cost of dwellings is likely to increase by more than 5 per cent by 2100.

The modelling shows that climate change is unlikely to affect all income types uniformly (Table 9.3). While wage income falls substantially, non-wage income is less affected.

Table 9.3 Changes to income types (per cent deviation from reference case)

Income type	2020	2050	2100
Income from labour	-1.0	-3.1	-7.9
Income from land	0.6	2.4	1.1
Income from capital	-0.4	-1.4	-4.8

Capital returns are less affected than wage income since capital-intensive sectors of the economy are less affected than the economy average by climate change. For example, although profits to mining fall, they fall by less than wage rates.[11]

Returns to agricultural land are also projected to be affected significantly less than real wages. Returns to agricultural land are high relative to real wages since the quantity of arable land has fallen considerably as a result of climate change. Since domestic demand for agricultural products is relatively insensitive to price movements, the shortage of land causes higher returns. In more practical terms, farmers will require high returns in order to continue farming land whose productivity is falling. While there are likely to be significant transitional costs, particularly for those farmers whose land becomes unviable, the returns to the farm sector are likely to be affected less than incomes for the general population.

Those that derive income from wages are likely to be more adversely affected, on average, than those that derive income from capital or land.

Among land holders there are likely to be clear winners and losers. For many farmers, climate change will make land unviable. However, for farmers in less marginal land, or those that are able to adapt their production methods to a world with less water, rising food prices may prove to be advantageous.

Implications for trade

International modelling using the global model (GIAM) shows that climate change will begin to have material effects on international economies from about 2050. By 2100, the economic impacts of climate change have increased substantially, with global GDP projected to fall by 7.3 per cent, relative to a reference case with no climate change.

The economic impacts on developing countries are projected to be greater than the global average. For example, India's GDP is projected to decline by 1.3 per cent by 2050 and 11.1 per cent by 2100, relative to the reference case. This is important for Australia, since Australia's reliance on developing countries for demand for its exports is projected to grow rapidly in the reference case.

Changes to terms of trade for the regions modelled in GIAM are shown in Table 9.4.

Table 9.4 Changes to terms of trade (per cent change from reference case)

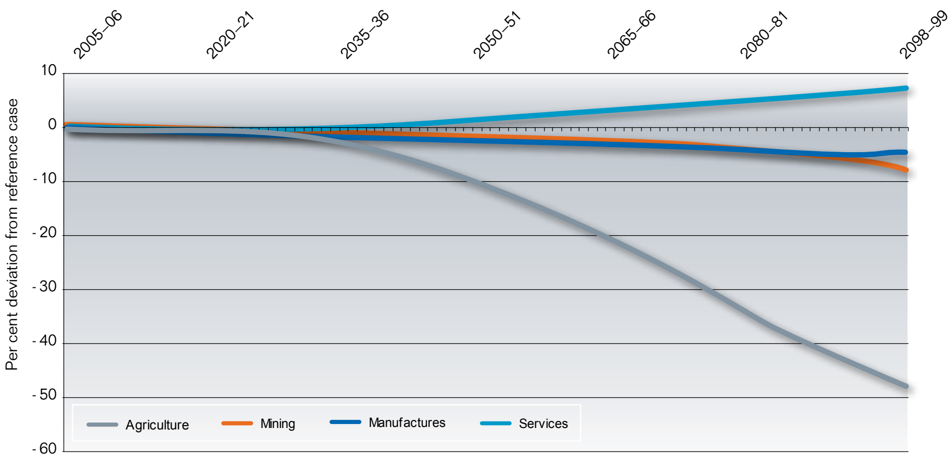
	2050	2100
United States	0.01	-0.92
European Union (25)	-0.02	-0.93
China	0.02	0.91
Former Soviet Union	-0.11	0.64
Japan	0.04	-1.35
India	0.02	0.40
Canada	-0.10	-0.58
Australia	-0.17	-2.78
Indonesia	0.05	0.84
South Africa	-0.05	-0.99
Other Asia	0.02	0.37
Rest of OPEC	-0.21	-0.14
Rest of world	0.04	0.33

The inclusion of global climate change damages affects the supply and demand for Australia's exports and imports and consequently affects Australia's terms of trade. In the global modelling undertaken by the Review, Australia's terms of trade are projected to be affected more adversely by climate change than those of any other country or region covered by the analysis. In particular, Australia's terms of trade are projected to deteriorate due to climate change impacts by about 2.8 per cent[12] at 2100, relative to the reference case.

The projected decline in Australia's terms of trade is dominated by declines in Australia's average export prices rather than changes in average import prices. In particular, as a result of climate change and the the associated changes in global production and demand for goods, Australia's average export price is projected to decline by about 3.2 per cent relative to the reference case. In contrast, Australia's average import price is projected to decline by only 0.4 per cent relative to the reference case.

The combined effect of lower trade volumes and lower prices reduces real incomes accruing to Australians from trade. The reduction in global demand, combined with the impacts of climate change on the costs of domestic production, and hence export prices, reduces export volumes of Australian commodities significantly. The projected changes in export volumes are shown in Figure 9.4. While exports of agriculture, mining and manufactured commodities are projected to decline, changes in the real exchange rates assist service exports.

Figure 9.4 Changes to export volumes, 2005–99



Industry impacts

The MMRF model produces projections for 58 industries. While this can be useful for identifying those industries likely to be disadvantaged or advantaged by climate change, some caution is required when analysing the results. Since the Review has only considered a subset of impacts in the modelling, there may be significant sectoral bias in the results. For example, the Review has not considered the likely effect that a decline in environmental amenity might have on tourism due to the difficultiy of estimating the effects of climate change on that sector. Despite this caveat, the industry results are useful in demonstrating that the impacts of climate change will not be felt evenly across the economy.

The modelling shows that output falls for almost every industry. However, some industries are particularly adversely affected. Agriculture is the most affected sector in the economy, reflecting the very large productivity losses in that sector.

As shown in Chapter 7, increased temperatures and reduced rainfall are likely to cause substantial reductions in agricultural output. However, the decline in agricultural output is substantially lower than would be implied by the productivity loss alone. Export volumes (Figure 9.4) fall by proportionately more than output, implying that domestic demand for agricultural products is relatively unaffected. Since food products are relatively price-inelastic goods, domestic demand is maintained despite significant price increases.

The mining industries are also adversely affected by climate change. Output of mining is projected to decline by more than 5 per cent, relative to the reference case, by 2100. The coal industry is by far the most affected, with output projected to decline by almost 10 per cent, relative to the reference case, by 2100. This result is mainly driven by changes in world demand, since the majority of coal produced in Australia is exported. The international modelling undertaken by the Review implies that world demand[13] for coal falls by almost 18 per cent, relative to the reference case. Iron ore activity is also projected to decline, relative to the reference case, for much the same reason as for coal.

State and territory results

As noted earlier, the Review has not considered all of the possible market impacts of climate change. For impacts that are region specific, their exclusion is likely to introduce a bias towards those states where impacts are able to be estimated most completely. For this reason, relativities between states and territories need to be interpreted cautiously.

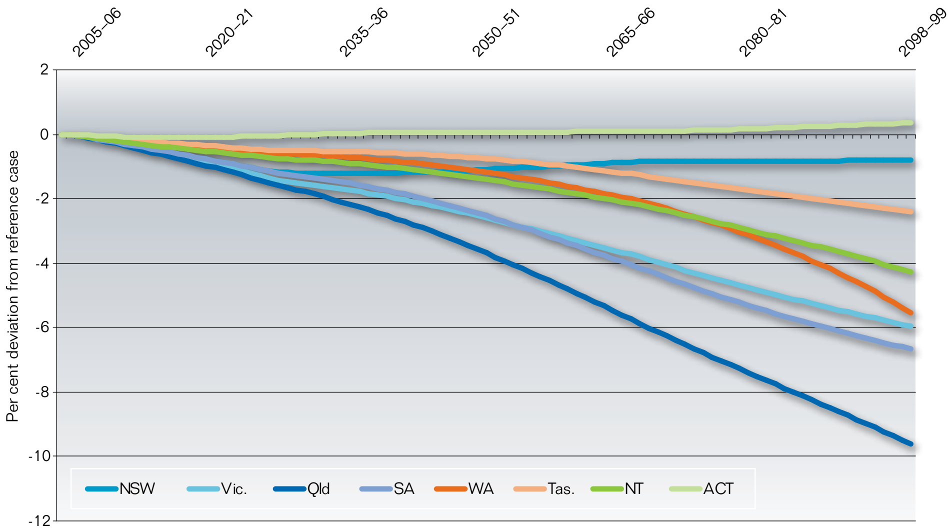
Despite this shortcoming, the Review's work highlights some key regional differences. Largely, impacts are most extreme in regions that:

- are disproportionately affected by climate change
- have a higher concentration of industries that are vulnerable to climate change, or
- have a higher proportion of industries that are vulnerable to changes in world demand.

The projected changes in gross state product (GSP) for each state and territory, relative to the reference case, are shown in Figure 9.5. The projected results of climate change differ significantly across the states and territories.

Some caution needs to be used in interpreting this chart since there are significant population changes projected in the modelling, and the GSP results are *not* presented on a per capita basis. Readers should also keep in mind that the results are presented as deviations relative to the reference case. That is, the results show that regions will grow less quickly than they would in a world with no climate change.

Figure 9.5 Projected changes to gross state product, 2005–99



Queensland is projected to be most affected by climate change for a number of reasons. Queensland has large export-orientated mining (especially coal) and agriculture sectors (primarily beef, sugar and to a lesser extent cotton). These sectors are expected to be hit hard by climate change. Global demand for coal is projected to decline sharply (world demand is projected to fall by almost 18 per cent by 2100 relative to the reference case)[15] and beef and sugar production is projected to fall significantly as rainfall declines. Reductions in economic activity and hence employment opportunities, relative to the reference case, slow the migration of people from interstate.[16]

Climate change is projected to have relatively large effects on GSP in Victoria and South Australia. In both states agriculture is expected to be hit hard by climate change. However, these regions are less affected than Queensland because the global impacts on mining commodities in these states are much lower.

Activity levels in the Northern Territory are less affected than in Victoria and South Australia since its economy is less dependent on agriculture.

Western Australia is less affected by climate change in the first half of the century, since its agricultural regions are initially unaffected. In the second half of the century, damages in Western Australia increase as climate change begins to affect its agricultural output and world demand for mining commodities begins to fall.

New South Wales is also projected to do less poorly than the average of the rest of the country in a world with climate change. There are two main reasons for this. Firstly, New South Wales is relatively intensive in services, which is the sector least affected by climate change. Secondly, agriculture in New South Wales makes only a small contribution to GSP. By 2100, agriculture contributes around 2 per cent to New South Wales' GSP compared with the economy-wide average of around 5 per cent. The relatively mild economic impact in New South Wales slows the rate of outward migration and increases the state's population relative to the reference case.

Tasmania is also relatively unaffected since climate changes are projected to be relatively small and its industries are less susceptible to climate damages. Tasmania's climate is relatively cool compared to the rest of Australia, and, unlike most other regions in Australia, it has a surplus of water resources.

The Australian Capital Territory is unaffected since its main activity is related to the running of government and the modelling assumes that government consumption is unaffected by climate change.

9.3 The contribution of individual climate change impacts to net economic impacts

This section briefly discusses each of the five key areas of impact considered as part of the economic modelling and their contribution to the net economic effects of climate change.

In order to demonstrate the relative contribution of each impact area, the Review has modelled each separately. While this provides an indication of the economic effects each impact area would have on its own, caution must be used in interpreting the results since the results are not additive.[17]

Each of the modelled impact area's effects on household consumption is summarised in Table 9.5.

Table 9.5 Projected changes to consumption from individual impact areas (per cent deviation from reference case)

	2020	2050	2100
Infrastructure	-0.53	-1.23	-2.42
Agriculture	-0.10	-0.67	-2.14
Global impacts	0.00	-0.08	-1.40
Human health	0.00	-0.02	-0.08
Cyclones	0.00	-0.01	-0.02

9.3.1 Infrastructure

The impacts of climate change on infrastructure are projected to have the most significant effects on Australia's output and consumption of goods and services. This result is perhaps not surprising, given the high value and diversity of infrastructure assets. As discussed in Chapter 7, the infrastructure impacts encompass a wide range of assets, including commercial and residential buildings, water supply and electricity infrastructure, and ports. The high value of these assets means that even marginal changes can have large economic implications.

A simple calculation can help demonstrate the economic importance of assets such as residential buildings. In 2005–06, residential buildings made up approximately 40 per cent of total Australian capital stocks. Returns to capital stocks, in the same year, contributed around 40 per cent of total income, which suggests that residential buildings alone contributed around 16 per cent to total income.

9.3.2 Agriculture

The impacts on the agricultural sector are projected to have large effects on economic welfare. A simple calculation can provide some insights as to the relative size of the economic effects of the impacts on agriculture. While agriculture contributes approximately 3 per cent to GDP today, by 2100 this has climbed to around 5 per cent under the reference case.[18] With other things fixed, a 40 per cent reduction in agricultural factor productivity would reduce GDP by around 2 per cent in 2100.

The back of the envelope method provides a reasonably close measure for the actual impacts because demand for agriculture is relatively insensitive to price changes. Rather than affect output, the loss of productivity will result in agriculture drawing more resources from the economy in order to meet this inelastic demand. We expect this result since food is an essential consumer good and climate change will most likely make food production more difficult. Producers will need to adapt to climate change and this adaptation will require significant additional resources.

In order to maintain production at levels justified by domestic and world demand and prices, agriculture will need more resources. These scarce resources will have to be drawn away from the rest of the economy.

There are a number of key assumptions and limitations which are important in determining how the direct impacts on agricultural productivity flow through as economy-wide effects.

It is assumed that domestic consumption of food products is relatively insensitive to price changes over a period in which incomes grow considerably. For example, the Review has assumed that domestic consumption of meat remains high despite significant increases in the price of meat.[19]

While the modelling undertaken by the Review shows food imports increasing, the Review has constrained the extent to which imports replace domestic food production. There are two key factors that have influenced the Review's thinking in this regard. First, growth in developing countries over the next 100 years is likely to result in increases in the cost of food produced overseas. Second, the Review has not undertaken detailed modelling to estimate the impacts that climate change may have on the cost of food production in the rest of the world.

9.3.3 Terms of trade changes from global impacts

The impacts of climate change in other countries will have significant implications for economic welfare in Australia.

The global modelling (GIAM) suggests that world GDP is likely to fall by around 7 per cent by 2100, relative to a reference case with no climate change. The modelling also suggests that losses in developing countries are likely to be higher than the global average.

This is important since, by 2100, developing countries in our region are projected to become our major trading partners. As discussed in section 9.2.6, in the reference case with no climate change fast growth in these countries is projected to boost demand (and hence prices) for Australian commodities and lead to significant terms of trade gains.

Terms of trade gains boost welfare in Australia by generating foreign income which can be used to purchase imports. In the reference case, by 2100 Australia's terms of trade are projected to be around 13 per cent higher than in 2005.

Declines in global activity, particularly in developing countries, work to undo many of the gains experienced from strong global growth in the reference case.

9.3.5 Health

The health-related impacts considered by the Review have relatively small economic effects. As shown in Table 9.7, by 2100 the impacts from health cause, in isolation, a 0.08 per cent decline in consumption, relative to a reference case with no climate change.

The interpretation of these results must be considered cautiously since, as outlined in section 9.2.5, the Review has only captured a component of the likely total health impacts. Nevertheless, the results show that, providing the appropriate preventive health measures are undertaken, the impacts of climate change on human health can be managed without large economic cost. The effects of climate change on health are important for values that do not weigh in the marketplace (see Chapter 2).

9.3.6 Tropical cyclones

The impacts of tropical cyclones are also shown to have a relatively small impact on Australian consumption of goods and services. While a single cyclone event has the potential to create significant economic damage, particularly if it was to hit a population centre in south-east Queensland, these events are relatively infrequent. Taken as a series of annualised losses, the economic impacts are small.

These results however, need to be interpreted with some caution. In the time available it was not possible to consider either the impacts of flooding associated with cyclones or the impacts that might be associated with a southward shift in the genesis of tropical cyclones. In addition, the Review was only able to capture the costs associated with damage to dwellings. There are also likely to be costs associated with damage to other infrastructure and from business disruption. This implies that the cyclone impacts captured by the Review may be underestimated.

9.4 A final caution

The fact that there are substantial costs of climate change do not make a case for any degree of mitigation. Mitigation has costs; and no degree of mitigation commenced in 2008 or 2010 will avoid all of the costs of climate change. The assessment of whether and how much mitigation is justified depends on comparisons of the costs of mitigation, with the costs of climate change that are actually avoided. For that comparison, we need the results of the economic modelling that will be reported in the supplementary draft report. It will also require assessment of a wider range of costs of climate change, as introduced in Chapter 2 and discussed further in Chapter 10.

Notes

1 Median rainfall and local temperature outcomes are assumed. See section 9.2.1 for further discussion. These outcomes have the highest likelihood of occurring based on current understanding and model outputs, but higher or lower outcomes are likely.

2 For more information see <www.climatechangeinAustralia.gov.au>.

3 In the Fourth Assessment Report, the IPCC estimates that the annual mean global surface temperature is likely to increase by between 2°C and 4.5°C following a doubling of carbon dioxide concentrations in the atmosphere—this is known as 'climate sensitivity'. The response is very unlikely to be less than 1.5°C, but values substantially higher than 4.5°C cannot be excluded. The best estimate of the IPCC is about 3°C.

4 The effects on the demand for tourism and other services from the slowing of growth and world incomes from climate change have been captured.

5 Some broad impacts to manufacturing have been captured in the modelling, such as productivity losses of workers from heat related stress as well as the impacts on trade. While the Review has excluded some impacts on manufacturing, particularly the effects climate change may have on some infrastructure assets, these are likely to be relatively minor.

6 For the electricity sector, MMA used the Strategist model; for the transport sector, the Bureau of Infrastructure, Transport and Regional Economics (BITRE) and CSIRO used the energy sector model (ESM) (http://www.csiro.au/science/EnergySectorModel.html); for land use and forestry, ABARE used its internal modelling capabilities for Australia and Lawrence Berkeley National Laboratories used its GCOMAP model to provide global estimates (Sathaye et al. 2005). International trade effects resulting from climate change were analysed using the ABARE/CSIRO Global Integrated Assessment Model (GIAM) (Gunasekera et al. 2008).

7 Using the A1FI emissions profile and MAGICC (Wigley 2003), the average global surface temperature change by 2090–99 is predicted to be around 4.3°C (4.5°C in 2100). Using the emissions profile from the newly constructed Garnaut–Treasury global reference case, and CSIRO Mk3L (Phipps 2006) the average global surface temperature change by 2090–99 is predicted to be around 3.0°C. There are two main reasons for this 1.3°C difference. The first is the difference in climate sensitivity between MAGICC and the climate model used in GIAM, CSIRO Mk3L. When forced by A1FI emissions, both models give results within the range of A1FI outcomes in the IPCC AR4 (~ +2.4 to +6.4°C in 2090–99 from a 1980–99 baseline), with the Mk3L outcomes towards the lower end of this range. Second, the climate forcing used in the A1FI MAGICC calculations involved a greater range of greenhouse gases and also included a projected decrease in aerosol concentrations over the modelling period. CSIRO Mk3L was forced only by changes in CO_2. CH_4, N_2O and changes in CFCs and aerosols were not included. Together, these amounted to a radiative forcing in the A1FI calculations that is 10 per cent higher than in the GIAM–CSIRO Mk3L calculations. (There are some small differences in the averaging periods used to calculate the changes.) Taken together, these differences mean there could be some downside conservatism in the estimates of the international impacts of climate change.

8 Consumption would normally be measured as the combined total of household and government consumption. In order to determine a single welfare measure the Review has chosen model 'closures' such that household consumption is an effective measure of both. That is, government expenditure levels are shocked such that levels are kept at their reference case levels plus additional expenditure required because of climate change. The Review has been careful to ensure that the welfare measure accounts appropriately for the additional expenditure households might incur to adapt to climate change. For example, households might be expected to incur additional expenditure in order to offset heat-related health effects. This expenditure is not welfare enhancing since it is required to bring welfare to levels they would have been at in the absence of climate change.

9 The terms of trade describe the ratio of export to import prices.

10 Another way to think of this is that the economy needs to produce and export more goods in order to purchase a given quantity of goods from foreigners. That is, we need to work harder to consume the same amount.

11 The rate of return on capital, in the long run, tends to return to equilibrium as capital stocks adjust. The level of capital stocks tends to approximate the change in output. Therefore a 5 per cent decline in output might be expected to cause an approximate 5 per cent decline in capital incomes.

12 The domestic modelling undertaken by the Review projects a slightly lower change to Australia's terms of trade. While the domestic and global modelling are linked via matching shifts in export demand schedules and import prices, it was not possible to ensure convergence between the two models since it was not possible to estimate detailed sectoral-level impacts for countries other than Australia.

13 Caution needs to be exercised in interpreting changes to world demand. An 18 per cent decline implies that, with prices fixed, exports will decline by 18 per cent. However, prices are not fixed in MMRF. With a typical export price elasticity of around 5, small changes to prices will change the export results.

14 A full description of projections for regional changes to precipitation can be found in Chapter 6.

15 The change in world demand is a combination of the effect of both world prices and volume demanded. An 18 per cent decline in world demand implies volumes would fall by 18 if Australian prices were fixed. However, prices are not fixed and hence volumes would not fall by 18 per cent.

16 In the reference case Queensland is projected to be a net beneficiary from interstate migration, with population projected to grow by almost 200 per cent, which is significantly greater than the national average of around 125 per cent.

17 Individual impacts are not additive because in a whole-of-economy model like MMRF, individual sectors interact with each other. Impacts on one sector will affect others. This complex interaction means that multiple impacts are likely to compound or offset each other.

18 In the reference case, growing demand for agriculture, rising international food prices and limits on the physical quantities of agricultural land mean that returns agriculture increase relative to today.

19 One factor influencing the Review's thinking on this issue is that incomes increase many times over in the reference case. While climate change will reduce incomes relative to the reference case, in 2100 they are still many times greater than they are today. In the reference case the share of income spent on food is significantly lower than it is today.

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10 THE WIDER COSTS AND BENEFITS OF CLIMATE CHANGE MITIGATION IN AUSTRALIA

Key points

An examination of the range of impacts through market processes with median expectations of climate impacts suggests that the modelling covers 65 to 85 per cent of total market impacts. Non-market impacts of climate change would be valued highly by Australians, but are not quantified in the draft report.

The insurance value of some lower probability outcomes could be extremely costly. An assessment of more extreme low rainfall outcomes for Australia, near the 10th percentile of the distribution, suggests that GDP costs could be in the order of 8 per cent in 2100, with household consumption of around 9.1 per cent in 2100, and reduction in real wages of around 14.8 per cent relative to the reference case.

Extreme economic disruption in developing countries from climate change could exacerbate severe economic effects on Australia.

The extent to which Australian mitigation is justified will be assessed by analysing the benefits of avoided climate change in the modelling and in sectors not subject to formal modelling, the insurance value of mitigation in relation to lower probability but high cost outcomes, and the value to Australians of non-market impacts avoided by mitigation. The application of a range of approaches to discounting for time will be brought into the formulation of advice on whether and how much mitigation is justified.

Chapter 9 presented an economic assessment of a number of important consequences of climate change for the Australian economy. These consequences were based on the Review's consideration of best-estimate climate change outcomes if no action were taken to reduce emissions levels.[1]

Chapter 2 discussed a framework for the assessment of the costs and benefits of climate change mitigation. Four categories of effects of costs and benefits of climate change and its mitigation were identified:

Category 1: Measured market impacts—those market impacts about which there is sufficient scientific and economic knowledge and data to allow a robust quantification; these were covered in the modelling discussed in Chapter 9.

Category 2: Unmeasured market impacts—market impacts that are in principle amenable to quantification but could not be quantified in the time available to the Review due to data and knowledge limitations.

Category 3: Additional insurance value of mitigation—extreme climate change scenarios and outcomes and the tails of the probability distributions. These impacts arise separately from the best-estimate market effects because of risk aversion: people are generally prepared to pay some insurance cost to avoid the possibility of large, adverse outcomes.

Category 4: Non-market impacts that Australians value—impacts that are not valued in conventional markets but have considerable worth to Australians.

10.1 What proportion of market impacts does the modelling include and how significant are the exclusions?

10.1.1 Measured and ummeasured market impacts of climate change

Chapter 9 presented the results of modelling the quantifiable market consequences of climate change associated with the Review's best estimate of climate change outcomes. These market impacts were chosen and modelled based on causal links with climate change, demonstrated in the applied science, available data and knowledge, or the Review's capacity to commission new and significant research in the time available. Where economic consequences were considered to be potentially high, such as for tourism, geopolitical instability and some aspects of infrastructure, but where inadequate empirical data and research were available, the Review chose not to include them as part of the economic modelling exercise.

As a result, the Review's modelling in Chapter 9 excludes a range of market impacts that, given more time and research, could be included in an economic analysis of the kind undertaken in Chapter 9. The Review looks forward to ongoing empirical research and further contributions to the modelling framework and methodology established in this draft report.

Table 10.1 provides an extensive list of the market impacts that are likely to be associated with best-estimate climate change impacts, including the set of market impacts that have been quantified in the economic analysis in Chapter 9. Categories of impacts are grouped into economic 'sectors' or characterised as 'economy wide' where impacts are not sector specific, such as international trade and commercial buildings. The table provides a qualitative assessment of the economic consequences of climate change based on each sector's direct impact and risk from climate change, as well as potential adaptive capacity. The lack of empirical evidence and research for a range of sectors and impacts means that a significant element of judgment has been used in this assessment.

As shown in Table 10.1, a number of market impacts have been excluded from the Review's modelling. However, when considered as a function of the risk associated with each direct impact, and the adaptive capacity and economic value of each sector, it is likely that these omissions may only contribute a small or moderate proportion of the likely total economic consequences of climate change.

This analysis is somewhat speculative in nature and does not allow a definitive assessment of the size of the economic consequences for excluded categories. It does, however, allow a broad evaluation of the magnitude of exclusions.

For the purposes of categorising economic consequences in Table 10.1, the Review has adopted the following definitions for low, medium and high economic consequences:

- high economic consequence: 0.5–1.5% of GDP
- medium economic consequence: 0.1–0.5% of GDP
- low economic consequence: < 0.1% of GDP.

Table 10.1 Assessing the market impacts of climate change

Sector	Direct impact	Modelled	Risk	Ability to adjust or adapt	Comment	Direct economic consequence
Economy wide—international trade	Changes to import prices	Yes	High	–	Commodity-specific shocks, but methodology overlooks sectoral dimensions of climate change.	High
	Changes to world demand (commodity specific)	Yes	High	–		
Economy wide—infrastructure	Impacts on commercial buildings—changes to building codes and planning schemes	No	High	High	Capital stock of dwellings (current prices) in 2006–07 was around $1.3 million, 40% of total capital stocks (ABS 2007a).	Medium
	Accelerated degradation of buildings—maintenance and repair costs	Yes	High	High		Medium
Economy wide—extreme events (tropical cyclones, storms/flooding, bushfires)	Increased intensity of tropical cyclones—damage to residential infrastructure and home contents	Yes	High	Medium	The current average annual cost of tropical cyclones is estimated at $266 million, a quarter of the cost of natural disasters (BTE 2001).	Low
	Increased intensity of tropical cyclones—damage to commercial buildings and business interruption	No	High	Medium		Low
	Southward movement of tropical cyclones—infrastructure and business interruption	No	High	Medium	High uncertainty regarding southward movement of tropical cyclones.	Low
	Higher frequency of storm events (e.g. flooding from non-cyclone events)—damage to infrastructure	No	High	Medium in short run High in long run	Estimated average annual cost of floods in Australia is $314 million (BTE 2001).	Low
	Bushfires—infrastructure damage, crop loss, emergency response	No	High	Low–medium	Bushfires estimated to pose an annual average cost of about $77 million (BTE 2001).	Low
Economy wide—sea-level rise	Increase in sea levels of 0.59 m, impacts on coastal settlements	No	High	High	Assessment assumes there is no significant sea-level rise this century deglaciation.	Low
Economy wide—human health	Heat-related stress, dengue fever and gastroenteritis—impacts on productivity	Yes	High	High	Assumes management and prevention of health impacts.	Low
	Other health impacts (productivity)	No	Low	High		Low
Agriculture	Changes in dry land crop production due to changes in temperature and CO_2 concentrations	Yes	High	Medium	All crops $19.5 billion (gross value of commodities) (ABS 2007b).	High
	Sheep, cattle, dairy—changes in carrying capacity of pasture from CO_2 concentrations, rainfall and temperature	Yes	High	Medium		High
	Impacts on sheep and cattle from heat stress due to temperature increases	No	Low	Medium to high		Low

Sector	Direct impact	Modelled	Risk	Ability to adjust or adapt	Comment	Direct economic consequence
	Impacts on pigs and poultry from heat stress due to temperature increases	No	Low	Medium	Limited research on potential impacts.	Low
	Irrigated agriculture—reductions in water runoff	Yes	High	Medium	Adaptation through land-use change, water conservation.	High
Fisheries	Reduced yields due to changes in water temperature	No	Medium	Low	Potential for higher adaptive capacity for aquaculture. In 2006–07, forestry and fisheries combined contributed less than 2% of total GDP (ABS 2008a).	Low
Forestry	Yields affected by water availability and CO_2 concentrations	No	Low	Low	Possibility of using other species.	Low
Mining	Slower growth in demand due to slower increase in world income (relative to a no climate change world)	Yes	High	Low	In 2006–07, the mining industry contributed 7% of total GDP (ABS 2007a).	Medium to high
	Reduction in water availability	No	High	High		Low
Tourism	International tourism affected by slower growth in demand due to slower increase in world incomes (relative to a no climate change world)	Yes	High	Low	Tourism as a share of GDP is 3.7%, which equates to $38 935 million. In 2005–06, 11% of exports of goods and services (ABS 2008b).	Medium
	Reduction in international demand for Australian tourism as a result of reduced natural amenity of tourism products	No	High	Low	Requires assumptions of changes in preferences and relative amenity versus absolute amenity.	High
	Changes in domestic tourism as a result of reduced amenity of tourism products	No	Medium	Low to medium	Domestic tourism is worth $29 028 million (2.6% of GDP) (relative to international tourism—$9907 million) (0.9% of GDP).	Low
Government (health)	Increased expenditure on prevention and treatment for dengue virus, heat stress and gastroenteritis	Yes	Medium	High	Public and private expenditure low to moderate.	Low
	Increased expenditure on prevention and treatment for other health impacts (air pollution, mental health etc.)	No	Medium	High		Low
Government (defence/aid)	Increase in defence and aid expenditure due to geopolitical instability in neighbouring nations	No	High	Low	Combined aid and defence budget for interventions in Timor-Leste and Solomon Islands, $900 million per year. Foreign aid 2006–07, 0.3% GNI (AusAID 2006). Defence expenditure 2006–07, $17 billion (ABS 2007c).	Medium

Table 10.1 Assessing the market impacts of climate change *(continued)*

Sector	Direct impact	Modelled	Risk	Ability to adjust or adapt	Comment	Direct economic consequence
Residential dwellings	Building degradation and damage resulting from temperature, rainfall, wind etc. Changes to building codes and increased maintenance and repair	Yes	High	High	Costs of adaptation likely to be high.	High
	Impacts on buildings due to extreme events (e.g. flooding)	No	High	High	Costs of adaptation likely to be high.	Medium to high
Transport	Degradation of roads, bridges and rail due to temperature and rainfall	No	High	High	In 2004–05 maintaining and improving the total road network cost $9 billion (BITRE 2008).	Low
Ports	Port productivity and infrastructure affected by gradual sea-level rise and storms	Yes	High	High		Low
Airports	Impacts on infrastructure due to sea-level rise, temperature and rainfall	No	Low	Medium		Low
Tele-communications		No	Low	High	Telecommunication services industry contributed about 2.5% of GDP in 2006–07 (ABS 2007a).	Low
Water supply	Decrease in rainfall reduces reliance on traditional water supply for urban uses and increases demand for alternative water supply options	Yes	High	High	High costs associated with adaptation options.	Low to medium
	Degradation of water supply infrastructure increases maintenance costs	Yes	High	High		Low
Electricity transmission and distribution	Degradation of infrastructure increases maintenance costs Productivity losses from blackouts due to severe weather events	Yes	High	High		Low
Electricity generation	Increased demand for electricity resulting from greater use of air conditioners	No	High	High	New generation costs. Net capital expenditure for the electricity supply industry increased in 2005–06 by $1.7 billion (27%) to $8.1 billion (ABS 2006).	Low to medium

10.1.2 Modelled market impacts

As discussed in Chapter 9, the Review has attempted to capture the majority of market impacts that were considered to have potentially significant economic consequences from climate change. Impacts were captured across a range of areas including:

- international trade
- primary production
- human health
- infrastructure
- tropical cyclones.

As shown in Table 10.1, there are a number of market impacts omitted from the categories of impacts that were modelled in Chapter 9. The most significant of these omissions are discussed below.

Human health

While a significant proportion of the total adverse impacts on health from climate change were excluded from the economic analysis in Chapter 9, the Review does not consider this to be significant in terms of economic consequences. Even if the modelled costs discussed in Chapter 9 were to double to reflect the excluded impacts, the net economic consequences from climate change would still not be large.

While the excluded health impacts are not considered to represent large economic consequences, they may represent considerable non-market effects.

Infrastructure

The Review has modelled the market impacts associated with four key infrastructure categories—buildings in coastal settlements, ports, electricity transmission and distribution, and urban water supply infrastructure in major cities.

As shown Table 10.1, there are several infrastructure-related exclusions in the modelling. Of these, the most significant are likely to be additional increases in the cost of building construction (both commercial and residential) as a result of new building design requirements that have not already been modelled, and increased road and bridge maintenance. The need for increased peak power usage to cool buildings may also be a significant omission.

To understand the possible implications of omitting these impacts, some simple calculations can be useful.

Residential and commercial buildings make up a large proportion of the economy's capital stocks, and hence a large proportion of expenditure is made on their maintenance, upgrade and construction. This means that even relatively small impacts can have large economic consequences. For example, a 5 per cent increase in the cost of constructing and maintaining buildings may have the effect of reducing GDP by as much as 0.8 per cent.[2]

While the Review has captured some of the impacts of climate change on building infrastructure (degradation of materials and insulation and double-glazing costs for dwellings) other significant costs may have been omitted (such as additional changes to building codes to cope with increased cyclone activity and temperature and rainfall extremes).

Evidence suggests that climate change is likely to increase the rate at which roads and related infrastructure degrade. Australia's road network is large. For example, it covers 812 000 kilometres and comprises over 37 000 bridges. If the cost of maintaining the road network were to increase by 25 per cent, GDP might be reduced by around 0.25 per cent.[3]

Agriculture

The estimated economic impacts on agriculture presented in Chapter 7 arise from average changes to climate variables. It is likely that climate change will affect the variability and predictability of the climate, as well as the average. This is particularly relevant for rainfall. More frequent droughts could have very different economic consequences than general reductions in precipitation of similar average effect.

In the absence of forecasts describing the level of future variability, it is difficult to provide an estimate of the degree to which increased climate variability would affect the economy.

Tropical cyclones

The modelling of the impacts of the anticipated increase in intensity of tropical cyclones includes only estimates of the costs to residential buildings and contents. It does not include impacts to commercial and industrial buildings or an assessment of business interruption and clean-up costs. However, it is unlikely that the inclusion of these costs would change the economic consequences of climate change significantly, since the modelled impacts (on a whole-of-economy scale) are relatively small. As noted in Chapter 9, the individual impacts from cyclones contribute only a small amount to the overall decline in consumption.

Also excluded from the analysis was the possibility of a southward movement in cyclone genesis. While there is no general consensus about the southward shift in cyclone genesis, research suggests that Australian tropical cyclones may move further south in Queensland, and hit the Australian coastline with greater intensity (Leslie et al. 2007). Since population densities are higher in the southern reaches of Australia's tropical regions (particularly south-east Queensland), there may be considerable costs associated with such changes.

Estimates by Geoscience Australia for the Review suggest that a single category 3 cyclone hitting the Gold Coast today could cause up to $7.5 billion in damage to houses alone. Allowing for commercial and other property damage as well as business disruption costs, this figure could climb as high as $25 billion.

An estimate by Munich Re Group (2006) suggests that if a tropical cyclone like Dinah (category 3, 1967) were to hit Brisbane, the Gold Coast and the Sunshine Coast now, the potential insured losses would be in the range $10–17.5 billion.

While the social and regional economic effects would be significant, such an event is unlikely to result in a large, economy-wide effect. In a trillion-dollar economy, a $25 billion repair bill could amount to a reduction of GDP in a single year of around 2 per cent. Economic activity could be expected to return to normal levels once infrastructure was repaired. The availability of insurance will spread much of the cost through time. Even if an event of this magnitude were to occur every 25 years, the annualised losses would be expected to be in the order of 0.1 per cent of GDP.

International trade

As discussed in Chapter 9, the Review has undertaken global modelling of climate change using the Global Integrated Assessment Model (GIAM) developed jointly by ABARE and CSIRO. This model was linked to the domestic modelling (the Monash Multi Regional Forecasting, or MMRF, model) by imposing the implied changes in world demand and import prices projected by GIAM.

While this methodology captures the broad implications of climate change effects for Australia, the results from GIAM are subject to a number of caveats. At this stage of its development, GIAM uses a highly simplified climate impact damage function. Regional climate change damages are assumed to be a function of regional changes in average temperature (relative to 2000) and the vulnerability of a region to potential climate change. Economic loss factors are applied as negative shocks to total factor productivity and do not differentiate between economic sectors in their impacts. As a result, impacts to agriculture from climate change are determined in the same way as impacts to services sectors. This means, for example, that detailed modelling cannot be applied to estimation of the impacts of climate change on food production. Further development and improvement would allow for sector-specific damage functions as well as the inclusion of responses to additional climate variables.

10.1.3 Market impacts that have not been modelled

As shown in Table 10.1, there are a range of impacts and sectors that have not been included in the Review's modelling. Of these, it is likely that impacts on tourism and geopolitical stability, and increased construction costs for buildings, will be among the most significant in terms of their effects on production and consumption of goods and services.

Tourism

International tourism is likely to be affected by climate change through three main channels: global incomes, relative prices, and environmental and social amenity. While the Review has captured the first two of these factors through its global modelling, the third has not been considered at all in the modelling.

As discussed in Chapter 7, climate change is likely to have significant impacts on environmental amenities that are important for tourism, for example, the Great Barrier Reef, south-western Australia (a biodiversity hotspot) and Kakadu. While it has been possible to assess the likely impacts of climate change on these environmental assets qualitatively, it has not been possible to estimate the likely effect this will have on international tourism.

Despite the difficulty of estimating the effect of climate change on tourism, it is likely that even small changes could have significant effects. International travel to Australia is projected to increase sharply as global incomes rise. In 2005–06 approximately 11 per cent of total exports were tourism related. This share is expected to rise substantially over the coming decades as incomes and the value of exports rise. This suggests that even small changes in demand may have significant economic implications.

While domestic tourism is also likely to be affected by climate change, this is, in the main, likely to be felt through regional changes rather than nationally. Unless Australians choose to spend less of their incomes on recreational activities, climate change may result in a change in the type of tourism activity rather than the absolute level of tourism.

A loss of environmental amenity in Australia may also cause a preference shift towards overseas travel. However, this is impossible to quantify, without making highly speculative assumptions about changes in consumer preferences.

Defence expenditure and geopolitical stability

Climate change is likely to result in both gradual changes and extreme climate events that will affect Australia's neighbouring developing countries. As discussed in Chapter 7, food security issues, severe weather events, sea-level rise, climate refugees, and energy and water security issues can contribute to increases in geopolitical instability.

It is likely that an increase in geopolitical instability in the Pacific region, and the globe generally, will require an increase in the capability and requirements of Australia's defence forces, and an increase in the level of Australia's spending on emergency and humanitarian aid abroad. These measures will reduce the income available to households and consequently reduce consumption.

In 2006–07 total expenditure on defence was approximately $17 billion. If climate change caused defence expenditures to increase by 10 per cent, this would imply the need for an additional $1.7 billion to be raised by government. In 2004–05 total household consumption was around $580 billion. Therefore, an increase in defence expenditure in the order of 10 per cent might reduce household consumption by around 0.3 per cent.

Previous Australian interventions in small neighbouring nations may also provide an indication of the potential size of future defence costs that may arise from climate change. It is likely, however, that climate change could lead to geopolitical pressures involving larger countries, and thus may lead to much higher spending than would be indicated by recent history.

The combined aid and defence budget for the five-year intervention in Timor-Leste, starting in 1999–2000, has exceeded $700 million per year. Australia's intervention in Solomon Islands is estimated to cost around $200 million per year (Wainwright 2005). This intervention, which started in 2003, is likely to continue until at least 2013, with the possibility for ongoing significant support.

The combined expenditure on regional defence force interventions has averaged over half a billion dollars per year since 1999 (M. Thomson 2008, pers. comm.).

Climate change may also require an increase the level of foreign aid to developing countries. Foreign aid expenditure in Australia is currently relatively small. In 2007–08 official foreign aid expenditure was only 0.3 per cent of gross national income. Aid expenditure would therefore have to increase substantially to have a large impact on welfare in Australia.

10.1.4 Size of market impacts associated with best-estimate climate change outcomes

The modelling discussed in Chapter 9 showed that the market impacts of unmitigated climate change that were able to be measured by the Review are projected to result in a decline in GDP, household consumption and real wages of 4.8 per cent, 5.4 per cent and 7.8 per cent respectively, relative to a reference case without climate change.

As discussed above, there are a range of market impacts that were not able to be estimated for inclusion in the modelling. As shown in Table 10.1, most of these impacts are relatively minor or the costs of adaptation and adjustment are considered to be relatively small. However, as discussed above, there are a small number of impacts that may have significantly increased the modelled impacts had they been included. The key impacts omitted include some infrastructure spending, impacts on tourism from a loss of environmental amenity, increased defence and foreign aid expenditure, and the effects of greater climate variability, reduced predictability on agricultural production and the cost of supplying water.

While a lack of quality data and a lack of understanding of the relationship between climate change and economic impacts make it difficult to quantify the magnitude of the economic implications associated with these omitted market impacts, sensitivity testing under sensible assumptions and simple estimates can provide insights into their relevance.

Based on the above discussion and simple calculations, it is possible, using the criteria outlined in section 10.1.1, that the omitted market impacts could contribute an additional 1 to 3 percentage points to the loss of welfare, as measured by household consumption. This suggests that the Review's modelling of median climate change outcomes may have captured in the range of 65 per cent to 85 per cent of market impacts.

These conclusions are based on a number of limitations and caveats, as discussed in Chapter 9.

10.2 Insurance costs of climate change mitigation—extreme climate change scenarios

The uncertainty about climate change and its environmental and socio-economic impacts introduces a wide distribution about the mean of possible outcomes. At the more extreme end, it is likely that climate change would introduce impacts that might be considered to be large, and perhaps catastrophic. In addition, the economic and social responses to these lower-probability climate outcomes could also be extreme.

Chapter 5 discussed in detail the possibility of severe and irreversible impacts on the world's climate by 2100 under a range of global emissions pathways. The higher temperatures associated with an unmitigated global pathway increase the likelihood of the occurrence of more extreme outcomes. Some of the extreme outcomes and consequences discussed in chapters 3, 5, 6 and 7 that are likely to have economic consequences for Australia, either directly or indirectly, include faster sea-level rise resulting from the melting of the Greenland and West Antarctic ice sheets; changes to the El Niño – Southern Oscillation; melting of the Himalayan glaciers; failure of the Indian monsoons; and temperature and rainfall outcomes towards the hot and dry ends of the probability distributions from the mainstream science.

Flowing from these extreme climate outcomes is the possibility for extreme environmental, social and economic responses. Tipping points and the occurrence of one or many of the extreme outcomes described above could trigger extreme consequences or responses in many countries.

For Australia, the possibility of extreme climate outcomes could be felt directly through extreme temperature, rainfall and other climate responses (e.g. sea-level rise, heatwaves and flooding), as well as indirectly through international trade and regional geopolitical instability.

As discussed in Chapter 2, an aversion to risk suggests a willingness to pay a higher price to avoid climate change than would be suggested simply by examining best-estimate climate outcomes.

However, there is considerable difficulty associated with considering outcomes that are far from the mean due to the uncertainty behind the likelihood, timing and extent of such outcomes. What can be said with confidence, as discussed in Chapter 5, is that with each additional increment of temperature change the likelihood of an event occurring increases.

When considering extreme climate change outcomes, the impacts, both environmental and economic, can be predicted with much less certainty. As temperatures rise above historical highs, and as climate events occur with increasing severity and frequency, it is increasingly difficult to predict impacts and economic agents' responses to them.

While accepting these uncertainties, the Review sees value in attempting to quantify some extreme outcomes and responses in order to adequately understand the potential costs of climate change.

To inform this risk assessment, the Review has considered a range of extreme climate change outcomes that could directly affect Australia. In addition, consideration has been given to the possibility of extreme outcomes internationally and their flow-through effect on Australia.

10.2.1 International trade—effects of enhanced impacts in developing nations

Developing countries are likely to be particularly vulnerable to climate change. These nations are more reliant on sectors susceptible to climate change (particularly agriculture) and are likely to have less adaptive capacity than more developed nations. Less stable political systems may also mean that societies could fracture in response to extreme climate change impacts. Asian developing countries, in particular, are vulnerable to sea-level rise and disruption of established patterns of rainfall and river flows.

Severe shocks can destabilise governance in developing countries and lead to regional conflicts. Shocks from climate change could be much larger than shocks of other kinds that have been seriously destabilising in the past.

To get an idea of how large the consequences of these disruptions might be, the Review has examined major historical events over the past two decades.

Chinese output fell by approximately 6.6 percentage points from its trend during the 1989–90 political crisis. Output of the Southeast Asian economies fell by about 12.0 percentage points below trend during the Asian financial crisis of 1997–98.

Might climate change bring on dislocations that are similar in magnitude to those in China two decades ago and Southeast Asia one decade ago? The inflationary impact of a dislocation of agricultural production as a result of disruption to the south Asian monsoon, or a break in the flows of the great rivers that have their origins in the Himalayas, would seem to be rather more disruptive than the triggers for short-term growth crises in east Asia over the past two decades. Major cyclonic events, superimposed on sea-level rises near the upper end of the range of possibilities, would be highly disruptive. Inflexibility in political and economic institutions could be expected to magnify the critical economic shock in many developing countries—as it did the inflationary shock in China in 1989, or the exchange rate shock in Southeast Asia in 1998, or, for that matter, the financial shocks in central Europe in the early 1930s and in Australia in the 1890s and 1930s.

It seems reasonable to assume that output growth lost in these circumstances is not recovered—as seems to have been the case in Southeast Asia in the 1990s. Indeed, growth in all Southeast Asian economies settled onto a substantially lower trajectory after the financial crisis.

The shocks to China in 1989–90 and to Southeast Asia in 1997–98 had large consequential effects on growth in Australia. The possibility of more widespread shocks associated with problems in developing countries' adjustment to climate change will be examined further. To illustrate the potential importance of these factors, the Review modeled a shock to India and China of the dimension of the 1989–90 China crisis, and to other developing countries of the dimension of the Southeast Asian financial crisis, after 20 years and repeated at intervals of 20 years. This would reduce Australian GDP in 2100 by more than 8 per cent relative to the reference case, and consumption by around 12 per cent.

10.2.2 Extreme rainfall outcomes

In Australia, changes in the frequency and intensity of rainfall and temperature extremes are projected to occur more rapidly than changes in the equivalent means (Chapter 3). While average temperatures in Australia are expected to rise in parallel with rises in global mean temperature, there are significant regional variations.

For rainfall, variability and uncertainty is pronounced due to the many localised influences on rainfall outcomes. Rainfall at the 10th percentile at the dry end of the distribution in the unmitigated scenario is projected to decline much more than at the 50th percentile in many parts of Australia. But at the wet end of the distribution, the 90th percentile, average rainfall in Australia increases a little from current levels.

At the global level there is considerable uncertainty as to how sensitive the climate is to changes in carbon dioxide concentrations (Chapter 3). A best-estimate climate sensitivity of a 3°C rise in response to a doubling of carbon dioxide concentrations has been defined (IPCC 2007), but much higher outcomes are possible. All the scenarios modelled and investigated by the Review for the Australian impacts analysis used the best-estimate climate sensitivity.

At the local level, a range of temperatures are possible in response to a given global increase. The best-estimate median unmitigated scenario discussed in Chapter 7 assumes a best-estimate rainfall and local temperature response to global change. Uncertainty in how the Australian climate will respond to a given global temperature is incorporated by considering a 'dry' rainfall sensitivity (relative to the median rainfall estimate) combined with a 'hot' temperature outcome. This sensitivity is associated with the 10th percentile rainfall outcome for Australia combined with a 90th percentile temperature outcome for Australia. Both are considered in the context of the same global mean temperature of 4.5°C by 2100. The climate variables associated with the dry scenario are discussed in Chapter 6.

As discussed in earlier chapters, there is a complex link between rainfall and temperature. This means that for any given global temperature, numerous combinations of local rainfall and temperature changes are possible. Based on this observation, and the advice of the CSIRO (R. Jones & S. Hatfield-Dodds 2008, pers. comm.), the hot, dry climate change scenario is considered to be a plausible outcome to investigate extreme rainfall changes for Australia under an unmitigated scenario.

The sector of the economy most sensitive to changes in rainfall is agriculture. Australia is already a dry country. Declines in rainfall (and increases in rainfall variability) will make it increasingly difficult to produce food. As discussed in Chapter 9, the impacts under the median unmitigated scenario are sizeable.

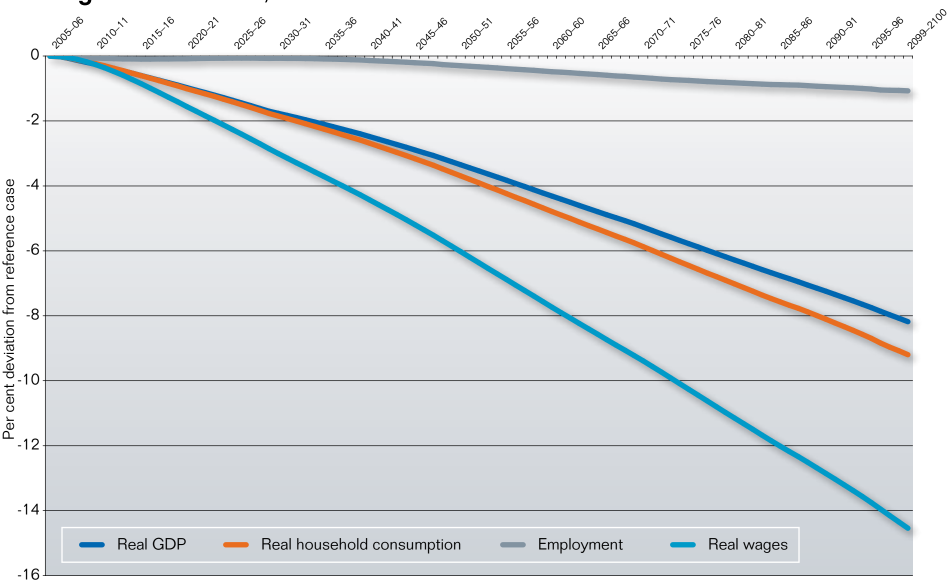
As evident in Table 6.2 in Chapter 6 under the hot and dry unmitigated scenario, much more severe reductions in rainfall are projected than under the median. This analysis focuses on the dry end of the range of possibilities with a 10 per cent probability of outcomes being this dry or drier. For example, rainfall declines by 28 per cent by 2050 and 70 per cent by 2100 in South Australia. These extreme rainfall changes lead to even higher reductions in streamflow. In many parts of the country, established river systems would simply cease to flow. The ability of both economic and biophysical models to accurately project impacts under these kinds of changes is limited. Despite this uncertainty, the projections for the dry scenario provide a picture of a possible economic future under a hot and dry unmitigated climate change scenario.

Under this scenario the economic impacts are substantially higher than for the median unmitigated scenario. By 2100, GDP is projected to fall by nearly 8.2 per cent, relative to a reference case with no climate change. Real household consumption falls by 9.1 per cent in 2100, relative to the reference case, and real wages by 14.8 per cent. Table 10.2 provides some key macroeconomic projections for this scenario. These projections are represented graphically in Figure 10.1.

Table 10.2 Projected macroeconomic effects of climate change, hot, dry unmitigated scenario (per cent deviation from reference case)

Variable	2020	2050	2100
Real GDP	-0.9	-3.2	-8.2
Real gross national expenditure	-0.9	-3.4	-8.6
Real household consumption	-0.9	-3.5	-9.1
Export volumes	-0.7	-2.1	-4.6
Import volumes	-0.4	-1.4	-3.7
Terms of trade	0.0	-0.3	-1.8
Real wages	-1.4	-5.8	-14.8

Figure 10.1 Changes to select macroeconomic variables, hot, dry unmitigated scenario, 2005–2100



10.3 Non-market impacts that Australians value

Table 10.1 provided an assessment of the market impacts of climate change for a range of climate change impacts and sectors of the Australian economy. What was excluded from that assessment was the consideration of non-market impacts that could result from those climate change impacts.

For example, for health, one of the possible impacts of climate change could be an increase in mortality. This is likely to have both market and non-market consequences. The loss of life or quality of life is a non-market impact and cannot be adequately captured in a modelling framework of the type used by the Review. The market impacts, on the other hand, may include a reduction in the labour force, a reduction in labour productivity and an increase in the requirements for health services. The results of modelling these market impacts have been presented in Chapter 9.

A range of non-market impacts will also result from the extinction of species or loss of environmental amenity, as many Australians place value on them. The loss of environmental amenity, such as the degradation of the Great Barrier Reef or the loss of a particular species of flora and fauna, could also have market impacts through reductions in the demand for tourism and recreation.

Reductions in the availability of water for urban uses may also have considerable non-market impacts. Households and communities may be required to reduce their consumption of water for recreational purposes.

In this discussion, and the Review's consideration of non-market impacts, the value of non-market services is defined by the value placed on them by Australians, as opposed to their intrinsic ecological value to other species.

There are a broad range of non-market impacts that are likely to feature prominently in Australians' valuation of the impacts of climate change. These includes impacts on:

- biodiversity
- health and longevity
- valued environments of many kinds
- unique environmental assets
- environmental support for established social and cultural institutions.

Chapter 2 discussed the utility of Australians in the context of non-market impacts. The discussion introduced the concept of a utility function that rises with Australians' consumption of goods and services, as well as with a number of non-monetary services. As incomes and consumption rise, non-market values are likely to become 'superior' goods. In other words, the relative value people assign to non-market values rises with income. As incomes and consumption rise over time—and the reference case has average consumption of material goods and of services rising ninefold over the 21st century—the substitutability of non-market services for conventional consumption diminishes. This implies a loss in utility from the occurrence of any one of the non-market impacts discussed above.

The consideration of non-market impacts is therefore an important component of assessing the consequences of climate change and the benefits of climate change mitigation.

It is possible to assess the monetary consequences associated with non-market impacts using alternative valuation techniques. Rothman et al. (2003)

provide a brief discussion of the range of techniques used to value non-market services. The majority of these techniques focus on implicit values that can be determined from surrogate or constructed markets. For example, hedonic pricing attempts to value non-market goods and services by comparing market prices, such as housing. In some cases, these prices can act as proxies for values placed on environmental quality, such as higher prices for housing in suburbs endowed with high environmental quality.

There are many complexities associated with non-market valuation techniques and current examples that attempt to assign monetary values to non-market services. The Review is not seeking in this draft report to estimate the value of non-market impacts to Australians, but is instead aiming to present the broad issues raised by their existence, and their implications for the evaluation of the costs and benefits of climate change mitigation. These issues will be discussed further in the supplementary draft report and final report, when we can bring together our assessments on these matters with the results of the modelling of the conventional economic benefits and costs of varying degrees of mitigation of climate change.

10.4 Assessing the costs of climate change beyond 2100

The Review's modelling of best-estimate climate change outcomes, as well as the evaluation of the extreme end of the probability distribution discussed in this chapter, was only able to project results to 2100. As noted in Chapter 2, the effects of climate change, and the effects on things that are valued by humans living today, do not end at the conclusion of the 21st century.

As evident from the analysis of projected changes to GDP and consumption through time in this chapter and Chapter 9, the economy does not stabilise at some new growth path by 2100 (see Figure 10.1 and Figure 9.3). This is not surprising since emissions are still growing, the climate is still changing and climate-related impacts are still unfolding.

Risk management therefore necessitates an evaluation of costs and benefits over much longer time frames. The weight that is ultimately attached to these longer-term effects depends on the discount rate. Discount rates, and the sensitivity of policy assessments to them, will be introduced to the analysis in the supplementary draft and final reports.

10.5 Implications for evaluating the costs and benefits of climate change mitigation policy

The Review's economic analysis up to this point has focused on the costs associated with unmitigated climate change. Chapter 2 discussed the next steps in the Review's approach to modelling climate change mitigation.

The Review's ultimate aim is to assess the costs and benefits to Australia of global mitigation to stabilise greenhouse gas emissions at 450 ppm and 550 ppm carbon dioxide equivalent, as a basis to providing advice on whether and to what extent mitigation is justified by the assessment of its costs and benefits.

As indicated in Chapter 2 and discussed in this chapter, the consideration of the extreme ends of the probability distribution, as well as the recognition of the range of non-market impacts of climate change, will be integral to the conclusions presented in the final report.

Notes

1 For the purposes of the modelling, the Review determined best-estimate climate change outcomes as the 50th percentile rainfall and 50th percentile temperature outcomes associated with mean global temperature change under an unmitigated climate change scenario. These outcomes are associated with the median of the rainfall and temperature probability distributions.

2 An increase in the cost of constructing and maintaining buildings is equivalent to a productivity loss since more capital inputs per unit of output would be required. If buildings make up around 40 per cent of capital stocks, and capital incomes make up approximately 40 per cent of total income, then a 5 per cent reduction in productivity of building stock would be expected to reduce GDP by approximately 0.8 per cent.

3 GDP in 2004–05 was just under $900 billion. If road expenditure were to increase by 25 per cent or $2.25 billion, GDP might be reduced by around 0.25 per cent.

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11 THE INTERNATIONAL RESPONSE TO CLIMATE CHANGE TO DATE: AN ASSESSMENT

Key points

Climate change is a global problem that requires a global solution.

Mitigation effort is increasing around the world, but too slowly to avoid high risks of dangerous climate change. The recent and projected growth in emissions means that effective mitigation by all major economies will need to be stronger and earlier than previously considered necessary.

The existing international framework is inadequate, but a better architecture will only come from building on, rather than overturning, established efforts.

Domestic, bilateral and regional efforts can all help to accelerate progress towards an effective international agreement.

Greenhouse gas emissions are a global public 'bad'. One country's emissions affect all countries. Global warming therefore requires a global solution. Individual countries will not on their own undertake adequate mitigation, since each country has an incentive to free ride on the efforts of others. An effective response to climate change has to be an effective international response. As a country that is vulnerable to climate change (chapters 6, 7, 9 and 10), Australia has a particularly strong interest in an effective international response to climate change.

An effective international response to climate change needs to cover both mitigation and adaptation. The main focus of the Review's discussion of the international response is mitigation. This is not to underplay the importance of adaptation, but adaptive responses are largely national and regional. There is, however, an international element required in the adaptation response (see section 13.2).

This chapter assesses the global mitigation effort to date, and concludes that progress on the current trajectory is too slow and limited to constitute an effective global response to the risk of climate change. Chapters 12 and 13 describe what a more effective response to international climate change might look like.

11.1 The evolving international framework for addressing climate change

11.1.1 United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) provides the foundation for the international collaborative effort to mitigate and adapt to climate change. The Convention was established in 1992, entered into force on 21 March 1994, and has been ratified by 192 Parties to date.

The UNFCCC articulates a global goal of the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (Article 2).

It also gives important guidance on the allocation of mitigation effort among countries. It divides Parties into different groups according to their commitments. Annex I Parties include the industrialised countries that were members of the OECD in 1992, plus countries with economies in transition.

Apart from reporting duties, all countries commit to 'formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions' (Article 4.1(b)). But developed countries are called on to do more. In particular, on the 'basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities', developed countries 'should take the lead in combating climate change and the adverse effects thereof' (Article 3.1). Developed countries are also called on to bear the cost of the financing 'needed by the developing country Parties to meet the agreed full incremental costs of implementing measures' (Article 4.3) to take actions to mitigate and adapt to climate change.

11.1.2 Kyoto Protocol

The Kyoto Protocol was adopted by the UNFCCC Parties in Kyoto, Japan, on 11 December 1997, and entered into force on 16 February 2005 once enough countries had ratified it. The Protocol commits developed and transition economies to limit or reduce their greenhouse gas emissions to specified levels during the commitment period of 2008 to 2012, with the aim of reducing their collective emissions by at least 5 per cent from 1990 levels (Article 3.1). Countries with target commitments are listed in Annex B to the Protocol, which largely coincides with Annex I to the UNFCCC.

The use of a five-year budget (2008 to 2012) is sometimes referred to as a 'flexibility when' provision, as it allows countries to average their emissions over time (Frankel 2008). 'Flexibility what' is also allowed under the Protocol, which includes fixed conversion factors for different greenhouse gases. Finally, the Protocol includes three 'flexibility where' mechanisms to assist countries to achieve their targets: international emissions permit trading, the Clean Development Mechanism, and Joint Implementation. In international emissions permit trading, if an Annex B country reduces its emissions below its Kyoto target it can sell surplus reductions to another country. The other two flexibility mechanisms enable credits from emissions-reducing projects in one country to be used to meet the Kyoto target of another country. Under Joint Implementation, projects are hosted in Annex B Parties. Under the Clean Development Mechanism, projects are hosted in non-Annex B Parties. Because the supplementarity principle of the Protocol requires that countries primarily achieve their emissions reduction goals through domestic efforts, these flexibility mechanisms play a supporting role. However, the Protocol does not place any quantitative limits on their use.

The Protocol also sets out specific rules regarding the accounting of emissions and removals from the land use, land-use change and forestry sector, establishes detailed accounting and reporting systems and creates a compliance committee.

11.1.3 The Bali Roadmap

The United Nations Climate Change Conference held in Bali, Indonesia, in December 2007 resulted in two negotiation tracks—the Convention track and the Protocol track, collectively known as the Bali Roadmap—aimed at achieving agreement on an arrangement to succeed the first Kyoto commitment period. While the exact shape of a future architecture is still unclear, both tracks are proceeding in parallel and have the same anticipated end date of December 2009, at which point Parties will come together in Copenhagen with a view to agreeing on the way forward post-2012.

The Convention-track negotiations will work towards a 'shared vision for long-term cooperative action', likely to be framed as a long-term global goal for emissions reductions. Developed countries have agreed to consider 'nationally appropriate mitigation commitments or actions, including quantified emission limitation and reduction objectives', while developing countries have agreed to consider 'measurable, reportable and verifiable' mitigation actions 'supported and enabled by technology, financing and capacity-building' (UNFCCC 2007a: 3). Underlying these undertakings is a commitment to put in place 'positive incentives for developing country Parties for the enhanced implementation of national mitigation strategies and adaptation action' (UNFCCC 2007a: 5).

The purpose of the Protocol track is to agree on second commitment period (post-2012) emissions reduction commitments for developed countries. This track will need to result in quantified emissions reduction targets for Annex I Parties and agreement on the time frame of the second commitment period.

11.1.4 Other international initiatives

The UNFCCC is the focus of international climate negotiations, but is no longer the sole home of international discussions on climate change.

Major Economies Meeting on Energy Security and Climate Change

The Major Economies Meeting process on Energy Security and Climate Change was launched by the United States in September 2007 with the purpose of bringing together the largest emitters of greenhouse gases to discuss a global response to climate change.[1] US President George W Bush nominated agreement in 2008 on a long-term global goal for emissions reduction as a key outcome for the process.

Group of Eight (G8)

In 2005, climate change dominated the Gleneagles Leaders' Summit agenda, resulting in the establishment of the Gleneagles Dialogue on Climate Change, Clean Energy and Sustainable Development. Bringing together the G8 nations[2] as well as key developing countries and other major emitters, the Gleneagles Dialogue has focused on technology and finance and will report at the 2008 G8 Summit in Toyako, Japan. The Toyako Summit (7–9 July 2008) will have a strong focus on climate change.

Asia–Pacific Economic Cooperation (APEC)

At the 2007 APEC Leaders Meeting in Sydney, Australia, the leaders of the 21 member economies[3] reaffirmed their commitment to the UNFCCC and agreed on an Action Agenda, which included APEC-wide aspirational goals of reducing energy intensity (the amount of energy used by unit of output) by at least 25 per cent by 2030 from 2005 and increasing forest cover in the region by at least 20 million hectares by 2020. Other agreements were to establish an Asia–Pacific Network for Energy Technology and an Asia–Pacific Network for Sustainable Forest Management and Rehabilitation.

Asia–Pacific Partnership on Clean Development and Climate

The Asia–Pacific Partnership on Clean Development and Climate is based on a model of cooperation and collaboration between partner governments,[4] business and researchers. Joint government–business task forces in eight sectors (cleaner fossil energy, aluminium, coal mining, steel, cement, buildings and appliances, power generation and transmission, and renewable energy and distributed generation) agree on projects that are then financed or provided with in-kind support by both government and industry participants. Progress to date has been limited by funding commitments.

Other international bodies

In addition, work on climate change mitigation and/or adaptation is taking place in many other international bodies, including many United Nations agencies, the World Bank and regional development banks, the International Monetary Fund, the Organisation for Economic Co-operation and Development, the International Energy Agency, and others. The UN Secretary-General has made climate change a priority issue and the UN General Assembly holds regular thematic debates on the issue. Heads of state and government made declarations on the urgent need to address climate change at the Commonwealth Heads of Government Meeting and the East Asia Summit (both held in November 2007).

11.2 National-level commitments and policies to mitigate climate change

11.2.1 Developed countries

Some countries have proposed national emissions reduction goals beyond the end of the first Kyoto Protocol commitment period:

- **Australia:** The Prime Minister of Australia announced at the Bali conference that by 2050 Australia would reduce emissions by 60 per cent over 2000 levels.

- **European Union:** The European Union has put forward dual emissions reduction goals: an 'independent commitment' for a 20 per cent reduction over 1990 levels by 2020, and a conditional offer for a 30 per cent reduction over 1990 levels by 2020. The trigger announced for moving to the conditional offer is 'a satisfactory global agreement to combat climate change post-2012',[5] which implies as prerequisites that 'other developed countries commit themselves to comparable emission reductions and economically more advanced developing countries commit themselves to contributing adequately according to their responsibilities and capabilities'.[6] The European Parliament and Environment Ministers have also proposed 2050 targets of a 60–80 per cent reduction relative to 1990 levels.
- **Individual European countries (EU member and non-member states):** Some European countries have made separate national commitments, often showing greater ambition than the EU approach. For example, the United Kingdom has committed itself to reducing emissions by 20 per cent on 1990 levels by 2010 and 60 per cent by 2050 (with scope for greater reductions if needed). Germany has committed to a 40 per cent reduction on 1990 levels by 2020. Norway is noteworthy for its ambition—30 per cent reductions on 1990 by 2020 and carbon neutral by 2050.
- **Canada:** In April 2007, the Canadian Government announced new targets to reduce Canada's greenhouse gas emissions to 20 per cent below the 2006 level by 2020, and to 60–70 per cent below the 2006 level by 2050.
- **Japan:** The Japanese Prime Minister recently announced a target of a 60–80 per cent cut in emissions by 2050 from current levels.
- **United States:** Under the Bush administration, the United States declined to ratify the Kyoto Protocol or to take a strong stance on domestic emissions reductions. However, the signs from presidential candidates, Congress, various states and even the judiciary indicate that major changes in the US position can be expected (Box 11.1).

Box 11.1 Recent developments in US climate change policy

Active participation by the United States will be a crucial element of an effective global climate change framework.

Under the Bush administration, the United States declined to ratify the Kyoto Protocol and has taken a back seat in international negotiations. In April 2008, President Bush announced a new national goal to stop the growth in US greenhouse gas emissions by 2025.

In contrast, both presidential candidates have committed to reducing emissions to 1990 levels by 2020. The Democrats have promised an 80 per cent reduction and the Republicans a 60 per cent cut, both from 1990 levels by 2050. Both candidates are in favour of taking on a more active international role and introducing a nationwide emissions trading scheme. This suggests that, no matter what the political persuasion of the new administration, the array of legislative cap and trade proposals introduced during the 110th Congress might be considered with a more open mind by the White House in future. The Lieberman-Warner Climate Security Act is the proposal that has progressed the furthest, though it too has so far been unable to command majority support. Its provisions would reduce overall US greenhouse gas emissions by roughly 63 per cent by 2050 (Pew Center 2007).

Meanwhile, the US states have moved ahead. Multistate, regional initiatives include the Regional Greenhouse Gas Initiative, involving northeastern states, the Western Climate Initiative, with California at its centre, and the Midwestern Regional Greenhouse Gas Accord. All have a cap and trade scheme at their cores, although with different levels of ambition and design. California has passed legislation requiring emissions to fall to 80 per cent of their 1990 level by 2050.

Existing federal legislation, such as the Clean Air Act, is also being used to tackle climate change. The Bush administration is opposed to this course of action, but in 2007 the US Supreme Court decided that the Act did in fact give authority to the US Environmental Protection Agency to regulate greenhouse gases and that the Agency would need to make a very strong case if it decided not to exercise that discretion.

While major changes in policy can be expected after the November 2008 election, there is still uncertainty and the prospect of delay. Even with majority support in the Congress, and a supportive president, US legislative processes mean that the timely passage of climate change legislation is far from guaranteed.

Many developed countries have policies in place to reduce emissions. These include emissions trading schemes, renewable energy targets, and fuel efficiency targets. For example, in addition to its emissions trading scheme, the European Union has a goal of sourcing 20 per cent of its energy from renewables by 2020. It has also legislated a suite of measures on building, appliance and vehicle standards. Japan has various renewable energy and performance standards in place for its industry. Canada aims to meet its interim and long-term targets by establishing a carbon trading scheme, forcing industry to improve its emissions performance and implementing measures such as new fuel consumption standards for cars and energy efficiency standards for buildings. Many other developed countries are pursuing similar policies and measures, though most are struggling to meet their Kyoto targets (section 11.3).

The United States and European countries have introduced mandatory requirements and subsidies for the use of biofuels. These have had strong effects in putting upward pressure on global food prices, with negligible environmental benefits.

11.2.2 Developing countries

All developing countries continue to reject containment of their emissions growth through the adoption of mandatory targets. Nonetheless, some developing countries have already made important domestic commitments or are on the way to doing so.

- As the largest developing country and now the world's largest emitter, **China** is particularly important (Chapter 4). As part of its 11th Five-Year Plan (2006–10), China has committed to reducing the energy intensity of its economic activity by 20 per cent below 2005 levels by 2010. In June 2007, China released its first National Climate Change Program, which confirmed the energy intensity target and also renewable energy and forest coverage targets. Under the program, the renewables goal is set at 10 per cent of the energy mix by 2020 (this has since been revised by the National Development and Reform Commission to 15 per cent by 2020), and an increase of carbon sinks by 50 million tons over 2005 levels by 2010 is mandated. China has also announced its intention to halve its energy intensity by 2020 over 2008 (DRC 2005). These are ambitious targets that will not be easy to realise.
- **India** is expected to release a national plan of action on climate change in 2008. The current five-year plan for India (2007–12) sets out a number of environmental targets, including increasing energy efficiency by 20 per cent by 2016–17 and achieving a 5 per cent increase in tree and forest cover.
- In 2007, **Brazil** released a white paper on its contribution to preventing climate change, focusing particularly on energy and avoided deforestation. Specific initiatives referenced in the paper include the Program for Incentive of Alternative Electric Energy Sources launched in 2002 which sets an overall goal of 10 per cent of annual energy consumption to come from renewables by 2022; and the National Ethanol Program, implementation of which has led to ethanol accounting for about 40 per cent of vehicle fuel currently used by Brazilians (WRI 2008).

- **South Africa** has launched a Long-Term Mitigation Scenarios process, designed to lay the foundations for a more comprehensive national climate change policy and eventually 'inform a legislative, regulatory and fiscal package that will give effect to our policy at a mandatory level' (Department of Environmental Affairs and Tourism, South Africa, 2008).

11.3 Assessment of progress under the Kyoto Protocol

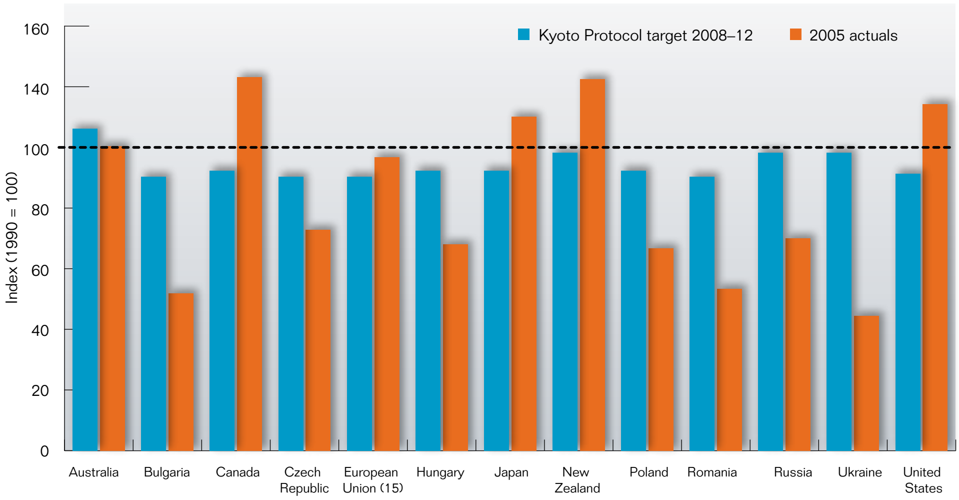
The decision not to ratify Kyoto by the United States and Australia after the election of the Bush administration seven years ago was of historic importance in disrupting an international approach. Australia's return to the international fold following the election of the Rudd Labor Government is an important corrective.

The performance of developed countries against their Kyoto Protocol targets varies (Figure 11.1).

- **Ahead of target:** Countries that were moving out of centrally planned economic systems, including Russia, Poland and Ukraine, were required to make similar reductions in emissions from 1990 levels to OECD countries. They currently have emissions at levels far below their targets due to the large fall in economic activity and emissions in the 1990s. Since these emission reductions were not the result of any mitigation effort but rather were achieved before the Kyoto Protocol was signed (due to economic restructuring with the collapse of central planning), the gap between emissions and the targets is referred to as 'hot air.'
- **On target without use of flexibility mechanisms:** Australia is one of the few countries that currently have national emissions at or close to the level required by the Protocol over the 2008 to 2012 period (in Australia's case due to one-off reductions in land clearing—see Chapter 8).
- **On target if flexibility mechanisms are used:** The domestic emissions of most countries are above their Kyoto targets. This is true for the European Union as a whole, and for Japan and New Zealand. They could still be in compliance with Kyoto if they were to purchase sufficient Clean Development Mechanism or Joint Implementation credits (see section 11.1.2), or buy permits from those countries that are ahead of target (i.e. the 'hot air' countries).
- **Off target:** In Canada, against a required 6 per cent cut, emissions had increased by 27 per cent as of 2005 compared to the 1990 base. In the United States emissions had grown by 16 per cent over the same period

against a required 7 per cent reduction. The United States has not ratified the Kyoto Protocol. While Canada did ratify, the current government has declared it will not be able to meet its target.

Figure 11.1 Kyoto targets and 2005 emissions, relative to 1990



Notes: Only Parties with emissions of 100 million tonnes of CO_2-e or more are included, except for New Zealand. The United States has signed but not ratified the Kyoto Protocol, and is not a Party to it. The 2008–12 target is simply the Kyoto target over the 1990 baseline. Growth in greenhouse gases from 1990 to 2005 for countries other than Australia excludes land-use change and forestry. Note that for countries other than Australia there may be discrepancies between greenhouse gas emissions as reported to the UNFCCC and as calculated in relation to Kyoto Protocol commitments. These are expected to be minor. For countries with base years other than 1990, the following years are used: Bulgaria—1988, Hungary—average of 1985–87, Poland—1988, and Romania—1989.
Sources: UNFCCC (2007b, 2008b); Australian Greenhouse Office (2007).

The Kyoto Protocol is more than a set of targets for Annex I countries. The main way in which the Protocol engages developing countries is through the Clean Development Mechanism, which promotes abatement projects. The Clean Development Mechanism has grown rapidly, but is flawed in a number of respects (Box 11.2).

Finally, it is only in the last year or so that developed countries have started to pay more attention to and put more targeted financing into research and development, and mitigation financing in developing countries (section 13.1).

Box 11.2 The Clean Development Mechanism: a flawed mechanism?

The Clean Development Mechanism (CDM) is a market-based offset mechanism, where tradable credits are awarded for emissions reductions on a project-by-project basis and the resulting credits are bought by firms or governments that are under an obligation to reduce emissions. As of May 2008, there were around 3400 CDM projects under way or in preparation, covering 2.5 billion tonnes of carbon dioxide emissions equivalent until 2012 (UNEP Risoe Centre 2008). Over the course of 2007, the CDM had primary transactions worth US$7.4 billion, with demand coming mainly from private sector entities in the European Union, but also from EU governments and Japan. The World Bank (2008) estimates that in 2007, the CDM leveraged US$33 billion in additional investment for clean energy, which exceeded the cumulative amount over the previous five years.

The CDM's geographic coverage is concentrated. UNFCCC figures (2008a) show that 64 per cent of CDM projects registered to date are in Asia and the Pacific (mainly China (20 percent) and India (32 percent)), 33 per cent in Latin America and the Caribbean, and only 2 per cent in Africa.

To many, the CDM is a 'win–win' solution for all countries—it provides developed countries with low-cost abatement opportunities and a way of engaging developing countries in mitigation efforts, and it provides developing countries with a source of funding for lower-emissions technologies and practices. However, it is becoming increasingly clear that the CDM is a flawed device, from both an environmental and a market perspective.

First, under CDM rules, a project must be proved to be additional, i.e. that it would not have been undertaken had it not been for the CDM. But it is becoming increasingly obvious that additionality is difficult to prove or disprove (Wara & Victor 2008).

Second, the project basis of CDM is problematic. It leads to high transaction costs and a patchy price signal for emissions reductions. There are moves under way to expand the CDM to cover programs of activities, but this may heighten concerns about additionality.

Third, an offset mechanism does not in itself lead to any global reduction in emissions. Rather, CDM credits are used by developed country parties wishing to emit more domestically. A CDM credit simply offsets domestic reductions in countries with targets.

Fourth, large-scale sales of CDM credits may stand in the way of developing countries taking on more comprehensive commitments. Recent signs that the European Union intends to restrict acceptance of CDM credits can be seen in this light.[7]

In summary, the fact that most developed countries are in a position to achieve their Kyoto targets is positive, and it is desirable for developed countries to be in part meeting their targets through financing the mitigation efforts of developing countries, as this provides international financing for these efforts. However, the large divergence between domestic effort and targets in some countries, the virtual repudiation of the Protocol by Canada, and the failure of the United States to ratify it are all serious threats to its credibility. The engagement through the Protocol of developing countries via the Clean Development Mechanism is inadequate, and the Protocol has not done enough to stimulate investments in research and development, and in mitigation financing in developing countries.

11.4 Projections given the current trajectory of mitigation effort

With emissions growing rapidly in recent years and projected to continue to do so (Chapter 4), the current trajectory of abatement action appears inadequate for achieving the UNFCCC goal of holding the risk of dangerous climate change to moderate levels.

To illustrate this point, assume that developed countries commit to reduce emissions by 20 per cent to 30 per cent by 2020 over 1990 levels (the range to which the European Union has committed itself).[8] For developing countries, the current trajectory of negotiations cannot be expected to deliver any reduction in global emissions above that credited to developed countries. If the Clean Development Mechanism continues to be the main vehicle for engaging developing countries in the international mitigation effort, then, even if it is expanded, all abatement in developing countries would continue to be on an offset basis: that is, all financed by developed country payments in lieu of their own reduction in emissions. Developing country reductions could then be modelled as zero, since, as set out in Box 11.2, any actual emissions reduction in developing countries would simply lead to a correspondingly smaller reduction in emissions in developed countries.

On these assumptions, what would global emissions look like in 2020? Using the Platinum Age assumptions on developing country emissions growth (Chapter 4), the level of global emissions by 2020 will be 58 Gt CO_2-e with a 20 per cent cut by developed countries and 56 Gt CO_2-e with a 30 per cent cut. Stabilisation trajectories for 450 and 550 ppm CO_2-e show that global emissions at 2020 need to be in the broad range of 40 to 50 Gt CO_2-e at 2020 (Stern 2007: Figure 8.4). Thus even the more ambitious proposed cuts in developed country emissions would not be sufficient to restrict global emissions to the extent required without additional reductions from developing countries. Indeed, developing country emissions alone under business as usual would start to exceed these stabilisation trajectories in the 2020s: according to the Platinum Age projections, developing country emissions exceed 40 Gt CO_2-e by 2020 and are almost at 50 Gt CO_2-e by 2030.

Exceeding emissions containment paths over the next decade and beyond would increase climate change risk. Offsetting the earlier overshooting would require deeper cuts in emissions in later years, possibly greatly increasing overall mitigation costs.

Clearly the current trajectory of effort traced out from the Kyoto Protocol to the Bali Roadmap and beyond will not enable the world to hold the risks posed by climate change to moderate levels. One of the reasons the current trajectory of mitigation effort is inadequate is that it has not responded to the acceleration in the growth of emissions seen so far this century, and projected to continue. As discussed in Chapter 4, earlier scenarios forecast much slower emissions growth even in the absence of concern about climate change. This earlier outlook is captured by the 'SRES median scenario', which is representative of the various long-term scenarios developed by the IPCC in the 1990s (Chapter 4: Figure 4.8). If the SRES median scenario were valid, then a 20 per cent emissions reduction by developed countries alone (relative to 1990) would result in global emissions in 2020 of 45 Gt CO_2-e. A 30 per cent reduction by developed countries would result in global emissions of 43 Gt CO_2-e. Thus, even without any reduction in emissions from business as usual by developing countries, the world would be in the vicinity of a stabilisation path. As Chapter 4 showed, the SRES median scenario can no longer be regarded as a reasonable guide to future emissions growth. Other emissions trajectories that show much more rapid growth, once considered extreme, now appear moderate or even cautious. The world has changed, but climate change negotiations have not yet adjusted.

11.5 Accelerating progress

Without strong action by both developed and major developing countries between now and 2020, it will be impossible to avoid high risks of dangerous climate change.

Chapters 12 and 13 analyse how the world can best move to a more effective international framework for responding to climate change. The magnitude of the task should not be underestimated.

Climate change negotiations have long been on a path that unhelpfully divides the world into two large groups. In addition, any multilateral negotiations concerning global public goods will face difficulties. The incentives facing individual delegations in a single, large multilateral negotiation are not conducive to reaching sound agreement. Each country will try to secure a better deal than others, with equity concerns figuring large and incentives for free-riding working against cooperative outcomes. Countries' circumstances and interests in the negotiations will differ widely, and geopolitical considerations will interfere. The dominant outcome is a low common denominator. This is evident from the experience with the Kyoto Protocol.

Here the world is dealing with a genuine international 'prisoner's dilemma', in which the cooperative outcome is the superior one, but in which countries have an incentive not to cooperate.[9] In the case of global warming, all countries are better off if they reduce greenhouse gas emissions than if no country does, but each individual country has an incentive to get the environmental benefits of other countries reducing emissions without having to incur any mitigation costs themselves.

There are three possible saving graces in the international space. One is the high level of community support for action in many countries including Australia, and the high international profile the issue now has, as evidenced by the attention the issue is receiving across global forums, and the growing number of countries, developed and developing, announcing emissions reduction targets and policies. The second is that a start has been made on international cooperation, and that some countries have taken steps, at some cost, towards reduction of emissions. The third is that international climate change policy is not played out just once, but rather plays out through interactions over time, allowing countries' policies to influence each other (Axelrod 1984), and allowing countries to evolve towards agreements that are individually and collectively rational—and considered fair (Barrett 2003). The global success at combating ozone depletion (Esty 2007)—albeit at a much smaller scale and for a less challenging problem—shows that effective international action on environmental issues is possible.

How can the world build greater ambition into current international efforts to mitigate climate change? The details are provided in the next two chapters on the basis of four key principles for accelerating progress.

11.5.1 Building on existing architecture

While the Kyoto Protocol is inadequate, and has only been partially implemented, it is a starting point and it would be counterproductive to attempt to start again with a new international architecture, based on a different set of principles, such as price rather than quantity targets. Existing frameworks should be built on, and used to broaden participation and deepen the level of ambition. The basic principles embodied in the Protocol are sound: the abatement burden should be distributed explicitly and equitably; and developed countries should support and provide incentives for mitigation efforts in developing countries. Proposals to move forward should build on these principles.

11.5.2 Developed country leadership

No significant progress in the multilateral sphere will be possible until the United States shows that it is serious about addressing climate change by, among other things, adopting a credible long-term target. Legislative initiatives under way in the United States are encouraging in this regard, and a new administration is widely expected to take a proactive role in international climate policy.

All developed countries need to be subject to, and meet, emissions reduction goals. While many will need to resort to international trading to reduce the costs of achieving deep cuts, it is important that developed countries show credible domestic abatement effort to demonstrate to developing countries not only their seriousness, but that it is possible to reduce emissions without sacrificing prosperity.[10]

A dual approach is needed. Accelerating progress requires that developed countries show leadership and good faith by accepting binding reductions immediately and unconditionally. But steeper cuts can be offered if developing countries also agree to restrict emissions. A number of developed countries, including Australia, have now indicated long-term reduction goals. Others need to follow suit.

Emissions reduction goals need to be complemented by more generous offers of assistance and collaboration by developed countries through both trading and public funding. (Details of the proposed mechanisms are presented in Chapter 13.)

Developed countries can exercise leadership by encouraging developing countries to come on board with regional initiatives (section 11.5.4).

Countries committed to effective international action on climate change need to provide negative as well as positive incentives for other countries to participate (Chapter 13.5).

11.5.3 Developing country participation

As the analysis of the preceding section showed, waiting until 2020 for any developing countries to commit to significant emissions containment policies (potentially the starting time for an agreement to follow the one currently being negotiated) would be to risk the prospect of achieving climate stabilisation at moderate levels. Reductions in developing countries' emissions below business-as-usual levels are needed in addition to developed country reductions, and not only as cheaper substitutes for them, as has been the case so far.

The differentiation between developing and developed countries, more recently reiterated in the Bali Roadmap, will continue to be important. However, interpretation of the UNFCCC phrase 'common but differentiated responsibilities' as meaning that only one group of countries is responsible for containing emissions is no longer viable. All countries need to be jointly responsible, but poorer countries should have more flexible targets, more room for growth, and the financial and technical support required to help them live within their emissions budgets.

For progress to be made, it will also be important for developing countries not to be seen as comprising a single category, and for relevant differences in circumstances to be acknowledged. In particular, more can and should be expected of major emitters and of fast-growing middle-income developing countries than of low-income countries. China, as a superpower and already the world's largest emitter, has a similar influence in the international negotiations as the United States.

Why would developing countries participate more actively in the international abatement effort? First, as they focus on the realities of prospective emissions growth and the risks associated with it, they will increasingly come to see an effective global agreement to combat climate change as being in their interest. China, South Africa and Brazil have already advanced a considerable way down that path. Second, major developing countries need to be offered financial incentives. The combination of transfer of public funds and technology, and the availability of funds from trading would provide powerful incentives.

11.5.4 Action by individual countries and groups of countries

Given the limitations inherent in any multilateral process of negotiations, accelerating progress will also require that countries act unilaterally and in regional groupings to move from the status quo and increase the chance of a successful multilateral outcome. Early unilateral and regional efforts will help secure a more ambitious post-Kyoto framework.

Agreement on difficult political and economic issues can be much easier to achieve among small groups of countries than in large multilateral negotiations. This is because in negotiations among small groups of countries it is easier to establish trust, to take account of individual countries' circumstances and preferences, and to link across issues. Furthermore, self-selected groups are much less subject to being held hostage by the least willing.

Formations of groups of countries that are prepared to agree on emissions reduction and technology transfer goals can accelerate global action by demonstrating that ambitious cooperative action is possible (see Box 13.1 for examples of technological cooperation). In particular, groupings that bring together developed and developing countries into regional trading and technology transfer systems have the potential to show that developing countries can live within, and indeed benefit from, national emissions budgets. Agreements reached between major developed and developing emitters have the potential to break multilateral deadlocks and give negotiations fresh impetus. They allow for direct high-level political input, without which negotiations will languish if not stall.

The hurdle for developing countries to take on emissions reduction commitments could be much lower in such a situation, as any commitments could be fashioned around the capabilities, needs and aspirations of each individual country. Similarly, it would make it easier for developed countries to enter into arrangements that include large-scale resource transfers to developing countries for climate change mitigation.

Unilateral, regional and multilateral efforts occurring in parallel might make for a messy process, but it is one that has the highest chance of success in the short time available. The more and the sooner individual countries and groups of countries undertake unilateral and regional efforts to mitigate climate change, the greater the prospects for a comprehensive and ambitious future global framework.

To ensure compatibility, unilateral and regional schemes would need to be based around common guiding principles. Early movers on regional agreements would need to base their actions on explicit principles for allocating a global emissions budget that they consider to have good prospects for wider international acceptability. Early action on the basis of such principles would then play a role in the encouragement of international discussion of principles and eventually in the movement towards international agreement.

Notes

1 Participants are the United States plus Australia, Brazil, Canada, China, the European Union (current President and European Commission representative), France, Germany, Indonesia, India, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United Nations.

2 The G8 nations are Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States. The European Commission is also represented at all meetings.

3 APEC's 21 member economies are Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong, China; Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; Philippines; Russia; Singapore; Chinese Taipei; Thailand; United States; and Vietnam.

4 Asia–Pacific Partnership on Clean Development and Climate partner governments are Australia, Canada, China, India, Japan, Republic of Korea and the United States.

5 See 'Questions and answers on the Commission's proposal to revise the EU Emissions Trading System', MEMO/08/35, Brussels, 23 January 2008, available at <http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/08/35>.

6 See the 2008 'Proposal for a Decision of the European Parliament and of the Council on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020', available at <http://ec.europa.eu/environment/climat/pdf/draft_proposal_effort_sharing.pdf>.

7 See 'Questions and Answers on the Commission's proposal to revise the EU Emissions Trading System', MEMO/08/35, Brussels, 23 January 2008, available at <http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/08/35>.

8 Strictly speaking, the distinction should be between Annex I and non-Annex I countries, but for simplicity this discussion refers to developed and developing countries.

9 The prisoner's dilemma is named after the situation in which two suspects would receive short sentences if neither informs on the other, and long sentences if both inform on the other. If only one suspect informs on the other, the informant will go free. The best solution for the suspects is the cooperative one (neither informs on the other), but each has an incentive not to cooperate (to inform).

10 As Morgenstern (2007: 218) comments: 'The prospects for international progress would certainly be enhanced if one could point to genuine success in the United States or other large nation… Even though international negotiations on climate change have been under way for almost two decades, to date no major nation has yet demonstrated a viable domestic architecture suitable for achieving large-scale emission reductions and none, except for special cases like the United Kingdom, which experienced large changes in its resource base, or Germany, which benefited from economic restructuring, has made substantial progress in actually reducing emissions.'

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12 TOWARDS AGREEMENT ON GLOBAL AND NATIONAL EMISSIONS LIMITS

Key points

Only a comprehensive international agreement can provide the wide country coverage and motivate the coordinated deep action that effective abatement requires.

Global emissions reduction goals can best be defined in terms of emissions trajectories and multiyear budgets.

The only realistic chance of achieving the depth, speed, and breadth of action that is now required from all major emitters is explicit allocation of internationally tradable emissions rights across countries. For practical reasons, allocations across countries will need to move gradually towards a population basis.

All developed and high-income countries, and China, need to be subject to binding emissions limits from the beginning of the new commitment period in 2013.

Other developing countries—but not the least developed—should be required to accept one-sided targets below business as usual.

The international response to climate change is too slow and patchy to be effective. How can we build on existing international frameworks and negotiations to deliver an international agreement that embodies the level of ambition required to avert high risks of dangerous climate change?

A satisfactory international agreement will be difficult to reach. The prospects depend on the community interest in mitigation in many countries, together with increasing international knowledge of the urgency of the risks, expanding the political possibilities in the period ahead.

Progress will be helped by unilateral, bilateral and regional mitigation initiatives that can generate working models for progress and reassure others that they are not acting alone. Nevertheless, only an international agreement can provide the wide country coverage and motivate the deep coordinated action that effective mitigation requires.

An effective international global agreement to limit the risks of climate change will need to cover two main areas. First, the quantum of mitigation effort needs to be agreed: by how much are emissions going to be reduced, both worldwide, and in each country? Second, while each country will be responsible for achieving its climate change goals, mechanisms for international collaboration will need to be in place to underpin and support national action. The most important of these will be international market trading and public funding for technological development and adaptation.

All of these areas are covered by the Kyoto Protocol, which takes as its starting point the global stabilisation goal of the United Nations Framework Convention on Climate Change (UNFCCC) and allocates emissions limits to most developed and transition countries. The Kyoto Protocol also introduces mechanisms for international collaboration. As argued in the previous chapter (section 11.5), while the Kyoto Protocol is clearly not an adequate global response to climate change, any more effective response will have to build on it. There is not the time to start again.

This chapter covers the first of the two areas: reaching agreement on global and national climate change mitigation goals. Chapter 13 discusses mechanisms for international collaboration.

12.1 Agreeing on a global goal

Determining limits over time on global emissions involves striking a balance between the benefits associated with smaller and slower climate change and the costs associated with greater and faster mitigation. The approach favoured by the Review is to limit the cost of climate change up to the point where the additional gains from mitigation are similar to the additional costs. In the end, a judgment needs to be made about the level of climate change that corresponds to the best estimate of a balancing point.

Targeted limits on climate change can be defined at three levels: at the highest level, in terms of impact or global temperature increase; at the next level, in terms of the concentration of greenhouse gases in the atmosphere, which drives temperature increase; and at the next level again in terms of emissions of greenhouse gases, which drive atmospheric concentration.

12.1.1 Impact goals

Targets for global mean temperature have been used to compress the multiplicity of possible impacts (ranging from glacial melting to increased weather-related calamities) into a single variable. The European Union, for example, has argued that global mean warming should not be allowed to exceed 2°C from pre-industrial levels (Council of the European Union 2007) .

Endorsement of a temperature threshold (and therefore of any target derived from it, for example, in terms of greenhouse gas concentration) cannot imply indifference to other factors. There may be tipping points associated with particular temperature thresholds, but the thresholds are not known with certainty.

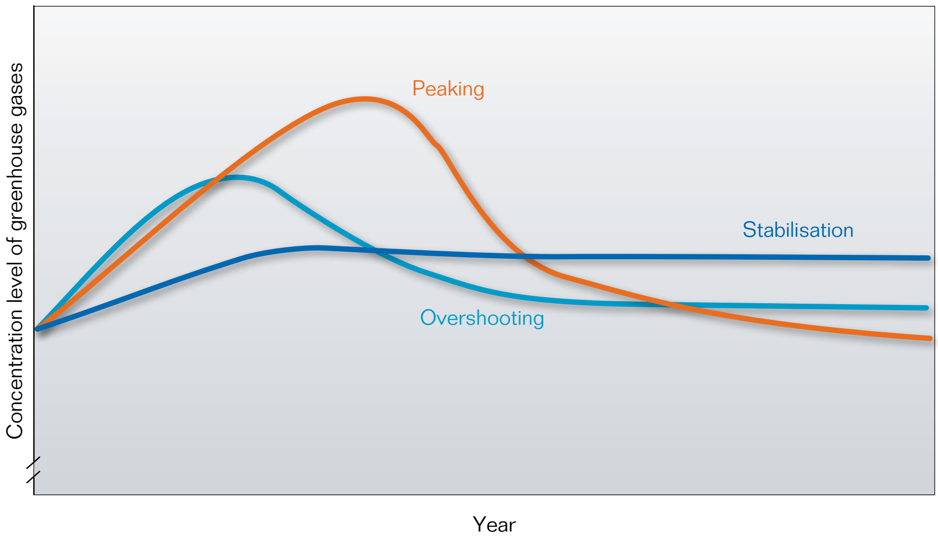
12.1.2 Concentration goals

Global warming increases temperature with a long lag. It might take more than a century after stabilisation of greenhouse gas concentrations for a new equilibrium temperature to be reached. Therefore, any goals in terms of temperature need to be translated into goals for the atmospheric concentration of greenhouse gases.

Chapter 3 introduced various types of concentration goals: stabilisation, peaking and overshooting (illustrated in Figure 12.1). Most attention has focused on stabilisation scenarios, and the global goal articulated in the UNFCCC is the 'stabilization of greenhouse gas concentrations in the atmosphere' (Article 2).

However, as discussed in Chapter 3, special challenges are introduced by the need to reduce greenhouse gas concentrations to low levels. There is great difficulty in doing that monotonically from where the world is now. Whether the ultimate aim is stabilisation (overshooting) or prolonged decline (peaking), there is a good chance that the optimal response to climate change will need to involve a period (of uncertain duration) during which concentrations fall. This assumes that emissions can be brought below the natural level of sequestration. Reducing emissions below this level would probably require the development and deployment of technologies for carbon capture, such as new approaches to biosequestration (see section 3.6.1).

Figure 12.1 Different concentration goals: stabilisation, overshooting and peaking



The Review models two global mitigation scenarios, one less ambitious, the other more. The strong global mitigation case is a stabilisation scenario at which the concentration of greenhouse gases in the atmosphere approaches 550 ppm carbon dioxide equivalent (CO_2-e) and stabilises at around that level thereafter. The ambitious global mitigation case is an overshooting scenario, which peaks at around 500 ppm CO_2-e and then stabilises at around 450 ppm CO_2-e. Any lower stabilisation objective, for example at 400 ppm CO_2-e, would need to involve a longer period of overshooting.

12.1.3 Emissions goals

Any concentration profile has an emissions trajectory associated with it. (An emissions trajectory defines the flow of greenhouse gases that converts, through various physical and chemical processes, into a stock of greenhouse gases in the atmosphere.)[1]

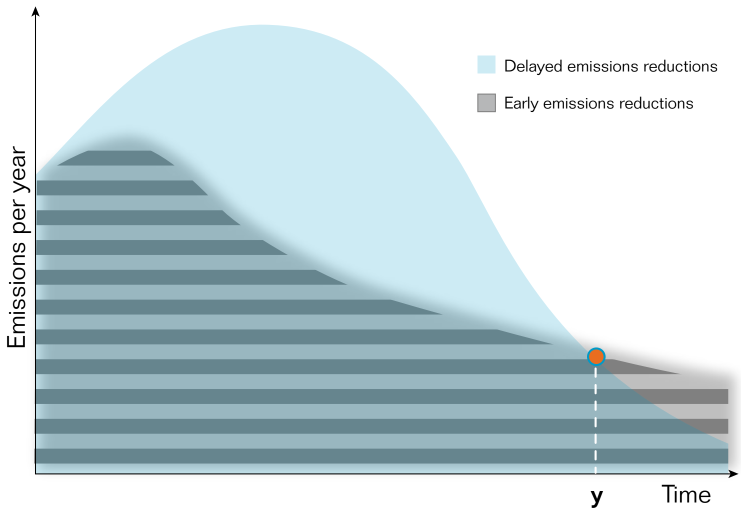
There are different ways in which goals for emissions can be expressed:[2]

- **End-period emissions:** This is the most common way of announcing targets (for example, that emissions will be reduced by 50 per cent by 2050). The advantage of this approach is its simplicity. The disadvantage is that a target at one point of time says nothing about the rate at which emissions should approach their target level, and so does not constrain cumulative emissions and therefore the concentration level at that point of time (see Figure 12.2).
- **Annual emissions:** Since a concentration profile implies annual values for emissions, annual targets for emissions can be articulated. The disadvantages of this approach are its complexity and lack of flexibility. There will be little difference in the environmental impact of two very similar concentration paths (since this is dependent on the stock of emissions), but there could be significant year-to-year cost differences (since the annual emissions would tend to vary with short-term economic and weather conditions).
- **Cumulative emissions:** This is the budget approach, by which the total emissions associated with a target profile over a number of years are summed up into a single target budget. In this approach, year-to-year variation from the target profile is allowed; what matters is that the multi-year budget is adhered to.

The Review makes extensive use of emissions trajectories (see, for example, section 14.2) to express emissions goals, and emissions budgets to provide intertemporal flexibility.

The benefit of the budget approach is its flexibility: it allows intertemporal trade-offs and smoothing. Costs could arise if the budget approach leads to long-delayed mitigation. There could be environmental costs (a faster rate of warming). Or, if there are climate–carbon cycle feedbacks, then slower mitigation could reduce the emissions budget associated with a stabilisation target since the faster rate of warming could reduce more quickly the ability of the terrestrial ecosystem to absorb carbon dioxide emissions (Jones et al. 2006). However, it is not clear that the budget approach would lead to deferred mitigation since smaller emission reductions in earlier years would have to be made up by greater, and possibly much more expensive, reductions in later years (Allen Consulting Group 2006). And variations in timing would have to be large to have material environmental impacts. Variations within five-year periods as proposed in Chapter 15 would not have material effects.

Figure 12.2 Different cumulative emissions from the same end-year target



12.1.4 Global goals for emissions to 2050

The 2007 Bali Roadmap calls for agreement on a 'long-term global goal for emission reductions' (UNFCCC 2007). Defining such a long-term goal, as well as a medium-term goal for around 2020, will be important for progress towards a meaningful global mitigation effort. Judgments about the level of stabilisation that is in Australia's interests will depend in part on the economic modelling currently under way for the Review's supplementary draft report. However, preceding chapters have already made the case that Australia is relatively vulnerable to climate change. Given the costs of international climate change mitigation, it is unlikely that the international community will want to go further than Australia judges to be in its interests.

IPCC (2007) analysis shows a global reduction range of 50–85 per cent at 2050 compared to levels in 2000, for the most ambitious class of stabilisation scenarios considered. Though, as discussed above, the emissions trajectory is just as important as the end point, a reduction in global emissions of 50 per cent by 2050 may be a natural attractor in defining a global goal. The Japanese Government has made this a focus of its agenda for the G8 Summit in Toyako in July 2008.

12.2 What form should national commitments take?

Once a global goal has been agreed, responsibility for its achievement needs to be allocated among countries. Unless all major economies agree to limit their emissions, it will be impossible to ensure that action at the global level adds up to an effective mitigation effort.

While any global agreement will emerge from negotiations—especially between the major emitters, and, of these, in particular between the two largest emitters, China and the United States—it is useful to spell out basic principles that could provide a framework for reaching agreement.

Proponents of price-based emissions control have argued for the adoption of national carbon taxes (Cooper 2000; Nordhaus 2007), or a common global carbon tax (Stiglitz 2006). Hybrid policies combining quantity and price controls have also been proposed, principally through cap and trade schemes, but with a government-backed price cap determining the cost at the margin (Roberts & Spence 1976; McKibbin & Wilcoxen 2002, 2008; Pizer 2002). A variant of the hybrid scheme has the price cap agreed internationally.[3]

At the heart of the economic argument for price control is uncertainty about abatement costs. The theory of prices versus quantities for pollution control (Weitzman 1974) shows that such uncertainty will invariably lead the policy to under- or overshoot the optimum: imposing a quantitative target will lead to higher or lower marginal abatement costs than expected, while a given tax rate will lead to greater or lesser abatement effort than expected. The resulting efficiency costs are thought to be lower under a price-based instrument for stock pollutants such as greenhouse gases, so getting the price wrong under a tax imposes lesser welfare losses than getting the quantity wrong under a quantity target.

Proponents of price-based emissions control have pointed out that a common global carbon tax or an agreement on an internationally harmonised price to apply in domestic permit trading schemes would avoid both questions of distribution between countries inherent in a cap and trade system, and the potentially destabilising effects of large-scale international financial flows.

While the introduction of a tax-based mitigation system would take the world significantly forward, the Review has come to the view that only an international agreement that explicitly distributes the abatement burden across countries by allocating internationally tradable emissions entitlements has any chance of achieving the depth, speed and breadth of action that is now required in all major emitters, including developing countries. Countries would take on quantitative commitments to limit and reduce emissions, differentiated according to broadly accepted principles, with trade in emissions rights between countries (cap and trade). Such an approach, after a period of confidence building, could help resolve the prisoners' dilemma that otherwise blocks mutually beneficial collective action. A quantity-based international agreement is more likely to succeed than a tax-based one for a number of reasons.

First, the tradable emissions entitlements approach builds on current international architecture and national practice. Quantitative targets have been the dominant form of greenhouse gas commitments so far. As in the Kyoto Protocol, quantitative targets frame the various existing and emerging national and regional climate goals and emissions trading systems, as well as the negotiations about national target commitments for the post-2012 period. Perhaps this is in part because the framing of commitments as quantitative targets appears to be politically more acceptable than taxes even if they imply similar costs. Be that as it may, as argued in Chapter 11, given the urgency of the situation, current efforts need to be built on, not overturned. Different architectures could be designed that might be superior, at least in theory, but time has run out for starting with completely new approaches that would require periods of trial and error.

Second, a cap and trade scheme provides incentives for developing country participation. Crucially for the goal of international cooperation, targets can be differentiated between countries without sacrificing economic efficiency. Under a price-based regime, commitments could be differentiated among countries by agreeing on lower emissions penalties for developing countries, but this would compromise the efficiency of the global mitigation effort and do less to provide a level playing field for emissions-intensive industries.

As discussed in Chapter 13, international trading in emission entitlements allows financial flows between countries. Such financial flows could offset abatement costs in developing countries, and so become a cornerstone of drawing them into an international policy framework.

Third, setting quantitative targets can control emissions levels more directly than setting emissions prices. This not only allows the extent of commitments to be more easily communicated, but also is preferable as climate change risks become more urgent to society and policy makers and as the possibility of catastrophic damage from climate change gains recognition (see Chapter 5).

Fourth, trajectories and budgets can be implemented with flexibility to prevent cost blow-outs of the sort feared by advocates of carbon taxes. Flexibility can be provided by defining emissions budgets over a number of years, allowing intertemporal flexibility across commitment periods, allowing substitution between different greenhouse gases, and allowing international trading of emissions rights. Emissions targets could be fine-tuned over time to yield the desired balance between abatement costs and emissions levels, just as taxes can, with similar costs associated with business uncertainty.

Fifth, uncertainty about emissions pricing within a cap and trade scheme has to be seen in the context of the manifold other demand and supply shocks, especially the natural price volatility in the energy and resource sectors. In particular, demand for and price of permits can be expected to fall in response to any large increase in the price of fossil fuels, as of the kind that the world has experienced over 2007 and 2008. This would be to some extent stabilising, unlike the rigid application of a fixed carbon tax.

Sixth, the adoption of national limits gives countries freedom to apply their own preferred mix of policies. A quantitative commitment under an international agreement does not mean that *domestic* policies need to be framed in quantity terms. A country could choose to place a tax on domestic emissions, introduce regulation aimed at reducing emissions, introduce a domestic emissions trading scheme, or use a combination of these instruments (see Chapter 14). International supervision of emissions commitments would be limited to monitoring emissions. By contrast, adoption of a carbon tax would require more intrusive international oversight (Frankel 2007). It would be necessary, for example, to ensure that countries did not offset a carbon tax by an increase in fossil fuel subsidies. Given the different tax treatment of fossil fuels around the world, it would be difficult, if not impossible, to ensure that national carbon taxes were both additional and comparable.

Carbon taxes could, however, play a useful role in international commitments in specified areas. In the foreseeable future, it is not realistic to expect each and every country to be subject to quantity limits. It would be reasonable in such a situation for those countries that are not subject to quantity limits to be under international pressure to introduce an offsetting carbon tax on at least the main trade-exposed, emissions-intensive industries (section 13.4). The revenue raised by such a tax would be retained by the government that imposed it. Such sectoral approaches would also be viable for emissions control in international aviation and shipping (section 13.6).

To help countries live within their emissions limits, there will need to be an international effort to boost investment in the research, development and commercialisation of low-emissions processes and products. The development of new low-emissions technologies is an international public good, the supply of which will need to be assured by national funding commitments. National funding commitments for both mitigation and adaptation assistance are discussed in detail in Chapter 13.

12.3 A graduated approach to national commitments

As discussed in Chapter 11, Annex B of the Kyoto Protocol allocates internationally tradable emissions rights to countries that belonged to the OECD in 1992 and transition economies (the Annex I countries of the UNFCCC). This group excludes a number of high-income countries including Singapore and Saudi Arabia. It excludes recently industrialised countries such as South Korea and Mexico, even though they are now members of the OECD. Many more countries will join the ranks of high-income countries over the years to come.

The principle that all high-income countries should adopt binding commitments to limit their right to emit would receive widespread support. There is also broad agreement that developing countries need to take on greater obligations, although no political resolution of this issue has been in sight. So far, developing countries have resisted taking on emissions targets. The 2007 Bali Roadmap calls on developing countries only to take *actions* to reduce emissions, in contrast to the *commitments* to be taken on by developed countries. How can a way be found through this conundrum?

Clearly, differentiation is needed within the group of developing countries. The poorest, least developed economies are not ready for a national approach. They could be involved in the mitigation effort through offset mechanisms such as a strengthened clean development mechanism, and international sectoral agreements where applicable (see Chapter 13).

But middle-income countries such as South Africa and Brazil and many others need to do much more. Some argue for a highly flexible approach, which would allow 'different countries to assume different types of international commitments—not only absolute targets, but also indexed targets, taxes, efficiency standards, and so forth' (Bodansky 2007: 65). Too many options, however, would make comparative assessment impossible, and therefore invite dilution of effort. Lack of a common framework would also place formidable obstacles in the way of international trading, which is the most likely route for developing countries to receive large-scale financing in support of their mitigation efforts.

Most developing countries cannot initially be expected to sign on to targets that would require them to buy emissions rights from other countries if they exceed their emissions budgets. One-sided targets—also referred to as opt-out or non-binding targets (Philibert 2000)—could be a helpful expedient for a transitional period. With a one-sided target, countries could benefit from taking on a commitment by going further than their target required and selling emissions rights, without obligation to buy if they missed the target.

Allowing countries to adopt one-sided targets has a cost. It increases uncertainty about whether countries will indeed follow through with their target commitments. To achieve similar global abatement as with binding targets for all countries, the countries with binding targets would need to take on more stringent commitments in order to reduce any shortfall from countries that opted out (Jotzo & Pezzey 2006). The very existence of an opt-out option might weaken the resolve of national governments to follow through with mitigation policies, particularly where there are vested interests to be tackled or politically difficult decisions need to be made, such as the removal of subsidies on petroleum products.

While recognising these drawbacks of one-sided commitments, the Review also recognises the reality that most developing countries, given their low income per capita, would simply not be prepared or, in many cases, able to purchase emissions permits internationally. The risk of such an obligation would prevent many from accepting a binding target in the first place. The Review therefore supports the use of one-sided targets for most developing countries, to facilitate immediate uptake of target commitments and as a transitional measure in place until perhaps 2020. After that, these countries would be expected to accept binding targets.

Some argue that developing countries should be given targets, but that those targets, at least initially, should be their business-as-usual levels. Under this approach, promoted by Stern (2008) in his proposal for a global agreement, the Growth Commission (2008) in its report, and Frankel (2007), developing countries would only reduce emissions below business-as-usual levels if developed countries paid them to do so. Essentially, this approach amounts to an expansion of the Clean Development Mechanism to an economy-wide level.

The flaw with this business-as-usual approach is that it would put the entire burden of emission reductions on developed countries. Since these countries account for a falling share in global emissions (see Chapter 5), it is unrealistic to hope to achieve substantial cuts in global emissions in this way. Developing country targets, albeit one-sided, need to be below business-as-usual levels.

The Review's proposal—for middle-income developing countries to adopt one-sided, below-business-as-usual emissions targets—goes further than most, if not all, current proposals for developing country commitments. Given the rapid growth in emissions, any international agreement that embodies a lower level of ambition will be an inadequate response to the urgency of the problem at hand. And, in the Review's framework, developing countries will have incentives to agree to such an approach: not only the prospect of financial gain through international selling of permits, but access to international public funding in support of both mitigation and adaptation.

The Review's proposal thus requires establishment of three groups based on level of commitment. At the top of the income range, countries are subject to binding emissions commitments. At the bottom, countries are subject to minimal commitments. In the middle, countries are subject to one-sided, below-business-as-usual commitments. How should countries be assigned to these three groups?

It is in the global interest for as many countries as possible to be in the first group with binding targets. This group should at a minimum consist of all countries currently in Annex I plus all other high-income countries. Where the high-income threshold is actually drawn, and therefore what other countries might be in this group, would be a matter for negotiations.

China is a special case. Because of its size, geopolitical importance and emergence as the world's largest emitter, no global agreement would be effective unless China took on binding targets. China's fiscal and technological position would allow it to do so. Of course, because of its lower income status, China's targets would not be as stringent during a transition period as those of developed countries (section 12.4).

Note that this first group, if it did include China, existing Annex I members and other high-income countries (using, for this purpose, the World Bank per capita income threshold of US$11 000) would account for approximately three-quarters of global emissions of carbon dioxide from fossil fuel combustion, the main source of greenhouse gases.

The second group, expected to take on one-sided targets, would comprise most of the developing countries. This would include all members of the US-led Major Economics Meeting process (section 11.1.4) that are not in the first group. As discussed in the next section, countries would be differentiated through per capita principles in the setting of their emissions limits. The second group would account for almost all of the remaining quarter of present-day global emissions from fossil fuels.

The third group would comprise countries classified as 'least developed' by the United Nations. It would also include any other developing countries that, on an objective assessment, do not yet have the necessary preconditions for a national approach—for example, those experiencing conflict or lacking the prerequisites for reliable emissions accounting. Countries in this group would be welcome but not required to take on one-sided targets at any time. They would be able to host clean development mechanism–type activities and sell offset credits, and would be expected to place a carbon tax on emissions-intensive industries producing tradable goods that were the subject of global sectoral agreements (Chapter 13).

It is worth reiterating that the above arrangements are proposed only as an initial, short transitional stage directed at achievement of a sound multi-decade international approach. At an early future point, desirably 2020, countries in the third group would be expected to take on one-way targets, and countries in the second group binding targets. Countries would graduate from group to group over time.

12.4 Principles for allocating emissions entitlements across countries

In the approach outlined in the previous section, all except the least developed countries would have national emissions limits, albeit of differing types (binding for high-income countries and some others, and one-sided for most developing). This leaves the important question of how emissions rights are to be allocated across countries. This section discusses possible principles and suggests for discussion an approach to guide the allocation of emissions entitlements.

Under the Kyoto Protocol, emissions budgets for Annex I countries for 2008–12 were defined as percentages of 1990 emissions, ranging within a relatively narrow band from 92 per cent to 110 per cent of base year emissions, around the average allocation of 95 per cent, with further differentiation within the European Union. Differentiation between countries was negotiated on an ad hoc basis, with little reference to underlying principles for allocation across countries, although on average richer countries signed up to larger reductions.

In future negotiations, involving a greater number of and more diverse countries, simply requiring somewhat differentiated reductions from a historical base, as under the Kyoto Protocol, will not serve the purposes of supporting international agreement. The stark differences in per capita emissions levels across countries need to be factored in, in order to gain acceptance by most developing countries. Emissions entitlements for the lower-emissions countries, which typically are at a relatively low income level also, would need to continue to grow but at a slower pace, while emissions entitlements in the richer countries would need to fall. For ambitious mitigation scenarios, few countries could be afforded growing emissions budgets, but strong differentiation in the rates of reductions would be required to make commitments acceptable.

Leaving emissions reductions to politics, negotiations and arm-twisting, without explicit criteria, would prove deeply problematic. While politics and special circumstances will inevitably have some role, limiting the scope for discretion will be critical if the pace of coordinated international mitigation action is to quicken. An allocation framework based on simple principles, if it received widespread international support, could facilitate international negotiations, and in the meantime guide individual countries' commitments ahead of a new international agreement.

To be effective, a future international policy regime will require the mitigation effort to be distributed using principles that are widely accepted and regarded as fair and practical. To be widely accepted, principles to guide the allocation of a global emissions budget across countries will need to be simple, transparent and readily applicable. To be considered fair, they will need to give much weight to population. To be considered practical, they will need to allow long periods for adjustment towards positions that give weights to population.

Various principles have been suggested. The UNFCCC emphasises *capacity*, with its call for greater and earlier mitigation effort by developed countries (those with more capacity). Graduation of a country to a more stringent level or type of commitment once it reaches some income threshold is a common feature of many proposals. Examples are the Pew Center Pocantico Dialogue (Pew Center 2005), the South–North Dialogue's proposal in Ott et al. (2004), and the São Paulo proposal (BASIC Project 2006). Section 12.3 argued for countries to take on more stringent types of commitments as they move from low to middle to high income status.

Some countries emphasise *responsibility*, and argue that future emissions rights should take account of how much each country has already drawn on the global emissions budget, by way of emissions in past years. Current industrialised countries have a disproportionate share in past cumulative emissions. Historical responsibility was formally introduced to the UNFCCC by the government of Brazil. The Brazilian proposal (UNFCCC 1997) called for the mitigation burden to be shared on the basis of the contribution to climate change of countries' past emissions.

It has also been argued that emissions rights should be based on the *effort* required to meet the limits imposed. Effort could be measured in terms of the impact of mitigation action on national GDP. However, this approach takes no account of differential starting points, and would require comparing the future state of the world to the counterfactual of what would have prevailed in the absence of the scheme. Quantitative estimates of future effort are highly uncertain and would be contested.

Underlying all these approaches is a concern with international *equity* made explicit in many allocative proposals. For example, the recent Greenhouse Development Rights framework (Baer et al. 2007) would apply equity considerations comprehensively to include adaptation costs and domestic income distribution. It is difficult, however, to see how broad agreement on what is equitable could be achieved in anything other than a very simple framework.

While all of these approaches have their strengths and weaknesses, the approach that seems to have the most potential to combine the desired levels of acceptability, perceived fairness and practicality is one based on *population* or *per capita emissions*. An approach that gives increasing weight over time to population in determining national allocations both acknowledges high emitters' positions in starting from the status quo and recognises developing countries' claims to equitable allocation of rights to the atmosphere. Any allocative formula that does not emphasise population as the basis for long-term emissions rights has no chance of being accepted by most developing countries.

The per capita approach is also broadly consistent with the emerging long-term emissions-reduction goals of several developed countries. Per capita emissions of the developed countries are today well above the global average of about six tonnes of carbon dioxide equivalent. Per capita emissions in, for example, the United Kingdom, Japan and the United States are (as of 2000) 11.5, 10.6 and 21.6 tonnes respectively. Under the long-term emissions-reduction goals announced by or anticipated in these countries, these levels would fall by 2050 to 3.9 tonnes (United Kingdom), 4.0 tonnes (Japan) and 2.7–5.5 tonnes (United States, using the commitments made by the two presidential candidates). These levels are all below today's global per capita average, and close to the 2–3 tonnes per capita average that stabilisation scenarios summarised by the IPCC (2007), together with UN population projections, suggest will be required for stabilisation at 450 to 550 ppm carbon dioxide equivalent.[4]

Indeed, it is inevitable that if global per capita emissions fall to as low as 2–4 tonnes per person by 2050, then (though variation in national emissions levels will still be possible through the trading of emissions rights), the current stark divergences in national per capita emissions will diminish over time.

The per capita approach also has the virtue of simplicity, in contrast to many other proposals on the table. Equal per capita emissions is a natural focal point, and contestable computations based on economic variables do not need to enter the allocation formula.

The per capita approach is generally referred to as 'contraction and convergence' (Global Commons Institute 2000) and has figured in the international debate for some time. It has been promoted by India and has been discussed favourably in Germany and the United Kingdom (German Advisory Council on Global Change 2003; UK Royal Commission on Environmental Pollution 2000). Recent reports have shown increasing support for this approach internationally: see, for example, Stern (2008) and the Commission on Growth and Development (2008).[5]

Under contraction and convergence, each country would start out with emissions entitlements equal to its current emissions levels, and then over time converge to equal per capita entitlements, while the overall global budget contracts to accommodate the stabilisation objective. This means that emissions entitlements per capita decrease for countries above the global average, and increase (albeit typically at a slower rate than unconstrained emissions growth) in countries below the global average per capita level. Importantly, emissions entitlements would be tradable between countries, allowing actual emissions to differ from the contraction and convergence trajectory.

The per capita approach addresses the international equity issue transparently: slower convergence (a later date at which per capita emissions entitlements are equalised) favours emitters that are above the global per capita average at the starting point, while faster convergence gives more emissions rights to low per capita emitters. The convergence date is the main equity lever in such a scheme.

An important group that would have difficulty with a straight convergence towards equal per capita emissions is the rapidly growing middle-income countries such as China, which are already around the global per capita average for greenhouse gases and would find it difficult or impossible to stop the per capita growth in their emissions immediately. To account for this, the per capita approach could be modified to provide 'headroom' to allow these countries to make a more gradual adjustment, without immediately needing to buy large amounts of emissions entitlements from other countries. (See section 12.5 for more detail.)

Some argue that relying on just one criterion is excessively simplistic. The UNFCCC itself states that national policies in developed countries to limit emissions should take into account 'differences in these Parties' starting points and approaches, economic structures and resource bases' (Article 4.2(a)). Submissions to the Review raised similar points about Australia's circumstances and resource endowments.

Contraction and convergence does, of course, take differences in starting points as the main consideration in the early years, gradually shifting the weight towards population. Moreover, country differences are handled within the per capita approach by allowing those with emissions-intensive economies to buy emissions entitlements from those with economies of lower emissions intensity. This maintains the competitiveness in emissions-intensive industries of countries with tight allocations relative to existing emissions, so long as all substantial economies are subject to constraints that generate similar carbon prices. For the domestic producer of emissions-intensive goods, the higher international price for the product compensates in an economically efficient way for the need to buy permits.

It might also be argued that a population-based allocation encourages environmentally damaging global population growth. This is unlikely, as population growth is decided by far more fundamental economic and social determinants. This argument is even less appropriate to countries—mostly developed countries, and first of all Australia, the United States and Canada—where population is growing through immigration.

Another argument against per capita approaches sometimes raised in developed countries is that emissions entitlement trajectories for some low-growth developing countries could be above their underlying emissions growth trajectory, allowing them to benefit from the sale of excess permits while making minimal mitigation efforts themselves. The modelling under way for the Review will give an indication of the likely empirical significance of this concern. Fundamentally, however, this argument overlooks the reality that international trading gives the incentive to implement mitigation measures to reduce emissions further, irrespective of the allocation.

Some submissions to the Review have argued that a per capita approach is against Australia's interests because of our current high per capita emissions. This is mistaken, for several reasons.

First, Australia's biggest national interest is in effective international action, and an emphasis on population is going to be required in any practicable allocation rule. Of course, Australia would gain from an international agreement that recognised only our own special circumstances. But special circumstances would then need to be recognised for all countries. Striving for such a system would be against Australia's interests because it would be difficult to agree on and thus would delay global mitigation action, and because such an agreement would probably have its environmental benefits diluted by special pleading (everyone would find a reason not to do very much).

Second, Australia's ongoing strong population growth means that Australia will find it easier to cut emissions in per capita rather than absolute terms. Australia's population growth rate is already above the world average. The reference case (Chapter 9) suggests that Australia's population will increase almost three times as much as global population through this century. If emissions entitlements and targets are framed in per capita terms, countries with growing populations will receive greater absolute allocations. Population growth considerations are centrally important to equitable distribution of the adjustment burden between Australia and other developed countries.

Third, reducing over time Australia's per capita emissions entitlements to the global average would not mean the end of Australia's emissions-intensive industries. The necessary condition is that the adjustments occur within an effective global agreement—towards which the allocation principle suggested here is directed. Rather, their continued expansion would be possible through permit purchases. Where Australia produces emissions-intensive goods for export, it is logical to cover the emissions from that production with purchases of emissions rights from international markets.

12.5 Shaping a per capita approach to the allocation of emissions entitlements

There are many ways to give effect to the principle that, over time, population will figure increasingly largely in any practical allocation rules for emissions rights across countries. Three aspects deserve particular consideration.

First, a *starting date* is needed. For example, base levels could be defined as actual emissions levels at the conclusion of the first Kyoto Protocol commitment period (2012). For Kyoto Protocol ratifiers, using the Protocol target levels (average emissions for 2008 to 2012) would ensure that good performance in the first commitment period is rewarded in the next.

Second, the *convergence period* needs to be defined. As discussed above, the convergence period is the main equity lever under the per capita approach, and would obviously be subject to negotiation. Since 2050 is a strong focal point in international negotiations, it would be a candidate target date for convergence.

Third, as discussed earlier, *headroom in emissions allocations* needs to be provided for emissions growth in rapidly growing developing countries. Headroom could take the form of challenging emissions-intensity targets for fast-growing developing countries, up to a predefined limit. Intensity targets (Baumert et al. 1999), also referred to as relative targets, would link emissions budgets to economic output. For example, annual permit allocations could be allowed to increase by half the rate of GDP growth for the countries that are being provided headroom. This definition of parameters would roughly coincide with the combination of China's (so far unachieved) goals for reductions in energy intensity and increases in the share of renewable sources of energy in the economy. This would be an important factor in making the approach work for the world's largest emitter and a possible standard throughout the developing world.

Other countries will need to have their allocations adjusted if the world is to remain on the same trajectory to a stabilisation target. A limit would need to be placed on the provision of headroom. One possibility would be to cap the growth in emissions rights allocations at the point where the developing country's rising emissions per capita reached a benchmark trajectory in per capita emissions. This benchmark trajectory could be based on an average of the emissions profiles of moderately emitting developed countries, which would be expected to be lower than at present at the point where the two trajectories intersect. Note that even with the provision of headroom, emissions entitlements to most developing countries and on average would be expected to fall substantially below business-as-usual levels.

The Review has developed an approach to the international allocation of emissions along the lines described above, which is being tested through economic modelling. The supplementary draft report will include quantitative allocation scenarios based on the modelling currently under way.

Notes

1 Just as with converting from concentration levels to temperature increases, so too converting from emissions to concentration levels involves uncertainty, in particular involving climate–carbon cycle feedbacks, the treatment of which can reduce permissible cumulative emissions associated with atmospheric stabilisation targets by 20 per cent or more (Jones 2006).

2 The issue of aggregating over different greenhouse gases is not tackled here (see Chapter 3).

3 A price-based commitment is an example of an input-based commitment. Another variant of input-based commitments is the 'sustainable development policies and measures' (Winkler et al. 2002) approach which would directly reward countries (normally developing countries) for implementing agreed policies.

4 For the actual commitments made by these countries, see section 11.2. UNFCCC data has been used as a baseline. All population projections are the 2006 medium variant projections from the United Nations. The exact global per capita emissions average at 2050 under the various stabilisation scenarios depends heavily on the trajectory of emissions through time, as well as on future population growth.

5 Neither report uses the term 'contraction and convergence', but both point to the need for all countries to aim for equal per capita emissions over the 'long term' (Commission on Growth and Development 2008) or by 2050 (Stern 2008). Stern (2008: 10) notes that this approach 'is a pragmatic … one. It should not be regarded as strongly equitable since it takes little account of the developed countries' much larger per capita contribution to stocks of greenhouse gases.'

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13 DEEPENING INTERNATIONAL COLLABORATION

Key points

International trade in permits lowers the global cost of abatement, allows greater flexibility for developed countries in meeting their commitments, and provides a financial incentive for developing countries to take on commitments.

Trade in emissions rights is greatly to be preferred to trade in offset credits, which should be restricted.

A global agreement on minimum commitments to investment in low-emissions new technologies is required to ensure an adequate level of funding of research, development and commercialisation. Australia's commitment to support of research, development and commercialisation of low-emissions technology would be up to about $2.8 billion in 2007—or more than $3 billion per annum by the time the proposed International Low Emissions Technology Commitment took effect in 2013.

An International Adaptation Assistance Commitment would provide new adaptation assistance to developing countries that join the global mitigation effort.

Early sectoral agreements would seek to ensure that the main trade-exposed, emissions-intensive industries face comparable carbon prices across the world. These would include international civil aviation and shipping.

A WTO agreement is required to support international mitigation agreements and to constrain unilateral action against countries thought to be doing too little on mitigation.

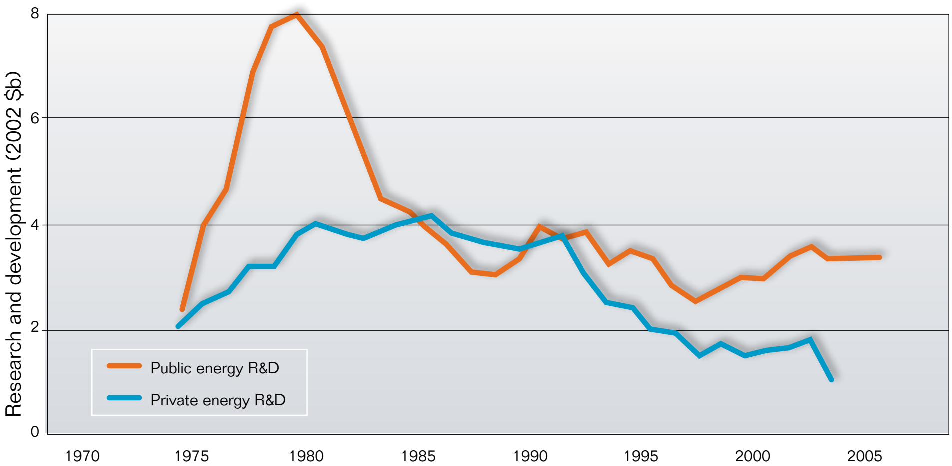
It would be neither desirable nor feasible for each country separately to pursue national emissions-reduction targets. It would not be desirable because lower-cost abatement options would be forgone, and higher-cost options accepted. It would not be feasible, for there would be no incentive for developing countries to participate in strong mitigation, and they would not. These are two fatal flaws.

No ambitious system of emissions allocation among nations will work unless it allocates entitlements rather than actual emissions. And mitigation efforts will not fully succeed without international public funding to develop and to transfer new technology as quickly and widely as possible. This chapter covers key aspects of international collaboration, from international public funding to emissions trading, to policy frameworks for particular sectors, trade rules and enforcement mechanisms.

13.1 International public funding for mitigation

One of the weaknesses of the world's response to climate change to date has been the limited extent of international public funding for mitigation. Levels of energy research and development, critical to enable the world to make the transition to a low-emissions future, have actually fallen over time.[1] Figure 13.1 illustrates the case of the United States, the world's largest investor in research and development. The lack of increase in energy research and development can be explained partly by the limited mitigation efforts seen so far (resulting in little indirect inducement of research and development). Nor has the issue been an important part of the public discussion. Research and development are barely mentioned in either the United Nations Framework Convention on Climate Change (UNFCCC) or the Kyoto Protocol.

Figure 13.1 Energy research and development expenditure by the public and private sectors in the United States



Source: Kammen & Nemet (2005a).

Unlike research and development, technology transfer features prominently under the UNFCCC and Kyoto Protocol. However, the unquantified assurances given in these treaties have not been translated into action. Some technology transfer has occurred under the Kyoto Protocol's Clean Development Mechanism, but nothing on the scale required to underpin broad-based mitigation in developing countries. The Global Environment Facility, a multilateral agency which has been designated as the 'financial mechanism' for the UNFCCC and a number of other environmental conventions, has been an active player in technology transfer, but on a limited scale; on average less than US$1 billion a year (including co-financing) was allocated to climate change projects between 1991 and 2004 (IPCC 2007).

More recently, low-emissions technology research and transfer have received increased attention, with support from prominent economists[2] and political leaders. Venture capital funds are also starting to invest in renewable energy (Pontin 2007). In February 2008, the US, UK and Japanese governments announced the establishment of 'a multibillion-dollar fund to accelerate the deployment of clean technologies and help the developing world deal with climate change' (Paulson et al. 2008). The three countries have committed about US$1–2 billion each to what is now called the Clean Technology Fund, to be administered by the World Bank. The G7[3] has issued a call to 'scale up investment in developing countries to support them in joining international efforts to address climate change' (AFP 2008). In the last few years, a number of collaborative initiatives have been launched to develop and transfer clean technologies (Box 13.1). The World Bank and regional banks have announced a new focus on energy efficiency and clean technologies, including renewable energy, with commitments to lend US$1–2 billion a year each (IPCC 2007). Australian governments have started investing in research and development on carbon capture and storage, and to a lesser extent in research on renewables. A number of Australian companies are investing large amounts of risk capital raised for the purpose in deep geothermal technologies.

Box 13.1 International research and development and technology transfer initiatives

In recent years, a number of international technology-related initiatives have been launched. Many of them are in need of additional funding. They would all be eligible for funding under the Review's proposed International Low Emissions Technology Commitment.

- The Generation IV International Forum is a multilateral partnership fostering international cooperation in research and development for the next generation of nuclear energy systems.
- The Carbon Sequestration Leadership Forum is focused on the development of improved technologies for the separation and capture of carbon dioxide for transport and long-term safe storage.
- The Methane to Markets Partnership focuses on advancing near-term methane recovery and use of methane as a clean energy source.
- The International Partnership for the Hydrogen Economy provides a forum for its member countries for advancing policies, common codes and standards, as well as developing demonstration and commercial utilisation activities related to hydrogen and fuel cell technologies.

Box 13.1 International research and development and technology transfer initiatives *(continued)*

- The mission of the Renewable Energy and Energy Efficiency Partnership is to 'contribute to the expansion of the global market for renewable energy and energy efficiency'. The partnership's broad membership includes national governments, business, development banks and non-government organisations.
- The Asia–Pacific Partnership on Clean Development and Climate brings together governments and companies from Australia, Canada, China, India, Japan, the Republic of Korea and the United States to collaborate on the development, deployment and transfer of cleaner and more efficient technologies (section 11.1).

Widespread adoption of national emissions goals, as advocated in Chapter 12, would not obviate the need for international public funding for mitigation. To the contrary, provision of such funding will be critical to the global endeavour to live within a tightening carbon constraint to correct for international market failures relating to public goods and missing markets:

- Expenditure on the research, development and commercialisation of low-emissions technologies has significant international public good characteristics, as it can benefit all nations and its rewards cannot be fully captured by private investors. Delivering this international public good will be critical for lowering abatement costs and increasing confidence that the mitigation task is a feasible one. Indeed, some have argued that international climate change mitigation policy should be predominantly about the development and provision of low-emissions technologies (Schelling 2002; Barrett 2003). This view underestimates the importance of price signals for providing incentives for change, and for inducing technological change (Köhler et al. 2006). No amount of technological innovation will make some potentially important emissions-reducing technologies competitive with unmitigated release of emissions to the atmosphere. Geosequestration of emissions from fossil fuel combustion is an important example: coal-fired generation will always be more expensive with geosequestration than without it. Nevertheless, deep cuts in global emissions will require the development of new energy technologies, and international externalities in research and development provision will require international public funding.
- International trade in emissions rights will be critical for providing incentives for developing countries to participate, but it will take several years even after a new international agreement is reached for the necessary international markets to develop. In the interim, developing countries will face a problem of 'missing markets.' Developed country governments and international

development finance institutions will need to step into the breach to provide developing countries with financing to kick-start the move to a low-emissions future (Carmody & Ritchie 2007). Such financing would provide critical technology—existing and new—to support the transition to a low-carbon economy, but could extend beyond the energy markets to other areas such as reducing deforestation.

How much public funding for research, development and commercialisation of low-emission technologies would be required? One estimate of global energy research and development needs for a stabilisation goal of 550 ppm carbon dioxide equivalent is in the order of US$30–100 billion per year until stabilisation (Kammen & Nemet 2005b). Another estimate for the same stabilisation level calls for annual spending of US$50 billion per year by 2050 compared to an estimated US$10 billion today (Bosetti et al. 2007).[4] Although some of this research and development will be provided by the private sector, in general these estimates understate the required public funding. They only cover energy research and development, and neglect technology transfer or other public financing for developing country mitigation. These estimates model requirements for stabilization at 550 ppm carbon dioxide equivalent, a level that may not do enough to reduce the risk of dangerous climate change. Stabilisation at a lower concentration level will require faster and greater development and uptake of new technology, and thus larger, earlier expenditure. The International Energy Agency (2008) examined the energy technology requirements for reducing global emissions by 50 per cent by 2050. It concluded that 'a massive increase of energy technology Research, Development and Demonstration … is needed in the coming 15 years, in the order of US$10–100 billion per year' (IEA 2008: 1).

Looking beyond research and development to the financing needs of developing countries, the UNFCCC estimates that by 2030 additional global investment and financial flows of US$200 billion annually would be needed, with flows to developing countries in the order of US$100 billion annually to finance mitigation that leads to constraining emissions at 2030 to current levels (UNFCCC 2007b). While the bulk of these investment flows are expected to come from the private sector, until international carbon markets are established there will need to be greater reliance on public sector funding.

Encouraging adequate global funding, ensuring equitable burden sharing, and deterring free-riding all contribute to making a strong case for embedding commitments to the international funding of climate change mitigation in an international agreement.

Such a commitment would apply only to high-income countries. This is consistent with the UNFCCC principle of 'common but differentiated responsibility'. It would reflect the burden the UNFCCC places on developed countries to meet mitigation costs in developing countries, and also the Bali agreement to scale up developing country mitigation action on the back of increased incentives from developed countries.

The Review therefore proposes that high-income countries support an **International Low Emissions Technology Commitment**. This would require high-income countries to allocate a small proportion of GDP above a threshold to such purposes. They would commit to a specified funding level, but would retain flexibility in the use of funds. Funds could be spent domestically or abroad, through national or collaborative ventures.

Eligible expenditures under the Commitment would include public funding on low-emissions research and development; public funding on technology commercialisation (at a discount of, say, 2:1 or 3:1); and public funding to kick-start the mitigation efforts of developing countries, for example through technology transfer and support for reduction in forestry emissions. Much of the spending will be in high-income countries since that is where the technological breakthroughs are more likely to be made. A significant portion would be in developing countries, especially prior to the establishment of international carbon markets.

Funding commitments would apply as a percentage of GDP above a certain threshold level of per capita income. The threshold for funding commitments could coincide with the threshold for classification in the high-income group of countries, so that a country just entering the group would initially have only minimal funding commitments.

The recommended size of the International Low Emissions Technology Commitment will be considered in the Review's final report. As a broad illustration of magnitudes, take an annual global amount of US$100 billion and the World Bank high-income threshold of US$11 000 per capita. Then for 2007 GDP levels (at then current exchange rates) under this formula, the 50 richest countries (accounting for two-thirds of global GDP) would have contributed on average 0.24 per cent of their GDP to the Commitment.

Australia's 2007 share under the above formulation would have been $2.8 billion, or 0.26 per cent of GDP. Australia would commit the public sector (federal or state) to spend at least this amount on research, development and commercialisation of new low-emissions technologies. It could acquit the commitments at home or abroad.

There is a strong argument for a steep ramping up of funding given the urgency of mitigation, the fact that research and technology transfer will bring about a permanent reduction in mitigation costs, and the need to induce developing countries to participate. Commitments might come down in future years as and when market mechanisms become effective and technological breakthroughs are made.

Developing countries would need to agree to and comply with the commitments that would be expected from them under the next climate agreement in order to be able to qualify as recipients of funds under the Commitment.[5] For the least developed countries, the expectation would only be to put in place a carbon penalty on large emissions-intensive export industries (see section 13.4). Most other developing countries would be expected in addition to take on one-sided targets (see section 12.3).

How funding for the Commitment is secured would be left to individual governments. Countries with an emissions trading scheme or carbon tax could choose to earmark a portion of permit sales revenue or tax revenue towards this commitment.[6]

Expenditures under the Commitment would not be restricted to the stationary energy sector. It would also cover transport, and various forms of biosequestration: research into increasing carbon content of soils, forestry management, and the use of algae for biosequestration (section 3.6.1). It would also cover research into geo-engineering (section 3.6.2).

13.2 International public funding for adaptation

Adaptation means different things for different countries. For most poor countries, an important response to the adaptation challenge is economic growth (Schelling 1997), which puts greater resources at the disposal of both citizens and governments to respond to climate change. Economic growth will also take people out of the sector that is most vulnerable to climate change—agriculture. Trade liberalisation will help countries adjust to shifting production opportunities, and will spread globally and render more manageable the shocks to food supplies that will come with climate change. Better education will help people in poor countries acquire the information they need to adapt. All of these are core development assistance matters that would benefit developing countries even if there were no climate change, but that will also help them to adapt to climate change.

It makes no sense to force an artificial division between the adaptation and development agendas. There is no need for a new adaptation architecture. The challenge is rather to make the existing aid architecture work better, and fully incorporate adaptation considerations into decision making.

A number of adaptation funds have been established under the UNFCCC and the Kyoto Protocol, but they are quite small (Box 13.2).

The non-aid policies of developed countries are also important for helping developing countries adapt. For example, developed country policies that promote free trade, especially but not only in food, and the flow of unskilled labour, can be expected to help them to adapt. Developed country policies on security and peacekeeping will also be important to help developing countries adapt if, as some predict (Collier et al. 2008), climate change leads to increased civil conflict.

Box 13.2 Adaptation funds under the UNFCCC and the Kyoto Protocol

The **Least Developed Countries Fund** was established to assist least developed countries (as defined by the United Nations), of which there are 49, to design and implement National Adaptation Programmes of Action. It is funded through voluntary contributions, and pledges amount to US$120 million (GEF 2008b). Australia contributed $7.5 million to the fund in 2007.

The **Special Climate Change Fund** is designed to complement other funding and, while mitigation activities are within its scope, its top priority is adaptation. It is funded through voluntary contributions, and pledges currently total US$60 million (GEF 2008a). Australia is not currently a contributor to this fund.

The **Adaptation Fund** was established under the Kyoto Protocol. This fund has only just become operational. The fund is financed through a 2 per cent levy on certified emissions reductions (CERs) traded through the clean development mechanism. It receives secretariat services from the Global Environment Facility and the World Bank has been invited to become the trustee. The majority of its board members come from developing countries. Initial funding is unlikely to be available before 2010 (World Bank 2008b), when it is estimated that revenue from the levy will total US$80–300 million per year (UNFCCC 2007b).

The movement of people resulting from climate change could eventually be massive. While most of it is likely to be internal, it could spill over national borders. Australia's Pacific island neighbours are already seeking assistance for moving sections of their populations that are experiencing sea-level rise and salt water inundation. To date, the focus has been on the small island countries of the South Pacific. In the event, the numbers of people involved will be much greater in Papua New Guinea and eastern Indonesia. While at some point it might be necessary for larger developed countries to create special classes of entry and residence visas for residents of climate-affected nations, a more immediate response would be to increase the adaptive capacity of small developing countries. For example, countries such as Australia and New Zealand could have a role to play in helping to improve labour mobility in the region. This would create international private-sector networks (a diaspora), which in turn would help the Pacific island countries to adapt and to diversify their risk.

Given the range of adaptive responses, it is difficult to calculate the adaptation cost of climate change even in one country, let alone across the world. The World Bank (2006b) estimates the incremental annual costs of adaptation to projected climate change to be in the range of US$10 billion to US$40 billion per year, of which about a third is associated with public finance.

It would be desirable for developed countries to make a quantified commitment to providing adaptation support to developing countries. Some would argue that such a commitment would represent compensation to developing countries for damage done through 'greenhouse pollution' inflicted by developed countries (Oxfam 2007). Whether or not this 'polluter pays' argument were accepted, an **International Adaptation Assistance Commitment** would provide developing countries with an assurance that they will receive support in adapting. Both the new mitigation and the adaptation commitments proposed by the Review would give developing countries incentives to participate more fully in the international climate change regime. Access to such funding should be conditional on developing countries fulfilling reasonable expectations on their contribution to mitigation efforts. Note that, as set out in Chapter 12, participation conditions would be minimal for the least developed countries.

While adaptation assistance would, by its nature, be categorised as official development assistance, developed countries would need to ensure that funding to meet their share of the International Adaptation Assistance Commitment was additional to rather than substitutive of existing aid programs.

Many developing country governments are not aware in detail of what the main impacts and risks of climate change will be in their countries. This knowledge is the starting point of adaptation, and needs to be created locally. The importance of research for effective adaptive responses suggests that a priority for international funding should be a collaborative climate change impact and adaptation research endeavour. Australia could usefully play a leading role in the development of a system of international climate change research, as it did in the development of the established system of international agricultural research (the Consultative Group of International Agricultural Research). The research contribution that Australia might make to this international objective will be elaborated in the Review's final report.

Australia's international adaptation response will be focused on our region, and in particular our near neighbours, through the South Pacific and Papua New Guinea,Timor-Leste and Indonesia. The 2008–09 AusAID budget announced regional adaptation funding of $150 million over three years to be focused on the Pacific island countries. Priority areas include improved scientific understanding of climate change impacts, strategic planning and vulnerability assessment, and financing for the implementation of priority adaptation measures.

13.3 International trade in emissions rights

13.3.1 Benefits and risks

Trading between countries in emissions rights is an integral part of the Review's approach to mitigation. The agreed emissions targets would need only to hold in aggregate for the world, not at the level of each country. Some countries could emit above their allocations, buying emissions rights from other countries that in turn remain below their allocations. Indeed, it would be a natural development for countries with comparative advantage, after taking the external costs of emissions into account, in production of emissions-intensive goods, to purchase permits in international markets alongside exporting large amounts of the goods.

International trading has several advantages.

- It reduces global abatement costs by ensuring that the cheapest abatement opportunities are sought out first, wherever they occur. Cost savings are greater when there are wide differences between participants' target commitments and abatement options, as is likely in a scheme with broad coverage. Estimates of aggregate cost reductions from global trade are in the range of 20–80 per cent (Stern 2008).
- A broader market can reduce price volatility, dilute country-specific shocks and provide greater certainty about domestic costs of meeting a target. This makes it easier to agree on and adhere to national emissions commitments.
- The tendency for trade to lead to convergence of emissions prices across countries will provide a level playing field for trade-exposed, emissions-intensive industries.
- Most importantly, the revenues from international trade provide financial incentives for developing countries to take on commitments. Developing countries, many of whom have cheap abatement options, can expect to reduce their emissions below their allocations, and sell the freed-up emissions rights. This is the principal direct incentive for developing countries to take on national targets, and requires developed countries to be willing to act as purchasers.[7]

International emissions trading also carries risks. Linking internationally is a form of shared sovereignty, which will imply some loss of control over aspects of mitigation policy. Fully linking into international markets means that the speed and amount of domestic economic adjustment are determined to a significant degree by the international price. Smaller countries, such as Australia, would lose control of the domestic price of carbon. While in general free trade is welfare promoting, for a government-created market, there is the risk that the resulting price might be too high or low relative to domestic perceptions of the optimal rate of mitigation. Linking can also be a cause of price volatility, for example if there were external policy instability. Risks can be reduced by limiting trading, as discussed below.

From these considerations, it is clear that the spread of international emissions trading offers great opportunities, but needs to be managed in a judicious and calibrated manner. Fully linked international markets are likely to emerge only over time.

Bilateral and regional trading and other forms of cooperation are natural stepping stones towards greater international integration. Such links are already being considered between existing and proposed emissions trading systems in Europe, North America, Australia, New Zealand and Japan, but could also occur between developed and developing countries. Links between individual developed and developing countries, or among groups of countries, will be easier to achieve than comprehensive global integration, and can build on established relationships. Developed countries will need to show leadership in their regions (see Box 13.3 in section 13.7 for potential for links between Australia, Papua New Guinea and Indonesia).

13.3.2 International trading options

Imposing restrictions on trading allows countries to retain greater control over domestic prices and abatement, although with higher overall costs of complying with a given commitment. Rules for allocating trading opportunities and the profit from price differentials have to be devised in this context. Under the Kyoto Protocol, there are unquantified limits on international trade under the supplementarity principle of Article 17. The greater the trust a country has in the international system, the less it will want to resort to limits. As a result, in Chapter 15, the Review suggests limits in the Australian emissions trading scheme on the use of international offsets, but not emissions permits, from markets that meet quality standards.

Direct trading through private firms provides flexibility and is likely to lower transaction costs, especially when trade involves firms from countries with national emissions trading systems. But trading can also occur through government gateways, which would introduce the option to impose conditions on the use of international payments. For example, to make financial transfers more acceptable in permit-buying countries, buyers could require that the revenue be used for climate- and development-related purposes in permit-selling developing countries. Any such arrangements would be negotiated between the parties involved in trade.

A fundamental prerequisite for selling permits is transparent monitoring that complies with standards accepted by the international community and in particular by the main permit buyers. With international trading, incentives to under-report emissions are heightened. An international authority, possibly under the auspices of the UNFCCC, would have to assess whether minimum standards are met, similar to existing procedures under the Kyoto Protocol.

Each country would be able to determine the countries with which it would trade, to protect the integrity of its own domestic system. The scope for selectivity would, however, be limited by indirect linking. For example, if Australia links to New Zealand, and New Zealand links to other countries, then Australia's market is effectively also linked to all of New Zealand's partners. Indirect linking will accelerate the tendency towards a similar permit price across countries.

Specific recommendations for how Australia should go about international linking based on consideration of these general options are provided in Chapter 15.[8]

13.3.3 International offset credits

International trading can also occur in offset credits—that is, emissions reductions claimed where no overall national commitment applies. So far under the Kyoto Protocol, most international trading is in offset credits derived from the Clean Development Mechanism (CDM).

As discussed in Chapter 11, the CDM has facilitated some developing country engagement in mitigation, but suffers from important limitations. Expanding the CDM beyond its project-by-project basis is being considered in the UN process to include programs and possibly policies, or to allow whole sectors of developing countries' economies to produce offsets. As discussed in Chapter 12, however, broad coverage of emissions sources with a safeguard for developing countries is better achieved through one-sided targets than through an expanded CDM. A one-sided target allows the quantitative commitment to be set according to agreed principles, without the arbitrary exercise of determining counterfactual baselines. And crucially, one-sided targets allow for commitments below business-as-usual emissions that are nevertheless expected to benefit developing countries through sales of freed-up emissions rights, while giving the safeguard of opting out. Ambitious global mitigation will require emissions containment in developing countries in addition to rather than in substitution for emissions reduction in developed countries. This is increasingly recognised internationally, including by the European Union, to date the principal backer of the CDM.[9]

If this framework were adopted, offset mechanisms would only have a role where there were no national commitments, leaving the CDM as a transitional mechanism to apply in countries that did not yet have one-sided targets.

To remove any disincentives for taking on national commitments, no new CDM projects should be accepted from countries that are expected to take on targets (see Chapter 15). In addition, implementation rules for the CDM would need to be further strengthened to ensure a high standard of environmental integrity. Buying countries may also decide to place quantitative or qualitative limits on credit purchases.

13.4 Price-based sectoral agreements for the trade-exposed, emissions-intensive sectors

Unless large producers the world over face a similar emissions price, there is a danger of artificial movement of production from countries applying strong mitigation measures to others, with adverse environmental as well as economic effects. The fear of 'carbon leakage'—a loss of competitiveness and possible international relocation of trade-exposed, emissions-intensive industries as a result of carbon penalties applying in some countries but not others—has been a powerful obstacle to strong domestic mitigation policies in many countries.

This fear can be exaggerated. Firms in different countries face very different cost structures already, in part due to differing government policies. To the extent that firms enjoy rents—and many have recently seen large increases in output prices—firms will be able to absorb carbon penalties without any adjustment at all (Lockwood & Whalley 2008).The chief executive officer of Australia's largest exporter of liquified natural gas recently drew attention to the inequities that would be associated with Australia but not its gas-producing developing country competitors applying a price to carbon (Voelte 2008). He neglected to mention that differences in royalty and taxation regimes at the margin between Australia and major competitors gave Australia a competitive advantage many times as large as any negative effects of a carbon price, for as far into the future as we can see. Nevertheless, carbon leakage can be a real problem, and one that creates powerful domestic opposition to attempts to impose economy-wide carbon prices.

Countries implementing domestic policies are considering various ways to offset competitive disadvantages to their trade-exposed, emissions-intensive industries—for example, by allocating free emissions permits under emissions trading, or by applying border taxes.[10] Domestic compensation causes difficulties in implementation of domestic climate policies (see the discussion in Chapter 15). Border tax adjustments, even if compliant with World Trade Organization rules developed for the purpose (section 13.5), can only ever be a backstop to international climate change agreements.

To avoid the need for second- or third-best domestic and trade solutions, comparable emissions pricing needs to apply to most or all of the main producers in trade-exposed, emissions-intensive industries. Clearly, effective economy-wide commitments for all relevant countries would be the best solution. But not all relevant countries will take on such commitments for the foreseeable future. The most straightforward mechanism to achieve a comparable carbon price is a sectoral agreement that subjects the main producers in each industry to a carbon tax if they do not have an effective national emissions limit.[11]

An agreement about taxes does not itself allow differentiation of commitments between countries (section 12.4), but this is not necessary in the case of the trade-exposed, emissions-intensive sector. Producers are part of a global market, and multinational ownership is widespread. Domestic governments would keep the revenue, giving them a direct incentive to implement the agreement. As foreshadowed above, access to global climate funds for developing countries could be made conditional on their taking part in relevant international sectoral agreements.

Only a small number of countries would need to be involved in the key industrial sectors to achieve broad coverage. Industries that are often mentioned in the international discussion as candidates for sectoral agreements include iron and steel, aluminium, chemicals, cement, and paper and pulp. The bulk of emissions from developing countries in these sectors arise from just a few countries. To cover 80 per cent or more of developing country emissions in each sector, just three developing countries would need to be involved in iron and steel; four each in aluminium smelting and pulp and paper making; seven in cement production; and nine in chemicals and petrochemicals (Schmidt et al. 2006).[12] From Australia's perspective, additional sectors of interest are non-ferrous metals beyond aluminium, alumina, liquefied natural gas (LNG), and the products of sheep and cattle (see Chapter 8).

Price-based agreements would require agreement about the tax rate for countries that were not operating under UN-compliant economy-wide commitments. The tax rate could be predetermined; set as an average of a basket of domestic emissions trading systems; or pegged to the price prevailing in one of the major developed country emissions trading markets (such as the European Union, Australian, or in future North American or East Asian markets).

In some industries, notably aluminium smelting and some steel production, indirect emissions in generating electricity would need to be taken into account. These emissions could be assessed according to a simple and robust approximation, based on the emissions intensity of the systems from which they draw their power, and made subject to the sectoral emissions tax. Indirect or embodied emissions that fell below a threshold would not be considered, in the interest of simplicity.

Appropriate regulatory and governance structures would need to be agreed, starting with a small number of the most important producing countries. Provisions would have to be reviewed periodically and implementation monitored by an international body. A 2013 start date for sectoral agreements should be the goal, directly following the Kyoto Protocol's first commitment period. If coordination among candidate countries begins immediately, there is a good chance to have some agreements in place by then.

It would naturally fall to the large producing countries, in particular developed countries including Australia, to take leadership in crafting an agreement among the major producers in each industry sector. To motivate the case for sectoral agreements along these lines, policy makers the world over need to gain a clear understanding that comprehensive emissions pricing for trade-exposed industries is not necessarily to their disadvantage. Production will expand where low-emissions energy sources are available. If production moves elsewhere because doing so is cheaper after carbon is priced, this is economically and environmentally efficient restructuring, and should not be discouraged.

13.5 Climate change and trade policy

The links between climate and trade policy are receiving increasing attention. In December 2007, the Indonesian Government convened the first meeting on climate change of trade ministers from major economies in conjunction with the Bali Climate Change Conference.

Trade barriers to the diffusion of low-emissions technologies, and of goods and services embodying them, reduce their impact. Liberalisation of low-emissions technologies markets can be pursued through both unilateral and multilateral channels (World Bank 2008a). In December 2007, the European Union and the United States introduced a proposal to give priority in the World Trade Organization negotiations to liberalisation of climate-friendly goods and to services linked to addressing climate change (WTO 2008). The principle is a sound one, but liberalisation should be comprehensive. The EU–US list does not include ethanol, an important exclusion, as ethanol production receives large domestic subsidies or protection in many countries, including Australia, as well as the European Union and the United States. Neither does it include motor vehicles, despite the interest that all countries have in rapid diffusion of low-emissions innovations in this sector.

The most contentious climate change issue in trade policy is whether countries should be allowed to impose border adjustments if they introduce carbon pricing ahead of others. Two rationales are suggested for such action. The first is to compensate domestic industries for a loss of competitiveness. The second is to apply pressure to other countries to impose similar policies.

The European Union proposal for the post-2012 EU Emissions Trading System and several of the climate change legislative drafts in the United States have flagged provisions for countervailing tariff measures. Economist Joseph Stiglitz (2006) has endorsed this line of action. Others note that such moves may open the doors to protectionism and trade disputes (Bhagusti & Mauroidis 2007), a view with which the Review sympathises.

As the Director General of the WTO, Pascal Lamy, recently commented, imposing taxes on imports to penalise countries with looser emissions controls would be a 'distant second-best to an international solution' on climate change (Point Carbon 2008). The global community has a strong interest in avoiding pressures for border taxes by moving sooner rather than later to the international agreements that avoid distortions in investment and production in trade-exposed, emissions-intensive industries. Nevertheless, if an international solution is not forthcoming, the pressure, and indeed the case, for border adjustments will grow.

Border adjustments could be imposed unilaterally. It is likely that the WTO would be open to the use of certain trade measures in support of climate change objectives (WTO 2008). However, any unilateral adjustments would certainly be appealed. Whatever the ultimate verdict, the case approach would lead to a 'long period of uncertainty and trade frictions' (Hufbauer & Kim 2008: 35).

The alternative course of action, recommended by the Review, is to work for a new WTO code on the subject (Hufbauer & Kim 2008). Such a code would provide a framework within which countries could impose border adjustments, and would greatly reduce the likelihood of the imposition of climate change–justified border adjustments degenerating into a trade war. It would give countries the right to impose adjustments on products in relation to competitors that do not impose comparable mitigation regimes (either economy-wide, through national targets (section 12.3), or sector-specific through price-based sectoral agreements (section 13.4)). Support for such a code would need to be unanimous. Developing countries have so far resisted modifications to WTO provisions on environmental grounds, but, given combined EU–US leadership, and the strong United Nations role in the emerging international mitigation regime, an agreement should be possible, though it would probably take several years to forge.

Pending such a global agreement (preparatory work on which should be a priority), border adjustments should not be imposed unilaterally by any country, because of the risks they would pose to global trade. Rather, if there is a need for unilateral adjustment (due to an absence of global agreements), as discussed in Chapter 15, domestic payments in WTO-consistent forms should be provided to firms.

13.6 International aviation and shipping

Emissions from international air traffic and maritime transport (known as 'bunker fuel' emissions) constitute a relatively small share of global fossil fuel emissions about 1.5 per cent and 2 per cent respectively of global emissions. But emissions from international aviation grew by 2.7 per cent annually over 2000–05, and shipping emissions (which are much more uncertain) are estimated to have grown by 3.1 per cent per year (IEA 2007). Both, and especially civil aviation, are expected rapidly to increase their shares of global emissions as incomes and international movements of goods and people rise under business as usual. At present, emissions from the international aviation and maritime transport sectors are not regulated under the UNFCCC or the Kyoto Protocol, due to difficulties of attribution and concerns about competitiveness.

The simplest way to incorporate these two sectors into an international mitigation regime would be to treat them as emissions-intensive, trade-exposed sectors, along the lines discussed in section 13.4. Emissions from these two sectors should be included against national limits.[13] If not, they should be subject to a comparable carbon tax.[14] Emissions would be attributed to countries on the basis of fuel purchase. Where a tax was in place, the fuel-supplying country would retain the revenue raised.

Most freight ships are registered in developing countries but owned by companies in developed countries (UNFCCC 2007a). This makes a sectoral agreement particularly important for shipping. Getting broad coverage may be significantly harder than in the case of aviation, because ships can bunker large amounts of fuel, and they have manifold options to refuel. Allowing countries to retain the revenue from the tax would give a positive incentive for enforcement.

For aviation, imposition of a fuel tax might require an amendment to the Convention on International Civil Aviation. Aviation has a range of non-carbon dioxide climate impacts, such as the emission of nitrogen oxides and the formation of condensation trails and cirrus clouds. The IPCC (1999) estimated that total radiative forcing effects from aviation are about 2–4 times greater than those of the carbon dioxide from burning jet fuel alone. Measurement is complex and uncertain, however, and this issue would best be addressed after the establishment of an initial sectoral agreement.

13.7 Forestry-related emissions

Forestry-related emissions (or, formally, land use, land-use change and forestry emissions) include emissions from changes in land use from one category to another (e.g. from forestry to grasslands or vice versa, referred to as deforestation, afforestation or reforestation), and emissions from land use when the category does not change (e.g. when a forest is degraded but stays a forest, generally referred to under the label 'forest management'). Forestry-related emissions differ in a number of ways from energy and industrial emissions. They are concentrated in the developing world, are difficult to estimate, and can be negative (when a forest grows and carbon is sequestered) as well as positive.

In the last few years forestry-related emissions have, for a number of reasons, received increased attention as a potentially important element of global mitigation, spawning interest in mechanisms for reducing emissions from deforestation and degradation (REDD).

- Forestry-related emissions are larger than earlier thought. As discussed in Chapter 4, the IPCC (2007) estimates annual global forestry-related emissions currently to be about 17 per cent of total greenhouse gas emissions. Although there is a large margin of error around this estimate, taken at face value it indicates that forestry-related emissions contribute more to global warming than the entire global transport sector.
- Reducing forestry-related emissions in many instances would be relatively inexpensive. The Stern Review (2007: 245) found that the cost of halting deforestation in eight countries responsible for 70 per cent of forestry-related emissions 'would amount to around US$5–10 billion annually (approximately US$1–2/t$CO_2$ on average)'. The World Bank (2006a) also found very low potential abatement costs, with dense tropical forests in Latin America cleared for economic gain amounting to just US$1–3 per ton of CO_2 released. Not all studies give such low costs. The opportunity cost of preserving forests varies greatly between sites, and is increasing with rising food and energy prices where conversion to crops or oil palm plantations is the competing land use. However, the general message that 'forestry can make a very significant contribution to a low-cost global mitigation portfolio' (IPCC 2007: 543) is sound.
- The current international regime gives very limited rewards for reductions in forestry-related emissions, and does little to foster sequestration. Developed countries are required to include emissions from deforestation, reforestation and afforestation (under Article 3.3 of the Kyoto Protocol) and can include other forestry-related emissions (under Article 3.4) if they choose. But most forestry-related emissions are in developing countries. The CDM has no scope for credits gained by reducing deforestation. Credits can be received

for establishing forests, but the rules around these are restrictive, and very few forest-related CDM projects have been undertaken.

A number of proposals have been put on the table for tackling forestry-related emissions. They take either a national, a sectoral or a project-based approach.

- The simplest framework for forestry-related emissions in developing countries would be for those countries, like developed countries, to take on national emissions reduction commitments, and include forestry-related emissions in that commitment. If developing countries bring emissions below target, as they would be expected to do, they would be able to trade their excess permits on world markets.
- The sectoral approach would establish separate baselines only for forestry-related emissions. There are a large number of proposals that take such a sectoral approach to reduce forestry-related emissions in developing countries (for a survey, see Hare & Macey 2007). As with the national approach, countries would be rewarded if they achieved or came under their forestry-related emissions targets. The financial payments could be either through a market mechanism or public funding.
- The project approach would work along the lines of the CDM and reward developing countries for reductions in emissions from a baseline at the project level. For example, if a particular at-risk forest were conserved, an attempt would be made to calculate the saving in emissions.

The many arguments against the efficacy of the CDM approach (see Box 11.2) all apply with greater force in the case of forestry, where domestic leakage is a particular concern (Forner et al. 2006). It appears neither desirable nor likely that such credits would gain widespread acceptance in international markets.

Sectoral approaches could be attractive to developing countries opposed to country-wide commitments. The quarantining they would provide of forestry from other emissions is attractive given the many uncertainties around reducing emissions from deforestation, but comes at the price of additional complexity. It is also far from clear which, if any, of the various competing sectoral approaches could command a consensus.

The national approach would require minimal institutional innovation, and is consistent with a simple, comprehensive approach to abatement. Chapter 12 argued that most developing countries should be given one-sided targets. Opt-out provisions could be particularly important for countries that have large forestry-related emissions, presenting potentially large but very uncertain abatement options. Bilateral or regional agreements might be required on the use of trading revenue, for example to allay concerns about displacing rural livelihoods. Averaging over time, and perhaps insurance mechanisms, would be needed to allow smoothing over baseline and commitment periods.

Note that a national approach would not commit developing country governments to introduce a domestic emissions trading scheme. Indeed, applying an emissions trading scheme to the forestry sector would probably not be appropriate for most developing countries. Instead, countries would be well advised to use a mix of regulatory and fiscal measures to increase forest cover.

Whichever approach were taken, any serious national effort to reduce forestry-related emissions would have to overcome three main challenges.

- Forestry-related emissions are difficult to measure. Measuring emissions from forest management and degradation is particularly difficult. Transparent monitoring systems will be essential if claimed emissions reductions are to provide the basis for financial flows. Ongoing emissions from cleared land (e.g. from the burning of dried-out peat) can also be large, but even more difficult to measure.
- Many developing country governments lack the policy mechanisms to effect a reduction in forestry-related emissions. In many countries the government's control over the forestry sector is limited. Deforestation might be driven by subsistence agriculture or by illegal logging (for a survey of global forestry policy issues and mechanisms, see World Bank 2006a). Governments will need to develop realistic and implementable strategies for increasing forest cover, including through better forest management as well as reduced land clearing, and reforestation.
- Logging is an export business subject to carbon leakage: reducing logging and forestry-related emissions in one country could lead to increased logging and emissions in another. Ultimately, for success, a comprehensive approach covering all major forestry emitters will be critical.

Although most forestry-related emissions are in developing countries, developed countries have a critical role to play. Apart from increasing sequestration within their own borders, they can help with emissions monitoring, and they can guarantee funding to developing countries if emissions reductions are achieved. Most importantly, they can kick-start action on a bilateral basis. Given the contentious and complex nature of the issue, it is possible that a satisfactory agreement on forest-related emissions will be several years in the making. In the interim, bilateral initiatives and regional cooperation will be particularly important. Given the nature of its neighbourhood, it stands to reason that Australia's regional initiatives will have a focus, albeit not exclusive, on forestry (Box 13.3). Progress will require developed countries including Australia to put significant sums on the table for emissions reductions that may have no formal international status for the time being.

Box 13.3 Regional partnerships for Australia: the potential for links with Papua New Guinea and Indonesia

Chapter 11 outlined the important role regional partnerships could play in promoting international action on climate change and especially how they could build trust and confidence between developed and developing countries.

Australia has the opportunity to develop such an approach with its neighbours, in particular Indonesia and Papua New Guinea. Both have expressed interest at the highest level in cooperation with Australia on climate change policy.

While there is a high level of uncertainty around the data, Indonesia's emissions are thought to amount to as much as two Gt CO_2 per year, around five times Australia's total CO_2 emissions, with over three-quarters of that from deforestation (WRI 2008). According to one source, in 2006, emissions from fires in peat land in Indonesia alone are estimated to be about 1800 Mt per year, about three times Australia's total emissions (Hooijer et al. 2006: 29). Papua New Guinea's annual forestry-related emissions may exceed 100 Mt CO_2 (WRI 2008), a quarter of Australia's total CO_2 emissions. Both countries would have a strong interest in reducing emissions from deforestation, provided they were compensated for the loss of economic opportunity through the sale of rights generated by the avoided emissions on an international market.

Ultimately, both Indonesia and Papua New Guinea should be linked to Australia's emissions trading scheme and able to trade any reduction in emissions below their national target levels with the Australian government or market participants. This would be beneficial to all sides: the financial flows would benefit Indonesia and Papua New Guinea, while Australia would benefit from access to low-cost abatement options. Such deep integration with a large emitting country would best be achieved within larger regional arrangements involving other developed countries, with Japan and New Zealand the obvious first candidates. For such a link to become a reality, important preparatory work has to be completed. Work in several of these areas is already under way under Australia's International Forest Carbon Initiative.

- **Emissions estimation:** More accurate estimation of forestry-related emissions is needed, not only from land clearing but also from forest management (and degradation) and from post-forest-clearance (for example, emissions from dried-out peat lands).
- **Forestry-related emission-reduction strategies:** Reducing forestry-related emissions will be a challenging task. The drivers of forestry-related emissions include subsistence farming, illegal logging and poor governance. Developing a strategy that will tackle these drivers and promote forest regeneration and reforestation will not be straightforward.

Box 13.3 Regional partnerships for Australia: the potential for links with Papua New Guinea and Indonesia (*continued*)

- **Other low-emissions options:** Reducing forestry-related emissions would be central to the Australia–Indonesia and Australia–Papua New Guinea partnerships, but should not be the sole goal of the partnerships. Papua New Guinea has excellent hydro potential, for example.

13.8 Enforcement mechanisms

The Kyoto Protocol has an enforcement mechanism that can be activated for breaches of greenhouse gas accounting or emissions target obligations. If a country does not meet its target, it has to make up the shortfall in the next commitment period with a 30 per cent penalty. This is a weak enforcement mechanism if subsequent commitment period targets are not defined in advance.

The problem of enforcing commitments is part of a more general problem of encouraging effective participation, which is regarded by some as the Achilles' heel of international efforts to combat climate change. In a world of sovereign states, countries cannot be forced to sign agreements, or to meet their commitments. In order to get countries to participate meaningfully, incentives need to be designed so that participation is in the self-interest of each nation. All countries share an interest in reducing the risks of dangerous climate change. In addition, four other sorts of incentives will be important.

- International trade in permits and offsets and access to international public mitigation and adaptation financing will provide financial incentives for developing countries.
- For developed countries, the decision to participate in global mitigation will arise out of the prospect of encouraging other countries to join, and out of pressure from domestic constituencies expressing a willingness to pay for a global public good.
- As more countries participate, there will be increased international pressure from those who have joined on those who stand outside.
- Trade sanctions have been proposed by some as an enforcement mechanism. As discussed above (section 13.5), border adjustments to take into account differential mitigation regimes have a role to play in a world where some countries are moving faster than others on mitigation, but only once a framework for their use has been developed and agreed under the World Trade Organization.

Enforcement requires monitoring. Under the UNFCCC and Kyoto Protocol, countries are required to produce reliable accounting (annual inventories) of their greenhouse gas activity. Countries must also have a national registry to account for their emission credits. Teams of experts, selected from a roster of individuals nominated by the Protocol Parties, check annual inventories for accuracy and completeness. If there is a dispute between the team and the party, the Protocol's Compliance Committee may intervene. The current system provides a solid foundation on which to build. As the number of countries subject to national emissions goals increases, the need for rigorous and robust monitoring will grow.

Notes

1 The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007: 20) found: 'Government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level'. The IPCC (2007: Chapter 13) reports that OECD energy research and development has been below US$10 billion per year since the early 1990s (in 2004 prices and exchange rates) and that research and development budgets for renewable energy exceeded US$2 billion (in 2004 prices and exchange rates) in the late 1970s and early 1980s but have been well below US$1 billion since the mid 1980s.

2 Jagdish Bhagwati (2006) has called for 'subsidising the purchase of environment-friendly technologies by the developing countries'. Larry Summers (2007) has recommended 'the provision of subsidised capital for projects that have environmental benefits that go beyond national borders'.

3 The G7 comprises Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.

4 Popp (2004) estimates annual energy efficiency research and development requirements at only US$13 billion in 2005, rising to US$33 billion in 2055, but the mitigation strategy he models is mild. It allows global temperatures to increase by more than 3°C. The stabilisation scenarios modelled by the Review would not be expected to result in such a large temperature increase.

5 The February 2008 statement by the UK, US and Japan governments indicated that the World Bank funding would support 'developing countries that undertake energy sector and climate related policy actions consistent with a low carbon growth trajectory' (Paulson et al. 2008). More explicitly, the United States has stated that it 'believes countries seeking access to the fund should be undertaking credible national plans to limit greenhouse gases and have those plans reflected in a post-2012 climate change agreement' (White House 2008).

6 It has been proposed that technology transfer commitments should be eligible for offsets (Forsyth 1999). Quite aside from its complexity, such an approach would miss the point that this commitment is in addition to an emissions reduction commitment.

7 A similar argument goes for the issue of excess Kyoto permits from Russia and some Eastern European countries, sometimes referred to as 'hot air'. Targets for these countries were negotiated knowing that emissions had fallen drastically as a result of economic collapse and industrial restructuring in the 1990s, and were an incentive for Russia and others to join the Kyoto Protocol. Trading units from these countries for compliance elsewhere is in the logic of the agreement.

8 See Appendix 2 of Garnaut (2008) for a fuller exposition of these options.

9 The EU's Head of Emissions Trading, Yvon Slingenberg, recently signaled that the European

Union wants a 'gradual shift from offsetting to cap and trade', with emissions cuts becoming 'more the contributions of developing countries' (Wynn 2008).

10 The European Union attempts to solve the problem by allocating free permits. Under the post-2012 phase III of the EU emissions trading scheme, it is proposed that affected sectors receive up to 100 per cent of their allowances for free, depending on the extent to which the industries are covered by an international agreement. The European Union has also flagged the possibility that tariffs may be used to neutralise any distorting effects from imports (European Commission 2008).

11 Sectoral agreements have received greatly increased attention recently and are explicitly mentioned in the Bali Roadmap. The various approaches raised in the international discussion (for example, Baron et al. 2007; Bradley et al. 2007; Egenhofer & Fujiwara 2008; Schmidt et al. 2006) are for more complex and less comprehensive schemes. Many revolve around best practice or technology standards, and therefore result in incentives applying only to low efficiency operations within each technology. Choosing the benchmarks and how they should develop through time is fraught with difficulty. Other proposals are for offset credits from specific sectors, but they present the same problems as the CDM. Comprehensive coverage could be achieved by separate international emissions trading schemes for specific sectors, but this would require negotiating targets in the absence of any obvious principles for allocating them and determining what each sector's cap should be.

12 The actual analysis is in terms of countries that are not in Annex I of the UNFCCC (section 11.1).

13 The European Union has proposed bringing aviation into its emissions trading scheme, with coverage of emissions from flights within as well as from and to the EU. Many non-EU states, however, are opposed to this proposal. An approach agreed to by a number of countries through international negotiations would have a greater chance of success.

14 Such an approach is likely to be more achievable in the short term than negotiating the sector's own version of a trading scheme, not least because of the lack of basis for setting targets. The International Civil Aviation Organization is, however, working on an emissions trading system for international civil aviation (ICAO 2008).

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14 AUSTRALIAN MITIGATION: OVERVIEW OF THE POLICY CHALLENGE

Key points

Australia's mitigation effort is our contribution to keeping alive the possibility of an effective global agreement on mitigation.

Any effort prior to effective, comprehensive global agreement should be short, transitional, and directed at achievement of global agreement.

The emissions trading scheme is the central instrument of Australian mitigation.

A well-designed, broadly based emissions trading scheme has important advantages over other market-based arrangements (such as carbon taxes and hybrid schemes. In particular, it is able to accommodate more easily international trade to lower mitigation costs and to facilitate developing country participation in international agreements. However a carbon tax would be better than a heavily compromised emissions trading scheme.

The role of complementary measures is to lower the cost of meeting the emissions reduction trajectories of the emissions trading scheme by correcting for market failures.

Once a fully operational emissions trading scheme is in place, the Mandatory Renewable Energy Target will not address any additional market failures. Its potentially distorting effects can be phased out naturally as the emissions trading scheme takes up the load of encouraging low-emissions technologies.

The Stern review referred to climate change as the 'greatest example of market failure we have ever seen' (Stern 2007: 1). A market failure occurs when the market alone is unable to allocate a resource efficiently, in which case it will be either over- or under-used compared to its true scarcity value. In the context of avoiding dangerous climate change, the misallocated resource is the atmosphere's limited capacity to absorb emissions.

To mitigate human-induced climate change effectively, a restriction must be placed on rights to emit greenhouse gases to the atmosphere. This limit must be reduced over time to the level that prevents any net accumulation in the atmosphere.

This chapter outlines the nature of the domestic mitigation challenge and offers a framework for considering how Australian policy makers should approach this task. Consequently, this chapter serves as a bridging point between the earlier and later chapters of this report. Chapters 3 to 10 present the global and Australian impacts of climate change and a policy framework for considering those impacts. Chapters 11 to 13 discuss the challenges and policy options for reaching a global agreement on limiting greenhouse gas emissions. Chapters 15 to 20 discuss a range of policy interventions.

There would be no point in Australia alone introducing mitigation policies. The entire purpose of Australian mitigation is to support the emergence of an effective global effort.

Is a comprehensive international agreement to reduce global greenhouse gas emissions possible or likely?

Reaching a comprehensive international agreement will not be easy, but there is a chance that Australia and the world will manage to develop a position that strikes a good balance between the costs of dangerous climate change and the costs of mitigation. The consequences of the choice are so grave that it is worth a large effort to take that chance while we still can. A significant mitigation effort by Australia and other developed countries is the cost of preserving some hope of a more comprehensive international agreement for avoiding dangerous climate change.

How Australia defines and implements its mitigation policy will establish its credibility and its place in negotiating a global agreement.

Nevertheless, until there is a comprehensive international agreement, there will be little difference between gross and net costs to the Australian economy from domestic mitigation policy. There will be no countervailing benefit arising from climate change avoided. Setting emissions limits will rely on a series of judgments about the value of Australia, with other wealthy countries, moving ahead of a comprehensive global agreement.

The period of Australian mitigation effort before there is an effective global effort will be short, transitional and directed at achievement of a sound global agreement. Section 14.1 therefore proposes a number of emissions trajectories, which balance the requirements of developed country policy leadership, with the costs of acting ahead of a comprehensive global agreement.

The supplementary draft report will provide estimates of the cost of unilateral mitigation as well as the costs and benefits of a global approach to reducing emissions. The modelling analysis now under way will enable the Review to provide guidance on the setting of interim targets in the supplementary draft and final reports.

Having established as a policy objective the reduction of Australia's greenhouse gas emissions according to a set of trajectories (and the conditions by which those trajectories might be changed), governments will have a range of implementation options for limiting emissions (see section 14.3). Chapter 15 discusses the preferred design features for an Australian emissions trading scheme in detail.

14.1 Emissions entitlement limits for Australia

Australia's average annual emissions entitlement limit under the Kyoto Protocol is currently 108 per cent of 1990 emissions over the period 2008 to 2012. There is no Australian limit for the post-2012 period. There is some prospect that one will be agreed as part of current negotiations for the second Kyoto commitment period, but this cannot be guaranteed. In any case, post-2012 limits need to be established quickly for the emissions trading scheme, since the latter will be derived from the former. (Because not all sectors will be covered by the scheme, the two will not be equal.) How then to determine an emissions limit for the post-2012 period in an environment of uncertainty?

Chapter 11 argued that developed countries should take a dual approach to the setting of carbon reduction goals. An initial commitment (or offer), set unconditionally, would meet the requirement that richer countries show leadership on climate change mitigation by going first. Another, more ambitious, offer would represent what Australia would be prepared to do in the context of effective, global action involving all major emitters. This would be Australia's conditional offer within an international negotiation.

Making both the initial commitment and the subsequent offer conditional on the basis of an assessment of comparative effort would ensure that Australia was playing its full role, without being isolated—either in front of or behind—other developed nations. Using the logic of the dual approach, Australia's initial commitment would be comparable with proposals put forward by other developed countries. The more ambitious conditional offer would be comparable with the efforts required by all major emitters in an effective response to climate change.

In Australia, adoption of emissions commitments also requires analysis of the domestic economic costs to ensure that they are feasible, and also justified by the benefits of mitigation. Since the modelling of economic costs is still under way, the Review's recommendations on emissions limits are reserved for the supplementary draft and final reports.

Subject to modelling to establish economic feasibility and desirability, Australia's initial emissions limit for the post-2012 period would be a limit comparable to those of other developed countries. When and if an international agreement is in place, Australia would adopt the limit agreed for it as part of that agreement.

Because Australian action alone will be of little consequence to climate change impacts, there seems to be no case for adjusting Australian limits for new information and developments of an economic or scientific kind. The changes to tighter trajectories would be triggered by developments in international policy. International policy discussion would consider changes in the science or the economics. As Australia revises its emissions limits in response to international agreements, the revisions would indirectly reflect scientific or economic developments.

Emissions goals are typically announced as end-point targets. There are two key end points in the current international discourse, 2020 and 2050. So as to influence the international dialogue, it would make sense for Australia's initial and conditional offers be made in terms of these end points. However, as discussed in Chapter 12, different trajectories to the same end-point target can give rise to very different cumulative emissions (that is, the carbon budget) and greenhouse gas concentration levels. The end-point targets should be defined simultaneously with trajectories for the release of permits to that point.

The ultimate trajectory of Australia's emissions limits will be given by successive commitment periods of the Kyoto Protocol and successor international agreement. For example, if the Kyoto Protocol is followed with five-year commitment periods then it will contain limits for emissions entitlements for 2013 to 2017, 2018 to 2022, 2023 to 2027, and so on. Over time, for the mitigation effort to be effective, successive commitments will need to be known in advance through the adoption of more explicit allocation criteria.

Since these variations to the emissions limit cannot be known in advance, the Review considers that smooth indicative trajectories should be defined between the end points, that is, between 2012 and 2020, and 2020 and 2050.

An emissions trajectory may take any number of paths:

- A linear movement from one point in time, to another in the future. This embodies a steadily increasing annual percentage rate of emissions reduction as the level of emissions declines. The European Union has opted for this approach (European Commission 2008).
- A concave curve, that begins with a more gradual emissions reduction in the early years, and then sees reductions occurring with increasing speed later. Such an approach may reflect an expectation of a highly efficient, low-emissions technology becoming available in later years.
- A convex curve would be the opposite, with steep emissions reductions occurring early, and the rate of reduction slowing later. This could reflect the assumption that there was ready access to 'low-hanging fruit' for reducing emissions in early years.
- A different shape determined, for example, through economic modelling, as the least-cost rate of emissions reduction. This would be subject to a range of limitations, and depend heavily on arbitrary assumptions, for example, on the rate of technological improvement.

There seems no strong rationale for preferring one shape of trajectory over others, provided that they define identical emissions budgets over time. Because there will be a deviation in actual emissions from any trajectory chosen (due to the prospect of hoarding, lending and trade, as discussed in Chapter 15), a linear trajectory is preferred for reasons of simplicity.

The linear trajectory for the emissions trading scheme proposed in Chapter 15, which would be derived from the overall limit, would be firm for a period of five years. That is, the scheme's emissions limit would be guaranteed or fixed for a period of five years and updated every year by one year (see section 15.2). In the years beyond the five-year outlook, the trajectories would be indicative only.

If, for some reason, Australia's international obligations were to change within the fixed five-year period, the Australian government would have to manage that change without changing the scheme's limits for the following five years. Any shift to a different trajectory for the scheme that was commenced in 2011 (for example, one that reflects a new international agreement) would only commence in 2016. Following this logic, the initial trajectory, based on the unconditional offer, would provide the basis for an aggregate limit for the emissions trading scheme from 2013 until at least 2015 (assuming the market commences in 2010). The Australian Government would need to take responsibility for purchasing international permits to cover any underperformance on agreed targets in the intervening years.

The ongoing relevance of the initial and conditional offers would need to be reassessed from time to time. Say, for example, that there were no comprehensive international agreement until 2020 (rather than from 2012). Then the conditional goal announced by Australia in 2008 might no longer be relevant. Likewise, if there were no progress towards an effective international agreement over the next decade, and if other developed countries failed to adopt or implement emissions reduction commitments, then Australian mitigation policy might need to be reassessed. This situation would require a less stringent emissions trajectory. The need for less or more stringent emissions trajectories would be reviewed with each material change in the international policy context.

Some countries and regions have moved to provide legislative backing to their emissions limits. This approach would have the advantage of reducing uncertainty, and providing a clear framework within which goals and trajectories could be changed.

14.2 Addressing the greatest market failure ever seen

The options for meeting the policy objective—reducing Australia's greenhouse gas emissions in a manner that reflects the atmosphere's true scarcity value—are typically categorised as being either regulatory or market based. Within these two categories, numerous policy instruments can be applied.

14.2.1 Regulatory responses

Regulatory responses to the mitigation objective work by either:

- mandating restrictions or banning particular items from the set of product choices available to consumers, and/or
- mandating, licensing or banning particular technologies or production techniques used by local firms.

Prescriptive approaches to reducing emissions can be haphazard. They are inevitably informed by officials' assessments of current and future mitigation opportunities, based on expectations about the rate of technological development and the changing state of consumer preferences. They are inevitably poorly based, and have difficulties in responding to the evolution of technology and consumer preferences.

14.2.2 Market-based approaches

Market-based approaches seek to alter price relativities in a way that reflects the externality embedded in goods and services—that is, direct and indirect emissions arising from the production and distribution process. Consumers are left to choose whether, when and how to substitute from high to low carbon-intensive products. As they do so, firms begin responding to new consumption patterns by investing in alternative technologies and new products.

Governments cannot simultaneously control both the price and the quantity of emissions. The choice of approach should take into account the importance placed on having control over the level of emissions, relative to the importance attached to being able to control the emissions price.

Four market-based approaches are reviewed below.

Emissions (or carbon) taxes

The administratively simplest pricing mechanism is to impose a tax on emissions, typically known as a carbon tax. Carbon taxes are straightforward to apply and avoid the need for governments to take discretionary decisions about who ought to be allowed to emit. Carbon taxes also provide certainty about the marginal costs of mitigation.

However, while avoiding the arbitrariness of regulatory interventions, the meeting of emissions reductions targets cannot be guaranteed. Compatibility with other systems internationally may also be limited. Moreover, the achievement of ongoing and increasing reductions in accordance with one of the trajectories outlined in section 15.2 would require variation of the carbon tax rate on the basis of continuing reassessment of the relationship between the rate of the tax and the level of emissions.

Emissions trading scheme 1: cap and trade

Under a cap and trade scheme, government issues tradable permits that allow the holder of the permit to emit a specified volume of greenhouse gases to the atmosphere. A permit is an instrument with clearly established property rights. The sum of all permits on issue equates to the total greenhouse gases that may be emitted to the atmosphere. Permits are issued according to the trajectories discussed in section 14.1.

The issuing of permits may involve government auction, or free allocation to particular parties. The decision about how to allocate permits involves a judgment over the allocation of the rent value of the permits.

Trading between parties allows permits to move into the hands within which they have greatest economic value.

As permits are traded, the price comes to reflect the balance between scarcity of permits and options to abate. The price is the balancing variable between the supply of, and demand for, permits. The price is determined by the market, not the government. It may entail some volatility, especially at the outset of the scheme when there is no or limited experience about abatement responses and costs. A well designed scheme will not eliminate volatility in the permit price but it can avoid the unnecessary dissipation of resources arising from second-guessing of policy makers by market participants.

Poor design would put at risk the environmental effectiveness and the economic efficiency benefits that are the reason for establishing an emissions market (see Chapter 15).

A cap and trade emissions trading scheme requires rules governing:

- the limit on emissions
- the creation and issuance of permits
- who must or can participate in the scheme
- the means by which permits are exchanged between buyers and sellers
- the timing and method of acquittal of obligations
- the consequences for non-compliance
- the roles of government and other bodies in operating the scheme.

Sectors not covered by the scheme can participate by creating offsets that can be sold to liable parties within the scheme. This provides incentives for mitigation beyond the scheme. As discussed in Chapter 12, cap and trade schemes also provide greater potential to access least-cost abatement opportunities internationally.

Emissions trading scheme 2: baseline and credit

Baseline and credit schemes also rely on the creation of tradable permits. These schemes differ from cap and trade schemes in that they effectively place the creation of permits in the hands of private parties (existing emitters) rather than the government.[1]

The baseline feature of these schemes involves an algorithm that provides existing emitters with some level of entitlement to emit. If their actual emissions are below this entitlement, then the surplus entitlement is converted into tradable permits (or credits). Emitters that exceed their entitlement must purchase permits to account for any emissions above their respective baseline.

Options for calculating the baseline entitlement include:

- emissions in a particular base year
- average emissions per unit of production based on installed technology in a base year
- average emissions per unit of production based on best practice technology
- any combination of these or other approaches.

The choice of algorithm introduces a high and unavoidable degree of arbitrariness into the design of a baseline and credit scheme. This would raise transaction costs and encourage rent-seeking behaviour (as the entire rent value of permit scarcity accrues to existing emitters).

Hybrid schemes

Hybrid models address the tension between wanting certainty in both price and quantity. The basic feature of these models is the establishment of an emissions trading scheme (cap and trade) with an imposed upper limit on the price of permits (McKibbin & Wilcoxen 2002; Pizer 2002). This involves initially issuing tradable permits up to a cap, but with a commitment by government to issue unlimited amounts of extra permits at a specified ceiling price.

Like the carbon tax, the hybrid approach with a ceiling price has the advantage of providing certainty about the maximum permit price while preserving some aspects of an emissions trading scheme to the extent that the market price can be expected to remain below the cap. However, it also combines the disadvantages of both worlds. In particular, the full institutional and administrative apparatus—and therefore cost—of an emissions trading scheme is required, without any guarantee of the required domestic emissions reductions. The use of ceiling prices would create a problem for Australia's role and credibility in international mitigation negotiations, since it would not allow firm commitments on levels of emissions.

A floor price for permits would require the scheme administrator to enter the market to purchase permits whenever the permit price fell below a specified value. A floor price is incompatible with international trade in permits as it would effectively create an unlimited liability for the Australian scheme administrator.

Ceiling and floor prices would dampen the incentive for development of secondary markets. The emergence of these markets is important in transferring risk to the parties best able, and most willing, to manage it.

14.2.3 The preferred approach for Australia

In determining the preferred approach for Australia's mitigation effort, the primary policy objective must be to meet a specified trajectory of emissions reductions at the lowest possible cost. Policy must be designed to facilitate this transition to a lower-emissions economy, with as little disruption as possible and at least cost to the overall economy.

Australian mitigation policy needs to be considered in the international context of action and commitments. The world is now some way down the track towards an international system based on emissions reduction targets, starting with developed countries. Regulatory approaches, carbon taxes, hybrid schemes and baseline and credit schemes would not be readily integrated with existing and emerging international arrangements that could provide Australia with lower-cost mitigation opportunities.

A well-designed emissions trading scheme (cap and trade) can be relied upon to constrain emissions within the specified emissions limit (or trajectory). Current as well as future prices are set by the market, without the need for bureaucratic clairvoyance in relation to prices or mitigation options and costs.

As with any policy intervention, an emissions trading scheme will involve transaction costs that represent a deadweight loss to the economy. Chapter 15 discusses optimal scheme design in detail. A well-designed emissions trading scheme needs to be free of disputation over key parameters and cannot provide opportunities for special interests to exert political pressure for favourable treatment—most notably, permit allocation. Policy makers would be better off to abandon an emissions trading scheme in favour of a broad-based emissions tax if they felt unable to resist pressures on the political process for ad hoc assistance arrangements.

With a well-designed and comprehensive emissions trading scheme in place, price signals will begin flowing through the economy reflecting the scarcity value of the emissions of greenhouse gases to the atmosphere. Consumers will begin modifying their behaviour and businesses will respond accordingly.

The scale and scope of this reform agenda cannot be underestimated.

14.3 Mitigation policy: a broader reform agenda

The emissions trading scheme will correct the biggest market failure by establishing the right to emit greenhouse gases to the atmosphere as a tradeable commodity. It is the most direct instrument for securing Australia's emissions reductions, if properly designed and allowed to play its role without extraneous interventions (for example, by attempts to control the permit price).

The supply side of the market is represented by the government-controlled issuing of permits in accordance with an agreed emissions reduction trajectory. As such, the Australian emissions profile is capped by the force of law and no further measures are required to control national emissions in covered sectors.

On the demand side are all the goods and services whose production or consumption results in the release of emissions. The demand side of the market is given force by the government requiring emitters to acquit permits if they wish to release greenhouse gases to the atmosphere. In so doing, the government must have the administrative machinery to enforce such a requirement credibly.

14.3.1 Understanding the impact of an emissions trading scheme

A fully functioning market mediates between the variety and priority of wants of consumers and the productive capacity of the economy. There are innumerable decisions by households and firms that determine the demand for permits. The price of permits will be determined by the balance between demand for, and supply of, permits.

A credible market will establish a forward price for permits that reflects expectations about the future demand for permits. The price rises at a rate of interest corresponding to the opportunity cost of capital.[2,3] The whole price curve—the spot price and all of the forward prices, together—embody the market's expectations of what is required to induce the necessary substitution of low-emissions alternatives for high-emissions goods and services, and for economising on the use of goods and services that incorporate high proportions of emissions.

The price curve provides fundamental stability to the market, with opportunities for hedging price risks, and adjusting quickly to new information. Any change in expectations in demand or supply or in the interest rate would see the spot and forward prices adjusting immediately.[4]

Economic effect of an emissions price

The emissions price flows through the economy in two ways.

First, it causes the substitution of higher-cost, low-emissions processes or goods and services for lower-cost established processes, goods and services. The former is a real cost to the economy as it involves the reallocation of resources to uses that would not otherwise have attracted them.

This substitution effect gradually decouples economic growth from its former reliance on processes and products with high greenhouse gas emissions. If permits are defined so that there is flexibility about when they are used (that is, allowing hoarding and lending as defined in Chapter 15), there is less price volatility, and the market can determine the optimal timing of use of permits.

Even though the price of permits can be expected to continue increasing, as reflected by the forward price curve, the proportion of the economy exposed to this higher cost will be ever-diminishing. Once substitution of some new lower-emissions for a higher-emissions process (or product) has been induced at a specified permit price, technological and institutional improvements and scale economies in the new process (or product) are likely to lead to relative cost reductions over time.

The second way in which the emissions price will flow through the economy is by generating rents from the scarcity of the permits. This involves a transfer of wealth from the economic agent to whom the price is ultimately transferred (in some cases businesses, but mostly households), to whomever receives the scarcity rents of the permits (established emitters if the permits are simply given to them; or to the government in the first instance, and then to the beneficiaries of reduced taxation or increased public expenditure, if the permits are sold competitively).

On the basis that this major environmental reform—the introduction of the emissions trading scheme—is not meant to arbitrarily increase the proportion of the economy under the control of the public sector, the proceeds of the sale of permits should be identified for return to the community, either to households or to business. Demonstration that revenues from the sale of permits had been returned to the private sector in one way or another would neutralise what could otherwise become a rallying point for opposition to effective mitigation policies.

Detractors of market-based mechanisms often argue that additional emissions reduction measures (be they regulatory or programmatic) are required in order to reduce greenhouse gas emissions. They are wrong.

Programs and other regulatory interventions—whether federal, state or territory—that seek to reduce emissions from specific activities within the community will not reduce emissions below the levels determined by the trajectory defined for the emissions trading scheme.

Under a cap and trade emissions trading scheme, emissions will not exceed the adopted emissions reduction trajectory unless private parties have contravened the law. If the sum of all decisions across the economy implies demand for emissions is in excess of supply, the price of permits will increase, and continue to increase, until demand is subdued and brought into line with the quantum of permits on issue.

Integration of the scheme within the broader economy

For the emissions trading scheme to have the desired effect of driving new consumption behaviour and investment decisions, it must be well integrated within the broader economy. Barriers to change must be removed or minimised in order that there may be an efficient economic response to the ever diminishing supply of permits.

The introduction of an emissions trading scheme, then, needs to be accompanied by a commitment to a broader economic reform process—one that allows carbon price shocks to dissipate across the economy quickly and smoothly.

Modelling major economic reform

As with all reform agendas, the commitment by government and the community must be ongoing and firm. Decisions must be made even in the face of unknown prospects for an international agreement and some uncertainty about how the domestic economy will respond. Economic modelling can be of some assistance. Building on the results reported in Chapter 9, the Review is undertaking further modelling of the costs of mitigation and the economic benefits from the climate change avoided. This will be an important input into the Review's consideration of interim targets for Australia's emissions reduction trajectory.

Modelling economic reform is always difficult. By definition, reform programs are intended to alter fundamentally some set of economic relationships within the economy. On the other hand, economic models are built upon known and measurable past behaviours. Experience shows that once economic agents have accepted the inevitability of change, they will alter their behaviour to account for the new conditions more efficiently and effectively than previously predicted. This experience suggests that economic models are likely to underestimate the benefits or overestimate the costs of economic reform. This bias may be further exacerbated by lack of data about the full costs of climate change impacts and a corresponding downward bias in the estimated benefits of avoiding climate change.

In the case of this reform, there is a possibility that costs will be higher than anticipated by standard models, because of the danger that it will promote a large diversion of resources away from commercially focused profit maximisation, towards seeking favours in permit allocation from governments. Avoidance of such outcomes should be a major objective of scheme design.

This lack of knowledge about how consumers and producers will respond should serve to constrain the ambitions of those who expect government not only to impose an emissions limit on the domestic economy, but also to manage the economy's response.

Policy makers must take care when determining the overall emissions reduction goal. If they determine the goal solely on the basis of assumed technological developments and known consumer preferences at a particular moment, they will probably underestimate the true potential of the economy to reduce emissions in the future—that is, overestimate the price of permits and the economic cost of adjustment. This course of action risks raising political resistance to the reform agenda. On the other hand, goal-setting that is based on assumptions about unknown technologies and unobserved preferences runs the risk of overestimating the capacity of the economy to adjust. Economic modellers and policy makers will tend to err on the side of caution, preferring the former approach (that is, modelling on the basis of existing technologies and known preferences).

14.3.2 Viewing mitigation as a reform agenda

Australians are well placed to deal with the challenges of this economic reform agenda. The reforms of the past have made the Australian economy more open, market-oriented and adaptable than at any time in its history. We have a good record in institutional design and in establishing genuinely independent agencies to implement those arrangements. In the case of an emissions trading scheme, we have the benefit of learning from schemes that have been implemented internationally, most notably, the three phases of the European Union's scheme.

Although it is tempting to compare the mitigation challenge to earlier Australian programs of economic reform, we must exercise caution here. Previous reforms—such as trade liberalisation, financial regulation and competition policy—were targeted at raising incomes by allowing the allocation of resources to their most productive uses. By contrast, the climate change reform agenda must be focused on minimising the potential for loss of income after the introduction of measures to limit the release of greenhouse gases.

As with all reform programs, altering pre-existing economic relationships within the economy is likely to generate winners and losers. Consumers who are willing and able to replace higher-emissions products with lower-emissions products will adjust relatively painlessly. Firms with less dependence on emissions-intensive production processes, or which have the ability to switch production process quickly in order to minimise their exposure to a carbon price, may find that their market share and profitability increase. Firms that have less flexible capital structures could be faced with having to choose between passing on the price (and losing market share) or absorbing the price of emissions at the expense of profitability. All things being equal, such firms may face some loss of market value.

As with all programs of economic reform, mitigation policy must be forward-looking. Policy interventions and the use of scarce resources should focus on improving future economic prospects rather than reacting to past decisions by governments or the private sector.

While it is not possible to foreshadow all the demands that will be placed on the revenue raised from the sale of permits, the case for compensatory payments to shareholders in firms that lose value is a relatively low priority for a number of reasons.

First, it will be difficult or impossible to assess the effects of the emissions trading scheme on an individual firm's profitability as the counterfactual supply and demand conditions in those markets cannot be observed. The potential information asymmetry problem would lead to disputation.

Second, there is no tradition in Australia for compensating capital for losses associated with economic reforms of general application (for example, general tariff reductions, floating of the currency or introduction of the goods and services tax) or for taking away windfall gains from changes in government policy (for example, reductions in corporate income taxes).

Third, alternative forms of assistance such as structural adjustment assistance that is targeted at the future competitiveness of firms (or in some cases, regions) is likely to provide a greater benefit to the overall economy than a backward looking, private compensatory payment to existing emitters (see following discussion on market barriers).

Fourth, this is a difficult reform, and a permit price that is high enough to secure levels of emissions within targets and budgets will have major effects on income distribution—including workers and communities dependent on emissions-intensive industries that may be unable to adjust readily to alternative employment. Directing scarce resources towards addressing these impacts will be a significant challenge and an unavoidable priority. There will also be large calls on the revenue from sale of permits for support of research, development and commercialisation of new low-emissions technologies, and for avoiding 'carbon leakage' through payments to trade-exposed, emissions-intensive industries.

Stationary energy, which in Australia is a particularly large source of emissions, is the dominant industry with expectations of compensation. It is the subject of detailed discussion in Chapter 20.

Trade-exposed, emissions-intensive industries

Trade-exposed, emissions-intensive industries represent a special case. All other factors being equal, if such enterprises were subject to a higher emissions price in Australia than in competitor countries, there could be sufficient reason for relocation of emissions-intensive activity to other countries. The relocation may not reduce, and in the worst case may increase, global emissions. This is known as the problem of carbon leakage.

Policy makers are therefore faced with a truly dreadful problem. Shielding these industries from the effects of a carbon price either undermines attempts to limit national greenhouse gas emissions or it increases the adjustment burden elsewhere in the economy.

Chapter 13 outlines the benefits of sectoral agreements in avoiding this problem while Chapter 15 suggests that Australia will need to show global leadership in pursuing such arrangements. Failing this outcome, Australia is faced with implementing special domestic arrangements (see Chapter 15). These transitional arrangements would be based on efficiency in international resource allocation and not on some false premise of compensation for lost profitability. There can be no doubt that the inherent arbitrariness of such assistance measures will make them the subject of intense lobbying, with potential for serious distortion of policy-making processes. Their continuation for more than a few years would be deeply problematic. The establishment of comparable carbon pricing arrangements in countries that compete with Australia in global markets for emissions-intensive products is an urgent matter.

14.3.3 Addressing the relationships between an emissions trading scheme and other policies

A variety of policies have been discussed or put in place with the aim of reducing greenhouse gas emissions from the sectors to be covered by an emissions trading scheme. The scheme is expected to deliver required reductions in emissions. Other policies operating alongside an emissions trading scheme can have no useful role in reducing emissions once the emissions trading scheme is in place. From that time, the only useful role for additional policies of this kind is to reduce the effect of market failures in adjustment to the emissions price, so as to reduce the cost of adjustment to the low-emissions economy. Rather, other policies should allow the scheme to achieve its emissions reduction goal at a lower cost than would occur if the scheme was operating alone.

The Mandatory Renewable Energy Target and the emissions trading scheme

The Mandatory Renewable Energy Target (MRET) was introduced in 2000 to drive the uptake of renewable energy and reduce emissions. MRET operates by placing an obligation on energy retailers to purchase a proportion of their energy from renewable sources in the form of renewable energy certificates. The value of a certificate is equal to the difference in the cost of producing the renewable energy and the average wholesale price of electricity. By design, MRET causes deployment of the lowest-cost eligible technologies. To date, the increase has been mostly wind and solar hot water. As renewable energy production is currently more expensive than alternative sources, this higher cost is passed on by retailers to households and businesses.

An important design feature of MRET is the shortfall penalty of $40/MWh, which operates as a cap on the certificate price. The shortfall penalty is not indexed. To date, the price cap has been largely untested because, although the price of renewable energy has been increasing, the average wholesale price of electricity has been increasing at a similar rate.

MRET is set to expand from the current 9500 gigawatt hours to 45 000 gigawatt hours (around 20 per cent of energy demand) by 2020. The expanded MRET will drive increasingly expensive options for the deployment of currently favoured technologies (for example, building wind farms in more remote areas) as well as the deployment of newer and more expensive technologies (such as geothermal and solar photovoltaic). This will lead to a higher renewable energy certificate price and higher electricity prices for consumers. Conversely, the recent uplift in world energy prices (coal and gas) raises the average wholesale price of electricity and puts downward pressure on the certificate price.

The emissions trading scheme differs in objective and operation from MRET, in that it caps the level of emissions and is neutral as to how that is achieved. The market is left to determine how the necessary reductions will be achieved. In some cases, this may lead to investment in renewable energy production, but in other cases it may lead to fuel switching or the deployment of more efficient operating practices among existing energy producers. The market, rather than government, is left to find the solution. A competitive market can be expected to deliver these emissions reductions at the lowest cost to the community and business.

Implementing the expanded MRET alongside the emissions trading scheme means that these two policy instruments, with their differing objectives, will be interacting in the electricity market. This clash of objectives will potentially be detrimental to electricity users (households and businesses) and electricity producers (incumbent and new providers). Many factors will affect the extent of this adverse interaction. The most notable is the trajectory of the emissions trading scheme and the ramp-up rate of MRET (see Table 14.1). Both schemes must, by force of law, meet their mandated targets. The concerns are threefold: What is the cost? Who will bear the cost? What are the long-term consequences?

On balance, the Review considers that carrying forward the existing, non-indexed shortfall penalty of $40/MWh into the expanded MRET provides the best opportunity for a smooth transition from MRET into the broader emissions trading scheme. The units of account are different for MRET and the emissions trading scheme, but it happens that $40/kWh in MRET under current conditions roughly corresponds to $40 per tonne of CO_2-e in the emissions trading scheme. Since the price cap is a feature of the current MRET, its retention would seem to be fully consistent with the government's commitment on the MRET. As the price of permits increases above $40–45 per tonne of CO_2-e, the emissions trading scheme would come to dominate investment decisions and the economic effects of MRET would be subsumed within the emissions trading scheme.[5] Maintaining the shortfall penalty will place an upper limit on MRET's higher costs relative to the emissions trading scheme, and on electricity prices, while maintaining the incentive for investment in renewable energy that can be delivered below this level. Furthermore, as the emissions trading scheme takes over from MRET, some of the rents previously accruing to investors in renewable energy (who will now be competitive with other forms of carbon-intensive energy) will shift to government and can be used to support research, development and commercialisation of newer technologies (see Chapter 16).

Modelling will be important to provide some indication of likely impacts of MRET on the permit prices and mitigation occurring under the emissions trading scheme. It will be critical that the interactions between MRET and the emissions trading scheme are fully understood when the parameters of the scheme are being finalised. These matters will be discussed quantitatively in the supplementary draft report.

Table 14.1 Interaction between the emissions trading scheme and the Mandatory Renewable Energy Target

Emissions trading scheme trajectory	MRET ramp-up rate: Gentle	MRET ramp-up rate: Aggressive
Gentle	• Low permit price • Moderate renewable energy certificate price • Moderate impact on retail electricity prices • Abatement activity outside MRET unlikely	• MRET cannibalises emissions trading scheme • Very low (even zero) permit price • Emissions trading scheme becomes non-functional • High renewable energy certificate price • High impact on electricity prices • Little abatement activity outside MRET • No incentive for investment in other low-emissions technologies
Aggressive	• Permit price steadily increases over time • As wholesale electricity prices rise, renewable energy certificate prices decline, possibly to zero—implying early phase-out of the MRET • Moderate-to-high impact on retail electricity prices—depending on level of mitigation undertaken elsewhere in the economy • Investment in portfolio of renewable and other low-emissions technologies	• Permit and certificate price paths would be highly dependent on interaction of the two schemes • Prices could be range from high to very low • MRET most likely to cannibalise emissions trading scheme • High impact on retail electricity prices • Most investment likely to be in increasingly expensive renewable energy options

Greenhouse Gas Reduction Scheme

The New South Wales Greenhouse Gas Reduction Scheme (GGAS) is one of the world's first mandatory greenhouse gas emissions trading schemes, originally designed to run until 2012.

Both the emissions trading scheme and GGAS cause a price to be applied to greenhouse gas emissions associated with energy consumption. It is not efficient or appropriate to have multiple emissions price signals. Therefore, NSW legislation provides that GGAS will cease to operate upon commencement of the emissions trading scheme (NSW Department of Water and Energy 2008).

There are several issues to consider in ensuring a smooth transition from GGAS to the emissions trading scheme, including:

- Treatment of accredited abatement providers. If emissions reduction projects under GGAS were not reaccredited at all under the emissions trading scheme, or they were reaccredited but scheme permit prices were lower than certificate prices under GGAS, this could reduce the income stream and project value.

- Forestry carbon sequestration projects. Reaccreditation under the emissions trading scheme would be necessary, and depend on rules developed for the inclusion of forestry in the emissions trading scheme.
- Unused GGAS certificates, which may be held by existing providers, intermediaries or parties with an obligation. Transition arrangements should not provide an incentive for oversupply of certificates, or holding of them in expectation of a higher price under the emissions trading scheme (and non-compliance with GGAS).

The voluntary market for emissions reductions

There is a growing market for individuals, households and businesses wishing to voluntarily purchase credits for greenhouse gas reductions, to offset emissions associated with their activities. Such measures include the purchase of Green Power, and offset credits from the Commonwealth Government Greenhouse Friendly program.

As the emissions trading scheme develops, both in depth and breadth, it is likely to cannibalise the market for such measures, although the nature and pace of such changes are uncertain.

Voluntary demand for offsets is likely to continue even with an emissions trading scheme. For example, the South Australian Government believes offsets will play a role in meeting its commitment to be carbon neutral by 2020 (Government of South Australia 2008).

Robust standards for voluntary offsets are important. It is likely, and desirable, that the voluntary emissions market will move increasingly toward the compliance market, in terms of standards.

As well as buying domestic offset credits, under an emissions trading scheme those looking to purchase emissions reductions voluntarily may buy and surrender compliance-grade credits, including emissions permits and domestic and international offset credits.

Electricity pricing

Consideration will need to be given to existing power purchase agreements with fixed prices, or which are silent on or prohibit the pass through of a carbon price. Early announcement of the emissions trading scheme design will allow retailers and customers to better manage the uncertainty about future carbon prices in new contracts. Parallels with issues that arose in relation to the introduction of the goods and services tax at the turn of the century will be helpful in the management of this transitional issue.

Electricity pricing issues are discussed further in Chapter 20.

14.3.4 Addressing market failures and other barriers to reform

While an emissions trading scheme will address the primary market failure of unpriced greenhouse gas emissions, other market failures have the potential to raise the economic cost of the structural adjustment process. Three market failures must be vigorously addressed if the benefits of an emissions trading scheme are to be maximised.

First, the market failure associated with research and development and innovation (or commercialisation of new technologies) must be corrected. Policies are required that recognise that private investors are not able to capture for themselves the full social value of their innovations. There is therefore a need for high levels of public expenditure on research, development and commercialisation of new, low-emissions technologies and approaches. Public assistance must be introduced in different forms for different stages of the innovation process.

Second, governments must address the possibility of market failures associated with the external benefits from pioneering investment in the provision of network infrastructure related to electricity transmission, natural gas pipelines, carbon dioxide pipelines associated with geosequestration, and transport infrastructure linked to urban planning. This may or may not require public expenditure.

Third, there are market failures in end use of energy, as a result of misplaced incentives, and externalities in gathering and analysing information. Correcting this market failure would reduce energy consumption and lower the overall demand for permits. Government intervention would include mechanisms for subsidising the provision of information related to innovation in reducing the demand for energy, and regulatory responses where these were the most efficient means of correcting market failures in information.

These market failures are addressed in chapters 16, 17 and 18 respectively.

A comprehensive mitigation strategy will also require government intervention to promote abatement activity in sectors not covered by the emissions trading scheme. The scheme's coverage should be as broad as possible as quickly as practicable. Sectors that are not expected to be covered should be provided with incentives and be allowed to interact with the scheme through other measures—most notably, the creation of offsets (see Chapter 15). The most significant opportunities may be in the area of improved carbon sequestration through better management of soil carbon.

The ideal mitigation strategy would embody measures that correct the tendency for regulatory and institutional arrangements, and policy uncertainty, to create significant barriers to change.

As already noted, governments will need to review existing policies to ensure that they do not adversely interact with the emissions trading scheme. Reviews should cover federal and state taxes and subsidies, procurement policies, industry assistance programs, product and technology standards, accounting standards and taxation rules. Such reviews will need to extend beyond programs and policies that directly compete with the emissions trading scheme for emissions reductions. The aim should also be to identify perverse incentives that might inadvertently inhibit investment in low-emissions technologies or promote activities associated with high emissions.

While Australian mitigation policy must be viewed as a wide-ranging reform agenda, it should also be considered within the broader economic context.

Commitments already exist for reducing the regulatory burdens on business, expanding investment in infrastructure, reviewing federal tax arrangements and reforming Australia's approach to human capital formation. The successful implementation of these other policy reform programs would assist the introduction of the emissions trading scheme.

As a market-based measure, the efficiency benefits of an emissions trading scheme will be enhanced by a broader suite of market-oriented reforms. Measures that seek to promote the development of global and domestic markets for products and commodities (beyond carbon) will assist in dissipating carbon price shocks, whether they originate in Australia or beyond.

Finally, a national emissions trading scheme must be the centrepiece of Australia's efforts to reduced greenhouse gas emissions. However, this should not be equated to the centralisation of all policy interventions relevant to the national emissions abatement challenge. State and territory governments have an important part to play in removing barriers and promoting broader reforms in areas within their jurisdiction. The division of responsibilities in the Australian federation will be discussed more fully in the final report.

14.4 Income distribution effects

As a market-based instrument with broad application, the emissions trading scheme can be expected to be environmentally effective and economically efficient, but will be poorly placed to deal with matters of equity. Individuals and households will be affected by its introduction to the extent to which firms pass on higher input costs in the form of higher prices. Regions and communities will be affected to the extent that they are dependent on particular emission-intensive industries or firms. Chapter 19 discusses distributional impacts and appropriate policy responses.

Notes

1 The Greenhouse Gas Reduction Scheme (or GGAS) established by the NSW Government, which has been in operation since 1 January 2003, contains elements of a baseline and credit scheme. GGAS was a world first but is relatively small in scale.

2 This is because investors will be choosing between alternative investments, with an emissions permit being one possible investment. Investors will assess whether the long-term value of holding an emissions permit is higher or lower than the return from an alternative investment. This leads to selling or buying of emissions permits until a forward price curve emerges that causes the expected return from holding a permit to be equivalent to that on alternative investments. The price would therefore rise at a rate of interest corresponding to alternative investments available to holders of permits.

3 Incidentally, it is a common error to see a rising forward price curve for emissions permits as reflecting an increasing external cost of emissions as the volume of emissions rises over time. Later emissions do not impose greater costs. Rather, the rising price reflects the market's approach to optimise depletion over time of a finite resource (Hotelling 1931), in this case the resource being the atmosphere's capacity to absorb greenhouse gases without seriously adverse consequences.

4 Any new information that increased optimism about new, lower-emissions ways of producing some product, whether they were expected to become available immediately or in the future, would shift downwards the whole structure of carbon prices, spot and forward. Any new information that lowered expectations about the future availability of low-emissions alternative technologies would raise the whole structure of carbon prices, spot and forward.

5 The assumed equivalence of a $40/MWh shortfall penalty and permit prices of $40–45 per tonne is calculated on an assumed average emissions intensity ratio of 1.0 to 0.9, respectively, for the electricity supplied beyond MRET.

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15 AN AUSTRALIAN EMISSIONS TRADING SCHEME

Key points

The emissions trading scheme will issue permits for greenhouse gas emissions up to limits and release them in line with the scheme's emissions reduction trajectories. Trade will move permits to entities for whom they have most value. The trajectories will be firm for five years, and indicative through to mid century. Permits should be sold through a competitive process.

The more sectors included in the emissions trading scheme, the more efficiently costs will be shared across the economy. The transport sector should be included.

While there are advantages in moving directly to an unconstrained scheme, 2010–12 could be a transition period. If there were a transition period, the Kyoto Protocol would define Australia's emissions reduction trajectory and permits would be sold at a low fixed price. These years would be used to pursue effective international sectoral agreements, en route to a global agreement.

Unlimited hoarding of permits will be allowed, and the independent regulator, the Independent Carbon Bank, will be able to lend permits within five-year periods. No hoarding of 2010–12 permits could be allowed if there were price constraints in a transition period.

International linking will play an important role in the scheme, with fewer constraints in later years within an international agreement.

The Commonwealth Government has committed to implementing an emissions trading scheme in 2010 as its central policy measure for emissions mitigation.

In considering scheme design, much can be learnt from experiences with other schemes, such as the New South Wales Greenhouse Gas Reduction Scheme and the European Union emissions trading scheme. The Review has also studied previous design proposals for an Australian emissions trading scheme, in particular those of the National Emissions Trading Taskforce set up by the state governments, and the Task Group on Emissions Trading established by the former Prime Minister.[1] In addition, the Review has considered movement toward emissions trading in other jurisdictions, including New Zealand, Japan, and parts of the United States and Canada.

The Review is undertaking its work in an Australian intellectual and political environment that has been changed and improved by the discussion and experience of these schemes. However, the Review has applied first principles in developing a rigorous framework to guide the development of an Australian scheme. Table 15.1 gives an overview of the proposed scheme's design.

The response to the Review's discussion paper on emissions trading (March 2008) has been wide-ranging and considered.[2] This chapter takes into account comments from interested people over recent months and in large numbers of written submissions to the Review.

Table 15.1 Overview of the proposed emissions trading scheme design

Design decision	Proposal
Setting an emissions limit	The overall national emissions limit should be expressed as a trajectory of annual emissions targets over time, which define long-term budgets. A number of trajectories should be specified upon establishment of the scheme. The first, up to 2012, should be based on Australia's Kyoto commitments (Australia's existing emissions limit). The others, for the post-2012 period, should reflect increasing levels of ambition. Movement between them should be based on determining the comparability of Australia's response to international effort. In its supplementary draft and final reports, the Review will provide advice to government on budgets, trajectories and targets for an Australian emissions trading scheme.
Changes to the emissions limit	Movement from one trajectory to another should only be on the basis of international policy developments and agreements (which should allow for new information and developments of an economic or scientific kind). Government should provide five years' notice of movement to another trajectory. Any gap between the domestic emisisons trajectory and international commitments during this period would be reconciled by the purchasing of international permits.
Coverage	Gases: Six greenhouse gases as defined by the Kyoto Protocol. Sectors: Stationary energy, industrial processes, fugitives and transport from scheme outset. Waste and forestry to be included as soon as practicable. The inclusion of agriculture to be subject to progress on measurement and administration.
Domestic offsets	Domestic offsets will have a small role, given broad coverage. Unlimited offset credits should be accepted from forestry before and during coverage in the scheme. The appropriateness of an offset regime for agriculture to be analysed further in the context of coverage of these emissions and advice provided in the supplementary draft and final reports.
Point of obligation	Set at point of emissions where efficient. An upstream or downstream point of obligation preferred where transaction costs are lower, accuracy of emissions measurement higher, or coverage greater.
Issuing (or releasing) permits	Permits released according to emissions reduction trajectory. All permits auctioned at regular intervals. (Note: Some permits may be used in lieu of cash in providing assistance to eligible firms that are in trade-exposed, emissions-intensive industries.)
International links	Opportunities for international linking of the Australian scheme should be sought in a judicious and calibrated manner.
Price controls	Not supported, except during transition period to end 2012.

Table 15.1 Overview of the proposed emissions trading scheme design *(continued)*

Design decision	Proposal
Inter-temporality (flexibility in time of use of permits)	Unlimited hoarding allowed. Official lending of permits by the independent carbon bank to the private sector allowed within five-year periods.
Treatment of trade-exposed, emissions-intensive industries	Global and sectoral agreements to achieve comparable treatment of emissions in important competitors to be pursed as a priority. If they have not been reached post-2012, assistance should be provided to account for material distortions arising from major trading competitors not adopting commensurate emissions constraints.
Governance	Emissions limit and policy framework for the scheme set directly by government. Scheme administered by independent authority (independent carbon bank).
Compliance and penalty	Penalty to be set as a compliance mechanism. Penalty does not replace obligation to acquit permits; a make-good provision would apply.
Use of permit revenue	Auctioning of all permits would provide a substantial amount of government revenue. All revenue to be returned to households or businesses after administrative costs of system. Competing priorities for this revenue include: • payments to trade-exposed, emissions-intensive firms • payments to households • support for investment in research, development and commercialisation of low-emissions technologies • cash reserves to purchase international permits/offsets to reconcile domestic emissions with international commitments.

15.1 Framework to guide scheme design

15.1.1 The objective of an emissions trading scheme

To mitigate climate change effectively, a limit must be placed on rights to emit greenhouse gases to the atmosphere, and this must be reduced over time to the level that prevents any net accumulation in the atmosphere. Australia's limit will represent an agreed share of a global limit.

An emissions permit represents a tradable instrument with inherent value that can be exchanged between sellers and buyers in an emissions permit market. This enables the movement of permits about the economy to their highest value (or most economically efficient) use. It does this while ensuring the integrity of the volumetric control, or emissions limit, imposed in order to satisfy the policy objectives of climate change mitigation.

After the policy objective of reducing emissions is established and it has been determined that this is most efficiently achieved by the implementation of an emissions trading scheme, the objective of the scheme should be kept as simple as possible in order to avoid compromising its efficiency. The singular objective of the scheme should be:

> *To provide a transactional space that enables the transmission of permits to parties for whom they represent the greatest economic value.*

Generally, other policy objectives—be they economic, environmental or social—should be pursued through alternative policy instruments that operate alongside the scheme. However, other policy objectives will inevitably influence the key design features.

The necessary conditions for a smoothly operating emissions market are guided by five principles, set out in section 15.1.2.

An effective and efficient emissions trading scheme can be achieved if it is implemented in line with the above objective and the five guiding principles.

Successful implementation will result in observable outcomes, such as:

- low transaction costs
- price discoverability
- emergence of forward markets and other derivatives
- investor confidence
- low-cost mitigation spread over time in a way that minimises the present value of costs.

15.1.2 Guiding principles for scheme design

Principle 1: Scarcity aligned with the emissions target

Without a scarcity constraint, a market will not exist as permits will have no value and there will be no demand for them.

Where the scarcity of permits is uncertain, market participants will factor in risk premiums (if they suspect that the commodity will become more scarce) or risk discounts (if they suspect that the commodity will become more abundant).

Principle 2: Tradability

If market participants have no means by which to exchange a good, there can be no market. Tradability requires:

- clearly defined characteristics for the permit
- an unambiguous identification of the benefits a permit bestows on its owner
- the mechanism through which trade takes place
- a common understanding of the terms and conditions of trade.

While many platforms exist for trade, the most critical elements in designing a platform are:

- accessibility for those wanting to participate in the market
- ability to secure the exchange quickly and at minimal cost
- transparency of offer and bid prices.

Principle 3: Credibility

Credibility, or faith in the enduring nature of the rules and institutions that define the emissions trading scheme, is essential for its ongoing success. Markets can quickly collapse if their credibility is shaken. This is all the more pertinent for markets that owe their existence solely to government decree.

As an emissions trading scheme exists entirely at the behest of government, market participants will be alert for any early signs of shifts in policy, management protocols or operating procedures that may undermine the integrity of the market. There may also be incentives to press for change if there appears to be a chance that the rules of the scheme can be influenced. Arbitrary changes to rules that benefit one party may come at the expense of financial interests of other market participants, or the community, or of the community's interest in the environment.

Reliable, steady and transparent operating rules are a necessary condition for the credibility of the market. These rules may need to be adjusted over time through reliable, steady and transparent processes.

Principle 4: Simplicity

Simplicity requires that rules for the scheme should be easily explained and implemented. Rules should apply consistently; and special rules, concessions and exemptions should be avoided. Rules should be unambiguous and internally consistent. Where one rule necessitates the creation of another rule to ameliorate unwanted consequences, the first rule is probably suboptimal.

Compromises to the simplicity of the scheme should not be made lightly as they will inevitably result in increased uncertainty and transaction costs for market participants.

Principle 5: Integration with other markets

An emissions trading scheme must be able to coexist and integrate with international emissions markets as well as with other financial, commodity and product markets in the domestic and international economies. This requires that there be no barriers to the appropriate transmission of information within and between markets.

If the scheme contains distortions that result in an emissions permit price that does not reflect its true scarcity value, this mis-priced market will adversely affect decisions about resource allocation by investors in other markets.

The converse is also true. Distortions in other markets may result in mis-priced outcomes in the scheme. However, the integrity of the scheme should not be compromised to compensate for distortions in other markets. Rather, policy makers should use the opportunity and insights gained from establishing the scheme to identify and correct distortions in other markets.

15.1.3 Exogenous factors

The decisions made about particular scheme design features will depend on the broader conditions within which the scheme is established—the factors that are exogenous to the design of the scheme.

The first is the international and global context—what are other countries doing? Is there is an international agreement (with narrow or wide participation) on emissions reduction? Without an international agreement, transaction and other costs will be extremely high, and the direct environmental benefits will be low. Australia, through domestic mitigation action and international diplomacy, can play a role in the emergence of an effective, international agreement (see Chapter 12 and 13).

The second is scientific and technological uncertainties. For example, uncertainties related to the measurement and verification of emissions can affect what sources are covered by the scheme, and how.

The third exogenous factor is the credibility of institutions—how much faith do participants have in the enduring nature of institutional behaviour in relation to the rules established at the outset of the scheme? The credibility of Australia's scheme will be influenced by the commitment of other countries to reducing emissions, as demonstrated by their actions.

15.2 The emissions trading scheme in operation

15.2.1 The current context: an international agreement and Australia's strategy

Building on the framework set out in section 15.1, this section identifies design features for an Australian emissions trading scheme in the absence of an effective international agreement.

Because a comprehensive global agreement is the longer-term objective in taking mitigation action, a domestic emissions trading scheme should support Australia in moving toward this ultimate objective.

15.2.2 Establishing the emissions limit set by the scheme

An emissions permit will enable the holder to emit a specified quantity of greenhouse gas—one tonne of carbon dioxide equivalent (CO_2-e), once. The emissions reduction trajectory will determine the number of permits that can be released each year. The emissions allowed under the trajectory, over time, should sum to an emissions budget.

The emissions limit set under the scheme will be derived from Australia's economy-wide emissions limit. A number of trajectories should be specified when the scheme is established. The first, up to 2012, will be based on Australia's Kyoto commitments—Australia's existing emissions limit for that period. The trajectories for the post-2012 period would reflect increasing levels of ambition. Movement between them would be based on determining the comparability of Australia's response to international effort.

In its early years, the scheme will not cover all emissions. The emissions limit set will, therefore, need to take into account the treatment of non-covered sectors and emissions to ensure those covered by the scheme are achieving the mitigation necessary for Australia to achieve its overall emissions budget.[3]

If Australia's emissions trading scheme offers flexibility in the time of use of permits—through hoarding and lending—actual emissions could be above or below the trajectory at a given time, despite staying within the overall, longer-term emissions budget. The term 'lending' refers to transactions of permits between the independent authority and the private sector. The term 'hoarding' is reserved for net banking of permits by the private sector. If actual annual emissions (and use of permits) were above the level specified in international commitment periods (and if this were not made up by reductions in the non-covered sectors), the government could purchase permits in the international market to meet commitments.

In its supplementary draft and final reports, the Review will provide advice to government on budgets, trajectories and point-in-time targets for an Australian emissions trading scheme.

Changes to the trajectory and conditions under which these might occur

Measures can be put in place to minimise uncertainty about changes to the emissions reduction trajectory. First, a number of possible trajectories would be specified upon establishment of the scheme.

To ensure predictability, the conditions that would lead to movement from one trajectory to another would be specified in advance. If and when it was announced that the conditions had been met for movement to a tighter trajectory, five years' notice would be given.[4] There would be five years of firm caps, extended by one year, every year, and then a much longer trajectory of indicative caps, stretching out to 2050.

The framework of trajectories established in Chapter 14 is one in which there is an expectation that the trajectories will tighten over time. Within this framework the market would price in the possibility of the emissions budget tightening in future. This would be reflected in a higher forward price for permits, which would be likely to encourage hoarding of permits by participants and discourage the use of the lending provision.

15.2.3 Who will the scheme cover?

Coverage refers to the scope of the scheme in terms of greenhouse gases and sectors. Emitters in covered sectors will have an obligation to acquit permits under the scheme.

Coverage of the scheme should be as broad as possible, within practical constraints imposed by measurability and transaction costs. This is desirable in order to:

- provide an incentive for emissions reductions in all sectors according to lowest cost abatement opportunities
- maximise market liquidity and stability
- distribute the costs of the scheme in ways that minimise distortions in resource allocation
- facilitate integration with other markets.

The maximum number of anthropogenic greenhouse gases should be covered in the scheme. The Kyoto Protocol covers six key gases that contribute to climate change (see Chapter 3). The Review considers this coverage appropriate for the scheme, given current information, and scientific and technological constraints.

Australia's emissions are from the following sectors: stationary energy and transport; fugitive emissions from fuel production; industrial processes; waste; agriculture; and land use, land-use change and forestry.

The Review acknowledges that there are measurement difficulties and site-specific variability with fugitive emissions from coal mining and oil and gas fields (DCC 2008a). Overcoming these issues, with a robust methodology to estimate emissions, should be a priority, although proxy measures could be used in the interim.

The Review holds that a sector should be included in the scheme unless the costs of measurement and verification are prohibitive.

Costs

Costs of including a sector in the scheme may arise from a range of factors:

- **Uncertainties in emissions measurement**—in order for a sector to be covered by an emissions trading scheme, there must a reliable and accurate way to monitor, measure or estimate, and verify emissions from that sector. If the proxy or 'rule of thumb' applied is inaccurate, it can create distortions—

failing to reward good performers, and failing to penalise poor performers. Further, if accuracy improves and the proxy undergoes major change in the future, this could cause significant market shock. (However, if reliable and accurate proxies can be identified, that sector should be included.)

Emissions measurement is easier in some sectors than others, depending on the nature of emissions and activities. Emissions uncertainty varies between sectors.

- **Costs of developing accurate monitoring, measurements and verification arrangements**—for some sectors these arrangements are already in place; for others, establishing them may require a significant investment of finances and time.
- **Transaction costs of participation in an emissions trading scheme**—if emissions can be appropriately measured, it still may not be cost effective for all sources of emissions to undertake that measurement, or take on an obligation under the scheme. Consequently, thresholds would apply to covered parties—for example, electricity generators or waste facilities. Parties that are too small to be covered cost-effectively should be covered upstream or downstream, but may not have a direct obligation (see 'Point of obligation' below).
- **Trade exposure**—the lack of a global agreement means that there may be contraction of production among Australian trade-exposed, emissions-intensive industries if they are affected by the scheme, while their international competitors are not subject to a commensurate carbon constraint. There will be costs associated with correcting these distortions.

Many of these costs apply to the agriculture sector, and some also to the forestry and waste sectors. There is considerable potential for sequestering carbon through change in land and forest management and agricultural practices. However, full inclusion of agriculture and forestry in an emissions trading scheme will require issues to be resolved regarding measurement and monitoring of greenhouse gases. To a lesser extent, there are difficulties associated with coverage of emissions from waste, due to the variability of these emissions, and the timing of their release. Issues related to the coverage of agriculture and forestry emissions will be discussed in a more general treatment of the role of these sectors in the low-emissions Australian economy, in the final report.

The Review considers that inclusion of waste and forestry on the earliest possible timetable is desirable. It is achievable at reasonable cost early in the scheme's life. Further analysis is required to assess the impact of including agriculture on the overall efficiency of the scheme. Its inclusion as a covered sector in the scheme is desirable in principle, but further analysis is required to determine whether it is the most cost-effective means of encouraging biosequestration and reducing net emissions from the sector. If a sector is not covered by the scheme, policies should be developed to drive net emissions reductions from that sector, consistent with contributing to Australia's overall emissions reduction goal.

The treatment of forestry, agriculture and waste is of large consequence for the Australian and global mitigation efforts. Among the many implications are prospects for large-scale participation of Indigenous lands in the mitigation effort (NAILSMA 2008). These matters will be discussed in detail in a chapter on the economic adjustment of agriculture and forestry in the final report.

By contrast, emissions from stationary energy, transport,[5] industrial processes and fugitive emissions from fuel production can be accurately measured or estimated at reasonable cost and could be covered by an Australian emissions trading scheme commencing in 2010. Depending on the nature of emissions and activities of covered sectors, their points of obligation may be different (see below).

Scheme coverage may also have implications for linking. For example, coverage of the agriculture and forestry sectors may present a complication to linking with the EU emissions trading market, at least in the short term, because of the European Union's reluctance to recognise land-use-related emissions units in trading. On the other hand, demonstration of credible inclusion would make the case for coverage of these sectors in others' schemes. It is highly desirable, indeed essential, that forestry and agriculture emissions eventually be covered by international agreements, and it is appropriate for Australia, as a country with an unusually large interest in these sectors relative to other developed countries, to improve international carbon accounting approaches in this direction.

Domestic offsets

A reduction or removal of emissions from activities in one area of the economy can be used to counterbalance, or offset, emissions in other sectors. Emissions reductions in sectors not covered by the scheme could be eligible to create offset credits. Offset credits would generally be treated as substitutes for permits, and could be used by parties covered by the scheme to meet their obligations. Lower-cost mitigation from offsets can replace higher-cost mitigation options within the covered sectors.

Where coverage of a particular source of emissions is not considered possible, or viable, such activities may be able to provide offset credits. This approach may be suitable for sectors in which emissions from some sources and activities, but not others, can be measured or estimated. Partial coverage of a sector in the scheme could create intra-sectoral distortions; allowing these activities to create offset credits provides an incentive for mitigation, but avoids this risk of distortion.

Several issues need to be considered in relation to offsets. For example, an offset project should provide an emissions reduction that is additional to that which would have occurred anyway. If it did not, allowing a credit would actually reduce the total national mitigation effort. This can be tested through several categories of additionality. For example, regulatory additionality would require emissions mitigation to be undertaken beyond what is undertaken to comply with existing legal or regulatory requirements. Such tests are arbitrary, and potentially a source of distortion, with the potential to undermine the credibility and scarcity principles of the scheme (see section 15.1.2).

Pending resolution of emissions measurement difficulties and its inclusion under the scheme, forestry is a potential source of domestic offsets. As reliable measurement rules of thumb are developed, carbon stored in wood products and biochar should also be reflected in carbon accounting and under the scheme. The increasing carbon content of growing forests should be brought to account; recent technological developments would seem to make that possible. Forestry offsets would provide an incentive for the sector to reduce emissions before it is covered under the scheme. The use of these offset credits should be unlimited.

The same approach could be applied to agriculture. However, given the magnitude and variety of difficulties associated with emissions measurement in this sector, it is worth investigating whether other policies may deliver greater emissions reductions, at lower cost, than an offset regime.

As a non-covered sector in the initial years of the scheme, waste should be considered for offset creation. The inclusion of waste raises issues requiring careful assessment. Ahead of being covered in the scheme, other policies to encourage mitigation in the waste sector should be pursued.

Section 15.2.7 discusses international offsets, and considers their role in an Australian emissions trading scheme.

Point of obligation

The point of obligation is the point in the supply chain—from those who produce goods and services that involve the release of greenhouse gases to the atmosphere, to those who consume those products—at which monitoring and reporting of emissions is required for the purposes of the emissions trading scheme (see Box 15.1). These emissions must be accounted for under the scheme by acquitting permits equal to those emissions.

The point of obligation is determined by the ease and accuracy of monitoring and estimating emissions, and the cost of doing so.

There is no need for the point of obligation to be the same across schemes in different countries. Point of obligation should be chosen for what is most effective for local conditions in each country.

A natural starting point when considering the point of obligation is the emissions source. However, it may make sense to select another point of obligation when there is evidence that transaction costs are significantly lower at that point, or if accuracy of emissions measurement is higher or coverage would be substantially wider. There is a reasonably strong, although not definitive, presumption that the source of emissions is the best point of obligation for stationary energy.

The possibility of allowing large energy users to opt in to accept an obligation for their (indirect) stationary energy emissions should be considered. This would require the generator to have the ability to track and net out that energy use. The existence of a power purchase agreement may support this option.

The point of obligation can be set at the facility level for oil and gas production, gas processing and fugitive emissions from coal mining. The point of obligation for pipeline system fugitive emissions could be placed on pipeline systems, as defined by operational control of the physical infrastructure, such as pipes, valves and compressor stations. Generally, industrial process emissions can be measured or estimated at their source.

Emissions from waste—primarily methane emissions from organic waste—could also be covered at source. This would allow emissions to be collected or measured with reasonable accuracy from the landfill facility or treatment plant.

By contrast, emissions from transport are released at a much smaller scale, by individual vehicles. For the transport sector, then, an upstream point of obligation may be a cost-effective way to cover a large number of smaller emitters. Many parties that produce fuel for the Australian market are located overseas, beyond the coverage of an Australian emissions trading scheme, so petroleum could logically be covered by making the point of excise the point of obligation. Large liquid fuel users, for example, fleets or freight operators, might be allowed to opt in to accept an obligation under the scheme.

A complication will arise where the relationship between fuel and emissions is not constant. For example, sometimes petroleum is used as an input in manufacturing processes (such as for plastics or petrochemicals), resulting in the release of few or no emissions. Where this is the case, such fuels sales would need to be netted out of an upstream party's obligation, or a credit system established so that producers could claim back the permit price passed through to their liquid fuel purchase.

In other cases, where practical difficulties interfere with measuring emissions at the source, a downstream point of obligation may be suitable. For example, under the New Zealand emissions trading scheme, a point of obligation further downstream is being considered for a subset of agriculture emissions—such as covering emissions from enteric fermentation and manure management through a point of obligation at the dairy or meat processor.

Box 15.1 Emissions monitoring, reporting and verification

The emissions trading scheme will require parties with an obligation to monitor and report their emissions to the scheme regulator. The system used to collect this information must be transparent, credible and efficient.

In September 2007, the federal *National Greenhouse and Energy Reporting Act 2007* was introduced.[6] This legislation will establish a national greenhouse and energy reporting system that will underpin the emissions trading scheme. Firms registered under the Act will provide information on their greenhouse gas emissions, energy production and energy consumption to the Greenhouse and Energy Data Officer. Those required to report will be facilities with over 25 kilotonnes of emissions, or production/consumption of 100 terajoules or more of energy in a given year. Thresholds have also been set at corporation level, and are to be phased in progressively during the first three years of the reporting system.

The system is in place from 1 July 2008, and the first year of reporting will be the 2008–09 financial year.

Data from the national greenhouse and energy reporting system should be the basis for making assessments about parties' obligations under the emissions trading scheme. However, additional data may be required, for example, in order to net out emissions from an upstream party's obligation.

Robust arrangements will also be required to verify emissions data.

15.2.4 Releasing permits into the market

Manner of permit release: auction or free allocation?

Governments can release permits by allocating them free to a range of potential recipients, selling them through a competitive process ('auctioning'), or a combination of the two. Whether a permit is sold or granted freely, the recipient will acquire the full economic and financial benefit it bestows because it is a scarce and valuable resource.

Ronald Coase (1960) demonstrated that economic efficiency will be achieved as long as property rights are fully defined, and that completely free trade of all property rights is possible.

The manner of permit allocation will not affect the operations of the scheme—the price of permits or the costs of adjustment to the scheme. The impact of an emissions trading scheme on the price of goods and services is independent of the approach adopted by governments for allocating permits (see Box 15.2). Whether permits are allocated freely or auctioned to existing generators, the impact on electricity prices—and consumers—will be the same. This is suggested by economic analysis, and has been demonstrated by the experience of the EU emissions trading scheme.[7]

Allocation of permits, however, will have large effects on the distribution of income (see Chapter 19). Costs and risks differ depending on the manner of allocation. Free permit allocation would be highly complex, generate high transaction costs, and require value-based judgments. If permits are to be freely allocated in part, or wholly, to existing emitters, a methodology must be developed for doing so. The most important aspect of this methodology would be the algorithm applied for distributing permits, which would require a baseline emissions profile against which an emitter's entitlement to free permits could be determined. There would be unavoidable arbitrariness in choosing a baseline.[8]

The definition of principles, collection and application of data, and resolution of disputes would be time-consuming. Indeed, it would seem to be impractical for Australia to administer a free allocation scheme in time for introduction of the emissions trading scheme in 2010. The complexity of the process, and the large amounts of money at stake, encourage pressure on government decision-making processes, and the dissipation of economic value in rent-seeking behaviour.

As well as having lower implementation and transaction costs, auctioning of permits is supported by the scheme design principles of credibility, simplicity and integration. Australia, with its well-established legal, regulatory and administrative structure, is in a favourable position for full auctioning of permits. This would maintain government discretion over the disbursement of the rent value of permits in the Australian economy in the most transparent and accountable manner. A sound auction design is important to avoid introducing new inefficiencies or distortions in the market.[9]

Revenue from the auction of permits will provide government with a tool to address the scheme's income distribution effects, and to offset market failures in the development of new, low-emissions technologies. The introduction of the scheme will be associated with many valid claims for increased government expenditure. Permit auction revenue will provide a means of meeting these claims, without placing pressure on public finances (see Chapter 19).

If payments are required for particular firms on efficiency grounds under the arrangements for trade-exposed, emissions-intensive industries, the amount of the payment would be assessed in cash. There would be no substantive implication if the government were to make the payment transparently in the form of permits of precisely equivalent value.[10]

Note that the method of permit release would be different during the transition phase (up to 2012), if permits were sold at a fixed price (see section 15.3).

Box 15.2 Pass-through of permit value

If a manufacturer is emitting as part of its production process and is required to purchase a permit via an auction, the cost will need to be recovered through the price received for the manufactured good.

Alternatively, if the manufacturer is granted a free permit, then it must decide whether the permit is of greater value if used or sold. If it is of greater value to use rather than sell the permit, the manufacturer will need to at least recover its opportunity cost. In other words, the recipient will need to attain value from the use of the permit at least as great as if the permit had been sold at the market price.

In such an instance, the manufacturer selling the domestic market in the absence of international competition faces the choice of either (1) continuing to manufacture (thus emitting greenhouse gases) and using its permits to acquit its obligation, or (2) selling some or all of the freely acquired permits, and reducing its production to a level consistent with its remaining permits. If the manufacturer decides to use rather than sell the permits, then it has forgone income. Therefore, the manufacturer will recover the price of every permit not sold by the income generated from continuing to produce.

It follows that the impact on the price of goods and services of pricing carbon through an emissions trading scheme is independent of the approach adopted by governments for determining the allocation of permits. Although the price impact is independent of the allocation method, the pass-through of permit price to the price of goods and services will depend on the competitive nature of the relevant market.

Studies of the power sector in certain countries under the EU emissions trading scheme indicate pass-through rates of between 60 and 100 per cent, depending on carbon intensity of the marginal production unit and other market or technology-specific factors concerned (Sijmi et al. 2006). There will be situations in which a firm will have to decide between passing through the cost of purchasing permits (or reducing emissions), risking a loss of market share, or absorbing those costs with a resultant loss in profit.

Rate of permit release

Permits should begin to be sold into the market as soon as possible after the full details of the scheme are finalised, and before the scheme commences in 2010. This will provide market participants with a guide to price before price figures directly in domestic market transactions. Emitting firms could ensure that they obtained necessary permits in advance of operation of the scheme. If the fixed-price permits are to be issued in the Kyoto period, some permits for use after 2012 should be sold into the market in small quantities from 2010. This will support the development of forward markets and provide guidance to market participants on future prices.

Auctioning will proceed on a fixed schedule—weekly, monthly, quarterly or on any other basis that suited market participants. The frequency and timing of auctions will have implications for business cash flows and corporate balance sheets. Some parties with an obligation, such as fuel companies, will be required to purchase permits for all emissions from their fuel. Fears about this financial risk have led some fuel companies to suggest that auctions should be as frequent as weekly. The Review expects deep market-supporting financial services to emerge quickly around the scheme, so that the market will be able to operate effectively across a range of frequency of auctions.

15.2.5 Financing purchase of permits

In the consultations on the Review's Emissions Trading Scheme Discussion Paper, many firms expressed anxiety about cash flow problems associated with purchase of permits. The Review does not think that this will be an important issue in practice: an elaborate financial services system will develop for the financing of permit purchases prior to acquittal, and acquittal will be after receipt of revenue from sales in most cases.

To ease anxieties without distorting the system, the Review suggests a simple expedient for at least the early years of the unconstrained scheme.

The independent regulator could issue to emitters on request a number of deferred payment permits (taken from the release trajectory). For example some anticipated permit requirements over the next five years could be set aside for direct purchase at the time of acquittal. These would be issued up to a maximum proportion (say, one-third) of expected annual requirements—enough amply to cover permits for which corresponding sales revenue had not been received at the time of acquittal.

These permits would have the characteristic that payment for them could be made at the time of acquittal. The payment price would be the market price on the day of acquittal. The effectiveness and need for these special measures would be evaluated at regular intervals and they should be disbanded once they are no longer considered necessary.

15.2.6 Accounting issues

Implementation of an emissions trading scheme will require resolution of issues relating to financial accounting standards and tax treatment, including:

- avoiding distortions between the purchase of emissions permits and other options for meeting emissions targets—that is, pursuing tax neutrality between purchasing a permit, undertaking capital expenditure to reduce or sequester emissions, investing in research and development or reducing production) (Prime Ministerial Task Group on Emissions Trading 2007)

- valuing permits, given that they are only valid once, but can be hoarded and loaned—how should a discount rate, or interest rate, be applied over time (Shanahan 2008)? The price of the permit will be rising over time—in 'normal' circumstances at the Hotelling rate—so that the interest rate, or the expectation of it, will be built into any lending transaction. The independent carbon bank may also choose to add a margin. Valuation will be on the basis of current market values (mark-to-market)
- recognition as income—a permit granted free to a trade-exposed, emissions-intensive enterprise would be treated as income.

15.2.7 International trade and links

The costs of any specified degree of mitigation can potentially be substantially reduced by international trade in permits. However, linking with an economy that has a flawed domestic mitigation system will result in the import of those flaws. Variations in the quality of mitigation arrangements across countries will make the decision to link with particular markets a matter for judgment. Ultimately, global mitigation will only be successful if countries can trade in emission permits. Opportunities for international linking of the Australian scheme should be sought in a judicious and calibrated manner. This section summarises the discussion in Chapter 13 on international trade in emissions as it applies to Australia.

Currently, opportunities for linking are limited, but are likely to grow. Because of the benefits of linking, the vision for the Australian scheme should be of a market that is fully integrated into global carbon markets.

The benefits of linking centre around the potential of international carbon markets:

- to reduce mitigation costs and price volatility
- to provide financial incentives for developing countries with opportunities for low-cost mitigation to take on commitments
- to make it easier to set and adhere to national emissions budgets
- to provide equal treatment or a level playing field for trade-exposed industries, through convergence of carbon pricing across countries.

Given the rapid growth of emissions-intensive industries in Australia, it might be expected that Australia will be a net purchaser of permits for some time. Linking opens the possibility of Australia remaining a large exporter of emissions-intensive products, to the extent that that is economically and environmentally efficient on a global basis, and balancing this with import of permits.

But linking also has risks. Since the Australian market is relatively small, if it is linked to other, bigger markets it will become a price taker. The price would be set by carbon markets in the European Union or the United States, Japan or

China should they develop and Australia link to them. This exposes Australia to risk from other countries' policies and market responses. Linking might lead to price volatility, for example due to external policy change.

There is a particular issue in relation to surplus eastern European permits from the Kyoto period. Some argue that the Russian permits and some others should not be purchased because they have not arisen as a result of mitigation effort. Future treaties would not be credible, however, if countries' targets are agreed to at the time of signature, but those countries are not allowed to reap the financial rewards if they exceed them. Pre-2012 purchases of such permits in Australia could be restricted to government, and not opened to the market.

From 2012 on, the following approaches are proposed in order to enjoy the benefits of trading while minimising risks. Note that separate approaches are required for trading in permit and offset markets, and for trading with countries that have an emissions cap but not a carbon market.

Linking with other permit markets

Determining strategic and policy parameters for linking with other permit markets should be a role for the Commonwealth Government. The independent regulatory authority would certify individual permit markets as being of a suitable standard for linking. Certification would be periodic. If there were a decline in quality, then the certification could be revoked. Once a market was certified as being suitable then unlimited trading with that market—or more precisely, unlimited acquittal of permits from the overseas market—would be allowed. All private sector parties would be allowed to trade, and there would be no limits on the amount of overseas permits that could be acquitted in fulfilment of obligations under the Australian scheme, at the individual or the aggregate level.

In the initial stages, it may be a useful precaution to set a quantitative limit on aggregate permit purchases from certified international schemes. (The EU emissions trading scheme, however, envisages no such limit.) Any such limit would be applied in aggregate (to all certified permits). The limit would only apply in unusual, potentially destabilising circumstances, and so should be set high enough that it is not actually expected to be reached in a typical trading period.

When making its assessment, the independent authority would assess the compatibility of the market proposed to be linked with the Australian one. Both markets need to embed mutually acceptable levels of mitigation ambitions (or one market will undermine the other by pushing prices too low). They both need to have adequate monitoring and enforcement mechanisms. And they need to have compatible market rules—for example, on the unit of emissions, and potentially on lending and hoarding.

When making its assessment, the independent authority would also need to consider indirect links. If Australia were considering linking to one market, which was itself linked to a third market, Australia would have legitimate reasons not to link to the second market if the rules governing the third market were not acceptable. Ultimately, the decision to link or not is within the gift of executive government, given the international dimensions.

In parallel, Australia should seek to strengthen international monitoring and enforcement, and to harmonise standards across markets. Deep integration with other markets (that is, joint regulation) should be sought where appropriate and where prospects for policy coordination exist.

Linking, and any resulting changes, would fundamentally affect the effect of the emissions limit under the scheme, and the functioning of the scheme. Therefore, advance notice of new links should be provided in the same way, and with the same period of notice, as a move to a different emissions reduction trajectory.

Decisions to cut links, or alter quantitative limits on acceptance of international permits, however, may need to be taken more quickly if market quality elsewhere deteriorates suddenly. As with the notice for change of trajectory, it would be open to the government to move more quickly in introducing the new trade opportunity, and to balance the revealed effects of the change on the domestic market by countervailing international permit sales or purchases.

Given Australia's close economic links with New Zealand, and common interests on greenhouse gas mitigation, linking or even deeper integration may make sense, if the New Zealand scheme is judged to be of sufficient integrity. New Zealand is moving quickly towards finalisation of its emissions trading scheme design. The Review suggests that, prior to the indelible conclusion of scheme design in either country, the Australian and New Zealand governments meet at ministerial level to discuss linking, and to identify any impediments to linking that may warrant adjustment to one or other or both scheme designs. Similarly, Japanese scheme design development will proceed over the next few years, and high-level consultations should take place to ensure that there are no unnecessary impediments to productive interaction. Proposals for phase 3 (post-2012) of the EU emissions trading scheme appear well designed. Australia should explore the possibility of trading with the EU scheme, although EU views on excluding forestry and agriculture from its scheme may be a problem for two-way linking in the early stages. Australia should seek, at a minimum, agreement with the European Union to accept EU permits into the Australian emissions trading scheme, thus making the EU permit price an effective ceiling price for the Australian market.

Building a regional market that encompasses (in the first instance) Papua New Guinea, other south-west Pacific developing countries, and—with greater difficulty and in the context of involvement by other developed countries—Indonesia, would also be desirable. Papua New Guinea and Indonesia have large opportunities to reduce land-use change and forestry emissions and to quickly replace coal (Indonesia) and petroleum with low-emissions fuels. To be fully engaged, these countries would need to accept national emissions targets. Australia should be prepared to work with these countries within the international framework and, if necessary, outside it, to accelerate progress on mitigation, and to demonstrate new modes of cooperating with developing countries.

Permit trading by and with governments

The Australian government could always trade directly with other governments and firms in other countries. This could be necessary in order to balance the actual emissions trajectory against Australia's national commitments under an international treaty. Such divergence could occur, for example, if Australia's international obligations were to change before its scheme's trajectory changed, or if domestic emitters chose to hoard or lend permits.

Trading through government gateways may also be necessary in purchasing permits from countries that take on recognised national targets, but do not have a domestic emissions trading scheme in place. The transition economies are currently in this category, and other developed countries may also decide not to implement emissions trading schemes domestically. Similarly, developing countries would be expected to be sellers of permits but are unlikely to have developed national emissions trading schemes. It is unclear how transactions with them will evolve, and therefore impossible to give precise guidance at this stage.

Linking with offset markets

Offset credits arise when emissions are reduced in a country or sector not subject to an emissions limit. Under the Kyoto Protocol, international offsets can be created as certified emissions reductions under the clean development mechanism (see Chapter 13).

Linking with international offsets, for example by accepting certified emissions reductions created from clean development mechanism projects, raises different issues to the acceptance of international permits. This is because of the inherent flaws in the design of offsets (see section 13.3). One of the objectives of the post-2012 agreement should be a much smaller role for international offsets, with countries moving instead to national targets, which are in many instances one-sided. To encourage participation by low-income developing countries that do not yet have targets, provision should be made for international offsets, but with restrictions on the source and quantity of offset credits that can be used under the Australian scheme. If the role of the clean development mechanism is substantially changed or expanded after 2012, a re-evaluation would be needed of international linking in general, both to offsets and to permit markets.

The European Union has limits on the extent of the clean development mechanism for use in its emissions trading scheme, expressed in terms of a share of expected reduction effort (European Commission 2008).

We suggest that the limit on international offsets be a fixed proportion to Australian permits. This would provide greater investor confidence and simplicity.

It is simplest to enforce the limit on acquittal of international offsets (certified emissions reductions) in a centralised way, through the regulatory authority. The authority would auction a limited amount of supplementary permits, each one of which would allow the holder to acquit one clean development mechanism credit. Once attained, these international offset credits could be traded and used as other permits, in fulfilment of obligations under the scheme. The market price of permits to acquit a certified emissions reduction would reflect the expected differential between the price paid for certified emissions reductions in the international market, and the domestic permit price in the emissions trading scheme.

15.2.8 Flexibility in meeting targets

Demand for permits, and therefore the price of permits, will fluctuate over time with economic and seasonal conditions, changes in consumption preferences and technologies. Rigid adherence to annual targets would place large and unnecessary short-term adjustment strains on the economy.

This problem can be partially addressed by setting targets spanning several years, as the Kyoto Protocol has done with its 2008–12 compliance period.

International trade in permits can also provide flexibility in matching the rate of permit use with domestic permit release schedules.

Other options for helping smooth permit prices, and helping parties meet obligations, including price controls and inter-temporal flexibility in the use of permits, are discussed below.

Price ceilings and floors

The disadvantages of price controls include the unreliability of emissions reductions in relation to targets, the exclusion of international trade in permits, the possibility of setting the price control at an inappropriate level, and the fact that it transfers risk to government (or its agency) from the private sector.

For the normal operation of the scheme, the costs of including price ceilings or floors outweigh the benefits. The specific advantages of a fixed price during the last years of the Kyoto period, 2010–12, are discussed in section 15.3.

Inter-temporality

The approach to setting emissions trajectories and budgets outlined in section 15.2.2 suggests an alternative and less problematic means of introducing flexibility in the face of fluctuations in demand for permits.

Permits are designed to allow the holder to emit a given unit of emissions, once, at any time throughout the scheme. Hoarding of permits by the private sector and lending of permits by the authorities within prudential restrictions can introduce flexibility without breaching emissions budgets. This helps to minimise volatility in permit prices and allows market participants to use permits at the time when they have greatest value. This inter-temporal flexibility would cause market participants to see the issue as one of optimal depletion of a finite resource. Optimisation over time would see the market establish a forward curve rising from the present at the rate of interest, forcing increasingly deep emissions reductions, in an order that would minimise mitigation costs.

Lending by the independent regulatory authority allows parties to use permits from the future— ahead of their scheduled release according to the trajectory—to meet current obligations.[11] Of course, the loan must be later repaid. The independent regulator would undertake prudential monitoring of the level of lending. It would place restrictions on the amount of lending if it became so large as to raise questions about the current or future stability of the market. Such restrictions on lending could be applied in terms of:

- Time—given the plan for the permit release trajectory to be fixed for five years, and the same period of notice to apply before major changes are made to scheme operations, permits should not be loaned for a period exceeding five years.
- Quantity—the independent carbon bank should lend amounts it believes will not destabilise current or future market.
- Eligibility—borrowers must be creditworthy. Criteria determining creditworthiness should be applied and communicated, so participants have a clear understanding of the likelihood of being eligible to borrow. Financial intermediaries would provide opportunities for others to borrow, at a higher price.

Box 15.3 Minimising risks associated with lending

Recent commentary has suggested that inter-temporal flexibility in the use of permits, and in particular lending, might affect the overall timing of mitigation—and delay mitigation—in a way that was environmentally disadvantageous; that it might breach international commitments on emissions reduction targets; and that it would lead to breaches of emissions budgets if loans of permits were not repaid.

On the potentially adverse effects of delayed mitigation on the environment, the multiple emissions trajectories proposed by the Review would create a bias towards hoarding of permits by participants and away from lending.[12] The initial budgets would be looser than the budgets that were expected to succeed them. The market would therefore tend to price in some probability of budget tightening, so that future prices were higher than those that would probably emerge from confident expectations that budgets would remain at their current severity. Such expectations would be likely to encourage hoarding.

The Review considers that, with the five-year limit on term of lending, environmental impacts due to variations in timing of acquittal of permits are not likely to be a material consideration. Such short-term lending is akin to smoothing, and would not be expected to have any global environmental impacts. This lending arrangement is similar to the five-year Kyoto commitment period and the five-year carbon budget approach in the UK Climate Change Bill. The Review's approach formalises the mechanisms by which participants can borrow, and has a five-year rolling, rather than fixed, period within which lending can occur.

In the context of international agreements on targets and trajectories, any unlikely strong tendency towards net lending in Australia would be accompanied by a requirement to buy permits abroad to meet commitments on emissions reductions. As a result, delays in reductions of emissions in Australia would be balanced by acceleration of reductions elsewhere.

On the suggestion that loans may lead to a blow-out in the emissions budget because they may not be repaid, this is a matter of governance. The authorities would need to ensure that loans of permits were made only to creditworthy borrowers, that they were backed by security, and that contracts were enforced—just as they would have to ensure that emissions were backed by permits.

Loaned permits should be repaid when the loan becomes due. The value of the permit at the time of repayment would generally be higher than at the time of lending, and participants would factor in that cost. Further, the independent regulatory authority could also apply an interest rate to cover risk and costs. The interest rate would be raised at times when the authorities judged it prudent to reduce the amount of lending.

15.2.8 Addressing distortion in trade-exposed, emissions-intensive industries

A truly dreadful problem

A potential distortion arises if an Australian emissions trading scheme is introduced in the absence of, and until such time that there is, an international arrangement that results in similar carbon constraints or carbon pricing among major trade competitors (as discussed in Chapter 13). If firms in the traded sector were subject to a higher emissions price in Australia than in other countries (which as price takers they were unable to pass through), there could be sufficient reason for emissions-intensive activity to relocate, in part or in whole, from Australia to countries with lesser constraints on emissions. In the worst case, this could result in carbon leakage.[13]

The concern arising out of differences in carbon constraints amongst our trade competitors is not that some Australian firms may reduce their level of production. Rather, the concern is that some firms may reduce their level of production too far—that is, beyond the level that would eventuate if competitor countries were subject to commensurate carbon constraints.

The risk to the Australian economy from this overshooting includes the consideration that once productive capacity is lost, the effect may not be reversible at a later stage when a carbon-inclusive world price eventuates in the relevant commodity and goods markets. (The overshooting problem is explained further in 15A.)

Therefore, under certain circumstances, there are environmental and economic reasons for establishing special arrangements for emissions-intensive industries that are trade-exposed.

Australia is not alone in facing distorted investment and production decisions in trade-exposed, emissions-intensive sectors in the absence of a global agreement. No jurisdiction (whether supra- or sub-national) is comfortable about subjecting its export- and import-competing industries to an additional tax on inputs when its current or potential trade competitors are not willing to take corresponding policy measures.

The dilemma facing policy makers is even more acute in relation to new investment by trade-exposed, emissions-intensive industries—investments that, but for the Australian permit price in the absence of a global price, would be attractive. Such investments could potentially lead to notable increases in domestic emissions. With a fixed supply of permits available, this would drive up the carbon price and increase the adjustment burden on other businesses and households. In Australia's circumstances, the additional costs on other firms and households could be high. They would be higher still to the extent that trade-exposed industries were 'protected' from the competitive effects of the carbon constraint.

In recent public debate and commentary, it has been apparent that industries will seek to influence the design of any such assistance arrangements in ways that maximise their respective returns from the scheme. This is to be expected. It also signals the scale of the challenge faced by policy makers in not succumbing to special interests.

The dreadful problem of trade-exposed, emissions-intensive industries facing Australian policy makers has the capacity to destabilise support for the emissions trading scheme. This problem is exacerbated by the resource boom of the Platinum Age (Chapter 4), which is driving expansion in some of our most emissions-intensive industries.

These are truly dreadful problems for every nation's emissions trading scheme in the absence of a global arrangement. Indeed, the dilemma created for individual governments is so great that it has the capacity to pervert individual domestic schemes to the point of non-viability. The sum consequence of the compromising of individual schemes could leave the world with little chance of avoiding dangerous climate change.

In the era of global trade, it takes only a handful of non-compliant countries—large or small, developed or developing—to drive all other countries to implement policies that significantly compromise the overall objective of reducing emissions.

However, there are options that may avoid this destabilisation and descent into ineffective global action before a binding, comprehensive international agreement has been struck.

Taking a multitrack approach

Australia may well have more to lose than any other country from an internationally fractured and partial approach to dealing with trade-exposed, emissions-intensive industries. The immediacy of this problem means that Australia must simultaneously pursue three potential options for solving this problem. This is not an 'either/or' choice. All options must be pursued simultaneously. Two of the options rely on international agreements while the third is a domestic arrangement. In order of preference, these options are:

- a comprehensive global agreement on mitigation under which all major emitters have national emissions limits (see chapters 12 and 13)
- effective sectoral climate change agreements for trade-exposed, emissions-intensive industries placing particular industries on a more or less level playing field. These agreements may require backing by a World Trade Organization agreement on border adjustments (see Chapter 13)[14]

and, as a last resort:

- domestic assistance measures for our most exposed industries that address the failure of our global competitors to act on limiting their carbon emissions.

Alongside the negotiation of a global agreement, the negotiation of sectoral agreements in priority areas for Australia (including metals, liquified natural gas (LNG), cement, and sheep and cattle products) must be an urgent and an immediate trade policy priority for the Commonwealth Government. We will need to step into a global leadership role as far as sectoral agreements are concerned.

But timely success is not assured. Contingency planning for the third option is also required.

In designing a domestic assistance arrangement, an important distinction must be made. Providing assistance to address the failure of our global competitors to act on limiting their carbon emissions is not the same as compensating domestic firms for the government's decision to implement a domestic emissions trading scheme.

The case for government intervention to support trade-exposed, emissions-intensive industries is made on the grounds of economic and environmental efficiency, that is, the overshooting and carbon leakage problems. As discussed in Chapter 14, there is no basis for compensation arising from the loss of profits or reductions in asset values following the introduction of the domestic emissions trading scheme.

Assistance should be provided in order to avoid a temporary loss of real production until our global competitors act to limit their greenhouse gas emissions. The assistance program should be designed with a view to the long-term comparative advantage of the Australian economy in a world of comprehensive carbon constraints, while at the same time not transferring a disproportionate share of the emissions reduction task to other businesses or households.

Domestic assistance arrangements for trade-exposed, emissions-intensive industries

Assistance measures addressing the overshooting problem should seek to ensure that production by trade-exposed, emissions-intensive industries does not fall below the level that would eventuate had international agreements been in place. This implies the following definition of the appropriate level of assistance:

Assistance received by a firm	=	Expected uplift in world prices of the relevant good or commodity	×	Expected level of production by the firm in the event of the new world price

The effect of these assistance measures is demonstrated in 15A.

The assistance payments should be made contemporaneously with firm sales. Calculation of the expected uplift in world prices, while requiring estimation applying appropriate global models, is not inherently difficult.[15] It will require the administering authority to have substantial analytic capacity, and to adopt transparent simplifications that can be revised in the light of experience and criticism. However, scheme administrators are at a significant informational disadvantage in trying to assess the hypothetical level of production by individual firms in a world of comprehensive carbon pricing. This is a problem of information. The information problem is exacerbated by information asymmetry.

A less principled starting point for calculating assistance might therefore be thought necessary, in a period prior to establishment of the mechanisms required for principled and rigorous assessment. This would be at the cost of introducing a degree of arbitrariness into the design of the assistance regime. Arbitrariness inevitably introduces complexity, higher transaction costs and reduced efficiency of the assistance regime. If the simplifications to the approach are nevertheless thought to be attractive, it is important that they still:

- ensure that assisted firms continue to have an incentive to pursue lower-emissions opportunities in accordance with national policy to reduce greenhouse gas emissions
- reward firms that are already advanced in reducing emissions by providing assistance at a similar rate to all firms in an assisted industry, whatever their current emissions profile, and whether they are new or established
- encourage the commencement of an adjustment process within trade-exposed, emissions-intensive industries towards a future reality in which they will be competing on the basis of their carbon-inclusive comparative advantage.

The emissions intensity and trade exposure of industries must be assessed against rigorous materiality thresholds. Failure to do so would lead the scheme quickly to become administratively unmanageable and invite pressures on the political system, as the openness of the Australian economy means that many firms have some level of exposure to international markets, directly or indirectly.

Materiality thresholds must be calibrated so that only industries that are at genuine risk of large, excessive reductions in domestic production, are eligible for assistance.[16] While the definition of 'large' is ultimately a matter for judgment, it must be defined in a mind that is aware of normal, cyclical fluctuations in operating conditions. This will be examined in the light of the modelling results.

It is also necessary to identify at which point in the production chain the eligibility criteria are applied. Often value is added further down the production chain, but at a lower level of direct and indirect emissions intensity. For example, the production of steel and iron ingots is far more energy-intensive than the processes that prepare product for use. For practical as well as principled reasons, the process rather than the industry is the relevant basis for assessment of assistance. Unless circumstances overwhelmingly dictate otherwise, the process should end with an internationally tradable product.

It is the value of direct and indirect emissions associated with value added that should form the basis of the eligibility criteria for assistance. However, difficulties in calculating value added on a process basis argue for substitution of sales revenue with a corresponding adjustment to the industry threshold ratio.

Industry threshold ratio (eligibility for assistance)	=	Value ($) of direct and indirect emissions from industry	÷	Sales revenue ($) by process

The threshold ratio would be set at a level above which the industry impost from the permit price would represent an unreasonable shock relative to other vagaries of internationally oriented business. Payments would be made for permit costs in excess of the threshold.

Chapter 9 suggested that under a reasonable set of assumptions about the threshold ratio and the permit price, only a limited number of industries might clearly satisfy the emissions intensity eligibility criteria. As the permit price rises, they may include—assuming an economy-wide emissions trading scheme—aluminium smelting, cattle and sheep products, cement production, and iron and early stage steel manufacturing.[17]

The Review considers that considerable investment must be undertaken in developing the capacity required to implement, a principled and rigorous system for assistance. As outlined in section 15.3 this capacity may only be required from 2013, if there is a transition period with a fixed permit price.

Assistance payments would be made as closely as possible to contemporaneously with the timing of acquittal obligations.

For those firms eligible for assistance, whether payments were provided as cash or free permits is immaterial, so long as the cash-equivalent of permits is calculated precisely at the time of payment. If used as the form of payment, permits would be drawn from the relevant year's release schedule for permits. Under such circumstances, recipients of free permits would have no greater or lesser incentive to hoard permits for future use than any other market participant.

General business tax cuts and payments to trade-exposed, emissions-intensive industries

Materiality tests and algorithms for assistance payments will to some extent be arbitrary and will impose some degree of deadweight loss on the economy. Policy makers can be expected to encounter extreme pressure to err towards generosity. This poses genuine risks to the credibility of the entire emissions trading scheme:

An overly generous threshold will make administration of the scheme prone to a large degree of discretion by officials.

The more firms that are eligible, the more expensive (and expansive) scheme administration becomes and the greater the incentives for firms to divert resources towards extracting rents from government, rather than investing in emissions savings and profitable business operations.

If the eligibility criteria are set too generously, the burden of emissions reductions will be shifted elsewhere in the economy.

This is not to say that firms that do not meet the eligibility criteria would not encounter some cost impacts (direct and indirect) from the introduction of the emissions trading scheme. However, governments simply cannot efficiently administer, and the community cannot afford, a firm-by-firm assistance scheme that effectively addresses this impact at such an atomistic level of application.

A more efficient and effective option would be for government to form a view on the appropriate total level of payments to trade-exposed, emissions-intensive industries, and to recycle that part of these payments that is not committed to firms that exceed the threshold, into broad-based efficiency-raising tax reductions to the corporate sector. The Review suggests that a total commitment of up to 30 per cent of permit value might be justified. That would be tested as data becomes available to the regulatory authority. Detailed advice on tax reductions could be provided within the Henry tax review. While this approach sacrifices the precision of targeted assistance schemes, well-designed tax relief has the potential to reduce rather than increase the deadweight loss incurred by the economy. Obvious candidates for reduction or abolition would be input-based or transaction taxes, which are highly inefficient. Any such tax cuts should be ongoing not transitional.

The inherent arbitrariness of any assistance measures will make them the subject of intense scrutiny and lobbying by special interests. Yet there will be no counterbalancing representation arguing against the lowering of the materiality thresholds—even though doing so inevitably shifts the burden onto others in the economy and community. Policy makers will stand alone in having to resist the temptation to appease narrow interests.

Timing issues

Despite their importance, global and sectoral agreements will not be in effect in 2010 when the Australian emissions trading scheme begins operating. The Review judges that, given effective Australian leadership and diplomatic commitment, there are reasonable prospects for international sectoral agreements for carbon pricing to be in place by the end of 2012, at least for some of the resource-based industries in relation to which the Australian economy would be at greatest risk.

15.2.9 Governance and compliance

Institutional arrangements

Scheme governance has large implications for the efficiency, stability, credibility and simplicity of the scheme. New institutions will be required to operate and regulate the emissions trading scheme.

Some of these functions are of a kind that are the indelible prerogative of government. These include decisions about establishing the scheme—setting the emissions limit, and providing assistance to those whose incomes are reduced by the introduction of the scheme (for example, structural adjustment assistance, and payments to low-income households). Government will undertake policy functions, as distinct from an administrative role.

Legislation of key features of scheme design, such as the permit release trajectory, can assist stability—particularly in the Australian situation of qualified government control of the legislative process.

The administrative content of several of the governance functions is of a kind that lends itself to independent administration, particularly due to the large amounts of money associated with administrative decisions (for example, payments to trade-exposed, emissions-intensive industries). Government would be under pressure from particular interests to favour them in administrative decisions. As with the customs and taxation functions, there is an advantage in delegating administrative judgments to an independent entity.[18]

The Review suggests that the administration of the emissions trading scheme be made the responsibility of an independent authority—the Independent Carbon Bank—established with a high degree of executive independence in the exercise of its powers. The closest analogue is the Reserve Bank of Australia. As with the Reserve Bank, the powers of the independent authority would be defined by legislation and by agreement with government. This same legislation would define the way in which government would exercise its policy responsibilities in relation to the scheme, and the obligations of private parties in relation to emissions and the need for permits.

The distinctive roles of government and of the proposed Independent Carbon Bank, are summarised in Table 15.2.

Table 15.2 Governance of an Australian emissions trading scheme

Functions of scheme governance	Policy—government responsibilities	Implementation—independent authority responsibilities
Emissions trading scheme rules	All, including coverage, point of obligation, and compliance (for example, setting the penalty). Broad offset rules and standards.*	
Setting emissions limit	Decide—and announce—the initial budget and trajectory, and the nature, extent and timing of changes to the budget and trajectory.	Administer movement from one emissions trajectory to another, when government has certified that the conditions of change have been met.
Permit issuance and compliance, and use of revenue from permit sales	Determine manner of permit issuance and setting fixed prices for permits from 2010–12. Set requirements for acquitting permits, and set penalties. Receive revenue for general allocation under formula.† Decide on the use of permit revenue.	Release permits in line with emissions trajectories established by government. Purchase permits abroad as required to reconcile domestic emissions in particular years with international agreements or to provide for the honouring of the five-year forward commitment after a change in trajectory. Enforce compliance.
Trade-exposed, emissions-intensive industries	If domestic assistance is requried, set policy for eligibility. Negotiate global agreements and encourage effective sectoral agreements.	Assess eligibility and make payments.
Use of permits and cost containment. Hoarding and lending, and supervision.	Set broad policy on hoarding and lending.	Make decisions on lending and interest rates, supervision of market participants and stabilisation interventions. Monitor the creditworthiness of borrowers, and more generally the relationship between hoarding and lending and the stability of the market.
Enforcement of trade rules	Establish international trade agreement and rules for international linking.	Monitor trade, certify that conditions have been met in particular cases; purchase international permits to reconcile domestic and international obligations (for example, to meet a 2020 target).
Market supervision		Monitor integrity of market and transactions in the market, for stabilisation purposes.

* There should be independent, expert review, amendment and approval of offset protocols and offset projects.

† Revenue would come from sale of permits, interest on loans of permits and profits from stabilisation interventions (losses a sign of counterproductive intervention and to be accounted transparently). The formula would leave the Independent Carbon Bank sufficient income to cover the costs of its overhead, plus monitoring and enforcement of the system, including international permit purchases that are necessary to meet international obligations.

Penalties and make-good provisions

If a party with an obligation under the scheme fails to surrender permits equal to its emissions during a given compliance period, a penalty could apply—as a punitive measure rather than as an alternative form of compliance.

In a domestic emissions trading scheme, a penalty is required to drive compliance with the national emissions limit. Compliance would be enforced for:

- acquitting insufficient permits to match actual emissions
- failing to repay lent permits.

In case of non-compliance, a financial penalty would apply. It would need to be high enough to discourage non-compliance and to avoid it becoming merely a price cap.[19]

To ensure the integrity of the emissions limit and credibility of the scheme, financial penalties would need to be accompanied by a make-good provision applying to the non-compliant party that requires them to acquire and surrender an additional quantity of permits sufficient to cover (make good) these excess emissions, for example, in the next compliance period.

Scheme reviews

The emissions budget or trajectory may change over time in response to international developments.

Over time, adjustments may be made based on experience of the scheme in operation.

The Review considers it appropriate to hold the first evaluation two years after scheme commencement.

A minimum period of notice should be provided before changes to the scheme are implemented. Any changes that affect the supply constraint, or the fundamental operations of the scheme, should be implemented only after five years' notice. Conditions under which changes would be made should also be detailed ahead of scheme commencement. This approach should apply to rules for international linkages and acceptance of international permits and offset credits, as well as for scheme trajectories.

15.3 Transition period: Australia's emissions trading scheme to the end of 2012

15.3.1 Limiting scheme adjustment pressures to 2012

There has been some discussion of whether there should be a 'transition period' in the early years of the scheme, in which a maximum price is placed on permits.

Chapter 14 discussed the problems of price caps and floors, in general, and concluded that they should not feature in long-term arrangements. Flexibility to avoid short-term spikes in price could be achieved through a combination of multi-year targets, international trade in permits, and hoarding and lending of permits.

Is there a case for fixed prices or price limits in a transition period?

It will be crucial that an unconstrained market system operate from early 2013. To be a credible party to international negotiations on the post-2013 arrangements, Australia must be in a position firmly to deliver on emissions reduction commitments that it makes. Minimisation of costs of achieving emissions reductions targets requires trade with other credible emissions trading systems, which would be precluded by price caps or floors.

Is there a case for price controls in the remainder of the Kyoto period, to the end of 2012?

An opportunity for treating 2010–12 differently from subsequent years arises out of the combination of Australia being more or less on track to meet its Kyoto targets, and now from the high energy prices in global markets leading to reductions in Australian energy use. Australia would be likely to meet its Kyoto targets with a relatively low permit price in the early years.

If this course were to be followed, it would be necessary to separate the markets for permits before and after the end of 2012. In particular, it would be necessary to stop the hoarding of permits acquired in the period of price controls, for use after 2012.

There is one way of placing high limits on the price that would not require separation of the pre- and post-2012 periods. This would be through the acceptance from the beginning of permits from a large, deep emissions permit trading system. The European Union's scheme is the currently available candidate. If European permits were accepted for acquittal of Australian scheme obligations from the beginning in 2010 this would set a maximum price at the European level. Such a price limit would be consistent with full and unconstrained operation of the scheme from the beginning, including full integration of pre- and post-2012 arrangements.

If a lower domestic price were sought for the transition period, it should take the form of a fixed price rather than a price cap since it is possible that Australia will overperform on the Kyoto targets even with a low carbon price. There is a good chance that, in the absence of hoarding of permits for later use, the price of permits would be zero or close to zero. A period of derisorily low prices would be damaging for the credibility of the scheme in its formative years. A fixed price to 2012 would need to be accompanied by sale of post-2012 permits from the time that full details of the scheme had been articulated. This would be important to provide guidance on post-2012 market pricing, and to establish the credibility of post-2012 arrangements.

Is there a case for a transitional period with a fixed price, rather than immediate movement to the unconstrained scheme?

Many business submissions to the Review argued for low prices in a transition period, to reduce uncertainty about effects on costs while firms learned how the system worked.

A low fixed price would greatly reduce and, depending on the price and other factors, may obviate the need for payments to trade-exposed, emissions-intensive industries during the transition period. This would be a large advantage, allowing time for diplomacy to work towards establishing satisfactory sectoral agreements.

The disadvantages are also considerable. The process of learning the operations of the new market, and building the financial institutions and instruments to support it, would be somewhat delayed. Some uncertainty may be introduced about the credibility of post-2012 arrangements. The use of some fruitful opportunities for low-cost early abatement would be postponed—increasing the cost of meeting more demanding post-2012 trajectories.

On balance, the Review favours direct movement to an unconstrained system, with European Union permits being available for acquittal of Australian obligations if the necessary international understandings can be secured. Nevertheless, the Review recognises the advantages as well as disadvantages of a transition period with fixed prices to the end of 2012, and sees this as a legitimate second-best approach.

15.4 Optimal design features of an emissions trading scheme under a global agreement

The emergence of a comprehensive global agreement on emissions reduction would realise the central objective of Australian mitigation policy.

Such an agreement would change the context for Australian policy fundamentally. Australia would be required to honour its contingent commitment to move to a tighter emissions reduction trajectory.

Table 15.3 Key design features during a fixed-price transition period

Design decision	Transition — 2010–12
Setting an emissions limit	Australia's focus for the period to 2012 will be meeting its economy-wide emissions reduction target, established by its Kyoto commitment, reducing emissions in certain sectors according to a specified trajectory. It is likely to be easily met with a low, fixed price for permits. Overperformance on emissions reductions may allow issue of additional permits in the first post-Kyoto period. Any underperformance would be met by official purchase of international permits.
Domestic offsets	Acceptance of domestic offset credits would be allowed, noting that purchase of credits would be expected to occur only up to the value of the fixed permit price.
Issuing (or releasing) permits	Permits to be released according to demand, rather than in line with the emissions reduction trajectory. Permits to be sold at a fixed price, rather than being auctioned.
Trading permits	Trading of permits would be allowed, but unlikely to occur—parties could buy a permit at any time at a fixed price, and permits would not appreciate over time, so parties would be likely to leave purchases until close to the end of the compliance period. During the period 2010–12, there should also be some forward trading of post-2012 permits (to be acquitted post-2012). This will help establish futures markets and provide a guide to permit prices post-2012.
International linkages	During the period to 2012, acceptance of international permits and credits would be allowed (subject to limits outlined above) but would not occur unless the price of certified emissions reductions and international permits were less than the fixed price permit in the Australian scheme. Government may purchase international permits or offset credits to meet its Kyoto commitment if Australia's national emissions exceed its target.
Inter-temporality	There should be no hoarding or lending outside the period (post-2012). Similarly, hoarding and lending would not be expected within the transition period. Since permits have a fixed value over the period, there would not be an incentive to save or to bring forward permits, so long as a participant had the correct number for compliance.
Treatment of trade-exposed, emissions-intensive industries	Global and sectoral agreements should be pursued as a priority. During the transition period, price impacts should generally stay below reasonable thresholds, thereby limiting or entirely avoiding the need for assistance to trade-exposed, emissions-intensive industries.
Compliance and penalty	The aim of compliance in the transition period is for parties to acquit permits equal to their actual emissions. A penalty would apply for failure to surrender sufficient permits. A make-good provision would not apply.

The tightening budget and trajectories in themselves would be challenging. The extent of the additional challenge would depend on the content of the international agreement. However, associated changes in the environment for mitigation policy would be helpful to Australian adjustment, and the expansion in the opportunities for trade in permits would reduce the costs of mitigation. The realisation of an international agreement would remove a negative influence on credibility: up to that point, critics of the Australian scheme could claim that the absence of a comprehensive global effort meant that the adjustment costs being borne by Australia were not buying a solution to the climate change problem.

Under the approach suggested in section 15.2.2, the government would give five years' notice of a change in trajectory. This would provide a cushion against immediate additional adjustment pressures. In any case, the move to the more constrained permit release trajectory would have been anticipated to some considerable extent in the market. Spot and forward permit prices for some time, and perhaps from the beginning of the scheme, will have embodied a positive probability of the change occurring. The associated higher permit prices will have encouraged hoarding of permits, which would provide another cushion for the immediate adjustment.

The authorities would need to cover any gap that emerges between permit use (actual emissions) and international commitments during the five-year notice period of a changed trajectory. This could be covered by purchase of international permits through the use of funds accumulated for the purpose. If a large tendency towards hoarding within the private sector had caused earlier permit use (and emissions) to remain below previous levels of international commitment, this would reduce the need to purchase international permits.

Distortions associated with the lack of emissions constraints or pricing in major competitor countries would be addressed by a global agreement on emissions mitigation. Payments to trade-exposed, emissions-intensive industries, were they to be in place, would fall away without explicit change of policy or institutional arrangements.

Opportunities for trade in permits are likely to have expanded gradually during the years leading up to a comprehensive global agreement. The trade-off between domestic autonomy in scheme arrangements and gains from international trade in permits will have moved strongly towards the latter. With a greater number of countries accepting binding targets, international offsets should play a smaller role.

Governance of the emissions trading scheme will be simplified by international agreement; much less intervention will be required. After the five years during which permit release continues on an agreed trajectory, and perhaps before the end of that period, the balancing of external commitments against rates of domestic permits release will be undertaken mainly through private international trade. The deeper, more mature international markets for permits are likely to be more stable than national markets, so the need for official stabilising intervention in the market in Australia will be reduced

The successful operation of an Australian scheme in more difficult times—before an international agreement—will provide confidence in the challenging new mitigation environment. Evidence that substantial adjustment to a low-emissions environment had been achieved without economic dislocation would inspire confidence to face the adjustment challenge ahead.

Notes

1 The National Emissions Trading Taskforce was established in 2004 by state and territory governments. The officials of the taskforce submitted its final report to the Garnaut Review, *Possible Design of a National Greenhouse Gas Emissions Trading Scheme: Final framework report on scheme design*, without endorsement from governments, in March 2008. The Prime Ministerial Task Group on Emissions Trading was established in December 2006. Its report was published in May 2007.

2 The Emissions Trading Scheme Discussion Paper, and stakeholder submissions received in response, can be viewed at <www.garnautreview.org.au>.

3 It will be important to implement measures to drive emissions reductions in the non-covered sectors ahead of their inclusion in the scheme, to ensure that the task of achieving an economy-wide emissions reduction target is not borne solely by sectors covered under the scheme.

4 Note that to provide confidence about forward prices, information should also be provided to participants about any other changes to the scheme that would significantly affect the scarcity constraint imposed by the scheme budget. For example, details should be provided about the acceptance of international permits or offset credits, and links to other countries, and the conditions under which such arrangements may change (see section 15.2.7).

5 Domestic and civil aviation and sea transport should be included, with trade-exposed, emissions-intensive industry principles applied if appropriate. Bunker fuels, which are used in international aviation and shipping, are not covered by the Kyoto Protocol or included in countries' emissions targets (Article 2.2). The European Union, subject to final agreement, will include emissions from domestic and international aviation—operators of all arriving and departing flights—from 2012 (flights within the European Union are to be covered in 2011) (European Commission 2008). A sectoral agreement between international transport providers, such as a global fuel tax, should be pursued as a priority (see Chapter 13).

6 Further information about obligations under the National Greenhouse and Energy Reporting Act and supporting regulations is available from the Department of Climate Change at <www.greenhouse.gov.au/reporting/>.

7 During the first two phases of the EU scheme, the majority of allowances were allocated free of charge, including to established fossil fuel–fired electricity generators. Generators have generally passed on to consumers the opportunity cost of permits that they were given free (European Commission 2005; IPA Energy Consulting 2005). Taking into account the demonstrated ability of generators to pass on the notional cost of emissions allowances, the European Commission has recommended that all permits for the power sector be auctioned in the post-2012 arrangements (European Commission 2008).

8 For instance, options could include emissions in a particular base year or years (say, 2008 to 2012); average emissions per unit of production, based on installed technology in a base year; average emissions per unit of production based on best practice technology; other approaches; or any combination of these.

9 See, for example, Evans and Peck (2007) for a discussion of key issues to consider in designing an emissions trading scheme permit auction.

10 If permits are allocated free, conditions should not be placed on their use (that is, they should be traded as normal) to maintain incentives to reduce emissions (and sell excess permits), and to minimise economic distortions associated with free permit allocation.

11 Once 'future' permits are loaned, the trade of these permits (private lending) of these permits should be unrestricted.

12 In order for hoarding to occur, there would have to be early and cost-effective mitigation opportunities beyond those set by the emissions reduction trajectory.

13 In this context, carbon leakage refers to a situation whereby production moves from Australia to other countries without carbon constraints and potentially with higher emissions intensity production processes.

14 It is possible that even with a broad international agreement in place, trade-exposed, emissions-intensive industries in some countries may continue to operate outside of a national emissions limit. As outlined in section 13.4, the sectoral agreements would ensure that trade-exposed, emissions-intensive industries in countries without national emissions limits would nevertheless face an emissions price comparable to those in countries which have such as limit. The WTO agreement, proposed in section 13.5, would allow countries to impose border adjustments to ensure that competitors in countries with neither national emissions limits nor sectoral agreements do not have an unfair advantage. The WTO agreement would also play the important role of preventing the use (or rather, abuse) of border adjustments as instruments of protectionism.

15 This modelling should be undertaken by an independent authority (desirably the Independent Carbon Bank, which would undertake an open process involving detailed consultation with relevant parties.

16 Note that as this is a measure addressing economic efficiency rather than compensation, the threshold continues to be defined in terms of real output rather than profits.

17 Borderline industries include: liquefied natural gas production; alumina refining; ceramic product, basic chemical and pulp manufacturing; other non-ferrous metals smelting; rice and pig production.

18 In designing the optimal governance arrangements, a continuing challenge to one aspect of the emissions trading scheme could generate uncertainty about it is as a whole. Questions of income distribution are likely to be the most contentious in relation to the scheme. For this reason, distributional matters that are outside of the design of the scheme are fundamentally important to the success of the reform—adjustment assistance to low-income households in particular. These are discussed in more detail in Chapter 19.

19 The Review believes a price ceiling has disadvantages. Instead, market participants can be assisted in meeting the emissions limit through other means of cost containment, particularly access to international permits and offset credits, and flexibility in the time of use of permits through hoarding and lending.

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15A Trade-exposed, emissions-intensive firms

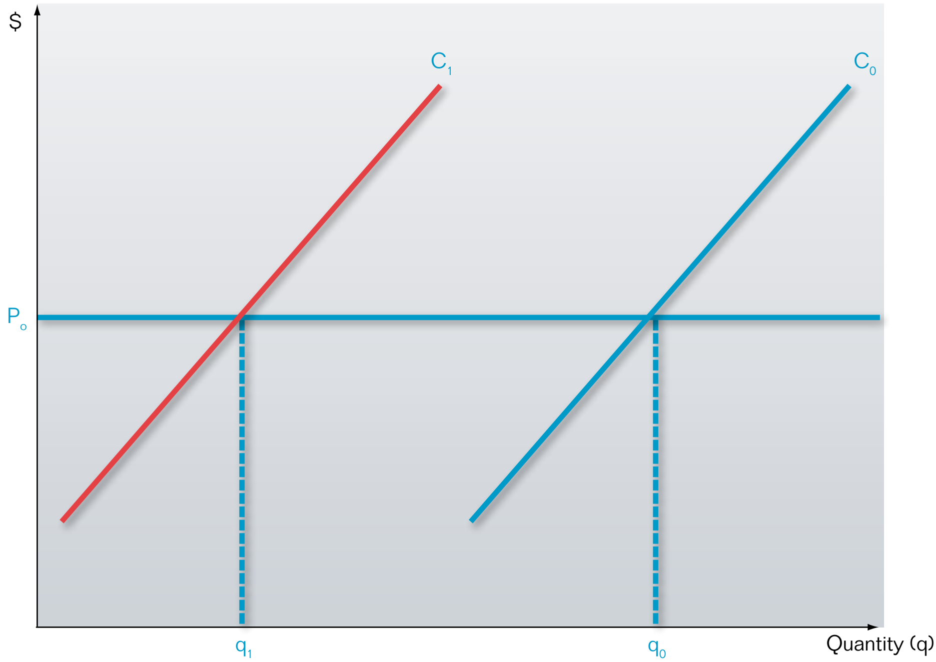
15A.1 The 'overshooting' problem for trade-exposed, emissions-intensive firms

Firms will seek to produce that level of goods or services that maximises their profits (though in the short term they might deviate from this objective in order to gain or maintain market share). With some factors of production assumed to be fixed in the short term—namely, the firm's capital stock such as plant and machinery—firms will produce at a point where their costs increase with each additional unit of production.

Where these firms compete in global commodity, goods or services markets they are assumed to be 'price takers'. Each firm's level of production has no bearing on the world price of the relevant product.

These descriptions of a trade-exposed, emissions-intensive firm can be usefully represented graphically with an upward sloping (marginal) cost curve (C_0) and a flat price curve set at the world price (P_0). The firm's resultant profit-maximising level of production is given by q_0 (Figure 15A.1).

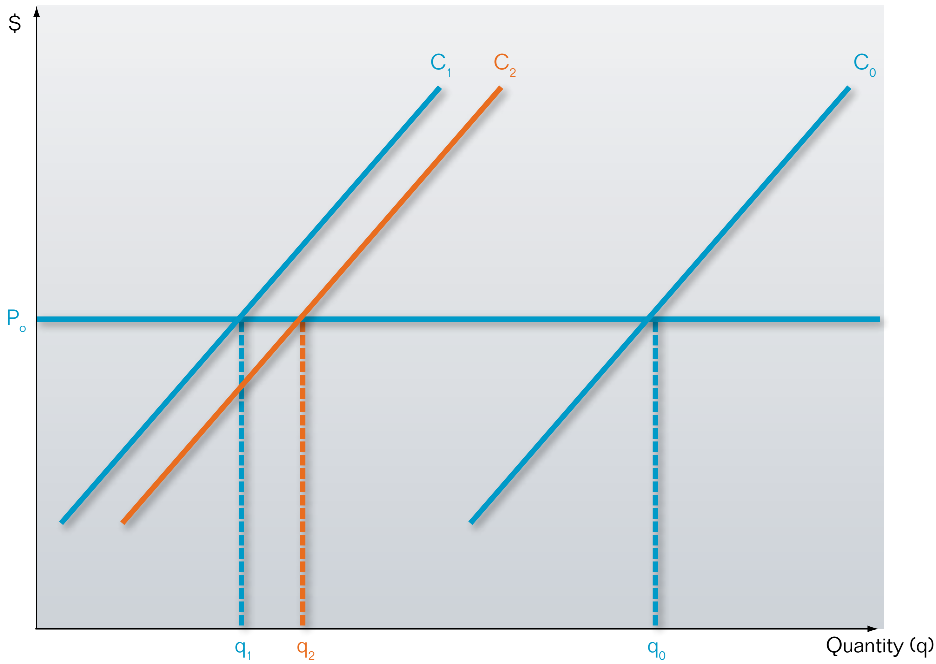
Figure 15A.1 Trade-exposed and emissions-intensive firm



The imposition of a carbon price increases production costs for all levels of production to the extent that firms employ emissions-intensive (direct and indirect) production processes. Graphically, a carbon price shifts the cost curve to the left (C_1) but has no bearing on the world price for the product (P_0). In response, profit-maximising firms will reduce their level of production to q_1 (Figure 15A.1).

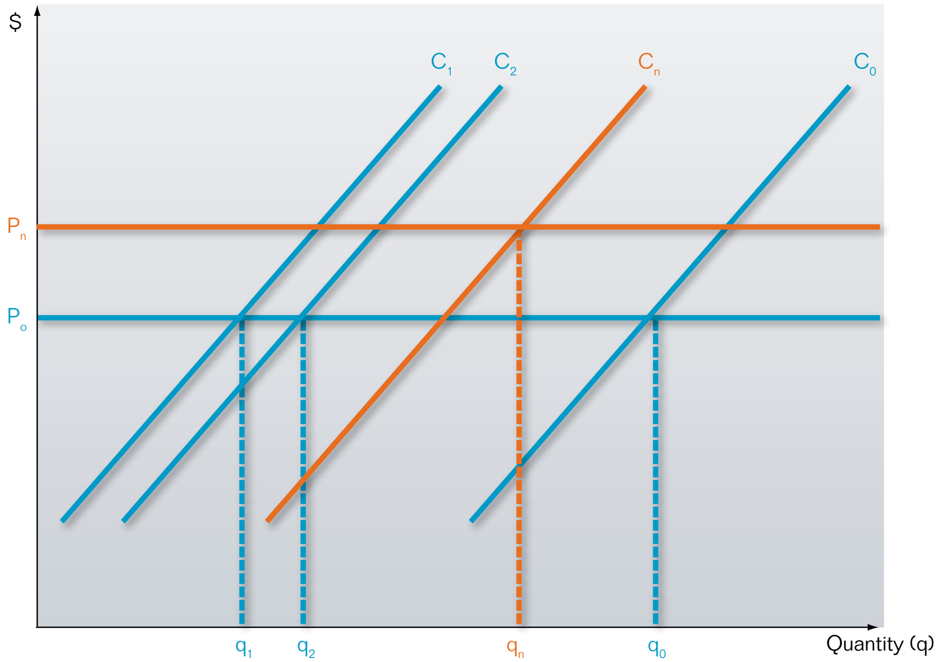
Over time, a firm facing a more expensive cost in its production process (namely, a price on greenhouse gas emissions) will look to switch from high to low emissions-intensive production processes in terms of both direct and indirect emissions. Graphically, this is represented by a shift of the cost curve to the right (C_2) (Figure 15A.2). While this has no bearing on the world price for the product (P_0), it will result in an increased level of production (q_2).

Figure 15A.2 Low emissions-intensive production



Eventually, as more and more countries adopt a carbon pricing regime, the world price of the relevant commodity, good or service will increase to P_n. In Australia, investment in new low-emissions processes by the relevant firm will continue until no further cost-effective improvements can be made to the production process. This is shown by cost curve C_n (Figure 15A.3).

Figure 15A.3 The overshooting problem



Under these conditions, the sustainable or long-run level of production for a profit maximising firm will be q_n. Figure 15A.3 shows an example where $q_1 < q_n < q_o$.

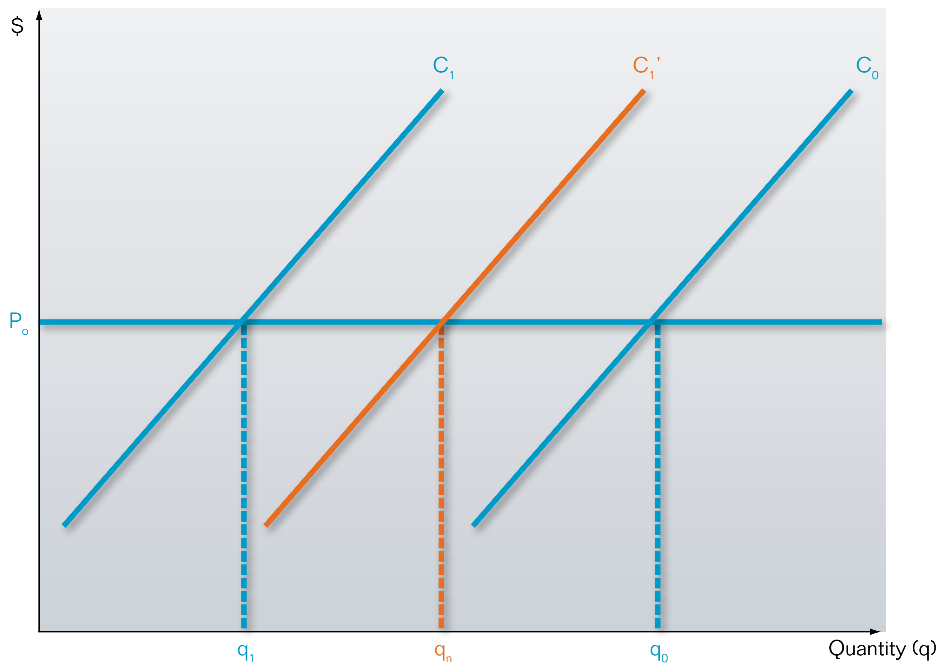
The overshooting problem is demonstrated graphically in Figure 15A.3 by the difference in production levels between q_n and q_1. This gap will reduce to $q_n - q_2$ as the firm undertakes new investment.

If Australia is relatively more efficient than international competitors, it is possible that q_n could be greater than q_o—in which case there would be no overshooting problem.

15A.2 Domestic assistance arrangements for trade-exposed, emissions-intensive firms

Transitional domestic assistance arrangements for a trade-exposed, emissions-intensive firm would seek to correct for the overshooting of the sustainable level of production q_n. By countering the effects of the carbon price on the firm's cost of production, the government would be seeking to shift the firm's cost curve so that the profit-maximising firm will not reduce production below its sustainable level of production q_n. This would be achieved by the government making a payment (in cash or permits) per unit of production so that the firm's cost curve is shifted to the right (C_1'). The unit value of the initial support given to the trade-exposed firm is given by the vertical distance between C_1 and C_1' (Figure 15A.4).

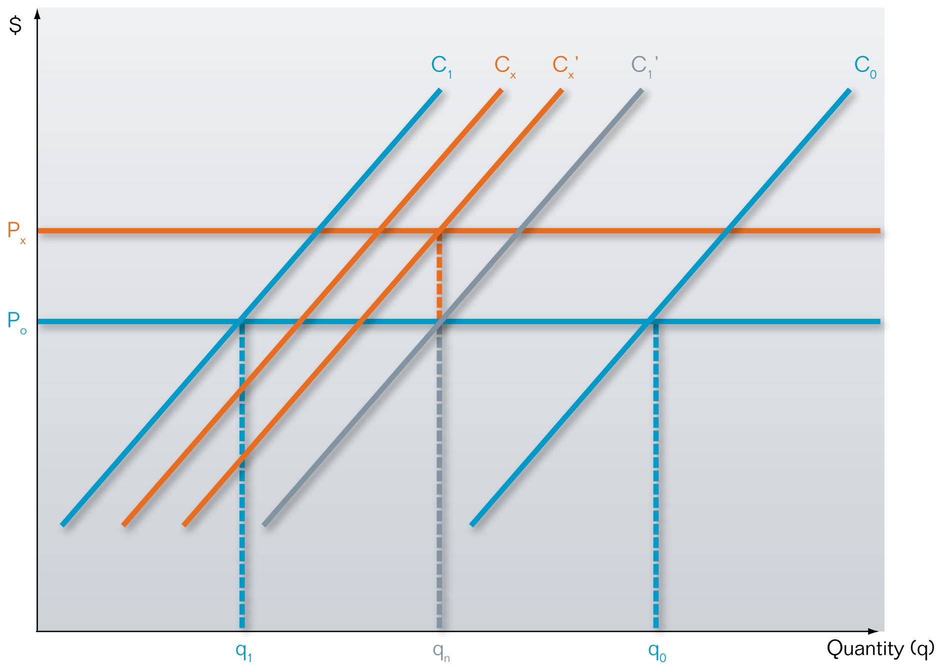
Figure 15A.4 Domestic assistance



In time, the firm will invest in new production processes (shown as C_x in Figure 15A.5). Further, an increasing number of countries are expected to adopt some form of emissions constraint leading to the price of the traded commodity or good increasing (to P_x), though not all the way to the sustainable world price (P_n).

The new level of support is represented by the vertical distance between C_x and C_x'. Under such circumstances, the level of transitional support provided to the trade-exposed, emissions-intensive firm will diminish over time—that is: $(C_x - C_x') < (C_1 - C_1')$.

Figure 15A.5 Domestic support diminishing over time



16 RESEARCH, DEVELOPMENT AND INNOVATION

Key points

Basic research and development of low-emissions technologies is an international public good, requiring high levels of expenditure by developed countries.

Australia should make a proportionate contribution alongside other developed countries, in its areas of national interest and comparative research advantage. This would require a large increase in Australian commitments to research, development and commercialisation of low-emissions technologies, to over $3 billion per annum.

There are externalities associated with private investment in commercialising new, low-emissions technologies.

To achieve an effective commercialisation effort on a sufficiently early time scale, an Australian system of matching grants should be available where private investors demonstrate externalities, low emissions and innovation.

A new research council should be charged with elevating, coordinating and targeting Australia's effort in low-emissions research.

The successful development and deployment of new low-emissions technologies across all sectors will be important in minimising the costs of adjustment to the emissions trading scheme.[1] As other countries adopt similar constraints on emissions, there will be new opportunities for expansion in sectors where Australia is able to develop an international comparative advantage.

Australia is particularly well positioned to develop and deploy a wide range of new mitigation technologies, particularly in the energy sector (Energy Futures Forum 2006). Although the potential for emissions reductions may initially appear to be concentrated in some sectors, if tighter emissions caps are implemented in the long term, new low-emissions technologies will be important right across the economy.

A wide variety of new and existing technologies were highlighted in submissions to the Review as being potential contributors to Australia's mitigation task. A selection of these is set out on in Table 16.1.

Table 16.1 Technologies relevant to mitigation cited in submissions to the Review

Industry	Technology type	Organisation/individual
Electricity generation	Geothermal (hot rocks)	Australian Geothermal Energy Group, Australian Geothermal Energy Association Geodynamics Ltd, Geogen Pty Ltd
	Improved generation efficiency (e.g. coal drying)	Australian Academy of Technological Sciences and Engineering, Anglo Coal Australia Pty Ltd
	Solar (photovoltaic and thermal)	Australia and New Zealand Solar Energy Society, Australian Academy of Technological Sciences and Engineering, Andrew Blakers, Beyond Zero Emissions, Barrie Pittock
	Other energy	BioEnergy Australia
Transport	Lower-emissions vehicles	Australia Automobile Association, BusVic
	Second and third generation biofuels and biomass	BioEnergy Australia, Environmental Health Central Australia, NSW Department of Premier and Cabinet, NSW Department of Primary Industries, MDB Biodiesel Ltd.
	Electric cars	Centre for Education and Research in Environmental Strategies (CERES), Australian Academy of Technological Sciences and Engineering, GetUp
Sequestration	Soil sequestration (biochar)	Tim Flannery, Department of Agriculture and Food WA, WSN Environmental Solutions, BEST Energies Australia, Beyond Zero Emissions
	Geosequestration	Australian Coal Association, BP Hydrogen Energy Australia Pty Ltd, Santos Ltd, ZeroGen Pty Ltd, Australian Energy Company Ltd
	Algal sequestration and biofuels	MDB Biodiesel Ltd, NSW Department of Primary Industries

Note: The categories in this table are illustrative only based on the general content of submissions. The table is not to be taken as a comprehensive, representative or exhaustive summary of the arguments presented. Please refer to the full submissions on the Review website for details.

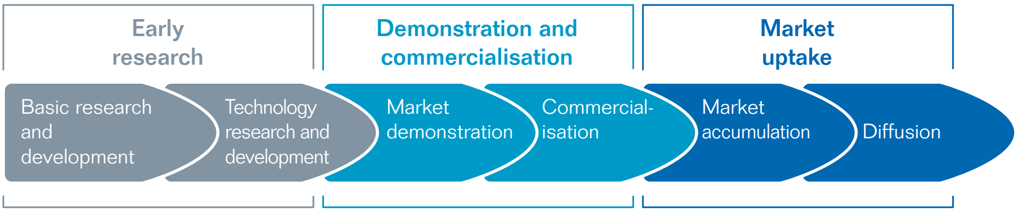
Emissions reductions could come from any and all sectors, including energy, transport, construction, agriculture, waste and forestry. Compared to the cumulative wisdom of the many market participants, governments will never be well placed to foresee the successes and failures of new goods, services and processes. Current official views of the relative merits of different technologies therefore should not be a factor in the policy development process. However, government must be mindful of the potential need for new institutions, regulatory frameworks or infrastructure as a result of new technologies (see Chapter 17).

16.1 What is innovation and how does it happen?

Although it entails a degree of simplification, the 'innovation chain' concept can help identify policies that are appropriate for different stages of development (Foxon et al. 2008).

For the purposes of economic analysis and policy development, the Review has adopted a simplified model of the innovation chain as shown in Figure 16.1. The three distinct phases of the innovation chain are discussed in greater detail below.

Figure 16.1 The innovation chain



Source: Adapted from Grubb (2004).

Early research: In this phase, contributions are made to basic science and knowledge, usually at research institutions at a laboratory scale, with few immediate commercial returns. The knowledge and information generated tend to be of benefit globally, are difficult to keep secret, and can be easily disseminated at low cost. Due to the stochastic nature of new discovery, there are also benefits for society when early research is coordinated or collaborative.

Demonstration and commercialisation: The new knowledge generated by early research is applied to the real world through pilot, demonstration and first commercial-scale projects. These activities tend to be capital intensive in nature, requiring research bodies or firms to take on substantial risk since the technology is yet to be proven in the intended operating environment. Because the technology may not yet be cost-competitive (even after factoring the impact of a price on emissions), commercial returns are problematic. Projects must therefore rely on high-risk venture capital funding, government support, niche market support or philanthropic patronage. Some studies have termed this phase 'the valley of death', where most technologies fail either technically or financially (Grubb 2004; Murphy & Edwards 2003).

Market uptake: Once new knowledge is converted into a tested product or service, it is sold to the open market. Technologies at the market uptake stage are technically proven and therefore able to compete with other mature products in the marketplace.

16.1.1 How will an emissions trading scheme affect technological development?

As the emissions trading scheme raises the costs of greenhouse gas emitting activities, new and existing low-emissions technologies will become more profitable. Mature technologies will be most affected by the demand–pull effects of an emissions trading scheme.

An emissions trading scheme will also spur private sector research and development activities by creating the long-term demand–pull for more low-emissions products and processes. However, there may be only limited impacts on early research activities since most early research is publicly funded. Changes to funding are dependent on how quickly the funding bodies respond through the reallocation of resources to new research areas.

Both public and private research and development will have a large impact on the economy-wide cost of emissions reductions in the medium to long term.

Note that over time technological change and development will naturally bring down the cost of various low-emissions technologies once they have been deployed. This has been the case, for example, with the internal combustion engine and fossil-fuel based generators over the past century.

In the case of energy technologies, rising fossil fuel scarcity will go a considerable way towards making some low-emissions technologies competitive, even in the absence of a carbon price. However, high fossil fuel prices can never make sequestration of emissions as cheap as free release into the atmosphere.

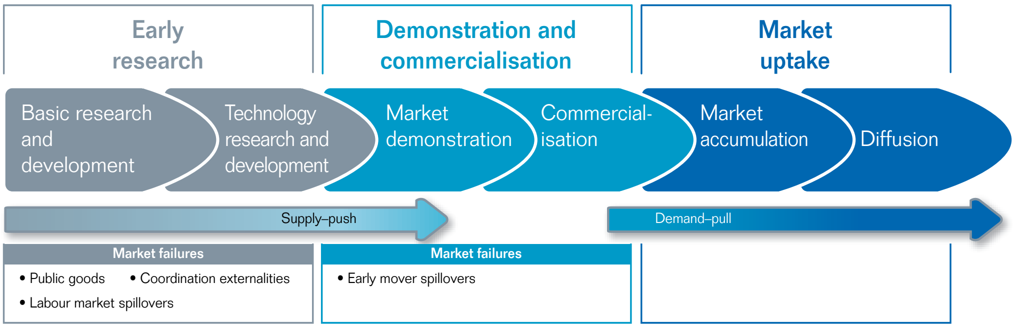
16.1.2 What are the barriers to an efficient market response?

While an emissions trading scheme will drive both the development and uptake of new low-emissions technologies, market failures that impinge on the efficient and competitive function of markets for new ideas and technologies may result in suboptimal levels of investment in innovation. These market failures stem from the special characteristics of ideas and knowledge, as well as the unique processes of knowledge creation.

If, as a result of market failures, there are suboptimal levels of investment in low-emissions technologies, then inferior, more expensive substitutes will need to be deployed to reduce emissions. This inefficient response will lead to a carbon price that is higher than it would otherwise be.

These market failures are most important in the early research and demonstration and commercialisation phases of the innovation chain (see Figure 16.2). The emissions trading scheme will create sufficient demand–pull for new low-emissions technologies, and thus there is generally no need for any additional support for innovation at the market uptake stage.

Figure 16.2 Market failures along the innovation chain



Correction of these market failures is a strong economic justification for government policy intervention. Economic studies have emphasised the role of innovation policy in delivering least-cost emissions reduction (Stern 2007; Productivity Commission 2007a; Jaffe et al. 2005). This rationale for government intervention holds true even in the absence of the climate change challenge, but as the emissions trading scheme delivers quick and profound shifts in the economic context, there will be a special requirement for high rates of technological improvement in low emissions technologies. The emissions trading scheme will raise the opportunity cost of an inadequate market response to incentives for new technologies.

Any justifications for policy outside the market failure rationale should be rejected (see Box 16.1).

Box 16.1 Wrong arguments for innovation policy in the context of an emissions trading scheme

Some rationales for government intervention in the area of innovation do not have a sound economic basis. A credible emissions trading scheme would address the issues of environmental integrity and urgency of action, such that the remaining rationale for technology policy should only be the correction of material market failures that could increase the cost of mitigation. Some wrong arguments for innovation policy in this context include:

- *There will not be enough innovation or time to develop new technologies for Australia to successfully meet its national targets.*

The cap on emissions is binding, such that emissions reductions will have to be delivered regardless of the technologies available. Ultimately, this cap may be met through reductions in consumption, if need be, in a very short time.

- *The permit price will initially be low and therefore will not drive much innovation.*

There is no reason for the permit price to be uneconomically low with the anticipated future scarcity of permits. If it seems to be the case, then this may reflect market optimism that suitable new technologies will be available in the future. If this is not the expectation, then the incentive would be to hoard permits for future use when scarcity, and therefore prices, are higher.

- *We need to invest in innovation to lessen the impact of the carbon constraint.*

Investing in innovation when there are no requisite market failures requiring correction is likely to lead to greater economic cost, not less.

16.2 Ensuring optimal levels of early research

16.2.1 What are the market failures in early research?

Public good nature of early research

Early research is characterised by substantial spillovers arising from the non-excludable or non-appropriable nature of knowledge. In most cases, once new basic knowledge is created, it is impossible to exclude others from benefiting from that knowledge (Arrow 1962). This is the strongest rationale for government intervention at the early research phase of the innovation chain (Productivity Commission 2007b). Excludability is further diminished by the often relatively low incremental costs of diffusion (Stephan 1996). This is especially the case when the knowledge is transparently embodied in a product or process, readily codified and easily diffused (Productivity Commission 2007b). In addition, knowledge is non-rivalrous in nature in that, once it is created, many individuals or firms can use and apply it, thus making it a public good.

Externalities from coordination

There is evidence both nationally and internationally that collaboration yields measurable benefits for participating individuals and organisations. In Australia, an analysis of Australian Bureau of Statistics data found that businesses that engage in collaboration are significantly more likely to achieve higher degrees of innovation (Department of Industry, Tourism and Resources 2006).

Currently in Australia, the cooperative research centres are the most direct approach to encouraging collaboration in early research.[2] Many of these centres, particularly those in the mining and energy sector and the manufacturing sector, undertake collaborative research in areas that are potentially relevant to climate change mitigation: advanced automotive technology, construction innovation, sustainable resource processing, coal in sustainable development and greenhouse gas technologies.

Positive externalities that spill into the labour market

The supply of skilled labour in some industries is closely tied to early research activities. Early research activities often have the added benefit of being vehicles for education and training because those who conduct research also usually teach. Therefore a shortfall in early research and development funding could also result in medium- to long-term labour market shortages. Even if the research itself does not result in immediate and significant direct economic benefits in the form of new technologies, the concurrent expansion and development of the labour force may still yield a substantial indirect economic benefit in the long run.[3] The Productivity Commission (2007b) found that the benefits of research and development in both universities and public sector research agencies is high, due to their orientation to public good research and their role in the development of high-quality human capital for the Australian economy.

16.2.2 Are current policies targeting early research sufficient?

Like most developed countries, Australia has an established institutional framework for allocating research funding across the economy. The Productivity Commission (2007b) has recently highlighted the expanding need for public good research in the light of future environmental, energy and climate challenges as one of the potential stresses on the Australian innovation system.

For example, despite being among Australia's stated national priority research areas (DEEWR undated), funding for energy supply research has increased only marginally off a low base in recent years (ABS 2006). Australia's expenditure on energy supply technologies, in general, ranks low among OECD countries (based on OECD 2008). Internationally, energy-related research and development is dominated by just a few countries (based on OECD 2008) such that the research activities and priorities of a small number of countries are likely to determine the global range of low-emissions technologies in the future.

In the absence of incentives flowing from a carbon constraint, falling levels of investment in early research in areas important to the mitigation challenge have been a global phenomenon (see Figure 13.1 in Chapter 13). For example, the Fourth Assessment Report of the IPCC found: 'Government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level' (IPCC 2007: 20).

These are imperfect indicators for low-emissions research since there can be many reasons for declining levels of early research funding in any one area; there is no definitive data on early research funding for low-emissions technologies.

The Review is of the view that the low levels of government expenditure on research and development in key areas like energy supply, juxtaposed with the rising importance of low-emissions energy technologies for Australia's mitigation effort, suggest that current funding levels do not reflect the priority placed on the issue by both the government and Australians more generally.

It is important that this issue be looked at from an international perspective since research is an international public good. Section 13.1 recommends that high-income countries support an International Low Emissions Technology Commitment, requiring them to allocate a small proportion of GDP to research, development and commercialisation of new, low-emissions technologies and technology transfer, at home or abroad. The chapter provided an indicative global figure for this fund of $100 billion per year, and an indicative Australian share of $2.8 billion.

16.2.3 New institutions to drive early research in mitigation technologies

The significant challenge of deep cuts to emissions suggests that Australia's early research agenda needs to focus more strongly on early research into low-emissions technologies, to shorten the lag between the introduction of the emissions trading scheme and the response of the research community.

Government has long attempted to resolve the issue of how much priority is appropriate for each area of research by establishing institutions, such as the Australian Research Council, that allocate resources according to strategic importance and national capability. This reprioritisation could be achieved through the creation of a new institutional body or structure charged with elevating, coordinating and targeting Australia's effort in low-emissions research. Such a body could operate in a similar way to the National Health and Medical Research Council (NHMRC[4]). It could oversee a new push in early research for low-emissions technologies, operating independently to correct the market failures discussed above.

Like the NHMRC, this research council could have three mutually reinforcing core functions:

- allocating public funding for early research across relevant areas based on clearly established criteria (see section 16.2.5)
- coordinating relevant early research activities within Australia and promoting links with research activities in the Asia–Pacific region and globally by pursuing and forging partnerships between organisations, or through funding criteria in favour of collaborative research programs
- guiding training in low-emissions technologies throughout Australia, including the development of higher education programs. New tertiary programs could include courses that develop interdisciplinary expertise for businesses to manage the implementation of emissions compliance, as well as the technical skills for the development and adoption of new technologies.

16.2.4 Where could additional funding for early research come from?

One possibility is that existing funds allocated to relevant research areas could be consolidated and reallocated by the proposed research council. However there are good reasons for not reallocating all existing funding. Firstly, it is important to maintain the continuity in the allocation of existing funds. Secondly, it is beneficial to maintain some plurality of funding sources; general institutions can co-exist with specific funding bodies, thereby ensuring that no one body holds the purse strings for all the funding in any one area. Some existing funding arrangements may continue on this basis, but a review of all programs may be warranted to identify those that are yielding limited returns on investment.

Additional funds for early research in low-emissions technologies could come from the revenue from the auctioning of emissions permits. The allocation of a consistent level of annual permit revenue towards public good research in fields relevant to low-emissions technologies could form the major portion of funds to be allocated by the proposed research council. It is sensible to use permit revenue to fund early research because there are strong links between the early research effort, the long-term cost of mitigation and the carbon price. More early research in low-emissions technologies should, over time, lower the long-term cost of mitigation and thus the carbon price.

All commitments of funds for early research would qualify under the International Low Emissions Technology Commitment proposed in section 13.1.

16.2.5 Criteria for allocating funds for early research

The allocation of resources to innovation in general is complicated by two trade-offs. First, there is a trade-off between the desire to provide technology-neutral support in order to avoid distorting the selection of technologies by the market; and the competing desire to concentrate resources on more promising areas. Policies to assist innovation must find the right balance between providing technology-neutral and technology-specific support; between encouraging options and achieving increasing returns.

Second, funding decisions must balance the role of knowledge generation within Australia and the adoption of ideas and technologies from the global research effort. Technologies with broad application and commercial potential are likely to be developed outside Australia. In many of these areas it will be sensible for Australia to be a technology taker rather than duplicating the international research effort.

Despite the desire to avoid 'picking winners', there is inevitably a good deal of discretionary judgment in decisions on allocation of public funding for early research. The proposed research council therefore should be guided by clear criteria to ensure that funds are allocated to areas that are likely to result in the highest economic value for Australia. There are two important criteria that need to underlie any funding decisions in early research: (1) Is this area of research of national interest to Australia? (2) Is this an area of early research where Australia has a comparative advantage?[5]

The criteria for both national interest and comparative advantage can be expected to shift over time. Therefore, the funding allocation should be subject to a transparent and independent process of periodic evaluation and review (Productivity Commission 2007b). There should be the swift termination of funding for projects that no longer meet the criteria or are simply unviable.

Criterion 1: Is this area of research of national interest to Australia?

Australia should only fund early research that is well aligned with its national interest. In the case of climate change mitigation, considerations should be based on both current circumstances and future projections, and could include:

- **Australia's emissions profile:** The high emissions intensity of electricity generation and the high levels of emissions from agriculture are two examples of unusual characteristics of Australia's emissions profile (see Chapter 8 for some indicators).
- **Technological solutions particular to local conditions:** Many technologies can be adopted from overseas and applied to the Australian context. The deployment of wind turbines from Europe is one example. However, some technologies will be subject to local factors such as geographical contours, geological formations, and climatic conditions and variations.

Box 16.2 Examples of areas of strategic interest for Australia

Technological solutions in carbon capture and storage, soil sequestration, solar technologies, algal biosequestration and geothermal energy are among the areas in which Australia has disproportionately strong opportunities and interests. The successful development of these technologies could be expected to have exceptional application within Australia.

Table 16.2 Brief assessment of two technology categories against criteria for national strategic interest

	Carbon capture and storage for coal-fired electricity generation	Algal biofuels
Australia's particular emissions profile	Coal-fired electricity generation is a major contributor to Australia's high emissions intensity of energy.	Some algal biosequestration processes could absorb emissions from coal-fired electricity generation and metals smelting.
Technological solutions particular to local conditions	Australia has a variety of geological formations that are suitable for long-term geosequestration.	Few other developed countries have the required natural conditions.
Sources of Australia's economic prosperity	Any proven technology that cost-effectively reduces the emissions from coal-burning will be highly demanded in the future when climate change mitigation becomes a global priority. Carbon capture and storage will also maintain the value of Australia's coal resources as a commodity both for domestic consumption and export.	Algal biofuels could provide energy security and economic growth as it has a higher yield per hectare than traditional crops, with much higher energy returns. Algal biofuels could also prove competitive with fossil fuels in light of increasing global scarcity.
Technologies that build on Australia's natural resource advantage	The abundant availability of coal, and subsequently low energy prices are sources of comparative advantage for Australia. The export of coal itself is a significant contributor to Australian GDP.	There are several regions around Australia that could potentially provide the intense insolation and saline and other non-productive land needed to cultivate algae for biofuel production at a large scale.

- **Sources of Australia's economic prosperity:** Sectors that are important sources of economic prosperity today or could become sources of economic competitiveness in the future are areas of research that coincide with a broader strategic interest for Australia.

- **Technologies that build on Australia's natural resource advantage:** Australia is in a unique position among developed countries of having a per capita abundance of a wide range of natural resources. Research that focuses on new technologies and processes which allow these resources to be exploited should score more favourably under this criterion.

Criterion 2: Is this an area of early research where Australia has a comparative advantage?

Australia should only undertake early research in areas where it has a comparative advantage. The Review recognises, however, that it is difficult to determine what exactly Australia's core areas of comparative advantage are in early research as there are no perfectly objective measures for comparing different fields and disciplines. The proposed research council would therefore need to consider a range of proxy indicators of comparative advantage when making funding allocation decisions.

In some instances, the absence of any comparative advantage should be very clear. For example, although the export of uranium is one source of economic prosperity in Australia (and therefore an area of national interest), the fact that Japan and France outspend Australia by a factor of 300 and 150 respectively on nuclear energy research each year (Commonwealth of Australia 2006) suggests that early research in nuclear generation is not a core priority area for Australia.

Australia's demonstrated strength in agricultural research is an example of an area of clear comparative advantage. In 2004–05, almost one-quarter (23.4 per cent) of all government expenditure on research and development could be attributed to plant production and plant primary products, and animal product and animal primary products.

16.3 Rewarding early movers

The early movers of a new industry are those that undertake the first demonstration and commercialisation projects. The spillovers from these early-mover activities mean that in the absence of government intervention, there will be suboptimal levels of private investment in demonstration and commercialisation projects.

16.3.1 Spillovers from demonstration and commercialisation

In most new industries, the early movers bear all the costs of demonstrating and bringing a new technology to market, while later movers share in all the associated benefits that spill over directly from the early movers' investments.

These spillovers can result in a strong disincentive for any firm to be the early mover, realising that it must ultimately compete with late movers who are able to carry out operations at low cost without having to bear the upfront investment. This is likely to result in an undersupply of early mover activities. For some new industries, multiple spillovers may cumulatively amount to a 'show-stopper' market failure resulting in no activity at all.

What may seem to be spillovers are not always real externalities, as there may be secondary mechanisms through which these spillovers are internalised. For example, early movers may reap the benefit from early gains in the form of brand reputation, product recognition and early leads in market share. These benefits may provide sufficient incentives to bear the upfront costs if the remaining spillovers are relatively small.

There are five main types of spillovers that result from early mover activities which government must address to ensure an efficient level of demonstration and commercialisation activity.

- **Knowledge externalities:** Early movers who make the initial high-cost investment to demonstrate or apply new technologies can generate substantial contributions to the knowledge base of an industry, which later benefits the industry more widely. These knowledge and information benefits over the long run have been observed in the steep decline in the costs of new technologies during the demonstration and commercialisation stages.

  While knowledge spillovers can be internalised through the creation and enforcement of intellectual property rights, such as through the patent system, this solution is inherently imperfect as not all knowledge lends itself to patent protection (Jaffe et al. 2003; Fri 2003). Furthermore, patent rights are not self-enforcing; remedying breaches often requires costly legal action (Martin & Scott 1998).

- **Skills spillovers:** Early movers contribute to the future of all firms in an industry by bearing the upfront costs to develop appropriate technical skills and capacity and associated training courses. This has a positive lingering effect in the labour market and later movers are able to draw on this increased pool of skilled labour, up to some economic limits.

- **Regulatory and legal spillovers:** Early movers may bear the large upfront costs of working with government and other industries to develop new regulations and harmonised standards. This could include significant costs associated with resolving legal disputes regarding new regulatory frameworks with government and other industries. Later movers benefit from regulatory clarity and have established avenues for secure agreements and contractual arrangements.

- **Support sector externalities:** The development of supporting industries inevitably requires some additional investment by early movers—for example, to identify suppliers with appropriate manufacturing capabilities, develop suitable products and product standards with those suppliers, and test new parts and components. Firms that enter the market at a later stage are then able to benefit from an established support sector without having had to bear the upfront costs.

- **Social acceptance spillovers:** Communities can be apprehensive of new technologies that are visually or acoustically intrusive, potentially dangerous, or simply novel and not yet fully understood. An early mover firm looking to commercialise such a technology will often bear the costs of capital-intensive demonstration projects and communication and information exercises to increase people's confidence in the safety and effectiveness of its particular technology. The higher level of social acceptance achieved is then enjoyed at no cost by later movers promoting similar technologies.

16.3.2 Are current policies for demonstration and commercialisation sufficient?

The Productivity Commission (2007b) has noted that the emphasis on innovation in Australia has moved towards demonstration and commercialisation projects: many recent low-emissions research and development policies have been targeted at the market uptake stages of the innovation chain (see Table 16.3). This could be because the scarcity of funding intensifies the pressure to focus resources 'downstream' on shorter-term, applied research aimed at the deployment of mature and commercial technologies.

Table 16.3 Research and development programs in Australia targeting low-emissions technologies

Policy/fund name	Description	Funding
Low Emissions Technology Demonstration Fund	This fund supports the commercial demonstration of technologies that have the potential to deliver large-scale greenhouse gas emission reductions in the energy sector.	$410 million over 11 years from 2004–05 to 2014–15
Renewable Energy Development Initiative	This initiative is a competitive merit-based dollar-for-dollar grants program supporting renewable energy innovation and commercialisation.	$100 million from 2004–05 to 2010–11
Solar Cities	This program is designed to demonstrate how solar power, smart meters, energy efficiency and new approaches to electricity pricing can be combined.	$93.8 million over nine years from 2004–05 to 2007–08

Table 16.3 Research and development programs in Australia targeting low-emissions technologies *(continued)*

Policy/fund name	Description	Funding
Energy Technology Innovation Strategy (Victorian Government)	This funding aims to assist the commercialisation of coal drying, coal gasification and geosequestration technologies to reduce greenhouse gas emissions from brown coal electricity plants. This funding supports some Low Emissions Technology Demonstration Fund projects.	$182 million from 2008
Queensland Future Growth Fund	This funding supports the deployment of low-emissions coal and renewable energy technologies. The fund will operate separately from the Queensland state budget.	$350 million
Green Car Innovation Fund	This fund aims to support the manufacturing of low-emissions vehicles in Australia. The fund will operate on a matched funding basis at a ratio of 1 to 3.	$500 million over five years from 2011–12 to 2016–17
National Low Emissions Coal Fund	This fund aims to reduce greenhouse gas emissions and secure jobs in the coal industry by stimulating investment in clean coal technologies with matched funds at a ratio of 1 to 2.	$500 million over seven years from 2009–10 to 2014–15
Renewable Energy Fund	This fund targets renewable energy demonstration projects with private sector funds matched at a ratio of 2 to 1. Funding will be distributed through competitive grants, based on the goal of encouraging a range of technologies across a range of geographic areas. Fifty million dollars has been earmarked for dollar-for-dollar matched funding for private investors in the geothermal industry.	$500 million over seven years from 2008–09 to 2014–15
Energy Innovation Fund	Investments are targeted equally towards the Australian Solar Institute (solar thermal), photovoltaic research and development, and general clean energy research and development, including energy efficiency, energy storage technologies and hydrogen transport fuels.	$150 million over four years from 2008–09 to 2012–13

Sources: Prime Ministerial Task Group on Emissions Trading (2007), Australian Treasury (2008).

Many of these industry support programs have the effect of providing incentives for early movers, but there is a conspicuous absence of a targeted technology-neutral program for dealing with the spillovers discussed in section 16.3.1.

The Productivity Commission (2007b: 371) found that this issue of poorly targeted policy was characteristic of technology programs in Australia more generally:

> Australia's current suite of business programs do not target rationales for public support (additionality and spillovers) effectively and, as a consequence, involve substantial transfers from taxpayers to firms without attendant net benefits. The need to raise taxation revenue to fund these transfers creates large efficiency losses.

16.3.3 A matched funding scheme to compensate early movers

The externality benefits from early-mover activities will vary widely on a case-by-case basis. Different projects in different contexts will generate different types of spillovers at a variety of levels. The prohibitively high administration and compliance costs of quantifying spillovers on a case-by-case basis means that such an approach will not be viable. In addition, some types of spillovers will be nearly impossible to measure short of complex and costly surveys.

There are a variety of vehicles through which compensation for these spillovers could be provided. These can be classed into three broad categories as set out in Table 16.4.

Table 16.4 Mechanisms for directly subsidising positive externalities in demonstration and commercialisation

Category	Instrument	Description
Tax instruments	Tax rebates or concessions	Tax concessions allow companies to claim a deduction of R&D-related expenditure, usually for a proportion beyond the actual expense incurred (i.e. more than 100 per cent)
	Accelerated depreciation	For research projects with high capital costs, approved accelerated depreciation of assets could be an alternative tax concession
Niche market creation	Technology target schemes	Policies such as the renewables targets may establish guaranteed niche markets for particular categories of goods
	Guaranteed revenue	Policies such as regulated feed-in tariffs can provide innovators with revenue certainty
	Government patronage	Government may itself provide a niche market for new products through its internal procurement policies or through advance purchasing contracts
Direct funding	Competitive grants	Competitive grants are a common means by which government subsidises specific projects selected by merit based on given criteria
	Income-contingent loans	Income-contingent loans compensate innovators for spillover by reducing their short-term exposure to risk
	Matched funding	Matched funding stimulates demonstration and commercialisation activities by lowering the costs associated with being the first mover by some fixed proportion

The Review considers that of these many instruments, matched funding is the preferred option based on a range of criteria.[6]

- **Simple and targeted:** Matched funding can be simple and directly targeted in its design to specifically address the spillovers that arise as a result of activities that bring technologies for emissions reductions to market.
- **Technology neutral:** Matched funding can be technology neutral across the whole range of economic sectors and has the potential to allow for all technological possibilities. Unlike technology targets, government procurement programs, or other niche market–type instruments, matched funding does not need to target, and therefore inefficiently favour, particular industries or technology types.
- **Maintains risk exposure:** Some policy instruments (such as those that provide a guaranteed return on investment) may inappropriately insulate investors from known technical and commercial risks. By leveraging private funds, a matched funding scheme would ensure that applicants continue to bear and manage the potential risks associated with bringing a new technology to market. Government need not form a complete view of the potential benefits or risks associated with each project, thereby avoiding potential information asymmetry issues. Similarly, it is unnecessary for applicants to demonstrate technical feasibility, commercial competitiveness or the pathway to uptake and diffusion as these criteria are implicit in the matched funding approach: unless there is real potential for the project to earn a return in the long run, the private investment would not be made.
- **Capped expenditure:** Matched funding can be designed so that the total expenditure does not exceed a given level of funding.
- **Transparency, impartiality and independence:** Matched funding is transparent to administer, and the amount of funding allocated is transparently accounted for in the budgetary process rather than being hidden in forgone revenue. The body or institution that administers a matched funding scheme can also operate at arm's length from government and thus be insulated from the political process.

  The current Low Emissions Technology Demonstration Fund (see Table 16.3) is in essence a matched funding scheme but has been an imperfect mechanism for correcting early-mover spillovers. Although it seeks to stimulate the demonstration and commercialisation of low-emissions technologies, the Low Emissions Technology Demonstration Fund lacks technology neutrality by favouring emissions reductions from particular sectors at a particular scale, and may compromise independence by relying on ministerial approval for the final selection of projects.

16.3.4 Where would the funds for early mover support come from?

Apart from appropriations out of general government revenue, a matched funding scheme could be paid for from three other sources:

- **Auction revenue from the sale of emissions permits:** There is a strong policy rationale for a substantial percentage of permit revenue to be allocated towards matched funding of demonstration and commercialisation projects. In particular, these funds could potentially result in increased availability of low-emissions substitutes in the short term and a lower carbon price.
- **Reallocation from existing funds:** This would occur when, after review, existing programs were shown to be inefficient in compensating firms for the external benefits that they generated.
- **Industry levies:** Matched funding schemes for research and development could be augmented by funds collected by individual industries. Given that most of the spillover benefits from early movers are likely to accrue to later movers within the same industry, these levies should be set aside strictly for new technologies within the source industry. Compulsory levies have been the established way of funding research and development in many rural industries for several decades.

  Levies on the coal industry for investment in research, development and commercialisation of carbon capture and storage technologies are another example. The futures of Australia's domestic-oriented and export coal industries are both dependent in the long term on the success of carbon capture and storage. In light of this, the Coal 21 Fund will raise an estimated $1 billion over the next decade from voluntary levies in the coal industry.[7] This could be extended.

16.3.5 Criteria for determining who qualifies for early mover support

The challenge with subsidies—whether through direct payments, tax system concessions or niche market support—is determining who qualifies, and what level of subsidy is appropriate. For any policy to target early-mover spillovers, an accurate and simple set of criteria is required based on three key questions:

- Will the technology contribute to lowering the cost of mitigation?
- Does the project qualify as an early-mover innovation?
- Are there expected spillovers associated with the project?

In assessing against the criteria, government needs to balance (1) the accuracy of the assessment process against (2) the complexity and associated transaction costs of the assessment process. The balance of considerations strongly favours simplicity and low transactions costs. The more complex the criteria, the more dependent the assessment process will be on the subjective judgments of the assessing panel and thus the less transparent it will be. Simple criteria would be more objective and contestable.

Criterion 1: Will the technology contribute to lowering the cost of mitigation?

Applicants must demonstrate the relevance of their technology to the mitigation challenge. In most circumstances, this should be immediately apparent; all technologies that contribute to the delivery of existing goods and services at lower-emissions intensity would qualify. It does not matter whether emissions reductions are the primary aim of the new technology,[8] but it is important that the potential contribution to emissions reductions be material.

Choosing the appropriate cut-off level to select only those technologies that can be expected to make significant improvements will require specialist technical advice.

Not all technical problems will lend themselves to measurable and comparable metrics. For example, there is no straightforward way to compare technologies that contribute to building insulation, space heating or cooling, chemical refinement or production. In these circumstances, technical expertise will be required to assess whether there are reasonable prospects of a material contribution to emissions reduction.

Criterion 2: Does the project qualify as an early-mover innovation?

Applicants will be required to demonstrate that the proposed project can be considered to be an early-mover innovation, at least in Australia. In short, projects that can be deemed to be pilot, demonstration or first commercial-scale projects should qualify, but determining whether or not a project falls into one of these three categories is not a straightforward exercise. Project proponents have the incentive to expand the scope of non-innovative projects at the margins to increase the chances of qualifying for funding, while other projects using non-novel technologies may in fact be making a significant contribution to the state-of-the-art knowledge at a highly technical level.

Given these potential complications, the Review proposes that this question be answered by an independent panel of experts. The panel will make some technical judgments to determine whether a particular project is materially different from current available technology. For guidance the panel would have to provide a transparent account of its assessment in two stages:

- **Selection of an appropriate comparator:** 'Current available technology' can be objectively defined as a technology that is currently contributing to the production of commercial goods or services in Australia or overseas.

- **Technical judgment of material difference:** The panel should then consider the particulars of the technology or suite of technologies being proposed and assess it against the comparator. In doing so it should examine the unique characteristics of the technology, the scale of the application, and the context within which the technology will be applied.

Criterion 3: Are there expected spillovers associated with the project?

As previously discussed, attempting to quantify the size of different spillovers on a case-by-case basis is impractical due to the severe measurement issues. Instead, government will need to base it's assessment on a proxy measure of whether the spillovers in any particular case are material. The straightforward proxy is the assessment of whether or not a particular project, if successful, would be a genuine early mover.

Three types of project would qualify under the proposed matched funding scheme: pilot projects, demonstration projects and first commercial-scale projects.

A second method for identifying early movers would be to adopt a scalar measure of quantity, and an associated cut-off point for the first fleet of early movers. For example, to determine whether a centralised electricity generation plant is part of a first fleet, the panel could objectively assess whether the proposed plant is part of the first five of its kind or within the first 1000 megawatts of its kind, whichever is less.

What is an appropriate ratio for matched funding?

For a matched funding scheme, the difference between the private and social rates of return[9] may be a good proxy indicator for the estimated spillovers from demonstration and commercialisation activities in general. Table 16.5 shows that estimates of the private rate of return on research and development spending by firms tends to be much lower than the social rate of return. Often the social rate of return is more than twice that of the private rate.

This comparison suggests that it could be appropriate for the proposed matched funding scheme to be based on a ratio of between $0.50 to $1.50 of public funding per dollar of private funding. Many matched funding schemes currently use a ratio of between 1:1 and 1:3 (see Table 16.5). Dollar-for-dollar matched funding is consistent with the evidence base.

Table 16.5 Estimates of private and social rates of return to private research and development spending

Studies	Private rate of return(%)	Social rate of return (%)
Minnasian (1962)	25	-
Nadiri (1993)	20–30	50
Mansfield (1977)	25	56
Terleckyj (1974)	27	48–78
Sveikauskas (1981)	10–23	50
Gotto & Suzuki (1989)	26	80
Mohnen & Lepine (1988)	56	28
Bernstein & Nadiri (1988)	9–27	10–160
Scherer (1982, 1984)	29–43	64–147
Bernstein & Nadiri (1991)	14–28	20–110

Source: Griliches (1995: 72).

It might be suggested that the ratio of matched funds be varied based on various criteria, such as the level of expected emissions reduction. The Review would oppose this approach, which would reward investors on the basis of a particular technical characteristic of the project. This would undermine the aim of technology neutrality, and contravene the original intent of the funding scheme, which is to compensate early movers for spillover benefits.

It is likely that in the early years of the emissions trading scheme the funds allocated from the permit sales revenue towards research, development and commercialisation will not be exhausted, as the market will need time to assess and put forward appropriate candidate technologies. There will also be some lags in the approval process. In this scenario, funds should be allowed to accumulate for use in future years.

On the other hand, it is also very likely that in at least a few years, demonstration and commercialisation activities will be at a peak and the claims for funds will be above the annual allocation, even after allowing for the surplus of funds accumulated in the early years and return on funding from successful investments. The funding scheme should include measures that automatically reduce the rate of matching once the budgeted level of expenditure has been exceeded.

16.4 An overarching framework for innovative activities

For many sectors, the transition to a carbon-constrained economy will require much more than incremental efficiency improvements. If the deep cuts necessary for the stabilisation of atmospheric greenhouse gas concentrations are to be achieved, far-reaching innovation will be needed. Technological lock-in however is an obstacle to such innovation (Foxon et al. 2008).[10]

Analysis of innovation systems suggests that it is important to create a long-term, stable and consistent strategic framework to promote investment in low-emissions technologies (Foxon et al. 2008). Stern (2007) shares these views. High policy uncertainty on the other hand can create the incentive to delay investment and raise investment thresholds in an already high-risk environment (Blyth & Yang 2006). Industries in Australia have continually expressed the need for greater policy clarity, continuity and coherence so that they can formulate expectations about future markets (Australian Business and Climate Group 2007).

A clear, credible and consistent policy framework will provide investors with long-term signals, and incentives to deal with the challenge of technological lock-in and accelerate Australia's technological transition to a low-carbon economy (Foxon et al. 2008). The most important overarching policies that will create investor confidence and overcome technological lock-in are the long-term emissions trajectory and the emissions trading scheme. Policy certainty and long-term investment signals can be backed up by strengthened international policy action that enhances domestic policy credibility (Blyth & Yang 2006).

Notes

1 In this chapter, the term 'low-emissions technologies' refers to those technologies that reduce the emissions intensity of existing technologies, reduce the need for emissions, or capture and sequester greenhouse gases.

2 A cooperative research centre is a company formed through a collaboration private sector organisations (both large and small enterprises), industry associations, universities, government research agencies such as the Commonwealth Scientific and Industrial Research Organisation, and other end users. There are currently 58 centres operating in six broad sectors.

3 For a survey and critical literature review of other types of potential missed economic benefits of publicly funded research, see Salter and Martin (2001).

4 The NHMRC is the single national organisation with diverse responsibilities in health and medical research, including the allocation of research funding, fostering medical and public health research and training, and the development of health policy advice.

5 Note that these criteria are not the rationale for funding support, but rather the principles by which funding support may be allocated once the case for additional public good funding to correct for market failures has been clearly established.

6 For a discussion of a range of other key design principles for business research and development programs, see Productivity Commission 2007b, Chapter 10.2.

7 The Coal 21 Fund is the the Australian black coal mining industry's funding commitment to research, development and demonstration of clean coal technologies.

8 Other aims could include improved efficiency in production, reduced waste or increased supply chain reliability.

9 The private rate of return is the benefit a firm receives on its investment, while the social rate of return is the broader benefit that accrues to both the firm and society more generally. The difference is therefore the spillover benefit that the firm is unable to appropriate.

10 Technological lock-in occurs when incumbent technologies benefit from positive feedbacks that come from being the status quo to the extent that superior technologies struggle to displace inferior incumbents.

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17 NETWORK INFRASTRUCTURE MARKET FAILURES

Key points

There is a risk that network infrastructure market failures relating to electricity grids and carbon dioxide transport systems could increase the cost of adjustment to a low-emissions economy.

The role of the proposed national transmission planner should be expanded to include a long-term economic approach to transmission planning and funding.

A similar planning approach is necessary to ensure that network infrastructure failures do not unnecessarily delay deployment of large-scale carbon capture and storage.

The Building Australia Fund should be extended to cover energy infrastructure.

There is a case for special feed-in tariffs for household electricity generation and co-generation. The case can be quantified by reference to timing and transmission considerations.

A well-integrated national energy network with the capacity to cope with potentially large shifts in flows will allow for structural change and the smoothing of shocks following the introduction of an emissions trading scheme and recent fuel price volatility.

The imposition of a price on emissions through an emissions trading scheme will drive demand for low-emissions goods and services. The price of emissions permits will depend in part on the availability of low-emissions alternatives, which in turn will rely on the infrastructure supporting those alternatives. Two important markets that will be particularly affected are energy and transport.

In energy, there are clear differences between the location and character of supply and demand today and into the future.

For energy, the transmission networks are geared to handle increments of supply from near the established grid, with consistent supply, on a large scale, and highly centralised. The new technologies tend to be far from the grid (geothermal, thermal solar, wind), have intermittent supply (wind, solar), operate on a smaller scale (including tidal), and be decentralised or embedded (photovoltaic solar, biomass). Without major change in the transmission infrastructure, new technologies will find it difficult to compete, even in circumstances in which they are expected to be highly competitive once compatible infrastructure has been established.

An emissions trading scheme will make higher-emissions forms of energy generation more expensive, shifting demand towards lower-emissions sources, and towards technologies that capture and sequester emissions. However, the extent to which consumers can express these preferences will be strongly dependent on the availability of appropriate network infrastructure to support the delivery of the new technologies.

In transport, an emissions trading scheme will make higher-emissions forms of transport more expensive, shifting demand to lower-emissions forms. Again, the degree to which consumers can express these preferences will be strongly dependent on the availability of lower-emissions transport and the appropriate network infrastructure.

A number of market failures may prevent the private sector from providing the optimal level of some forms of infrastructure services:

- **Public goods:** Infrastructure that is a pure public good (that is, non-rival and non-excludable) may be underprovided because the infrastructure provider is unable to capture the full benefits of its investment.
- **Natural monopoly:** Where infrastructure is best provided by a single firm, the firm may, without competition, underprovide and overcharge for use of the infrastructure.
- **Externalities:** Where infrastructure has positive or negative spillovers to third parties, the level of infrastructure provided may not be socially optimal. Subsets of externalities in infrastructure important to the supply of energy and transport include:
  - **Early-mover spillovers:** The first individual or firm to invest in infrastructure may face all of the costs, but some of the benefits accrue to later movers.
  - **Coordination externalities:** Private companies may not coordinate to provide infrastructure where trust is low or the cost of reaching agreement is high.

There may be circumstances in which private activity can overcome the failures. Occasionally the cost of a market failure will be less than the cost of government intervention, with all of its political economy and other risks and costs. But even in these cases, regulatory or fiscal intervention by government may be required to ensure an optimal response.

This chapter discusses market failures in:

- infrastructure for the transmission of electricity
- infrastructure for the distribution of electricity
- infrastructure for the transmission of gas
- infrastructure for the transportation of carbon dioxide for geosequestration.

Transport and urban planning infrastructure and services will be discussed in the Review's supplementary draft and final reports.

Because the vast majority of electrical energy in Australia is bought and sold on the National Electricity Market,[1] the Review's analysis of barriers to electricity infrastructure provision will focus on that market.[2] That said, the analysis of potential problems and solutions will be relevant to the other electricity markets in Australia.

17.1 Infrastructure for the transmission of electricity

17.1.1 Public good aspects of electricity interconnectors

In the National Electricity Market, electricity is imported into a region when demand exceeds the capacity of local generators, or when the price in an adjoining region is low enough to displace the local supply. Interconnectors are the high-voltage transmission lines that transport electricity between adjacent regions. However, an interconnector's ability to transfer electricity is limited by the extent of its physical transfer capacity. When the technical limit of its capacity is reached, an interconnector is constrained.

The adequacy of interstate interconnection will be a key infrastructure issue for the National Electricity Market in the near future. There are two public good arguments for reducing these constraints in light of the expected changes required for Australia's transition to a carbon-constrained future.

First, adequate interconnection will allow the National Electricity Market to accommodate any structural change in the electricity sector that may be required. The emissions trading scheme will deliver quick and profound shifts in the fundamental relative economic values of low- and high-emissions forms of electricity generation. Dramatic price changes for fuel source commodities such as tradable coal and natural gas would also contribute to the pressures for structural change. Both the permit price and international commodity prices will result in changes to the regional comparative advantages associated with different fuel sources.

There will therefore be a special need for a network of interconnectors with enough capacity to cope with the potentially large shifts in interstate flows of electricity over time. Market fragmentation due to limited interconnector capacity means much of the generation capacity must remain within a region, even if there are more economic sources elsewhere.

For example, the high price of export coal may make brown coal electricity from Victoria cheaper than black coal electricity produced in New South Wales, even with the permit price. However, interconnector constraints between these regions may mean that local demand in New South Wales still has to be met by black coal generation. Alternatively, a large fall in black coal export prices may generate the opposite pressures. The inability to capitalise on comparative advantage may thus adversely affect the economic fortunes of both brown and black coal producers. Confidence in the capacity of a national system will be particularly important for the period of transition, and interconnector constraints will have a high opportunity cost in the form of higher energy and higher emissions permit prices.

While it may seem inefficient to have permanent abundant excess capacity in the interconnectors between regions, in the world of structural change Australia is entering, it could become more likely that generation cost differences will exceed the distribution losses and infrastructure costs. A fine balance will be required: there needs to be adequate interconnector capacity that promotes efficiently located generation, but not to the extent that the sunk costs of that capacity outweigh the public good benefits.

Second, adaptation to climate change and more frequent disruptions of electricity supply will require deeper interconnection capacity. Having excess capacity in interconnectors provides additional security for the system as a whole.

Adequacy of current arrangements

At present, interconnector constraints do not appear to be significant; the most constrained interconnector is DirectLink from New South Wales to Queensland, which was constrained for 285 hours in 2005–06 (Energy Supply Association of Australia 2007). That being said, any investments in additional generation capacity could be deferred in the light of limited interconnection capacity.

The current regulatory arrangements provide for the sharing of interconnection costs between the regions involved, subject to a dual test of reliability and market benefits. While the same tests can be applied when delivering these benefits across state boundaries to balance supply and demand and while the benefits of reliability often accrue to both regions, there may be situations where one region reaps most of the benefits. In these circumstances, the sharing of costs may be a challenge.

One obstacle to the construction of additional interconnector capacity could be state government protectionism in relation to native energy generation. State governments may place limits on interconnectors to ensure that local generators are able to maintain market share within their region.

Interconnectors can also be privately provided. The recent announcement of a private transmission line from central Queensland to the Hunter Valley suggests that the current regulatory and investment environment is providing the opportunity and incentives for investment in interconnectors where economically appropriate.

Reforms to the regulatory and institutional arrangements for the planning and funding of improvements to interconnector capacity are under way. The key focus of reform should be the facilitation of new private interconnection capacity. Attention should be given to whether there are adequate private incentives to install socially optimal levels of capacity to allow flexibility in the amount of interstate electricity trade.

17.1.2 Market failures in transmission network extensions

Many new sources of electricity could come from areas not currently serviced by transmissions lines or, alternatively, where the electricity distribution or transmission network is not currently able to cope with the additional energy output from new generators. In either case, extension or augmentation of the transmission network may be warranted. There are, however, two barriers to successful network augmentation that could significantly slow or even halt the progressive deployment of lower-emissions generation technologies.

Free-rider problems and first-mover disadvantage

The current regulatory regime requires those seeking connection to cover the cost up to the point of connection. For a single remotely located generator (including wind, solar and geothermal) the additional cost of connection is likely to be insurmountable. If the costs can be shared between multiple generators, the likelihood of a successful network extension increases, but still may not eventuate because there is a strong incentive to free ride on the efforts of early movers.

The first party (or parties) that connect to the network are faced with all the cost of extending the network. Later parties are then able to connect to the expanded network at a substantially reduced cost. The incentive is therefore for potential larger-scale generators to delay the development of their investment in the hope that others will take the first step, or to select plant sizes and locations that simply 'use up' existing capacity in sections of the grid.

Barriers to achieving optimal scale in network extensions

Current processes for extending the electricity network are likely to be suboptimal from a societal perspective because they do not provide any mechanism for the exploitation of economies of scale. In some circumstances, it may be desirable to provide additional transmission network capacity ahead of generation capacity. At present, additional network capacity can only be funded by the broader customer load if it is the best alternative to meet reliability requirements or provides net market benefits. From this perspective, it will usually be better not to install the additional network capacity until there is concrete proof of need,[3] and so projects may not install new capacity at a socially optimal scale.

Funding for network capacity will thus depend on the project proponent, who will have no incentive to fund a larger capacity than required. When the next project to develop a resource in close proximity is proposed, the transmission network will have to be augmented, and the additional cost will exceed the incremental cost of the new capacity had it been built into the network from the outset.

These tendencies are exacerbated by the long lead times for transmission investment compared to the shorter lead times for generation capacity or changes to demand load. Responses to these market signals will typically come too late.

17.1.3 Expanded role for proposed national transmission planner

Current electricity market reforms propose the introduction of a national transmission planner[4] to promote the development of a strategic and nationally coordinated transmission network. The proposed planner would have regard to 'the most efficient combination of transmission, generation, distribution and non-network options that will deliver reliable energy supply at minimum efficient cost to consumers under a range of credible future scenarios' (Australian Energy Market Commission 2008: 10). It would also take into account demand side, embedded generation and fuel substitution alternatives (see Australian Energy Market Commission 2008).

These new arrangements are expected to deliver a coordinated and efficient national transmission grid that meets local and regional reliability and planning requirements, and is flexible enough to respond to generation and load changes.

The core function of the national transmission planner will be to prepare and publish a national transmission network development plan each year. An integrated long-term development plan will contribute to improving the efficiency of transmission network investment decisions by providing signals for efficient generation investment (see Australian Energy Market Commission 2008).

The Review endorses the recommendations for national transmission planning arrangements in the draft report by the Australian Energy Market Commission (2008), and proposes that the role of the national transmission planner be extended to incorporate (1) an economic approach to transmission planning and (2) financial incentives for priority projects.

An economic approach to transmission planning

The Review endorses the Australian Energy Market Commissions' proposed recommendation that the national transmission network development plan should 'present a broad and deep analysis of different future supply and demand scenarios … taking account of various policy, technology and economic assumptions and looking out at least 20 years into the future' (Australian Energy Market Commission 2008: 23). The Review proposes that the national transmission planner also adopt an economic approach to transmission planning that covers more forward-looking demand and supply scenarios, rather than simply focusing on technical feasibility. The Renewable Energy Transmission Initiative in California provides some important lessons for such an approach (see Box 17.1).

The national transmission planner could undertake a similar process to that followed in California's Renewable Energy Transmission Initiative, but unlike the California initiative, the planning process should be technologically neutral and consider potential projects for both the renewable and non-renewable fuels. The process would start with a resource assessment that builds on existing assessments. Resource assessments typically stop short of identifying economically 'developable' potential, and are thus inadequate for use in transmission planning. Instead, the planner would analyse the resources considered in previous studies and identify the most cost-effective developable renewable resources in areas throughout Australia. Among other things, this analysis should also take into account engineering feasibility and environmental factors that may not have been considered in previous studies in order to avoid areas that cannot be developed for technical or environmental reasons.

This analysis would be informed by a comprehensive stakeholder consultation process with private sector generation companies. Firms would submit proposals and estimates of the costs of developing the generation resources within an area and delivering that energy to consumers. These project and technology costs would by necessity be estimates, intended primarily to provide information to compare areas. The open and transparent process would support the emergence of a consistent set of assumptions.

Ultimately, based on analysis of developable potential, comparative economics and other factors, resource areas would be grouped into high-demand zones. These areas would then be prioritised to allow identification of economically efficient suitable network extensions.

Financial incentives for priority projects

The Australian Energy Market Commission (2008: ix) states that, 'the [national transmission planner] will be required and resourced to produce its own development strategies, including its own transmission investment options'. The Review proposes that in addition to the identification of options, financial incentives are necessary to overcome the free-rider issues of transmission augmentation. Incentives can reduce the likelihood of transmission extensions being hindered by early-mover problems, and help to ensure that augmentation is undertaken at a socially optimal scale.

Box 17.1 California's Renewable Energy Transmission Initiative

The Renewable Energy Transmission Initiative is a statewide initiative of the California Energy Commission that aims to identify the transmission projects needed to accommodate the state's renewable energy goals. The purpose of the initiative is to bring together all of the renewable transmission and generation stakeholders in the state to participate in a consensus-based process to identify, plan and establish a rigorous analytical basis for regulatory approvals of the next major transmission projects needed to access renewable resources.

The initiative will assess all competitive renewable energy zones in California (and possibly also in neighbouring states) that can provide significant electricity to California consumers by the year 2020. It also will identify zones that can be developed in the most cost-effective and environmentally benign way and will prepare detailed transmission plans for zones identified for development.

The effort will be supervised by a coordinating committee made up of California entities responsible for ensuring the implementation of the state's renewable energy policies and development of electric infrastructure. There are five core steps to the process:

1. identifying competitive renewable energy zones having densities of developable resources that best justify building transmission to them
2. ranking zones on the basis of environmental considerations, development certainty and schedule, and cost and value to California consumers
3. developing conceptual transmission plans to the highest-ranking zones
4. supporting the California Independent System Operator Corporation, investor-owned utilities and publicly owned utilities in developing detailed plans of service for commercially viable transmission projects
5. providing detailed analysis regarding comparative costs and benefits to help establish the basis for regulatory approvals of specific transmission projects (starts in steps 1 and 2, but is revised based on new information developed in steps 3 and 4).

The Office of Gas and Electricity Markets in the United Kingdom undertakes a similar exercise with its long-term electricity network scenarios.

Source: RETI Coordinating Committee (2008).

As currently conceived, the national transmission network development plan will outline the strategic long-term development of the transmission network, but network service providers will still be responsible for upgrading their transmission systems. The national transmission planner will not be empowered to compel any particular investment outcome[5] and investment decisions will remain wholly with service providers.

The national transmission planner can play a more substantive role in the development of National Electricity Market network infrastructure by adopting a planning process that identifies and coordinates the overarching interests of transmission network service providers and new entrants and by providing the national transmission planner with a pool of funds to support suitable network projects.

It is envisioned that for appropriate projects, early movers and the national transmission planner would share the initial upfront capital costs of the infrastructure project. Public funds managed by the planner would be used to pay for the portion of capacity that would be expected to be taken up by later market entrants. The regulatory structure would include arrangements that allow the planner to recover its investment from later users either through access charges or, preferably, eventual sale of the asset into private ownership. To ensure that network economies of scale are exploited, the fund would need to be sufficiently large to bear the upfront investment costs incurred during the initial phases of augmentation, up to the time that the full capacity of the network is utilised.

It is proposed that funds be made available for this purpose from Infrastructure Australia, and its newly established $20 billion Building Australia Fund. The Building Australia Fund is currently earmarked for national transport (roads, rail and ports) and communications infrastructure (broadband) that cannot be delivered by the private sector or the states. It would be appropriate for the Building Australia Fund to be extended to finance high-value national electricity transmission infrastructure.

17.2 Infrastructure for the distribution of electricity

17.2.1 Externalities of embedded generation

There are three main externalities of embedded generation that may contribute to inefficient investment decisions. The possible inefficiencies relate to overinvestment in network infrastructure and centralised generation, and underinvestment in embedded generation like solar photovoltaic and cogeneration.

- **Reduced transmission losses:** Energy losses from electrical resistance in transmission cables are significant when electricity is transported over long distances. The average weighted distribution loss in Australia in 2005–06 was 5.9 per cent, with the highest loss factor of 7.2 per cent in Tasmania (Energy Supply Association of Australia 2007). Embedded generation does not suffer transmission losses to the same extent as generation located far from demand centres.[6] However, current rules do not provide recognition for the reduction in losses that embedded generation brings to the system. While National Electricity Market rules currently require network businesses to pass on these savings[7] to larger embedded generators, there is no requirement to similarly compensate the smaller embedded generators.
- **Benefits of deferred network augmentation:** During times of peak system demand, the marginal network costs are much higher than the averaged network charges faced by customers. This is because the cost of network augmentation to manage system load is driven solely by the extent of peak demand. The costs of building and maintaining infrastructure capacity increase with the level of the peak. Any embedded generation at peak periods helps to avoid or defer the high costs of network augmentation. In an efficient market, the price paid for electricity supplied would include the benefits of avoided network augmentation.
- **Higher value of energy supplied during peak periods:** There is significant variability in the wholesale price of electricity in Australia. For example, in 2005–06 the average volume weighted price for electricity in New South Wales was $43.04 per MWh—but there were spikes in the spot price in the peak summer periods of up to $9738.95 per MWh (just below the market bidding cap of $10 000 per MWh) (Energy Supply Association of Australia 2007). However, because embedded generation does not participate in the wholesale market, it does not experience these price spikes—either higher during peak periods or lower during off-peak periods. This is mainly an issue during peak periods, when embedded generation may be more competitive with more expensive forms of centralised generation and therefore more likely to be profitable.

These three externalities from embedded generation can be seen in the market for small-scale solar photovoltaic generation. Solar photovoltaic generation that provides energy during high demand periods is significantly undercompensated for its lower levels of losses, network benefits and timing of supply. This will increasingly be the case as temperature rises, since daytime peaks in demand as a result of air conditioner use would correlate more strongly with solar photovoltaic output.

The current regulatory framework encourages and rewards investment in infrastructure because revenue is directly related to the value of the asset base. This means that deferred augmentation as a benefit of embedded generation would be in direct conflict with the incentive structures for network businesses, making suboptimal investment decisions even more likely.

To date, feed-in tariff policies have been implemented primarily on the basis of infant industry assistance. This is not a valid reason for support. The market failure associated with new industries is best corrected by providing direct support for research, development and commercialisation of new technologies (see Chapter 16). If this were the sole basis for higher feed-in tariffs, its application would raise the cost of the transition to a low-emissions economy.

There are, however, valid economic arguments for an appropriate feed-in tariff regime, at levels commensurate with the associated external benefits.

17.2.2 What should the value of a feed-in tariff be?

There are two main ways by which feed-in tariffs can be paid—gross metering and net metering. Gross metering pays the embedded generator for all electricity it generates, while net metering pays for just the energy exported to the grid (gross generation minus local energy consumed).[8] Feed-in tariffs in Spain and Germany, for example, are calculated on a gross-metering basis. In Australia, most feed-in tariff commitments have been based on the net quantity of energy exported to the grid.

For small embedded generation systems installed by households or firms that are consuming electricity throughout the day, it is likely that no exports to the grid will be possible. However, the benefits of embedded generation (lower transmission losses, deferred costs for network augmentation, and displacement of high-cost generation during peak periods) are present for every unit of electricity produced, not just the amount exported. A feed-in tariff based on gross metering is thus a more accurate means of pricing these benefits.[9]

17.3 Gas transmission infrastructure in Australia

Australia's gas transmission system is privately owned, and today serves the dual purpose of connecting gas fields to gas markets and interconnecting regional systems. Interconnections provide a degree of supply diversity and security.

Do the market failures identified in section 17.1 for electricity transmission also apply to gas? While the theoretical impediments, such as first-mover and free-rider barriers, do, no doubt, exist in the gas market, there is evidence that the market has been able to overcome them.

First, Australia's east coast gas transmission system underwent rapid expansion over the last 30 years through private sector investment, with little need for government intervention. The network has expanded to support the growth in demand and the diversification of supply sources—all through the private sector ownership structure. In some cases, pipelines originally built by state governments are now under private ownership.

A recent example illustrates the way in which this market has functioned efficiently without government intervention. The SEA gas pipeline connects the Victorian and South Australian gas systems through its link between Port Campbell and Adelaide. The pipeline was the outcome of an alignment of the joint interests of gas producers in Victoria and a gas generator and gas retailers in South Australia, and was ultimately constructed as a three-way joint venture. In addition to direct access for Victorian gas to the South Australian market, the pipeline provides diversity and security of supply to both states directly, and to the overall east coast market indirectly.

Second, in contrast to electricity transmission, the majority of Australia's gas transmission pipelines are not regulated. Pipeline owners use pricing structures with their shippers that have avoided such a requirement.

One key driver for this outcome is that gas pipeline developers and owners are able to contract directly with shippers. This contrasts starkly with the electricity market. Parties with a vested interest in the development of a gas pipeline, such as gas producers, wholesalers, retailers or major end-use customers, have been able to align their commercial interests to deliver the requisite facility.

There is no reason to suggest that existing impediments would be any more significant following the introduction of an emissions trading scheme. Lessons should be drawn from the circumstances that have led to this market operating efficiently without government intervention.

17.4 New infrastructure for the transportation of carbon dioxide

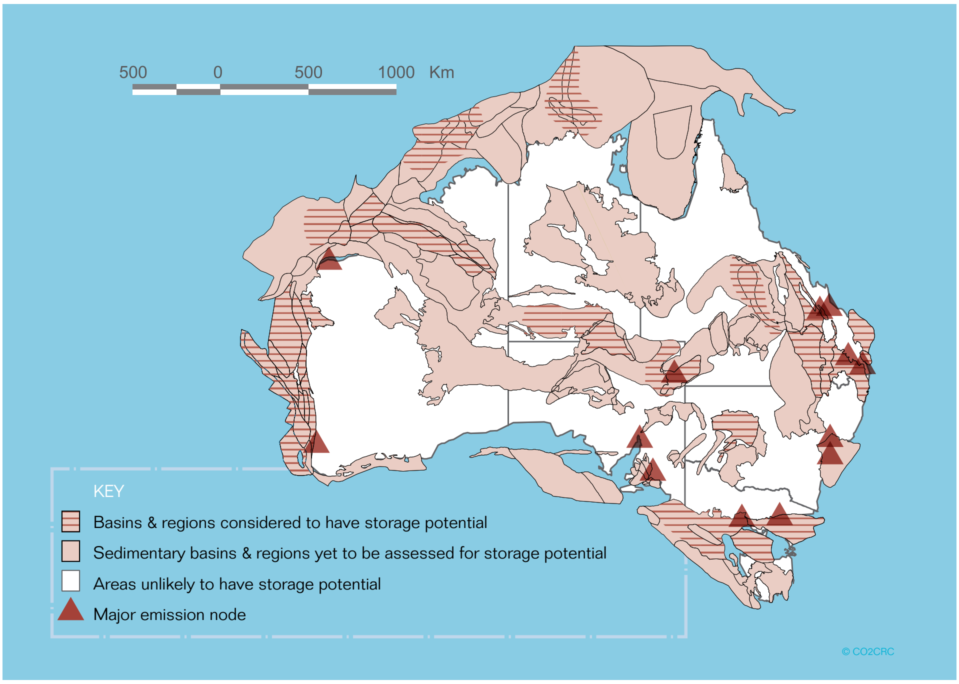
17.4.1 Infrastructure challenges for the transportation of carbon dioxide

Due to the relative immaturity of the technology for geosequestration of carbon dioxide, current projects in Australia are located close to storage sites of varying capacities. This close proximity eliminates the costs of transportation over long distances.

As the number of sources and discovery of suitable sites increases, there will be a corresponding increase in the need for pipeline networks to transport carbon dioxide between locations. In the long term, some suitable sequestration sites could be relatively isolated, requiring an even larger pipeline network. There may also be good arguments for locating a point source far from a sequestration site if the source needs to be close to a natural resource that is expensive to transport. The current location of many coal-fired power plants close to coal seams is an example.

While fossil fuel electricity generation is the primary candidate for geosequestration technologies, transport infrastructure policy must be flexible enough to cope with a variety of non-electricity-related carbon dioxide applications.

Figure 17.1 Major sequestration sites and carbon dioxide sources in Australia



Source: Image courtesy of CO2CRC.

Carbon dioxide gas is most efficiently transported when compressed to a supercritical state (a temperature and pressure at which it shows properties of both liquids and gases). Because of its potential corrosive effects, water (and possibly some contaminants) is removed before transport. Compressing carbon dioxide also enables the injection and storage of greater volumes. Carbon dioxide can be transported by truck, rail or, in the case of a geological storage site deep beneath the seabed, by ocean tanker. However, pipelines are the economic mode for transporting large amounts of carbon dioxide for distances of up to 1000 km. This method of transporting pressurised carbon dioxide is already a mature technology. In the United States, for example, about 40 million tonnes per year travels through a 2500 km network of high pressure pipelines (mainly in Texas) for the purpose of enhanced oil recovery (International Energy Agency 2001).

17.4.2 Potential roles for government

Government needs to consider the future need for a system of pipelines for transporting carbon dioxide from the point of capture to the point of storage. There is a potential for market failures in the provision of such a pipeline network in three phases.

Pre-commercial planning

While carbon dioxide geosequestration technology matures and approaches commercial feasibility, an appropriate independent body could start assessing appropriate carbon dioxide sources, sequestration sites, existing projects and potential future projects. This process could go beyond a study of technical feasibility, and explore economic competitiveness based on consultation and proposals from the carbon capture and storage industry. The aim would be to identify the major centres for carbon dioxide capture and sequestration around Australia, and thereby highlight some of the possible long-term priorities for key pipeline infrastructure.

Government should not act on its plans for physical infrastructure until substantial demand has been confirmed. However, planning and foresight are necessary given the long lead times between the recognition of need and the completion of any infrastructure project of this scale.

Establishment

Once the industry has matured to the point of being potentially commercially competitive, government will need to be prepared with efficient mechanisms for initial development and funding of a pipeline grid. As has been the experience with the gas industry in Australia (see section 17.3), it is possible that the physical infrastructure for carbon dioxide transport could be successfully provided by the private market, thereby requiring minimal intervention by government. If the private market can overcome the natural monopoly market failures and coordination failures that are characteristic of network infrastructure, this would be the preferred outcome.

However, the magnitude of these market failures or the cost of delays in overcoming them may warrant government intervention. This could involve supporting the construction of the main pipelines at a socially optimal scale, regulating pipeline construction, providing a contingent subsidy, or providing adequate information regarding sites and sources. If government funding were required in the establishment phase then future users should be charged for use of the spare capacity so that the funds could be recovered. Government could divest itself of the asset by sale to a private operator as the pipeline approaches full utilisation.

As discussed in section 17.1.3 in relation to electricity infrastructure augmentation, a program (also based on the Californian Renewable Energy Transmission Initiative) could provide an efficient mechanism to determine the initial coverage and scale of a carbon dioxide pipeline grid. As discussed in section 17.1.3, it would be appropriate for the body administering the resource assessment process to be able to fund identified carbon dioxide pipeline priorities (with some excess capacity to cater for additional users in the future) if this proves to be necessary. Arrangements for cost recovery and eventual sale to the private sector should be structured so as to maintain incentives for purely private pipeline investment.

Long-term management and access

Since the pipeline system would be a natural monopoly, access arrangements for multiple users may be required. The gas industry has privately established these arrangements; the carbon dioxide sequestration industry may be able to do the same. If not, the Australian Competition and Consumer Commission would need to establish an appropriate regime.

Notes

1 The National Electricity Market is a wholesale market for electricity supply covering the Australian Capital Territory and the states of Queensland, New South Wales, Victoria, Tasmania and South Australia. In 2005–06, approximately 88.6 per cent of electricity generated was sent out in the National Electricity Market.

2 The report commissioned by the Review from McLennan Magasanik Associates contains detailed discussion of market failures in the National Electricity Market (see www.garnautreview.org.au).

3 This onerous burden of proof is necessary to ensure that only essential infrastructure extensions are undertaken and to avoid the possibility of multiple underused extensions to the grid.

4 The Council of Australian Governments and the Ministerial Council on Energy have provided some guidance and prescription on the characteristics of the new arrangements.

5 The Council of Australian Governments has explicitly agreed that the national transmission network development plan will not replace local planning or bind transmission companies to specific investment decisions, override network service providers' performance standards, or constrain the time frames for the revenue approval process for transmission companies.

6 There are technological solutions to transmission losses such as lower-resistance power lines, but the capital costs are currently prohibitive.

7 This is known as the avoided transmission use of system charge.

8 The selection of the type of tariff will depend on the technological capabilities of the meters installed.

9 Some argue that a gross-metered feed-in tariff is undesirable because, from a sustainability perspective, it does not encourage embedded generators to consume less electricity, whereas under a net-metered scheme profits can only be made by exporting more to the grid. This reasoning is erroneous because the incentives to consume should come through the retail tariff paid for electricity, not through the feed-in tariff system.

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18 INFORMATION AND AGENCY BARRIERS

Key points

There are potentially large and early gains from better utilisation of known technologies, goods and services, including energy efficiency and low-emissions transport options.

Externalities in the provision of information and principal–agent issues inhibit the use of distributed generation and energy-saving opportunities in appliances, buildings and vehicles.

Some combination of information, regulation and restructuring of contractual relationships can address many of the market failures blocking optimal utilisation of proven technologies.

There are significant opportunities for low-cost reductions in emissions across the Australian economy through the deployment of existing technologies and practices. These opportunities include energy efficiency and fuel switching in homes, industry and transport.

This chapter examines these opportunities. The Review's final report will make recommendations on these matters.

The introduction of an emissions trading scheme will increase returns from adopting opportunities to lower emissions. However, market failures will impede adoption of opportunities that may be privately cost-effective. Policies that tackle these market failures would lower the cost of mitigation across the economy.

Tackling these market failures will require changes to entrenched practices and procedures. It will require new skills, supported by significant investment in relevant education. As economies orient themselves towards lower-carbon products and services, demand for these new skills will increase, with potential benefits for individuals, firms and nations that have invested early in education.

Designing effective policies will involve case-by-case analysis and sometimes cycles of testing, evaluation and refinement. Given this complexity and the need for tailored policies in various sectors, this chapter suggests a policy framework rather than detailed policies.

18.1 The impact of information and agency barriers

Two kinds of market failures are especially important in inhibiting the adoption of low-emissions technologies and practices. One relates to externalities in the supply of information and skills. The other involves a principal–agent problem—where the party that makes a decision is not driven by the same considerations as another party who is affected by it.

A substantial proportion of the low-cost low-emissions opportunities in Australia are in sectors that are affected by information and principal–agent market failures. Much of the mitigation potential in these sectors could be achieved relatively early.

18.1.1 Which sectors are affected?

The market is more likely to overcome information and principal–agent barriers in sectors involving large firms. Market failure is most likely to occur where mitigation opportunities are small relative to the transaction costs of securing them, such as:

- energy efficiency, fuel switching and small-scale generation in buildings, industry and transport
- emissions reductions in agriculture, forestry and waste.

18.1.2 How much mitigation potential exists in these sectors?

Various studies attempt to estimate the extent of mitigation opportunities in different sectors. Work by the IPCC (2007: 9, 409) suggests that the majority of global mitigation potential to 2030 at under US$20 per tonne of CO_2-e would occur in sectors affected by information and principal–agent market failures, with around 5 billion tonnes of mitigation potential in the building sector alone out of a total abatement potential of 9–18 billion tonnes in all sectors.

Box 18.1 What is energy efficiency?

Energy efficiency generally refers to reducing the amount of energy required to deliver an amount of a service, such as kilowatts per unit of heat. The International Energy Agency (2006) has estimated that increased energy efficiency could account for 45 to 53 per cent of global emissions reductions in projections to 2050.

Once an emissions trading scheme is in place the cap will prevent emissions from increasing in covered sectors. In this context, appropriate energy efficiency programs can increase individuals' welfare, by delivering more of a service for the same amount of energy.

Energy efficiency does not always correspond to economic efficiency, which involves maximising the efficiency of use of all resources (Sutherland 1994). Where efforts to improve energy efficiency require more input of capital, labour and other resources than is saved in energy, economic efficiency would be reduced.

Nevertheless, the evidence indicates that there are opportunities for increased energy efficiency in Australia that are economically beneficial (Allen Consulting Group 2004), although there are methodological issues in accurately determining the quantum of the opportunity (Productivity Commission 2005). If these opportunities are taken up, the need to expand generation in the next twenty years may be reduced, which could further lower the cost of mitigation, since the cost of renewable and low-emissions energy plants is likely to decline over this period.

Similarly, work by McKinsey & Company (2008) suggests that the majority of technically low-cost mitigation opportunities in Australia occur in sectors affected by information and principal–agent market failures. McKinsey & Company estimates that in 2020 Australia's emissions could be reduced by around 11 per cent below business as usual levels through zero and negative net cost mitigation opportunities, which are predominantly in the transport, buildings and industry sectors.

Many of these studies are overly optimistic as they do not include potentially unavoidable transaction costs from the uptake of more efficient products, such as time spent in information gathering and decision making. They may also use low discount rates, overestimate savings and ignore policy costs (Stavins et al. 2007). On the other hand, many are also conservative in limiting the potential for technology development that could increase the potential for mitigation. Despite the difficulties in estimating the full range of costs and benefits, these studies are useful first steps.

18.1.3 Rationale for additional policies

An effective emissions trading scheme would address the issues of reducing greenhouse gas emissions and urgency of action. The rationale for other policies to support the uptake of low-emissions technologies and practices should be the correction of market failures that increase the cost of mitigation. If these market failures cannot be tackled cost-effectively then there is no case for action, which would increase the cost of mitigation.

Any other justifications for additional policy measures should be rejected.

18.2 Public good information

Individuals can never have perfect information relevant to a decision they are making. However, development of an efficient market in goods and services requires individuals to know:

- the options available
- the rough costs and benefits of the different options
- how to deploy the options (including hiring experts)
- the cost of investigating the options.

Information on the emissions produced or energy used by some technologies can be difficult to determine without extensive testing (Sorrell et al. 2004), which may make information barriers particularly widespread in markets for low-emissions options.

Governments should not be expected to fill the gap in every situation where individuals lack sufficient information to make good decisions. Producing, finding, and processing information has economic costs that need to be considered in decision making. However, where information barriers are caused by market failures, governments may be able to improve the efficiency of the market.

These market failures include the public good nature of some information and bounded rationality. They are discussed below, together with policy options to address them.

18.2.1 Public good information market failures

Some information is a pure public good, as it is not possible to exclude individuals from using it, and one person's use of that information does not prevent others from using it.

Where information has public good characteristics, it is likely to be underprovided by the private sector (Jaffee & Stavins 1994a). The private sector may disseminate information with public good characteristics, such as consumer magazines. However, as firms are not able to capture all the benefits from public good information, there is insufficient incentive to make information as extensive and widely available as consumers may demand.

Training and education are also important public goods (Brown 2001). Even if individuals have access to information, they may require new skills or a wider body of knowledge to use it (Consumer Affairs Victoria 2006). Given the wide range of technical issues involved in some low-emissions options, gaps in the skill sets of specialists such as engineers or tradespeople could prevent the uptake of low-emissions options across a range of sectors.

Bounded rationality

Even where individuals have access to sufficient information, they may make decisions that appear personally suboptimal for reasons of 'bounded rationality'. Bounded rationality is the concept that individuals and firms may not be able to always make perfect or optimum decisions, as their knowledge and processing abilities are limited. In some cases, socially suboptimal outcomes result.

Firstly, gathering and processing information has costs. A study of energy efficiency investments by Danish companies estimated that transaction costs relating to information gathering and decisions accounted for 3 to 8 per cent of the costs of the investment (Hein & Blok 1995).

Even if individuals have access to information, the personal costs of gathering and processing the information may exceed the personal benefits. Therefore, individuals may choose to remain uninformed even when better information could help them to make decisions that would be more advantageous in the absence of information costs.

For example, Sathaye and Murtishaw (2004) suggested that even if consumers were aware that compact fluorescent lamps could save money, they may need to spend 45 minutes to accurately assess potential savings and locate a shop that sold these lamps. If individuals valued their time at US$20 per hour, this would more than double the 'price' for the first purchase of this type of lamp. However, if individuals could pass this initial cost barrier, over their lifetimes they would probably save significantly on their lighting costs.

Secondly, as the costs of making optimal decisions can be high, some theorists suggest that in many situations people make decisions that are sufficient to meet their needs, rather than optimal (Simon 1955). This type of decision making may be personally optimal for an individual when considering limits to her time, attention and other resources.

One example of this type of behaviour is the use of rules of thumb in decision making. Rules of thumb can include personal habits and cultural norms, such as the widespread use of pay back periods in estimating whether capital investment is worthwhile.

Some rules of thumb deliver broadly accurate results. Kempton and Montgomery (1982) found that the way that individuals estimated savings from investments in insulation were often inaccurate. Even in those cases where households attempted to determine payback periods, they significantly underestimated the cost-effectiveness of investments in insulation.

Finally, in addition to rules of thumb, there are some predictable biases in human decisions that could result in decisions that are both personally and socially suboptimal (Kahneman & Tversky 2000). Some of these biases are relevant for investment in low-emissions options, particularly:

- biases towards the status quo
- high rates of discounting of future costs and benefits compared to immediate costs and benefits.

Finally, individuals also have difficulties in processing, retaining and using information, and may not attempt to weigh up the costs and savings of low-emissions options. Even where savings are known, households may pay them limited attention compared to their perceptions of upfront costs, effort, comfort and social norms (Komor & Wiggins 1988). Bounded rationality presents a challenge to the uptake of some cost-effective low-emissions options.

18.2.2 Policy option: information and education

Government funding for the provision of information and skills can tackle the undersupply of these public goods directly. Information and education programs have strong synergies with an emissions trading scheme, as they can help individuals to identify the carbon price and respond to it. This is particularly important during the scheme's initial phase, when the costs of many goods will change.

However, there is considerable evidence that the effectiveness of basic media campaigns and pamphlets is limited due to bounded rationality (Cone & Hayes 1980). Information programs for households are more effective if they consider social and attitudinal issues and involve alternative communication techniques such as audits, community-based programs and diffusion through social networks (Shipworth 2000). Developing these types of programs generally requires:

- identifying target groups and assessing their knowledge, attitudes and behaviours
- developing communications, possibly using social networks
- testing, evaluating and improving the program before rolling it out.

If governments follow the advice given out by information programs, such as undertaking energy efficiency audits, this can support the credibility of such programs (Bjornstad & Brown 2004).

Where extensive knowledge and skills need to be conveyed, education and training programs will be more effective than information programs. However, education programs have significant ongoing direct and opportunity costs to the provider and the student.

Box 18.2 Tailored information: TravelSmart

Some individuals do not have basic information about the transport options that are available to them and the costs and benefits of those options. Interviews in Perth suggested that information failures may have prevented 24 per cent of all trips being switched from car to other modes of transport. The TravelSmart Household Program in Perth aims to overcome these information failures through tailored information provision, including:

- localising and simplifying information to make it relevant to people's needs
- providing motivation through dialogue and personalised communication
- assisting new users of public transport to navigate the system.

Tailoring information and education programs

Information or education programs need to be targeted and tailored to ensure that the right individuals receive suitable knowledge and skills. Target groups for programs should include:

- the general public—for programs that raise awareness of the benefits of energy efficiency, provide basic information on low-emissions practices, and educate consumers on how to identify the costs and benefits of different low-emissions options
- market intermediaries such as retailers and estate agents—for basic education programs
- managers and other non-specialists in business—for programs that raise awareness of practices for energy and carbon management
- specialists—for programs that cover practical skills in the installation and maintenance of low-emissions options for trades such as building and plumbing, and a mixture of theory, knowledge and skills for professions such as engineering (Desha et al. 2007).

Programs also need to be tailored around the information needs and structures of sectors. Where there are already suitable bodies such as outreach programs in the agricultural sector, these may be valuable in diffusing skills and knowledge. In some cases new structures may be required, such as the independent Carbon Trust that was established in the United Kingdom to specialise in delivering knowledge and skills to firms.

Box 18.3 GreenPlumbers

The Australian GreenPlumbers program has trained and accredited more than 3500 plumbers in skills such as installing solar water heaters and leak minimisation since 2001. The program was developed by the Master Plumbers and Mechanical Services Association of Australia with support from private firms, the Commonwealth Government, local councils and the Royal Melbourne Institute of Technology.

In industry, formal education and reskilling courses are generally suitable for addressing the lack of skilled professionals, such as engineers. However, there are also gaps in organisation-wide skills that support energy management, such as energy reporting (Paton 2001). Here companies may need to be engaged directly, as general information provision may be limited in its effectiveness (Energy Consult 2002).

Voluntary industry programs, such as the Australian Government's Energy Efficiency Best-Practice Program, appear to have had success in engaging companies to improve their skills and reduce their emissions (Paton 2001). The final review of this program found that it had been cost effective, and that projects planned under the program could save $74 million by 2010 (Energy Consult 2002).

Investment in learning

While there are likely to be long-term benefits to individuals, firms and nations that invest in education during the transition to a carbon-constrained economy, there are also likely to be significant upfront costs. These upfront costs may present barriers to learning.

Specialists, such as electricians, may face upfront costs but uncertain benefits from learning new technologies. As clients often rely on specialist advice on which technology to install, they may not be in a position to demand more efficient equipment. This may result in the 'lock-in' of some higher-emissions technologies. If this occurs, certification programs could provide an incentive for specialists to learn new information.

Similarly, some companies may not be able to determine the benefits of learning about energy management before the learning takes place. Some programs, such as the Australian Government's Energy Efficiency Opportunities Program, complement voluntary training on energy management with some mandatory components that encourage firms to learn new skills. Some early results of the program are promising, with one plant that had already invested in energy management finding more than a million dollars worth of savings through participation in the program (Department of Resources, Energy and Tourism 2007).

There may be a case for such mandatory requirements early in the transition to the carbon-constrained economy. However, in future these may be unnecessary, as new energy management processes become integrated into standard business practices.

However, education and information programs will not always be effective, as bounded rationality means that individuals may not pay attention to information, may forget information rapidly and, even where they are sufficiently aware and have incentives to make a decision, may not act on the knowledge (McKenzie-Mohr & Smith 1999). In addition, information programs may be less effective when they attempt to convey complex information to individuals, where habits or practices are entrenched, or where other market failures are in operation. In these cases governments should consider other policy options, such as the use of specialists or minimum standards.

Information and education programs are likely to be most effective in cases where bounded rationality is restricted, such as:

- situations where the information is close to the point of decision, such as energy labels on appliances that are examined along with the good
- education programs for specialists, as they are more likely to regularly use and hence retain the knowledge gained. In addition, it is generally cheaper to educate a small number of specialists than a large number of non-specialists.

18.2.3 Policy option: use third parties

Specialists, such as energy service companies, can use economies of scale in gathering and processing information to overcome information gaps and bounded rationality. These companies are paid by firms to make decisions about which technology to buy, thus spreading the cost of gathering information across several parties. As a result, the cost of information to each firm is lowered.

Unfortunately, transaction costs make current forms of energy service contracting less suitable for smaller parties with significant information and bounded rationality problems, such as households and small businesses (Sorrell 2005). Take-up of basic household energy audits, which can be quite cost effective, can be low due to bounded rationality and the inability of households to determine the value of specialists' advice before it has been given.

Various countries have attempted to foster the market for energy service contracting and auditing. For example, energy retailers could offer contracts to households for 'services' such as heating, hot water and appliances, creating an incentive for the retailers to improve households' energy efficiency. Although there has been limited success to date in fostering these markets (Eoin Lees Energy 2006), there is a case to support testing this approach, as it may be an efficient option if successful.

One alternative has been for governments to subsidise third parties to provide advice or directly install low-emission options in houses and businesses. Generally, if the number of audits and subsidised installations is limited and schemes rely heavily on households to make the decision to take up these options, they will tend to favour informed individuals who are already motivated to save energy. Given the distributional impacts, if these programs are limited in scale they should focus on low-income households.

Another alternative is to create obligations or incentives for parties, such as energy retailers, to deliver energy efficiency improvements in households and firms. Market-based schemes have the advantage that they are more flexible and responsive than government schemes, and are used extensively both the United States and Europe. The UK scheme has been particularly successful in encouraging market transformation, with energy-efficient washing machines now dominating the market and becoming cheaper than less efficient machines (Eoin Lees Energy 2006). However, there are challenges in estimating the energy savings from these programs, and there appear to be errors in many estimates of the cost-effectiveness of these types of program. These schemes appear to be worth testing, but the detail of design will be critical and any scheme that is introduced in Australia should be rigorously monitored and evaluated.

18.3 Information asymmetry

18.3.1 Information asymmetry market failures

Information asymmetry occurs when two parties to a transaction do not have equal access to relevant information.

There are potentially significant information asymmetries where appliances, vehicles and houses are not energy rated. It would be extremely difficult for non-experts to determine the ongoing energy use of an appliance, for example, without outside assistance. This allows opportunism, as a product manufacturer could mislead a buyer on the efficiency of a product, which the buyer is unable to verify.

As noted by the Productivity Commission (2005), market participants may attempt to gather or verify information to reduce information asymmetries through such expedients as hiring an energy-efficiency auditor to examine a house before they buy it. However, this can be costly and individuals may choose not to invest in further information gathering, avoid the transaction or place a risk premium on the transaction.

There may be some features of low-emissions options that increase the likelihood of information asymmetries. Goods can be classified as:

- search goods, where quality can be determined before purchase

- experience goods, where quality can be determined after purchase
- credence goods, where quality cannot be easily determined even after purchase.

As noted by Sorrell et al. (2004), market failure is least likely for search goods and most likely for credence goods. For search goods, there is limited information asymmetry. For experience goods, repeat purchasing can overcome the information asymmetry to some degree. However, repeat purchasing is limited for major purchases such as houses, appliances and vehicles. Furthermore, some goods, such as water heaters, may be credence goods with respect to qualities such as energy use, as it is costly to determine their energy use even after purchase. For credence goods, repeat purchasing will not address information asymmetries.

Adverse selection

Information asymmetry can lead to adverse selection, which can occur where sellers are better informed than buyers, resulting in lower-quality goods dominating a market (Akerlof 1970).

In a market where it is difficult for buyers to verify whether a product is of good or bad quality, they may be unwilling to pay a premium for goods that are actually of good quality. Even if manufacturers voluntarily give information on a product's quality, buyers may be wary of this information (Aronson & Stern 1984).

Where this occurs, there would be limited incentives for manufacturers or developers to produce more energy-efficient products (Jaffee & Stavins 1994b). For example, in the markets for appliances and houses there is a strong incentive for producers to lower the upfront costs, which will usually be associated with avoidance of energy-saving features. As a result, most goods for sale on the market will be less energy-efficient, even if buyers would prefer to buy more energy-efficient appliances if they could be sure of their quality.

In some cases the private sector may be able to implement mechanisms to reduce the extent of adverse selection, such as using a third party to verify the quality of the product. However, the private sector may not always be able to coordinate cost-effective responses to adverse selection.

18.3.2 Policy option: mandatory disclosure

Ensuring that both parties in a transaction have access to sufficient information will generally be the most effective way to address information asymmetry. Therefore, it should be the first policy that governments consider when information asymmetry market failures are identified.

Disclosure schemes, such as energy efficiency ratings, complement an emissions trading scheme as they assist individuals to act on the price signal.

Disclosure schemes will be far more effective if they are mandatory, as sellers are only likely to apply voluntary labels to high-performing products, leaving consumers unable to select among average and poorly performing products (Productivity Commission 2005). In addition, the disclosure mechanism, such as an energy efficiency label, needs to be designed with bounded rationality in mind, in order to be as easily understood by individuals as possible.

It is argued that labelling programs for appliances are successful in assisting the uptake of more energy-efficient products in Australia and other countries (George Wilkenfeld and Associates & Energy Efficient Strategies 1999: 49).

There is a strong case for application of mandatory disclosure to goods where it is cost effective. This will be largely determined by the administrative cost of the scheme, its accuracy and the potential savings to consumers.

The potential for accurately and cheaply rating energy use will vary between goods. For refrigerators, it is relatively easy to cheaply assess their energy use—most households' patterns of using a refrigerator will have limited effect on the comparative efficiency of different models. For vehicles, the situation is more complex as a driver's behaviour may influence the efficiency of some cars relative to other cars, but even partially accurate ratings are likely to be valuable.

Mandatory disclosure may not always be able to address information asymmetries, if bounded rationality prevents one or more parties from usefully applying the information, or if one of the parties is not the actual decision maker (see section 18.5). In these situations, minimum standards may be an appropriate policy response (see section 18.6).

18.4 Early adopter spillovers

18.4.1 Information spillover market failures

Some actions by parties can result in benefits to other parties, without those other parties paying for them. Early adopters of some low-emissions options bear additional costs in gathering information, developing skills for adopting the option and testing the reliability of the option (Jaffee et al. 2004). In some cases, the boundary between early adoption and innovation can be blurred. However, early adopters are often unable to capture the knowledge and skill spillover benefits that accrue to other firms, other industries, and the community more broadly. This acts as a disincentive to early adoption of novel technologies and practices.

For example, if a firm installs a relatively new technology in its manufacturing plant it will face higher risks than if it had used a more common technology. The firm may also have to pay consultant engineers higher fees to cover their costs in learning how to install a technology. While much of the benefit will accrue to the firm, its early adoption will have demonstrated the reliability of the technology to others and provided training to consultant engineers that could benefit future clients.

Most new technologies take time to diffuse. Spillovers and other market failures may extend the time (Jaffee & Stavins 1994a). This delay in diffusion could increase the cost of mitigation.

It may sometimes be possible to overcome the costs faced by early adopters by providing information and training. In other cases, knowledge and skills need to be developed through testing and demonstration—of a relatively new industrial technology, for example—by early adopters.

18.4.2 Policy option: support for early adoption

There is a case for government support for early adoption of new technologies to address spillovers.

This can involve governments, households and the private sector adopting and demonstrating relatively novel technologies. For example, Melbourne City Council's Council House 2 demonstrates a range of technologies that are novel in the Australian building industry. This project also developed skills in the local construction industry.

Support for early adoption needs to be targeted at the type of spillover that is generated. For example, if the primary spillovers arising from early adopters are related to skills, support for early adoption should focus on sharing skills as widely as possible.

Similarly, if programs aim to demonstrate that novel vehicle technologies are reliable, they need to focus on diffusing this information. Supporting a set number of early adopters in conjunction with diffusing information may be more effective than supporting a larger number of adopters without diffusing information. However, as people are more likely to trust known sources (Yates & Aronson 1983), demonstration programs may need to involve regional and community components.

18.5 Principal–agent problems

18.5.1 Principal–agent market failures

Principal–agent problems can occur when one person (the principal) pays an agent for a service, but the parties face different incentives and the principal cannot ensure that the agent acts in her best interest. For example, engineering consultants that are contracted to select a motor for a manufacturing plant do not face the same incentive as the manufacturing company to lower the ongoing energy cost of the motor.

Principals and agents may be able to negotiate to align their incentives more effectively. In the example above, the manufacturing company could stipulate that the engineering consultant use a particularly efficient motor. Principal–agent problems persist when:

- it is hard to monitor a contract due to information asymmetries
- it is difficult to enforce contracts, or
- the costs of negotiating and establishing a better contract exceed the benefits. For example, while residential tenants can attempt to renegotiate leases, offering to pay more rent if landlords improve energy efficiency, the effort is likely to be substantial (Sanstad & Howarth 1994).

Principal–agent problems may entirely insulate some decisions from a carbon price, potentially reducing the adoption of low-emissions options. For example, as residential tenants pay energy bills, landlords may not install energy efficient appliances (IEA 2007a).

Categories of principal–agent problems

The type of principal–agent relationship can influence both the nature of the problem and the appropriate policy response. The International Energy Agency has categorised four types of principal–agent relationships that could affect energy use (see Table 18.1), depending on:

- who chooses the energy-using equipment
- who pays the energy bills.

In all four types the principal uses the equipment.

Table 18.1 Four types of principal–agent problems

	Principal chooses technology	Agent chooses technology
Principal pays the energy bill	**Type 1:** The principals select the energy-using equipment and pay the energy bill. They have an incentive to select efficient equipment and lower their energy use. There is no principal–agent problem.	**Type 2:** The agents select equipment on behalf of the principals, and the principals pay the energy bill. As a result, the agents may not have an incentive to select efficient equipment. This type of relationship occurs between landlords and tenants.
Agent pays the energy bill	**Type 3:** The principals select the equipment, but do not pay for the energy bill. As a result the principals have no incentive to select efficient equipment or lower their energy use. For example, staff select company cars but do not pay ongoing fuel costs.	**Type 4:** The agents select the equipment on behalf of the principals, and pay the energy bill. As a result, the agents have an incentive to select efficient equipment, but the principals do not have an incentive to lower their energy use. This occurs in hotels.

Source: Derived from IEA (2007a).

Principal–agent relationships have repercussions throughout the wider market for goods. For example, the first-hand car market dictates which cars are available in the second-hand car market. Therefore, the principal-agent problem that arises from company car purchases could have significant repercussions on Australia's car fleet.

18.5.2 Policy option: linking principals and agents

Where possible, principal–agent problems should be tackled directly by either:

- improving the ability of principals to monitor and enforce contracts, or
- fostering contracts that better align the interests of principals and agents.

Where information asymmetries prevent principals from monitoring contracts, mandatory disclosure may be an effective way to reduce principal–agent problems.

Where contracts do not align incentives well there is a case for governments to develop new standard contracts that can be used by a range of parties, resulting in benefits from economies of scale. Parties often use standard contracts that may not be optimal due to high costs for individual parties to develop new contracts. An example of a new standard contract, 'Green Leases' for commercial properties, is discussed in section 18.7.3.

New contracts have been mandated in Japan to tackle problems in the vending machine market (IEA 2007a). Previously, Japanese beverage companies typically rented space from building owners for vending machines, but building owners paid the electricity bill, resulting in a Type 3 principal–agent problem. To address this barrier, the Japanese Government stipulated that contracts for vending machines should make beverage companies responsible for both selecting the appliance and paying the energy bill. In combination with standards for vending machines, this policy appears to have driven a 34 per cent increase in energy efficiency in vending machines between 2000 and 2005, in contrast to similar but unregulated display cabinets.

There may be limits to the extent to which improving the links between principals and agents can eliminate principal–agent problems. Examples include:

- bounded rationality reduces the ability of parties to respond to mandatory disclosure
- the transaction costs of enforcing new contracts exceed the benefits, or power imbalances impede principals from enforcing contracts.

Other policies should then be considered. There is a case for minimum standards to provide some level of protection for principals in these situations. As noted by the Productivity Commission (2005: 200): 'The case for mandatory standards appears to be strongest when split incentives typically cause individuals to use products that are very cost ineffective'. Regulations in such situations should reflect the best interests of the majority of principals, considering the possible loss to principals if regulations dissuade a large number of agents from entering into contracts.

18.6 Minimum performance standards

Minimum standards, such as minimum energy efficiency standards for appliances, can circumvent the need for individuals to identify and avoid appliances that have high ongoing energy costs (Jaffee et al. 2004). Standards can address several of the market failures discussed in this chapter.

There is a case for standards where bounded rationality and principal–agent problems render other policy options ineffective. However, the argument for standards needs to be made on a case-by-case basis. Generally, standards should be considered only after other policy options, as they:

- reduce flexibility
- reduce the opportunity for individuals to make choices
- operate on the presumption that government can make better decisions than market participants, both now and in the future.

Given the likely limits on information available to governments, standards should focus on:

- performance, rather than specifying technology
- features that are unlikely to affect consumers, such as energy efficiency, rather than features that consumers may value, such as the size of appliances
- removing poorly performing products, as it will be generally easier to identify the products that are the least cost-effective for the majority of users, than the products that are the most cost-effective options for all parties in all circumstances.

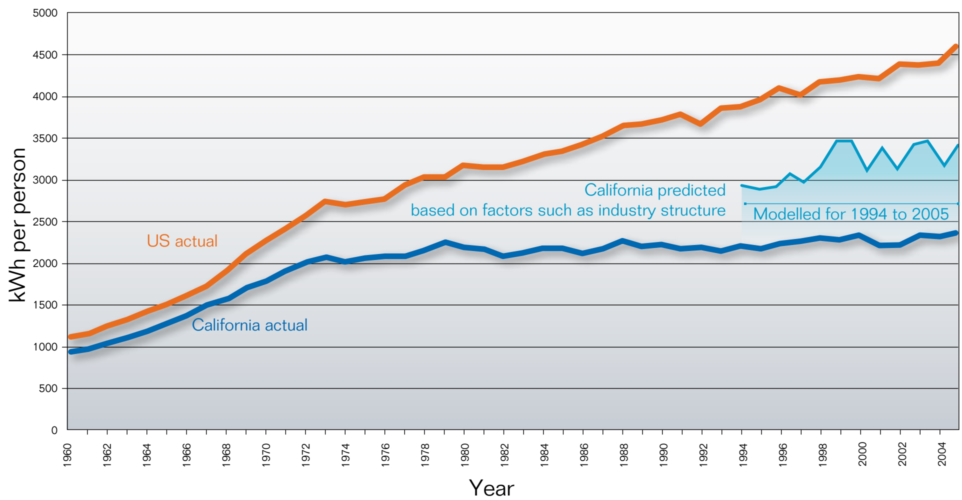
If standards are designed appropriately, with good knowledge of the costs and benefits and sufficient lead time for industry to respond, experience from both Australia and abroad has indicated that they can be cost effective in supporting the uptake of low-emissions options (IEA 2007b).

National Mandatory Efficiency Performance Standards for refrigerators and freezers were introduced in Australia in 1999 and revised in 2005. This set of standards removes appliances from sale that do not meet minimum benchmarks of energy efficiency. Retrospective analysis in 2006 estimated that these policies saved more than 3000 gigawatt-hours of energy by 2005, savings that were 34 per cent higher than was forecast in the original Regulatory Impact Statements (Energy Consult 2006).

California has been held up as a particular success story in improving energy efficiency, with electricity sales per capita remaining steady at the same time as output per person grew strongly. Although this is likely to have been partly driven by California's industry structure and higher electricity prices, recent work indicates that energy policies account for a substantial proportion of the state's higher level of energy efficiency (Kandel et al. unpublished) (see Figure 18.1), with building and appliance standards accounting for around half of these savings (Geller et al. 2006).

Estimates of the costs and benefits of appliance standards have been contested, particularly in the United States (see for example, Meyers et al. 2002; Sutherland 2003; Nadel 2004). However, this debate does not suggest that standards are unsuitable, but merely underlines the importance of using robust methodologies in assessing the benefits of appliance standards and regularly updating standards to ensure that they remain relevant.

Figure 18.1 Residential per capita electricity consumption in the United States, California and as predicted for California



Note: The area between California predicted and California actual (modelled for 1994 to 1995) indicates possible savings from energy efficiency policies.

Source: Kandel et al. (unpublished).

18.7 Applying the market failure framework to buildings

Residential and commercial buildings account for 23 per cent of Australia's emissions from electricity use alone, and their emissions are growing rapidly (Centre for International Economics 2007). Buildings can have a life of more than 50 years. Decisions that are made now will have consequences for future emissions.

While reducing the ongoing energy use of approximately 150 000 dwellings constructed each year will have long-term impacts, the emissions from the greater than seven million existing private dwellings also need to be tackled (ABS 2006b, 2007).

Low-cost technologies and practices that can reduce emissions from buildings in Australia include:

- a more selective use of energy-using appliances
- installing more efficient appliances
- improving insulation.

18.7.1 Market failures in purchasing and using buildings

The market failures already discussed apply to the purchase and use of appliances and buildings in both the residential and commercial sectors. These are explored further below.

Information asymmetries

While tenants and appliance users face a strong incentive to lower ongoing energy costs, developers and manufacturers do not face this incentive unless they can command higher prices for more efficient buildings and appliances (Golove & Eto 1996). This requires buyers to be able to confidently assess the energy efficiency of buildings and appliances. Adverse selection may also affect decisions by owner-occupiers. If occupants expect that they will sell a building soon, they may not capture the full benefit of investments in energy efficiency through energy savings (Bjornstad & Brown 2004), unless prospective buyers can assess the building's energy efficiency.

Public good information and bounded rationality

Even where appliances and buildings have energy efficiency labels, individuals will not take up more efficient options if they are unaware of the benefits of energy efficiency, or are unable to calculate ongoing savings. While market intermediaries, such as real estate agents, could provide information, they often lack skills and training (Dutruge 2006). Imperfect information and bounded rationality also affect how individuals use appliances, which strongly affects the energy used by appliances and buildings.

Commercial tenants are more likely than households to have access to information, and are more likely to be able to process it effectively (Kempton & Montgomery 1982). However, firms may still lack the time and skills to process and evaluate the information effectively (De Canio & Watkins 1998), and internal factors may impede decision making.

Principal–agent problems

In the Australian rental market, landlords are generally responsible for the purchase and maintenance of fixed appliances, such as water heaters. The tenant pays the energy bills and a fixed rent to the landlord, which is agreed when the contract is first signed. Therefore, during the period of the lease there is no incentive for landlords to invest in improving the energy efficiency of their properties, even if energy prices rise (IEA 2007a).

This appears to affect the energy efficiency of the 28 per cent of homes that are rented in Australia (ABS 2006a). A survey in South Australia, for example, found that rented houses contained different types of fixed appliances to other houses. For example, low-flow shower heads were installed in over 42 per cent of owner-occupied households but only 25 per cent of private rental homes (ABS 2004).

In the commercial sector, industry sources suggest that at least 70 per cent of offices are leased rather than owner-occupied. However, commercial tenants are generally more aware of energy costs and are often in a better position to negotiate with landlords.

Spillovers

Early adoption of novel technologies, including new heating, ventilation and cooling systems in commercial buildings, can face higher costs and demonstrate their reliability to other parties.

18.7.2 Market failures involving specialists

There are overlaps in market failures where specialists are involved in the installation of appliances (for example, replacing hot water systems) and construction.

- **Specialists may lack the information or skills** to install low-emissions options (Lovins 1992). This may be a particular problem in building construction, where integrated processes require several parties, such as architects, engineers and construction workers, to be familiar with a technology in order to use it.

- **Clients need to have sufficient information** to demand more efficient appliances and buildings. If specialists are aware of a low-emissions option, they may be able to persuade clients to select that option. However, clients may be wary of specialists' advice, particularly if the low-emissions option has higher upfront costs. This could result in adverse selection for skills, as it would reduce the benefits to specialists of investing in learning about low-emissions options. Design quality may be particularly affected by adverse selection, as clients face difficulties in determining the quality of design. As a result, time and cost pressures may result in contractors using off-the-shelf or familiar designs (Sorrel et al. 2004).
- **There are principal–agent problems** between clients and specialists. In particular, construction is characterised by many parties, including clients, developers, architects, engineers and construction workers, who are linked by contracts and subcontracts. Specialists often lack incentives to lower ongoing energy costs, and asymmetric information limits the ability to monitor and enforce contracts. Contractors may substitute technologies that are specified in the design with cheaper options, particularly if they are unfamiliar with the specified technology.

  Some contracts may create disincentives for agents to specify more efficient equipment (Lovins 1992). Engineering fees are often set as a percentage of the capital cost of building services, which creates an incentive for engineers to select equipment that is larger, and more energy-intensive, than required (Sorrell et al. 2004).
- **There are spillover benefits** from early adoption. Parties developing or adopting novel building designs face higher costs. In doing so, however, they demonstrate the value and reliability of new technologies and provide training to specialists. In the building sector first movers may also develop new processes in the industry. Energy-efficient buildings generally require more integrated design and construction processes than are typically used (Sorrell et al. 2004), requiring the development of new processes and contracts. However, once a construction team has used these improved processes it can implement them again.

18.7.3 Policy responses in the building sector

A variety of policy responses will be required in the building sector to address the multiple and interacting market failures.

Mandatory labelling for equipment and buildings

Australia already has a labelling program in place for appliances. Labelling should be extended to appliances that use sufficient energy for the benefits of labelling schemes to exceed the administrative costs.

The Australian Capital Territory has introduced a mandatory energy efficiency rating scheme for houses at the point of sale. A recent study suggests that there was a statistically significant correlation between house prices and energy efficiency ratings (Department of the Environment, Water, Heritage and the Arts 2007). Modelling results suggest that, for a house worth $365 000, increasing the rating by half a star would, on average, increase its market value by $4489.

There are some concerns with the accuracy of building rating schemes (Williamson 2004). These criticisms correctly raise the issue that efforts need to be made to ensure that rating tools are as accurate, flexible and useful as possible. Overall, there appears to be a case for a national mandatory energy efficiency rating scheme for buildings.

Education, tools and certification for specialists

The building sector is already an area of skills shortage, and responding to carbon constraints is likely to exacerbate this skills gap. Modelling by the Dusseldorp Skills Forum suggests that, under an emissions trading scheme, employment would grow rapidly in the construction sector, accounting for 10 per cent of national employment growth in the period 2005 to 2025 (Hatfield-Dodds et al. 2007). There is a case for governments to assist in training new workers and reskilling existing workers through:

- developing retraining courses and incorporating energy-efficiency components into vocational and university courses. Desha et al. (2007) suggest that engineering courses in Australia currently vary considerably in their coverage of energy efficiency
- providing tools such as design guides and advisory services
- fostering on-site training through demonstration programs (see next page)
- introducing accreditation to provide an incentive for specialists to learn.

Behaviour change and third-party programs

Increased awareness and skills among consumers is essential to enable the adoption of privately cost-effective low-emissions options, even in situations where specialists are involved.

There is a case for using third parties to provide tailored advice to households and small businesses. These programs can be effective in changing household energy use (Nadel & Geller 1996). For example, the Home Energy Advice Team program in the Australian Capital Territory partly subsidises audits for homes. These programs provide private information (Productivity Commission 2005) and so have some distributional consequences, but if they can be developed to be cost effective they could lead to changes in both household behaviour and building efficiency that benefit households and the economy more widely.

As noted earlier, some programs go further to provide incentives or obligations for third parties to identify and implement energy efficiency improvements in homes and businesses, such as the Victorian Energy Efficiency Target. These programs may be more effective at improving energy efficiency, but there may be significant methodological problems and it is not yet clear how cost effective these programs can be. As discussed in section 18.2.3, there is a case for testing these types of programs, but they should be rigorously assessed and focused on low-income households.

Improved contracting

The Commonwealth Government has developed 'Green Leases' that set out obligations for landlords and tenants to cooperate in reducing energy and water use (Christensen & Duncan 2007). The Commonwealth Government demonstrates and promotes the viability of these leases by using them when it leases commercial property or leases out its property to commercial tenants. Given the extensive principal–agent problems in buildings, there is a case to promote improved contracting in leasing, construction, engineering and services.

Research and demonstration programs

There are significant overlaps between the various stages of research, development and diffusion in buildings. Innovation occurs in the development of new products, installation of components, configuration of components and integration of components to change the overall performance of a building (Gann et al. 1998).

As noted by the International Energy Agency (2006), only 3 per cent of energy research and development expenditure in the countries that are members of the agency was directed to buildings from 2001 to 2005, even though this sector is projected to account for 18 per cent of global emission reductions by 2050. There is a case for expanding the role of the Cooperative Research Centre for Construction Innovation.

Skill spillovers and on-site training are also critical in the building sector. Programs that focus on integrating training into demonstration, such as Lochiel Park in South Australia, could have significant benefits.

Building and appliance standards

There is a case for appropriate appliance and building standards. Standards for new buildings and renovations need to be proportionate, simple and sufficiently flexible to allow owners to have features that they value and to allow innovation in the sector.

Ideally, standards should be national rather than state-based in order to lower the cost of building standards on the industry, with variations in standards based on climatic zones. Building standards should also be accompanied by an indicative pathway for the standards that may be introduced in the future, to assist the sector to adapt its practices. Such a pathway, which is updated as new information becomes available, could be a powerful tool to diffuse information on possible future trends in energy prices to developers and building owners, who may not otherwise consider such issues.

There is also a case for minimum standards for rental housing at the point of lease (Scott 1997). Such regulation would need to consider the equity impacts of standards and regulations on rental housing costs.

18.8 Conclusions

The Review will consider the various policy interventions that might reduce the costs of market failures related to information externalities and principal–agent problems and provide clear recommendations in the final report.

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19 INCOME DISTRIBUTION EFFECTS OF CLIMATE CHANGE MITIGATION POLICY

Key points

Low-income households spend much higher proportions of their incomes than other households on emissions-intensive products.

The direct price effects of the emissions trading scheme will be regressive. The effects will fall heavily on low-income households, so the credibility, stability, efficiency and longevity of the scheme require the correction of these regressive effects by other measures.

Correction of income effects in the lower half of the distribution is also necessary for anti-inflationary reasons through the early years of the scheme.

Approximately half the proceeds from the sale of all permits could be allocated to households.

Part of the payments to households could assist energy efficiency adjustments. The bulk could be passed through the tax and social security systems, with heavier energy efficiency commitments in the early years. The Henry taxation review could consider these issues.

This chapter provides a brief and preliminary survey of income distribution issues associated with the introduction of an emissions trading scheme. The Review is conducting modelling of distribution effects, which will be reported in the supplementary draft report. More detailed analysis of the policy response to distributional issues will be presented at that time.

The main guarantor of equity during rapid structural change is maintenance of economic growth and full employment within a flexible economy. Contemporary Australia is well placed to absorb major structural change, and it is important to the success of implementation of strong mitigation policies that this continue to be the case. Australia is currently experiencing high demand throughout the country for skilled labour of the kind that may be temporarily displaced by the differential impact of an emissions trading scheme. It is also experiencing shortages of unskilled labour in many regions.

While sustainment of these favourable circumstances is the hope of all citizens and the focus of official policy, these hopes and intentions may not be continuously realised. The mitigation regime, if it is to achieve its purpose, will need to last for a long time, and maybe indefinitely. Even a happy century would include periods of diminished prosperity. And even if labour displaced by the structural change associated with the mitigation regime were quickly employed elsewhere, there would still be important income distribution effects to be considered.

The emissions trading scheme is likely to be introduced into an environment of recent and perhaps continuing large increases in fuel, electricity and food prices—precisely the goods and services whose prices will be affected most by the scheme. In the early years, and perhaps for many years, other causes of increases in fuel, electricity and food prices will be much more important than the scheme.

This might be thought to make the introduction of an emissions trading scheme easier. What does it matter if prices that have increased by large amounts increase a bit more?

But it will in fact make the introduction of the scheme much harder. Households will not be able easily to distinguish between the varying sources of price increases, while agitators against the scheme will be busy spreading disinformation. And the price increases with other origins will have heightened the sensitivity of consumers and the polity to any further increase in prices.

Equity issues were always going to be critical to the successful introduction of the emissions trading scheme. The febrile environment of historically exceptional increases in energy and food prices, independently of the scheme, makes the development of measures to counter the potentially regressive effects of the scheme even more important. The transparent and effective communication of responses on equity issues to the community will be the key to acceptance of the scheme, and therefore to its credibility, stability, efficiency and longevity.

19.1 Impacts will flow through the economy, and will be uneven

An emissions price will influence patterns of production, consumption and investment. This, in turn, will change the distribution of income.

The distributional consequences of the emissions price will be spread unevenly throughout the economy. The way in which the emissions price flows through the economy is described further in Box 19.1.

Box 19.1 Economic versus legal incidence of the emissions price

There is an important difference between the legal and economic incidence of the emissions price. The legal incidence will rest with a range of industries that have emissions or imputed emissions above a certain threshold—that is, 'points of obligation'. Parties with an obligation will need to acquire and acquit permits equal to their actual emissions. Such parties may include:

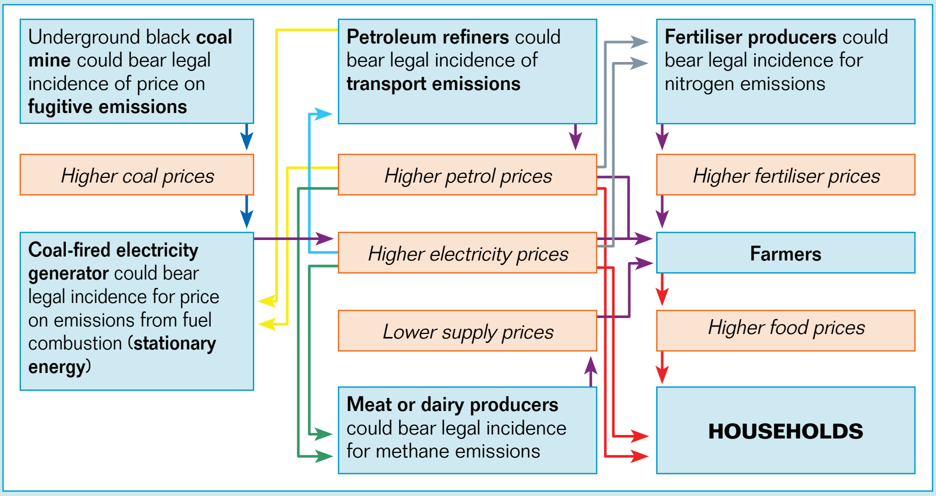
- electricity generators, for emissions from electricity production
- factories, for the release of industrial process emissions during production
- point of excise for (imputed) petrol emissions.

Parties will meet their obligation in a number of ways. They may purchase permits to cover their actual emissions, reduce their own emissions, reduce production (and associated emissions) or pursue some combination of these activities.

Most sectors will pass the cost of purchasing permits and reducing emissions down the supply chain. Pass-through will be quick and complete in some industries, and incomplete in others, depending on the nature of the competitive environment, and especially competition from imports. It is likely to be complete for petroleum products, and substantial but less than complete for electricity.

With a price on emissions, production costs will increase, with electricity, natural gas, petrol, diesel, chemicals, fertiliser and other inputs costing more. These costs will be reflected in higher priced goods, from cement and steel, to paper and plastic. This will have an impact on the input costs for a range of industries, including construction and retail. Through the supply chain, those disposing of waste will also be likely to pay more, and transport costs will be higher.

Figure 19.1 Who pays the emissions permit price?



Box 19.1 Economic versus legal incidence of the emissions price *(continued)*

Costs will be embodied in final and intermediate products, and be passed down the supply chain until these goods and services are sold to consumers.

Much of the cost of reducing emissions will eventually rest with consumers, who will pay higher prices for products.

As well as affecting consumer prices, the carbon price will be felt in other ways. For example, it may affect firms' profits, and wages. Whether these impacts are positive or negative will depend on a range of factors, including who has power in the marketplace.

19.1.1 Impacts will change over time

The emissions price will fluctuate over time around a rising trend. The price will depend on the emissions limit set for the scheme, the demand for emissions-intensive goods and services determined by income growth and the structure of the economy, the level of hoarding and lending of permits, international links and the costs of producing low-emissions substitutes.

In the transition period at the commencement of the emissions trading scheme, 2010–12, the permit price is to be set at a fixed, low level. Because those with an obligation will not be required to pay more than this price for permits, or be driven to undertake mitigation activities with a cost above that level, impacts on the rest of the economy will also be limited. When the scheme commences unconstrained operation in 2013, with the likelihood of higher permit prices, effects on household costs will increase.

The permit price is not a reliable guide to the effect of mitigation on costs and prices in the long term. Once a low-emissions technology has been brought into the market by a specified emissions price, it is likely to undergo faster technological improvement than other technologies because it is new. As a result, the general price impact of a given amount of increase in the permit price will fall over time.

19.1.2 Why income distribution impacts warrant a response

The price imposed by the emissions trading scheme is not intended to result in large, arbitrary transfers of wealth, and particularly not regressive changes in income distribution.

There will be a role for government in alleviating the effects of climate change mitigation policy on those people who are most affected by an emissions price and least able to respond (see Box 19.2).

How and the extent to which government compensates for real income losses among low-income households will become an important issue in wage determination in response to higher consumer prices following the introduction of the scheme. It will therefore become an important element in determining whether the introduction of the scheme will be inflationary, warranting the imposition of contractionary monetary and fiscal policy.

Box 19.2 Equity and social welfare

Economic efficiency is of utmost importance in designing the emissions trading scheme. Distributive efficiency is also an important consideration. Distributive efficiency occurs when goods are distributed to those who gain the most utility[1] from them (Lerner 1944).

It is accepted that income has diminishing marginal utility—that is, that an extra dollar has more utility to the poor than to the rich. Income distribution is a key dimension of welfare. If maximising welfare is the objective of society, then the introduction of an emissions price without consideration and assistance to low income households will reduce social welfare.

The initial transfer of wealth as a result of the emissions trading scheme will have impacts on the distribution of income—some inequitable. The way in which the wealth transfer is handled in the longer term—that is, the use of permit auction revenue—will determine whether or not that income distribution is corrected. Therefore, in responding to the impacts of the emissions trading scheme, equity must be considered.

In addition to matters of principle, there are highly practical reasons for containing the regressive income distribution effects of mitigation. If the application of the emissions trading scheme is seen as being unfair, it is unlikely to have the community support that will be necessary for stability and credibility over long periods of time.

The potentially regressive impacts result directly from an emissions trading scheme. However, they can be dealt with efficiently only outside the scheme, and not by altering scheme design.

Two basic approaches are available for addressing the regressive income distribution effects of the scheme. One involves simply compensating disadvantaged households. This is done most efficiently through the tax-transfer system. The second involves assisting adjustment to a low-emissions environment through influencing the availability or selection of goods and services.

Where the former response can be implemented in a way that reduces barriers to efficient participation in the labour market, or that reduces the deadweight costs of other forms of taxation, it brings an efficiency gain that helps to offset the costs of mitigation. Similarly, where the latter can be implemented in a way that reduces the effects of market failures in adjustment to the emissions price, it carries an efficiency gain of another kind, which in some circumstance could be substantial. Therefore the form in which support is provided to households has potentially large economic consequences.

19.2 Effects of an emissions price on households

19.2.1 Prices for goods and services

A major part, if not all, of the costs faced by electricity generators will be passed down the chain from electricity generators, distributors and retailers and finally to households through higher prices for electricity. Consumers will pay more for a range of other goods and services as businesses pass on the emissions price. Petrol and food prices will rise as a result of the scheme's coverage of emissions from transport, energy and eventually fertiliser and stock.

These higher prices will require households to spend a greater proportion of their income to obtain the same goods and services purchased before the introduction of an emissions price. This will reduce households' real incomes and purchasing power.[2]

Low-income and regional households

Low-income households spend a greater proportion of their income on basic necessities, including electricity, petrol and food, than households with higher incomes (Figure 19.2). For example, the proportion of income spent on transport fuel, gas and electricity is around 9.5 per cent for low-income households, and around 4.5 per cent for upper-income households. Emissions pricing is therefore regressive—that is, as the income of the individual rises, the impact will be smaller in terms of the proportion of income.

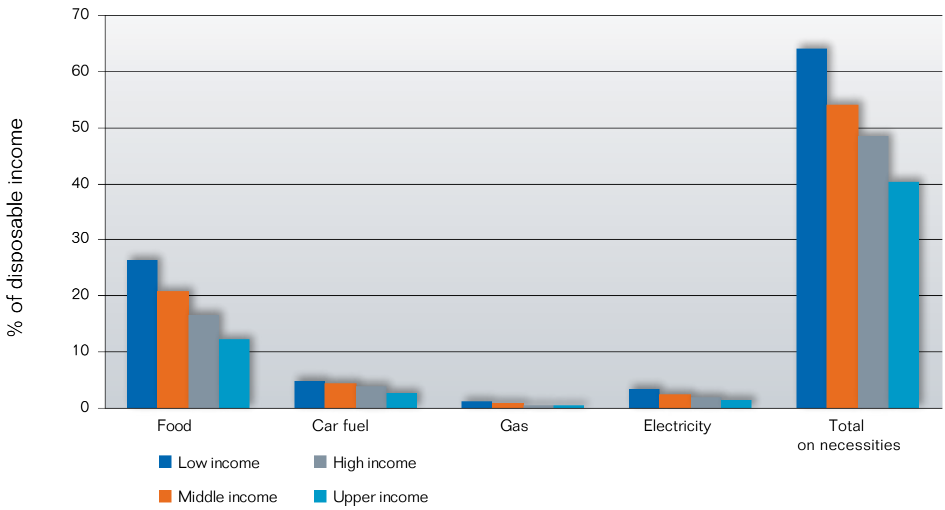
There is also likely to be differentiation between the impacts on people living in and outside capital cities. First, higher product prices will be exacerbated by higher transport costs, disadvantaging rural or outer-suburban dwellers.

More significantly, however, because of their dependence on private transport, non-urban and outer-suburban dwellers are likely to be worse off under an emissions trading scheme than their capital city counterparts. These households will be particularly vulnerable to rising petrol prices because of their need to drive longer distances to access services—such as shopping, medical care, and schooling—and because of the limited accessibility of adequate public transport.[3]

Evidence suggests that the impacts arising from increasing fuel costs will be unevenly distributed across cities, with vulnerability concentrated in the urban fringes (Dodson & Sipe 2007).[4] The urban fringes are associated with low incomes, and usually with limited access to adequate public transport (Randolph & Holloway 2005; Baum et al. 2005).

Small, remote Indigenous communities through northern and central Australia are likely to be another group particularly affected given their reliance on diesel fuel for power supply as well as transport.

Figure 19.2 Expenditure on basic goods as a share of disposable income



Note: Income deciles used to group households into low, middle, higher and upper income households are based on total current weekly household income from all sources divided by the (modified OECD) equivalising factor, and weighted using sample weights. The lower and upper percentiles for low, middle, high and upper income households are 10 and 29, 30 and 49, 50 and 69, and 70 and 100, respectively. Reported are the mean shares of household expenditure on necessities expressed as a percentage of disposable income. Results weighted using sample weights.

Source: Unique expenditure codes from the Household Expenditure Survey 2003–04 (ABS 2006) grouped as 'necessities' by the Melbourne Institute of Applied Economic and Social Research.

The impact of rising fuel prices, combined with low incomes and limited access to public transport, means that for some very low-income households, lowering the use of private transport will be the primary means of reducing exposure to costs. Reduction in mobility has negative flow-on effects, such as feelings of isolation and social exclusion (eds Currie et al. 2007; Dodson et al. 2006).

19.2.2 Households' capacity to respond to effects of emissions prices

The longer-term burden for households will depend on the extent to which they can reduce their exposure to emissions prices and respond to price signals and changes in community and industry structures. Key questions are:

- What low-emissions substitutes are available?
- Are there any constraints on the uptake of those substitutes?

Ability of low-income households to respond to higher energy prices

Reducing energy use would reduce households' exposure to higher prices. The demand by the household sector for energy—particularly electricity—is generally considered to be inelastic in the short term (IPART 2003; Kamal & Stern 2001; NIEIR 2007; Owen 2007).[5]

However, over the longer term there is likely to be greater price elasticity of demand for energy, as consumer preferences change and assets are turned over for more energy efficient appliances and houses. In responding to higher petrol prices, in the longer term households may move toward private transport that is less emissions intensive or, where the alternative is available, switch to public transport.

In many cases, lack of access to lower-emissions substitutes and barriers to their uptake make it difficult to reduce energy demand. For instance, one factor constraining uptake of energy efficiency by households is a lack of information (see Chapter 18).

Rental households or those living in public or community housing will be further constrained in adopting low-emissions substitutes. Around 29 per cent of households rent their homes (ABS 2007). They have limited incentive to access substitutes, such as insulation, space heating, hot water systems and cooking appliances. Investing in such technologies is generally the decision of the property owner.[6] Those in rental and public housing are disproportionately low-income households, meaning that there is a range of constraints to responding effectively to the emissions price (ABS 2007).

Ability of low-income and non-urban households to respond to higher transport fuel prices

Demand for private transport also has a low price elasticity where there are limited substitutes.

As petrol prices rise, responses will be determined by the proximity of public transport services. Where substitutes are available, there will be a switch in demand away from private transport and fuel. However, for many households public transport is not available. As noted above, this is particularly the case in outer-suburban and regional areas, which tend to have a higher concentration of low-income households (Wulff & Evans 1999; Baum et al. 2005; Dodson & Sipe 2007). The emissions trading scheme will raise community interest in and pressure for extension and upgrading of public transport infrastructure and services, but in the best of circumstances, change in services will be slow. Noticeable improvements in public transport for many communities are likely to occur over decades rather than years.

Households' reliance on emissions-intensive industry

It is possible that an emissions price could affect some industries in ways that cause damage to some communities. While there may be impacts on business owners and shareholders, these are unlikely to generate distress of a kind that would warrant intervention on equity grounds. Industry impacts may be concentrated in particular regions or towns, such as regions that rely heavily on the affected industries. Such concentrated effects are likely to be felt in rural and provincial rather than metropolitan communities.

Ability of communities to respond to adverse impacts on a local emissions-intensive industry

The availability of substitutes, including low-emissions technologies to retain industries' viability in the long term, can determine the fate of regions that are heavily reliant on emissions-intensive industries.

For example, regions that are home to coal-based electricity generation—and eventually coal exports as mitigation is taken more seriously in Asia—may face a bleak future if carbon capture and storage technology is not made commercially viable. Without this technology, some fossil fuel-fired power generators will be negatively affected by an emissions trading scheme. Reduced operation would, in turn, have implications for the welfare of workers and the communities in which these industries are based. On the other hand, commercially successful carbon capture and storage could turn the coal-based areas into regions of expansion and prosperity.

Adverse effects on employment and incomes in particular regions would require specific responses.

19.2.3 Addressing equity issues

The Review's recommendations on responses on equity grounds to the income distribution effects of the emissions trading scheme will be provided when the modelling results are available, in the supplementary draft report. Meantime, it may be useful to set down some pointers to the directions of current thinking.

More than half—probably significantly more than half—of the costs of the emissions price are likely to be passed through to the household sector in the first decade of the emissions trading scheme. In some sectors, notably transport, the pass-through is likely to be immediate and complete.

If the permits are sold at auction, as recommended in Chapter 15, the sales revenue should be able amply to cover full compensation of the bottom half of the income distribution. As a rule of thumb, it may be equitable and good policy notionally to allocate half of the permit sales revenue to payments to households, focusing on the lower half of the income distribution.

The payments to households could take two forms, each of which could be structured to make positive contributions to economic efficiency. One would be expenditures linked to adjustment to the low-carbon economy: information and other measures related to energy efficiency for appliances, housing and vehicles. The second would be through changes to the tax and social security systems, to be integrated with the Henry taxation review.

The income distribution effects during the period of the low, fixed carbon price (2010–12) would be small. This might be a good period to emphasise consumer-level energy efficiency in motor vehicles, appliances and housing design. One are of focus should be electricity generation in remote communities

The distribution effects would become more important, within the unconstrained emissions trading scheme from the beginning of 2013. Adjustments through the taxation and social security systems would then be permanent.

It is crucial that assistance to energy efficiency be designed to avoid dampening the emissions price signal.

Notes

1 Utility can be considered to be personal satisfaction or benefit derived by individuals from the consumption of goods and services.

2 Even in the absence of an emissions trading scheme, energy and food costs are likely to rise over time. Simultaneously, incomes for all income groups are expected to increase. The extent to which expenditure as a share of income changes over time will depend on the increases of prices compared to incomes. This will be considered further in the supplementary draft and final reports.

3 There is some evidence of a relationship between car ownership, income and location. Currie and Senbergs (2007) suggest that for many low-income households in urban fringe locations, car ownership is ‘forced’ upon them as a result of low access to public transport and distance to local activity centres.

4 This study applies the ‘vulnerability index for petrol expense rises’ (VIPER), which illustrates the spatial distribution of oil vulnerability at the local suburban scale. VIPER considers three variables to provide a composite vulnerability index: (1) socioeconomic index for areas; (2) household motor vehicle ownership; and (3) car dependence for the journey to work (Dodson & Sipe 2007).

5 In this context, inelasticity means that energy demand change is unresponsive to changes in price.

6 Chapter 18 discusses this issue as a principal–agent problem.

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20 THE ENERGY TRANSFORMATION

Key points

Australians have become accustomed to low and stable energy prices. This is being challenged by rapidly rising capital costs and large price increases for natural gas and black coal. These cost effects will be much larger than the impact of the emissions trading scheme for some years.

Australia is exceptionally well endowed with energy options. Support for research and development and for structural change in transmission infrastructure will allow Australia's natural endowments in renewable energy to be efficiently brought to account.

The interaction of the emissions trading scheme with support for research, development and commercialisation will assist transition to a near-zero emissions energy sector by mid century.

The future for coal-based electricity generation, both domestic and exported, and for mitigation in developing Asia depends on carbon capture and storage becoming commercially effective. Australia should lead a major international effort towards the testing and deployment of this technology.

Specific support for emissions-reducing investment in the coal-based electricity-generating regions is warranted, for smooth energy sector adjustment and established generating regions.

If the world is able to meet the challenge of climate change, there will be a transformation in Australia's stationary energy sector in the context of adjustment to its mitigation policies. The story will unfold over the next 40 years. We will see the emergence of something close to a zero-carbon energy sector in Australia and in all developed and substantial developing countries.

The transformation as described in this chapter will be a response to the forces and actions that we know today and can reasonably expect in the future. The Review acknowledges that there is great uncertainty—about the climate science, the development of technologies and, most critically, the capacity for human ingenuity to adapt to changing circumstances.

Key forces that will drive the Australian energy transformation include:

- the global response as it evolves from the current ad hoc and partial arrangements to a comprehensive global commitment
- adaptation to unavoidable climate change

- the impact of the emissions trading scheme
- the impact of other policies that address market failures, including transitional support for trade-exposed, emissions-intensive industries, and assistance for research, development and commercialisation of new technologies
- the economics of key energy supply chains, particularly related to coal, gas and oil
- the speed and extent of changes in energy demand.

The transformation of the stationary energy sector will have three broad phases:

- an initial adjustment phase involving a transition from high-emissions growth to greater use of known lower-emissions technologies
- a technology transition phase as new technologies, some of which may exist through this phase only, emerge and then facilitate and accelerate the restructuring of the sector
- a long-term emergence phase to sustainable, low- and zero-emissions technology platforms.

As the results of the global and domestic modelling that will translate this story into more precise economic relationships are not yet complete, this chapter is necessarily more qualitative than the Review's final report.

20.1 The role of energy and the basis for transformation

The current reliability and low price of energy have been largely taken for granted by the Australian community. The realities are changing rapidly.

Australia has been able to source its energy from an abundance of domestic primary fuels. This has resulted in a domestic energy price that has been very low on a global basis.

The energy sector, driven by the reforms of national competition policy and progressive privatisation, has been evolving to the point that it represents a physically and financially sophisticated and increasingly national sector, delivering security of supply, competitive prices and new investment. This evolution remains unfinished, with regulatory responsibility for monopoly sub-sectors still to make the full transition to national bodies. Several jurisdictions retain government ownership, and economic regulation is still in place where competition should be capable of delivering greater consumer benefits.

The energy sector makes a larger contribution in Australia than in other developed countries to greenhouse gas emissions (Chapter 8).

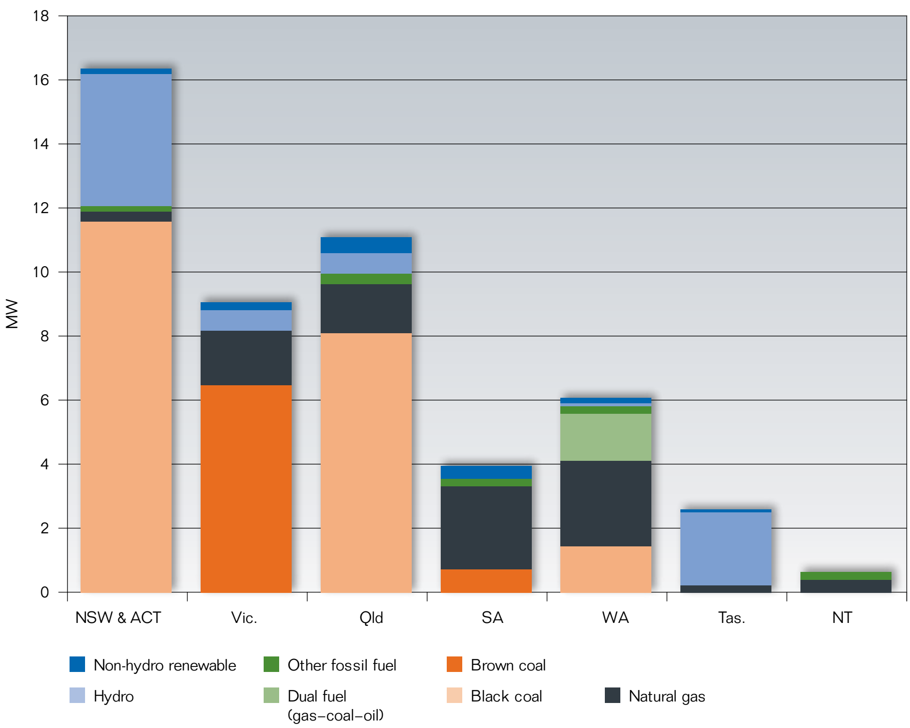
An energy sector that addresses the mitigation issue will therefore need to establish a balance between driving change towards a low-emissions future, building on the underlying national reform agenda, and preserving as much as possible of the energy sector's positive contribution to the Australian economy.

20.1.1 Australia's energy sector in the economy

Energy-related sectors such as electricity, mining and transport account for some 11 per cent of GDP and around half of total exports (ABARE 2006). Growth in energy consumption has historically moved closely with GDP, with a tendency for this growth to be slightly below GDP since the early 1990s.

The stationary energy sector is dominated by electricity generation and manufacturing processes. The total level and fuel mix varies across the country and reflects different regional economic structures and local fuel sources (see Figure 20.1).

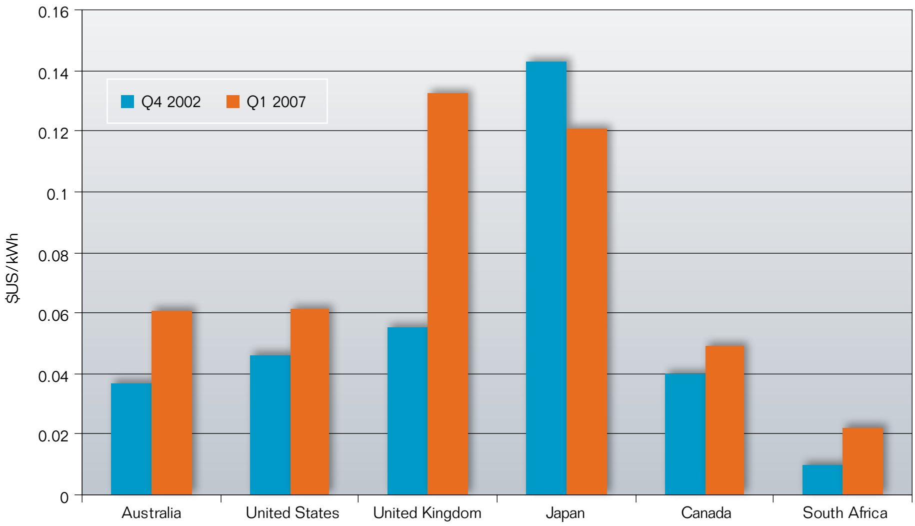
Figure 20.1 Installed electricity generation capacity



Source: Energy Supply Association of Australia (2007).

Nationally, the availability of large and accessible coal and gas resources has delivered electricity and gas prices that have been low in comparison with those of comparable countries. Substantial recent movements in domestic electricity prices have not been unique to Australia (see Figure 20.2).

Figure 20.2 Comparison of industrial electricity prices



Note: Exchange rate movements have been significant sources of changes in relativities 2002–07.
Source: IEA (2003, 2008).

20.1.2 The process of evolution in the absence of climate change

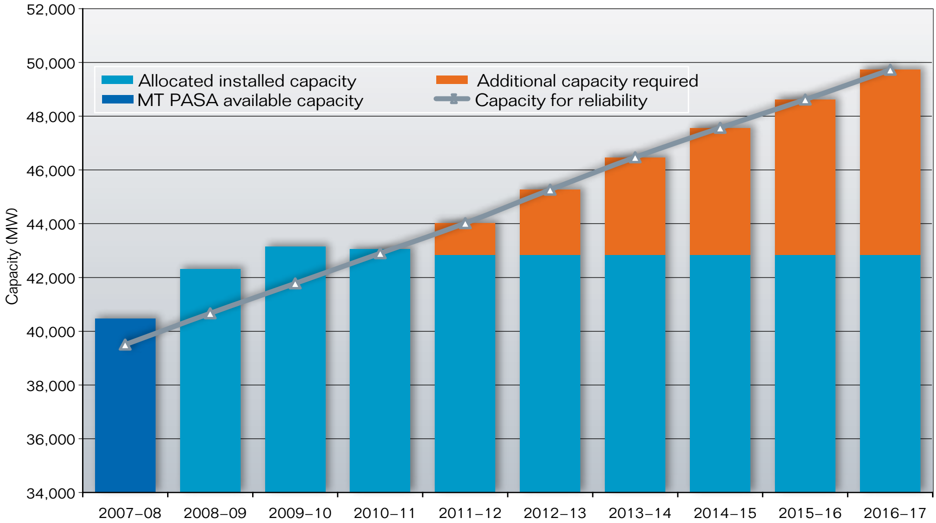
The last decade or so has witnessed a remarkable era of change in Australia's electricity sector. In the early 1990s, the sector was largely publicly owned, with vertically integrated gas or electricity monopolies operating in individual states and little or no interaction between fuel sources. Since then, competition policy has led to a fundamental restructuring of the retailing and generation sectors towards a variety of business models. The integrated generator–retailer across both electricity and gas is taking an increasingly dominant role.

The distribution and transmission pipeline sectors in gas are entirely, and electricity partially, privately owned. The electricity transmission grid remains largely government-owned. Distribution and transmission assets generally exhibit natural monopoly characteristics and are subject to economic regulation, for which responsibility is gradually passing to the national Australian Energy Regulator.

Progressive privatisation has led to new investment and new market participants across all sectors. The result is a highly competitive, increasingly national market with considerable regional interconnection, sophisticated financial structures and flexible fuel substitution. This era of change has delivered choice and broadly stable prices for customers and an attractive climate for investors, while maintaining and increasing supply security.

Power generation based on black and brown coal for baseload supply, transmission interconnection for flexibility and additional security, and gas-fired plant to meet the growing demand for peak and intermediate demand have all been important in this period of rapid change. Almost 5000 MW of net additional generation capacity was added between 1999 and 2006, with further capacity either under construction or planned in response to the consistent and ongoing growth in demand (Figure 20.3).

Figure 20.3 National Electricity Market: summer supply–demand outlook



Note: MT PASA = medium-term projected assessment of system adequacy. This is NEMMCO's forecast of demand and supply to identify gaps and opportunities for new investment.

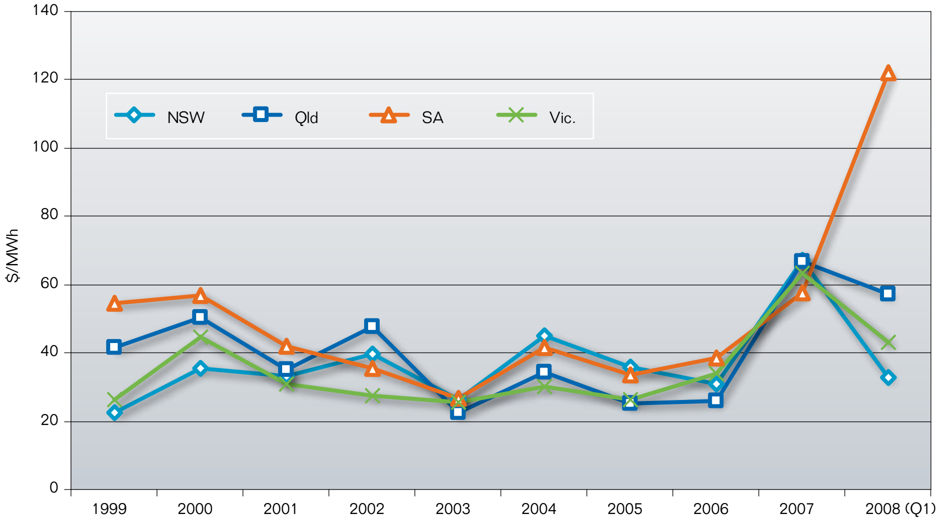
Source: National Electricity Market Management Company (<www.nemmco.com.au/data/markets_data.htm>).

During this period, the supply and demand for both gas and electricity have grown steadily, and prices have been generally stable. Domestic prices for thermal coal were relatively low and steady. In the case of gas, the market has witnessed a growth in the depth and breadth of supply sources in response to renewal cycles of long-term contracts, the requirements of the Queensland Government that a minimum proportion of electricity be generated from gas, the increasing role for gas in meeting peak electricity demand, the development of new gas fields, and the emergence of coal-seam gas as a major new supply source. The electricity market has been characterised by strong growth, which has been met by:

- the construction of inter-regional transmission to balance over- and under-supply
- increases in the operability of existing plant
- construction of new plants.

It is only since 2006 that the market has seen some price uplift (see Figure 20.4). Announced price increases have been large in 2008, and are likely to continue independently of any emissions trading scheme impacts.

Figure 20.4 Average electricity market prices, 1999–2008



Source: NEMMCO (2008).

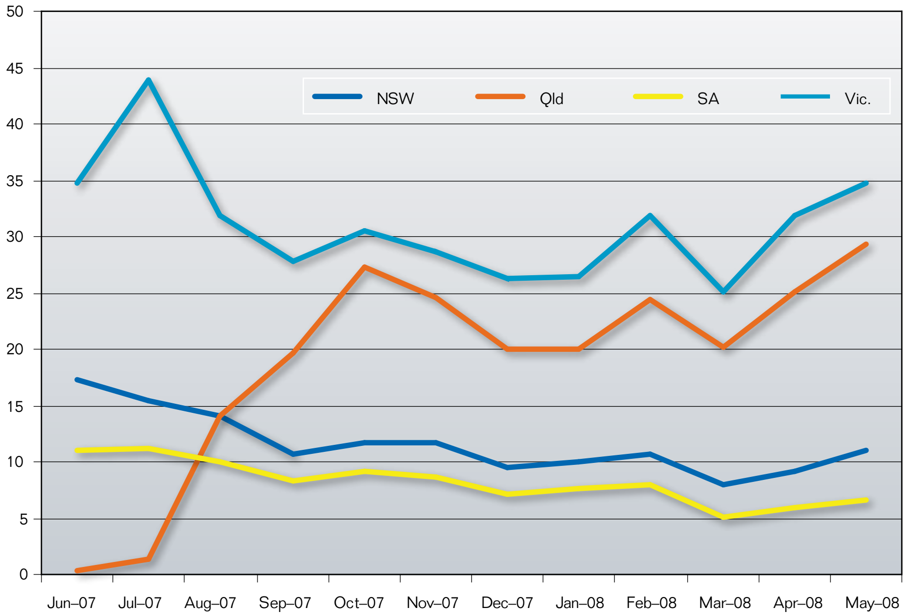
The National Electricity Market operates through the National Electricity Market Management Company (NEMMCO). This entity, owned by the relevant governments and funded by the industry, is responsible for:

- operating the power system within technical requirements
- registering participants in the National Electricity Market
- meeting demand in the lowest-cost way
- maintaining prudential standards for participants
- financially settling the market on a weekly basis
- coordinating inter-regional transmission planning.

With the trend to a seamless gas and electricity energy market, there has been agreement across the industry to bring both markets into a common structure with a single central operating entity, the Australian Energy Market Operator. The process for establishing this body is under way.

The most significant remaining step in the implementation of competition policy reform is the removal of retail price regulation. State and territory governments have been cautious about relaxing the regulatory process. At the same time, the market has been evolving through competitive activity, as evidenced by the number of customers switching their retailer as full retail competition has been introduced (see Figure 20.5).

Figure 20.5 Electricity customer transfers—annualised monthly proportion of market



Source: NEMMCO (2008) and Energy Supply Association of Australia (2007).

Through the Ministerial Council on Energy, there is now agreement for the Australian Energy Market Commission to review the status of competition in each jurisdiction with a view to opening up the market to full competition, while maintaining structures that protect consumers who are in financial hardship. There has been a general move away from cross-subsidies and towards directly funded community service obligations. Subject to this review, the commission will recommend on the appropriateness of and approach to the removal of remaining retail price controls.

The first step in the review was carried out in the second half of 2007 for Victoria. The commission concluded that gas and electricity competition is effective. Further, and as part of its remit, the commission has made a recommendation to the Ministerial Council on Energy and the Victorian Government to continue the phasing out of retail price regulation. This is accompanied by recommendations to maintain and enhance the existing customer protection framework.

Privatisation of energy sector businesses began with Victoria in the early 1990s. Competitive retail electricity businesses in Queensland were sold in 2006–07. The former Commonwealth government blocked a move by the New South Wales and Victorian state governments to sell Snowy Hydro (currently jointly owned by the three governments) into the private sector in 2006. There is considerable tension in New South Wales as the state government grapples with privatisation of the retail sector and some form of transfer of economic responsibility for its generation assets to the private sector.

These structures and processes generally allow the private sector's assessment of supply and demand to determine the need for additional capacity and to deliver this capacity in a timely fashion. They have generally been successful for gas exploration, production and transportation. They have also been successful for electricity generation, although some jurisdictions have experienced discomfort with the process. There are mixed views across the industry as to whether there are appropriate mechanisms to deliver the most efficient and timely investment in electricity transmission (see Chapter 17).

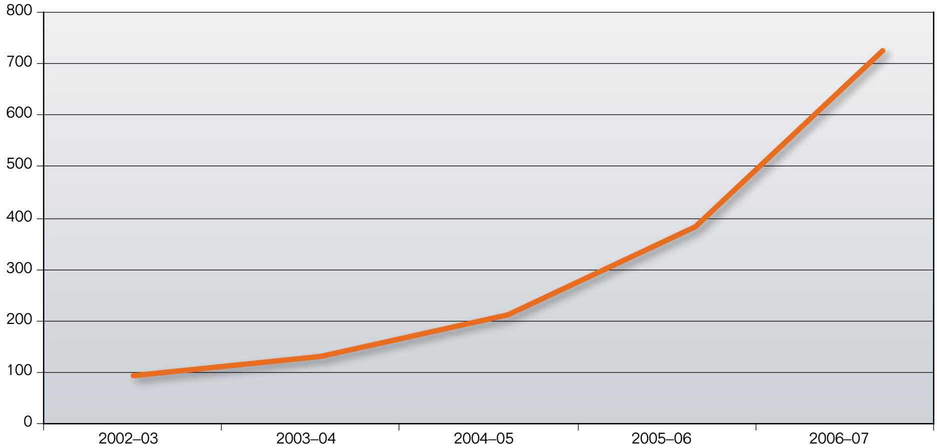
20.1.3 Nature's revenge

Although Australia is likely to meet its Kyoto Protocol commitment of 108 per cent of 1990 emissions by 2008–12, this will be achieved despite a high underlying trend in emissions growth from fossil fuel combustion. Significant reductions in Australia's greenhouse gas emissions will require a fundamental transformation in the way Australians consume and produce energy. The strengthening commitments of other governments to mitigation policies raises risks for Australia's large coal exports unless Australia and the international community can find an economically efficient means of sequestering emissions from fossil fuel combustion.

In the last several years, there have been three major developments in the Australian energy sector's response to the climate change challenge.

First, a mixture of federal and state policies has driven investment in a specific set of lower-emissions technologies. The federal government's Mandatory Renewable Energy Target (MRET), the NSW Greenhouse Gas Abatement Scheme (GGAS) and the Queensland Gas Scheme have been the principal instruments. Second, the increasing public awareness of climate change has seen the emergence of a voluntary market exemplified by the continuing rapid growth in Green Power (see Figure 20.6). Finally, there has been a general hesitancy to invest in new power generation assets outside existing schemes in the absence of a clear, broad and stable policy framework.

Figure 20.6 Green Power customers, 2002–03 to 2006–07



Source: Green Power, June 2008 (<www.greenpower.gov.au/audits_and_reports.aspx>).

20.2 Drivers of the transformation

The energy industry is not new to change in the face of external pressures. Different societies at different times have moved away from gathering trees for firewood and charcoal; from burning coal in homes and commercial buildings for heating; and from 'towns gas' made from coal to natural gas. The key to these changes has always been the interaction between economic and environmental factors. One driver has been increased scarcity of resource bases, which in due course would underpin a transition from fossil fuels. With the challenge of climate change, the introduction of a price on greenhouse gas emissions will accelerate the transition by bringing down the relative cost of alternatives to fossil fuels.

Two primary sets of drivers will dictate the pace and direction of the energy transformation as envisaged by the Review. They are the dynamics of the supply and demand surrounding key fuel sources; and the global and domestic policy response to mitigation of climate change.

20.2.1 Global fuel dynamics

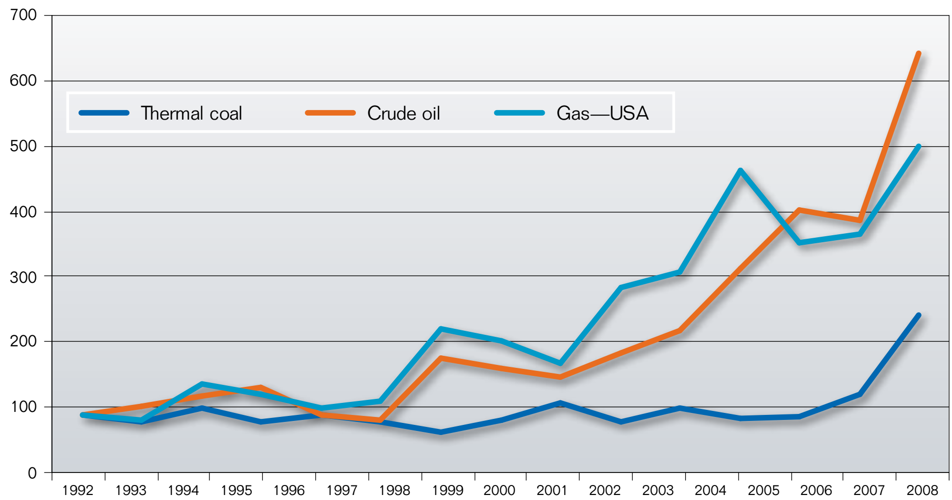
In the last few years, the dynamics of what had been a relatively benign environment for the domestic energy sector has been challenged:

- A major escalation in capital costs across sectors, with particular impact on capital-intensive industries. Industry advice to the Review indicates there have been increases of 60 per cent in construction costs per installed kilowatt of power plants since 2004.

- A major uplift in global coal prices—180 per cent over the past three years and 118 per cent over the past year—has been driven by recent strong demand in China and India and a supply system that takes some time to respond with new infrastructure and transport capacity.
- Increases in global prices for traded natural gas, which have not kept pace with even greater increases in oil prices.

These movements in energy commodity prices are illustrated in Figure 20.7.

Figure 20.7 Energy commodity prices indexed to 2000 (2000=100)



Source: ABARE (2008), State of Nebraska (2008) and Government of Western Australia (2008).

In Australia, the first of these forces, rising capital costs, is starting to affect electricity prices. Those effects were exacerbated from early 2007 with the effect of drought on the availability of water for hydroelectric generation and power station cooling. The existence of long-term domestic contracts for black coal, the unsuitability of brown coal for export and the absence of liquefied natural gas (LNG) export infrastructure on the east coast have largely cushioned Australian prices from the other two forces.

This position is not sustainable: contracts will be renegotiated, new coal export infrastructure is being developed and several east coast LNG export projects have been announced. To put these price increases into perspective, a \$10/t price on carbon dioxide could add \$8–10/MWh to the wholesale electricity price. An increase of \$3/GJ in the gas price, to somewhere closer to but still short of export parity would add more than \$20/MWh to gas-fired electricity. An increase of \$100/t to black coal prices would add approximately \$53/MWh to coal-fired electricity.

While there is clearly considerable scope for substitution across fuel types, the cost of fuels will largely determine the response of the energy sector over the coming decades. In the discussion of the four broad fuel types in the Australian energy sector that follows, the outlook for oil, with traditional sources becoming increasingly constrained by resource availability or increasing extraction costs, will tend to act as an external determinant of prices for the other fuels, at least in the long periods required for large expansion of production and transport capacity for the more abundant fossil fuels.

Coal

The following assessment flows from considering three distinct coal types: brown coal, thermal black coal and coking black coal. Coal sources generally get to the point of consumption in one of three ways:

- as part of an integrated coal supply/power generation entity
- through commercial contracts with generators
- through export contracts.

The first of these recognises the favourable integrated economics that can come from optimising around a single financial unit when the resource is at the low end of the value range and coal prices are relatively low. This model generally applies in Victoria and Queensland, including the recently established plant at Kogan Creek.

The second is characterised by relatively long-term contracts. The most obvious example is in New South Wales, where the government established these structures, separating mining rights from electricity generation, when it corporatised the energy sector some years ago. In the past they have provided some flexibility for competitive market forces to optimise outcomes and keep domestic prices low. However, firms within such structures are highly vulnerable to the continuation of high export prices combined with tendencies towards internationalistion of low-quality black coal markets. Coal generators relying on the purchase of exportable coal will be at an increasing disadvantage in competing with generators with tied access to coal in Victoria and Queensland. A tight global market for thermal coal has made much lower quality black coal exportable.

The third arrangement underpins the export market, where annual contracts apply and where prices reflect the dynamics of global supply and demand.

Coal demand is experiencing a period of unprecedented growth, driven by China and India (Chapter 4). This has resulted in contract price increases of more than 100 per cent over a short period. As contracts for the domestic supply of thermal coal expire and where the supplier has the potential to access this export market, there is upward pressure on these prices also. Such prices, if they hold up for an extended period, have the potential to encourage coal-drying technologies and underpin an enhanced economic outlook for Australia's brown coal resource.

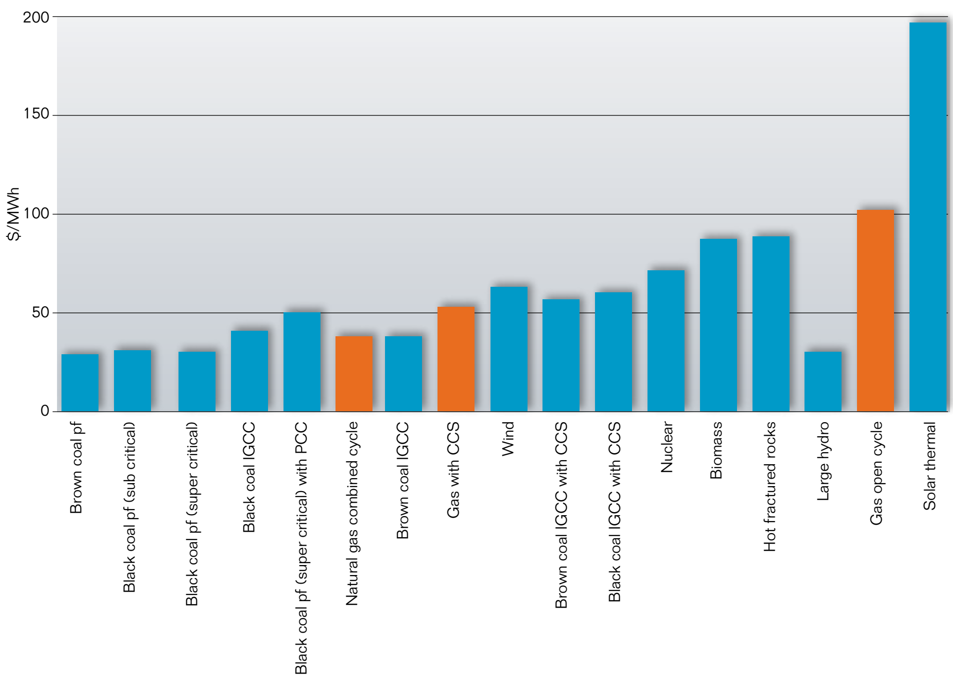
In the absence of any expectation of a significant slowing of Chinese growth (see Chapter 4), the likely longer-term outlook is for prices in real terms to remain well above the levels of the late 20th and early 21st centuries, but to come down from current peaks as supply expands. There is no foreseeable constraint on coal resource availability, although the exploitation of deeper and more distant deposits is likely to keep prices on a rising trend in the long term.

Gas

Natural gas in Australia has two physical markets. The east coast has gas coming from the Cooper Basin in Central Australia and the Gippsland Basin in the south east. The North-West Shelf supplies the local West Australian market but also provides increasing and large volumes of liquefied natural gas for export. Over the last decade or more, gas prices in Australia have been relatively stable, with no significant new sources of supply or demand being developed.

Gas for power generation has remained confined to a relatively small peaking demand, where the higher fuel cost could be offset by lower capital costs. Figure 20.8 indicates the cost of gas-fired power generation relative to other sources and uses 2006 estimates for the costs of fuels and capital in the absence of an emissions price.

Figure 20.8 Estimated electricity generation costs of selected electricity generation technologies, 2006



Notes: pf = pulverised fuel; IGCC = integrated gasification combined cycle; PCC = post-combustion capture; CCS = carbon capture and storage.

Source: Wright (2007).

As long-term contracts came to an end, new sources of supply emerged, as did an increase in the gas transmission network to provide greater security of supply and competition between basins. The uptake of gas for power generation to meet increasing peak and intermediate demand and the introduction of the Queensland Gas Scheme have further influenced these developments. The most notable has been the growth in the coal-seam gas sector. This growth has been rapid and is likely to increase explosively over the period immediately ahead.

Recent and rapidly increasing global demand has resulted in a lift in prices in Western Australia.

The increasing confidence in large coal-seam gas reserves in Queensland has led to recent announcements of liquefied natural gas export infrastructure in the east. The potential to access the global market has then resulted in upward price pressure on natural gas prices, at the same time as the potential to gain commercial value from the lower-emissions intensity of gas-fired power generation relative to coal is being recognised.

Domestic gas prices can be expected to rise rapidly towards export parity and remain at that level over the longer term.

Nuclear

The global uranium industry has recently seen signs of a surge in demand. China and India have committed themselves to programs that are immense by any previous standards anywhere. In China, with the larger of the expansions, nuclear will still account for no more than 6 per cent of total power in 2020. Some countries which have not been installing new capacity for many years, including the United Kingdom, have decided that, on balance, nuclear power stations should have a role to play alongside other low-carbon electricity sources (HM Government 2008). This renewed demand arises from a combination of influences from climate change, energy security and relative costs. With more than one-third of currently estimated global uranium resources, Australia is well placed to benefit from this growth.

The 2006 Uranium Mining, Processing and Nuclear Energy Review for the Commonwealth Government concluded: 'Although the priority for Australia will continue to be to reduce carbon dioxide emissions from coal and gas, the Review sees nuclear power as a practical option for part of Australia's electricity production, (Commonwealth of Australia 2006:1). This conclusion was based on a cost of nuclear power of $40–65/MWh, which is within the range of the $35–80/MWh estimate of the Nuclear Energy Agency and the International Energy Agency from 2005, but below ranges specified in the more recent official UK publications of $60–80 MWh. Nuclear power stations will have been disproportionately affected by the recent increases in capital costs on account of their exceptional capital intensity, and will have been rendered less competitive by this development. Newer-generation nuclear technologies indicate potentially lower costs.

Australia has better non-nuclear low-emissions options than other developed countries, especially (but not only) if carbon capture and storage is commercialised within the range of current cost expectations. Australia is a major net exporter of a wide range of energy sources, notably coal, liquefied natural gas and uranium. Transport economics should favour local use of those fuels in which the gap between export parity and import parity price is greatest (first liquefied natural gas, then coal). As a consequence, Australia is not the logical first home of new nuclear capacity on economic grounds.

In Australia, as well as in most other developed and developing countries, public acceptability is an important barrier, that would need to be recognised as a constraint and a source of delays and increased costs by any government committed to implementation of a nuclear power program. The Australian Government is firmly against Australian nuclear power generation, and the Coalition parties retreated quickly from nuclear advocacy in the face of community antipathy during the 2007 federal general election. It would be imprudent, indeed romantic, to rely on a change of community attitudes as a premise of future electricity supply for the foreseeable future.

Given the economic issues and community disquiet about establishing a domestic nuclear power capacity, Australia would be best served by continuing to export its uranium and focusing on low-emissions coal, gas and renewable options for domestic energy supply. However, it would be wise to reconsider the constraints if:

- future nuclear costs come in at the low end of the estimates provided above
- developments in technologies reduce the need for long-term storage of high-level radioactive waste
- there is disappointment with technical and commercial progress with low-emissions fossil fuel technologies, and
- community disquiet eases.

Renewable energy

In recent years, power generated from non-hydro renewable sources has increased as a result of MRET and, to a lesser extent, Green Power demand. It represented 8 per cent of capacity and 5 per cent of delivered electricity in 2005–06. The design of MRET and the prevailing relative cost of renewable technologies mean that this additional capacity has been dominated by wind, with contributions from solar hot water and biomass. Other potential forms of additional renewable energy include solar (photovoltaic and thermal), geothermal and wave/tidal power. Each of these technologies faces its specific challenges of relative costs, community acceptability, technical feasibility and intermittency.

While all forms of low and near-zero emissions technologies will benefit from the price uplift of the emissions trading scheme, and renewables are receiving an initially much larger boost from the increase in fossil fuel prices within Australia, genuinely new technologies will require support for research, development and commercialisation (see Chapter 16).

There is little likelihood of expansion in storage-based hydroelectric generation in Australia, although there is scope for much better utilisation of existing storage capacity in the new environment in which renewable power has greatly increased value. The anticipated growth in intermittent supply technologies (wind and solar) and ongoing, above-average growth in peak demand mean that existing hydroelectric infrastructure will play an enhanced role as a provider of flexible and readily available stored energy to meet short-term demand peaks.

This role could be substantially expanded through judicious investment aimed at making the hydro-electricity assets important balancing components in the eastern Australian system. Australia's main hydroelectric assets—in the Snowy Mountains and Tasmania—will have increased value, far beyond that suggested by their installed capacities (3676 MW and 2278 MW respectively) alone. Power from intermittent sources at times of low demand and price can be used to pump water into hydroelectric storage for use at times of greater demand and value. Public ownership, and in the case of Snowy Hydro ownership by three governments, have applied constraints on the supply of capital to the optimisation of the value of these major national assets. These constraints have high opportunity costs in the emerging environment. It is important that the constraints be removed.

What might have been

In the absence of climate change, global and domestic forces would drive significant change in the Australian economy and the energy sector in particular.

The first key force for change is global demand for Australia's commodity exports, driving rising terms of trade and a GDP that roughly trebles to 2050 (Garnaut–Treasury reference case). Population and Australian household incomes both rise strongly. In the longer term, the depletion of relatively low-cost resources leads to modest increases in energy prices, accelerated by a progressive shift towards electricity as the central energy source. In this scenario greenhouse gas emissions grow without constraint, with Australia's emissions projected to double by 2050 through rising energy consumption and ongoing dependence on fossil fuels.

Chapter 9 describes the impact of unmitigated climate change on the Australian economy. It is worth dwelling briefly on this scenario before focusing on how it will change in the course of successful transition to a low-emissions economy.

Adverse climate change impacts lead to a deterioration in demand for Australia's commodity exports, such as coal and other minerals. Agriculture is further affected as increased temperatures and reduced rainfall are likely to reduce output.

Storm, wind, bushfire damage and increased levels of materials degradation are likely to lead to additional transmission and distribution losses across the gas and electricity networks.

The most significant impact that will require adaptation planning in the energy sector is that of urban water supply (Chapter 7 and Box 20.1).

There will also be an impact on energy infrastructure demand through reinforcing ongoing growth in the peak summer period.

Box 20.1 Energy and water—joined at the hip

Changes in water availability will affect the energy sector in three ways.

In 2007, the drought exposed the obvious dependence of part of the market, the hydro generators, on water supply.

However, it also exposed the extent to which generators depend on water for cooling. This is likely to lead to a move towards air-cooled plant in future, with an associated reduction in efficiency.

Finally, the move to desalination plants to supplement water supplies will impose a significant additional demand for power of about 3–5 kWh per kilolitre.

The specific risk to electricity transmission and distribution networks that arises from the increased frequency of extreme weather events is illustrated by the power supply outages experienced in January 2007, when a bushfire caused disruption to the transmission system between New South Wales and Victoria.

These challenges amplify the need to maintain momentum towards a truly national energy market at the same time as responding to the structural adjustment imposed by the mitigation task.

20.2.2 The domestic emissions trading scheme

The implementation of an emissions trading scheme will unleash far-reaching change, as the market responds to the emissions reduction trajectory and delivers an assessment of consequent short- and long-term pricing expectations. In the energy market, the short-term price implications will cause a direct adjustment in marginal cost structures and asset values. The long-term price expectations will provide long-needed clarity to frame major investment decisions for new energy infrastructure, including, but not limited to, baseload power generation. In addition to investment in technologies with known operating and cost characteristics, this longer-term perspective, is expected to facilitate research, development and commercialisation of technologies assessed to have greater mitigation potential in the future. The Review's recommended support for research, development and commercialisation of low emissions technologies will have a powerful effect in accelerating innovation—in ways that were not present with MRET, GGAS and the EU emissions trading scheme. The overall domestic mitigation policy suite suggested by the Review (Chapters 14 to 18) provides the necessary and sufficient policy conditions to unleash the transformation described below.

20.3 The path to transformation

In considering the way forward, it is possible to identify three broad phases over time. These are not prescriptive or precise, but separate the ebb and flow of particular developments as they unfold, especially future changes in technology.

From the perspective of 2008, the first phase could be expected to apply over its initial 5–10 years, the second over the next 10–15 years and the third beyond that.

In this draft report, the phases are described qualitatively. The economic modelling results for the mitigation scenarios will enable the supplementary draft and final reports to significantly expand on these descriptions.

It is clear that Australia is ideally placed for this transformation with abundant coal, gas, uranium, geothermal, solar and other renewable sources, alongside exceptional opportunities for geosequestration and biosequestration of carbon dioxide.

Therefore, while major structural change is never without its challenges, energy supply security is not likely to be one of them.

20.3.1 Phase 1—commitment and adjustment

The first few years from the beginning of the emissions trading scheme may generate relatively low prices as the trajectory follows Australia's Kyoto commitment. Whether or not there is a separate transition period, the primary and secondary markets will quickly establish a spot and forward price curve for emission permits beyond 2012.

As the constraints tighten from early 2013, low-cost mitigation opportunities and expectations of tightening of trajectories in response to international agreement are likely to lead to some hoarding of permits.

As this phase evolves, with divergence of the trajectory from the business-as-usual path, the next set of responses is likely to involve some fuel switching, constrained by transmission interconnection and gas availability and cost, involving existing gas-fired open-cycle plants being operated more intensively. Competitive tensions will derive from the relative emissions intensities of existing coal-fired plants as the merit order moves quickly to incorporate the permit price into short run marginal costs. Increased price volatility is likely to be a feature of this period—around a rising tendency in prices driven by factors outside the emissions trading scheme, but augmented by the emissions price.

The fuel mix and cost implications will be strongly influenced by the extent to which new black coal contracts in the domestic electricity sector are negotiated at higher prices and the speed with which domestic gas prices move towards global price parity. The implications for brown coal generators will, in the short term, be dominated by these factors affecting their competitors and the east coast electricity prices, and therefore their capacity to recover lost volume in prices. After that, either partial fuel substitution within coal-based generators, or other changes to existing plant to reduce emissions intensity will have major effects. In the still shorter term, it is possible that some existing, coal-fired generators with captive coal supply will stand to reap significant benefits from the higher price environment driven by increases in capital costs and gas and black coal prices. There will be a vigorous search for in-plant mitigation. Beyond the commercial limits of in-plant emissions reduction, it may be economical for such generators to purchase domestic offset credits or international permits to maintain production despite high emissions intensity, in an environment in which high gas and black coal prices are underpinning higher electricity prices.

Box 20.2 Will the National Electricity Market survive?

The National Electricity Market (NEM) has evolved over a number of years and industry has simultaneously evolved business strategies to optimise commercial outcomes within the current market and policy framework.

The emissions trading scheme has major implications for NEM participants and these business models and strategies, including substantial changes in bidding and contracting behaviour. However, the NEM and its participants are expected to draw on the experience to date, enhanced by that of coping with MRET, GGAS and the Queensland Gas Scheme, to rapidly develop new strategies and structures.

Chapter 17 of this report highlighted a specific issue that relates to the development of network infrastructure to support efficient technology responses to the emissions trading scheme. Outside that issue, the structure, policies, procedures and governance mechanisms of the NEM are expected to accommodate the implementation of the emissions trading scheme.

This process will require close involvement of the key industry agencies with business to ensure any unforeseen consequences are identified and addressed early.

An added complexity arises from the fact that these changes will occur at the same time that the NEM is evolving to become the Australian Energy Market as described in this chapter.

In this phase, new baseload generation capacity is likely to be based on established, combined-cycle gas turbine technology, ideally designed for post-combustion capture of carbon dioxide. It is possible that the rising permit price will shadow the gas price over this period—a possibility that will be explored in the light of the modelling to be discussed in the supplementary draft report.

Offsets, trade in permits, and hoarding and lending of permits would all provide the flexibility necessary to avoid unacceptably high permit prices and flow-through to delivered energy prices deriving from short-term disruption of supply or demand expectations.

The Review recognises that this period will generate acute pressures for owners and operators of existing coal-fired plants, some of which have been optimised to run efficiently in a mode that will be challenged in this new world. As described in Chapter 14, the Review has concluded that compensation in such circumstances is a low priority. Appendix 20A addresses in some detail the specific arguments raised in relation to emissions-intensive electricity generation. However, a range of other factors will tend to ameliorate the otherwise negative consequences for well-managed coal-based generators:

- There will be opportunities for some relatively low-cost reductions in emissions, including through coal drying.
- There will be capacity to recover volume loss through price. The strong upward pressure on competitors' costs for reasons beyond the mitigation regime will strongly favour established producers with sources of non-tradable coal including some of these generators most affected by the emissions trading scheme. Some of these generators will not see a loss in cash flows for several years, and may well see opportunities for increasing profit in the early years.

Near-zero emissions coal technologies

For Australia, the importance of reducing emissions from coal combustion is of large national importance.

Coal underpins Australia's domestic electricity supply sector, and is by far our biggest export commodity. The $22 billion contribution to exports in 2007 is set to leap dramatically in 2008–09 to almost $50 billion, mainly through much higher prices.

Under any realistic scenario, Australia's response to climate change, both internationally and domestically, will be inextricably intertwined with the role of the coal industry. If this industry is to have a long-term future in a low-emissions economy, then it will have to be transformed to near-zero emissions, from source to end use, by the middle of this century. A range of technical, environmental and economic challenges must be addressed effectively to achieve this objective, in a time frame consistent with a global agreement on climate change and Australia's own domestic commitment (Box 20.3).

The relevant industry sectors, namely the domestic coal-fired generation sector and the domestic and export mining sectors, as well as the communities who live and work in centres of coal mining and coal-fired power generation, all have a vital stake in the development of low-emissions ways of using coal in electricity generation and in manufacturing processes.

The Review has identified five key reasons why Australia has a strategic interest in the future of near-zero coal technologies.

First, the central role that coal-fired power generation has played in Australia's energy sector over many decades and its major contribution to our emissions are described in Chapter 8 and earlier in this chapter. An early resolution of the future role of coal-fired generation will be critical in shaping a smooth transition for Australia's energy sector into a component of a low-emissions economy.

Second, the significant role that coal plays as Australia's biggest export means that we have a major economic interest in working with other coal-exporting countries and the importing countries themselves to determine as quickly as possible how and when low-emissions coal technologies can assist these countries to follow lower-emissions development paths. It is in our interest for other countries to have a way of utilising coal on a long-term sustainable basis. The coal export industry is at risk, sooner or later, unless low-emissions ways of using coal are applied successfully in our major Asian markets.

Third, a number of Australia's rapidly expanding neighbours in developing Asia also have a high and increasing dependence on coal for their electricity generation and for key manufacturing industry sectors. The trend in the large developing countries, including China, India and Indonesia, is described in Chapter 4, where the recent end to a period of falling emissions intensity of growth is highlighted. The heavy reliance on coal is expected to continue for some time and will be exacerbated by any shift towards coal for the production of transport fuels in the face of continued high oil prices (Garnaut–Treasury reference case). The coal dependence of such rapidly growing regional neighbours provides an additional national interest rationale for giving priority to this work. Australia has a strong interest in continued economic growth in its Asian neighbours.

Fourth, the successful participation of China, Indonesia and India, amongst other major developing countries, in effective global emissions reduction will be difficult without the development on low-emissions technologies for using coal. At the same time, the effective participation of these countries in ambitious emissions reduction is essential for the success of the global mitigation effort.

Fifth, there are possible scenarios in which significant adverse impacts arise for communities dependent on coal and coal-fired power generation, notably those in the Latrobe Valley, the Hunter Valley and Central Queensland. In these cases, there is good reason and well-established policy precedents for government to provide assistance to individuals and communities. The continued health of the industry could obviate the need for other assistance measures. If the new low-emissions technologies are not successful, it is likely that governments will need to apply, in the coal-based electricity generating regions, such measures as the retraining of workers for new employment (as with textile and steel workers in the 1980s after reductions in protection); and grants to communities to support improvements in infrastructure that would be helpful to the attraction of alternative industries;

The priority that should be given to the transition to low emissions in the coal industry is further accentuated by the need to resolve whether a near-zero coal future is even feasible, either partially or in total. If it is not, then Australia needs to know as soon as possible, so that all who depend on the coal industry can begin the process of adjustment, and so that adequate and timely investments are made in other industries.

The Review has identified three key funding initiatives that would provide the necessary momentum:

1. Technology innovation in the sector will benefit from the early research funding described in Chapter 16, as will investment in demonstration and commercialisation from the suggested matched funding scheme. This large source of funding will be available across all emissions-reducing technologies on an even-handed basis. It is proposed that this facility be financed out of 20 per cent of the receipts from sales of emissions trading scheme permits.
2. A specific allocation of additional funding, of the order of $1–2 billion, is proposed to accelerate structural adjustment in the industry. This would match industry funding on an equal basis, and would be available to support new investment in reducing emissions in coal-based generation, in existing and new plant related to reduced emissions from power generation in established areas of coal-based generation.

   For example, funding could be provided to retrofit a facility with low-emissions technologies to support drying of brown coal and restructuring of boilers to use the product, or improve use of materials and logistics. Such investment is seen as a pre-emptive form of structural adjustment assistance, and will be more cost effective than assisting communities only after they are under stress.

   Such assistance to industries would be provided in cases where business investment commitments indicate that there are prospects for improved commercial performance through reductions in emissions.

   This facility is directed at forward-looking structural adjustment, and not at compensation for loss.

   A number of arguments have been made for compensation to electricity generators. The Review has considered them and summarised its response in 20A.

3. Australia has the opportunity and the interest to play a leadership role in leading and coordinating a major global effort to develop and deploy carbon capture and storage technologies, and to transfer those technologies to developing countries. The core of this funding could come from a large expansion of the allocations already committed by the federal, state and territory governments, and by the coal industry. The Review understands that a number of governments of other developed countries would be prepared to make complementary commitments to the program. Australia's roles as the world's largest exporter of coal, and as a coal supplier and close economic partner to major Asian developing countries, would make it the natural leader of such an effort. The Review will explore this concept more fully for the final report,

   Australia's expenditures under initiatives 1 and 3, but not 2, would contribute to acquittal of its obligations under the International Low Emissions Technology Commitment proposed in Chapter 13.

In this phase, the assessment of low-emissions coal technologies, and their potential contribution, will be determined. From today's perspective it is possible to identify the challenges and issues central to this assessment, and these are described in Box 20.3.

A rising permit price will provide increasingly strong support for incremental technology enhancements, with higher capital costs for newly built plant favouring retrofitting of existing plant for carbon dioxide capture.

Transport technologies

Carbon dioxide transport is relatively well developed as a technology. The issues associated with the provision of appropriate transport infrastructure will be discussed in the final report.

Sequestration technologies

As with capture, there are two categories of sequestration.

The first, geosequestration, involves storing the carbon dioxide permanently underground or below the seabed in depleted oil or gas reservoirs or in deep saline aquifers. Another possibility is sequestration in deep coal seams where the injection of carbon dioxide could enhance coal-seam gas recovery. The challenges in this area mostly involve geology and geophysics, including seismic mapping and developing a robust regulatory regime that may have to coexist with the extraction of gas or petroleum products.

There are several projects under way or proposed in Australia that will test various aspects of these technologies, including that being undertaken by the CO2CRC in the Otway Basin in Victoria.

A more intriguing, and potentially highly valuable, approach is biosequestration. There are, for example, proposals to produce biofuels from algae, the growth of which is enhanced by access to a constant stream of carbon dioxide.

Box 20.3 The technologies of zero-emissions coal

At its simplest, the challenge is to develop technologies that allow coal combustion with zero, or near-zero, carbon dioxide emissions while maintaining its relative competitive position as a fuel. Carbon dioxide is an unavoidable product of combustion. This means that the carbon dioxide must not be released into the atmosphere. This outcome can be achieved by capturing it somewhere during the process and then either converting it to some environmentally benign end product or consigning it to permanent storage (sequestration). If the source point of the carbon dioxide is physically distant from the final destination, then some form of transport will be required.

Most of the so-called clean coal technologies are well developed individually, although they are rarely, if ever, deployed comprehensively at the scale required by the current challenge. It is also likely that, at least in the short to medium term, some combination of technologies will be applied in a cost-effective way that makes major reductions in current emissions without getting close to zero.

There are broadly two groups of technologies related to carbon dioxide capture.

Members of the first seek to capture the carbon dioxide from an existing gas stream, such as the exhaust stack of a generation plant. These are of most relevance to existing plants and have the significant advantage of extending the life of such assets. The most significant challenge in this area is that such plants were not designed with carbon dioxide capture in mind and the exhaust gas stream is generally low in carbon dioxide, making the capture more expensive and energy intensive.

Members of the second deploy fundamentally different new approaches to create, at some point in the process, a concentrated stream of carbon dioxide that is more readily suitable for large-scale capture. The challenges here are those of technology commercialisation and cost in the early stages.

Clearly, those technologies that apply after coal has been gasified, or a carbon dioxide stream created, are equally applicable to carbon dioxide capture and sequestration from gas-fired power generation plants. With large gas reserves, including coal-seam gas, Australia also has a strong strategic interest in such applications. Process streams involving coal gasification can potentially be applied to the production of transport fuels as an alternative to electricity generation.

What are the issues?

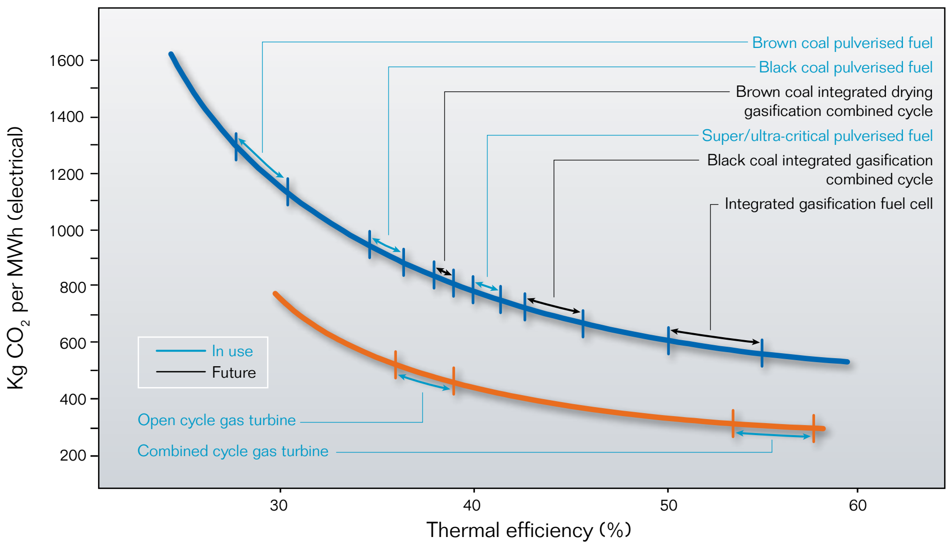
There is a range of technical, regulatory, environmental and economic issues associated with each set of technologies described above. To address these issues, a series of focused projects will need to be implemented, each addressing a relevant technological issue. In this context we note the Commonwealth Minister for Resources and Energy's positive response to the call by the alliance formed by the Australian Coal Association, the Construction, Forestry, Mining and Energy Union, the Climate Institute and WWF–Australia, for a national task force on carbon capture and storage.

Many of the individual technologies are technically proven. The issues of scale, integration and economics are likely to be the greatest challenges.

Finally, but most significantly, there is the challenge posed by the scale of the task. This will ultimately involve the annual capture and sequestration of several hundred million tonnes of carbon dioxide in Australia alone. In addition to the challenges already mentioned, such scale will place a considerable strain on regulatory processes and human resources.

If the considerable challenges these technologies pose can be successfully addressed, a very different medium- and longer-term future emerges. Those same forces of high capital costs, high world gas prices and relatively strong export coal prices will strongly favour retrofitted (post-combustion capture) coal plants with captive coal supplies and low-emissions profiles and ultimately, near-zero emissions plants involving integrated coal drying and gasification technology. At the same time, projects such as those envisaged by the Monash Energy Project will move to the stage where the technical and economic feasibility at commercial scale will be fully tested. Such technologies straddle both stationary and transport energy opportunities (see Figure 20.9).

Figure 20.9 Reduction in greenhouse gas emissions through increasing efficiency



Source: Wright (2007).

Energy efficiency opportunities are envisaged to begin slowly with the support of the programs described in Chapter 18, and accelerate as the rising permit price provides an increasing incentive for their adoption. The capital replacement cycles of homes and businesses and any application of mandatory appliance and building standards will also influence the rate at which this uptake is accelerated.

In the absence of other policy instruments, most renewable energy technologies have a cost disadvantage that may limit their roles in the energy supply or emissions mitigation story until emissions prices have risen above threshold levels. However, research, development and innovation funding across the development cycle will be driving substantial investment in a range of technologies with the potential to be competitive over time, as the emissions cap tightens and the price rises. As discussed in Chapter 14, this dynamic will be strongly influenced in the early years, while emissions permit prices are low, by the expanded MRET that is proposed by the government.

20.3.2 Phase 2—transition

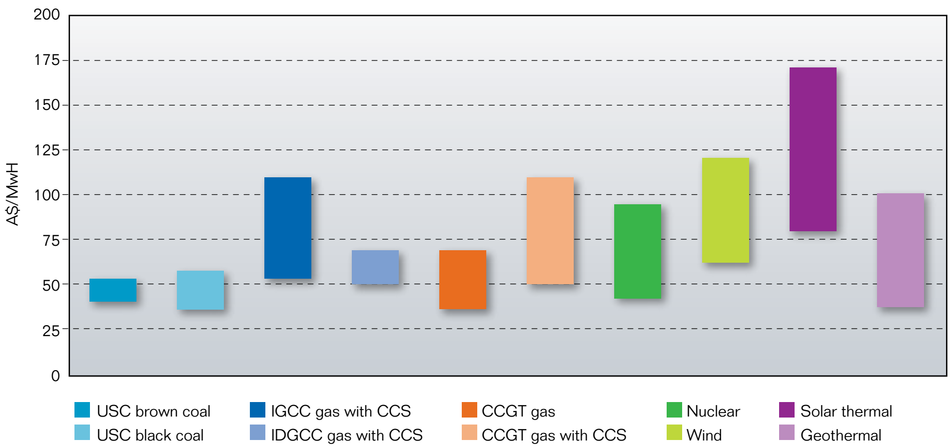
The second phase of the transformation will see the resolution of the tension between the pull of global gas prices and successful deployment of the first coal-fired power stations with carbon capture and storage, on the one hand, and an extension of the gas story as more stable gas prices combine with delays in achieving competitive near-zero emissions coal outcomes on the other. Either way, this scenario plays out to Australia's comparative advantage of a diversity of fuels, including coal and gas.

This phase is likely to be dominated by technology shifts as the investment in research, development and commercialisation from the first phase delivers the first and subsequent commercial-scale models of new generation capacity. New baseload fossil-fuel generation plant is likely to incorporate coal drying and coal gasification technologies. It is expected that all technically feasible retrofitting of oxy-firing and carbon dioxide capture will be added to existing coal and gas-fired plants, accompanied by carbon dioxide pipelines and commercial-scale geosequestration operations. For other coal-fired plant, where such changes are not economically feasible, this phase will see increasing cost pressure as the permit price rises. This phase is characterised by investment in technologies for which the electricity costs have been demonstrated at commercial scale through the investments in research, development and commercialisation of the first phase. Victoria's brown coal resource, unsuitable in its natural state for export, could be expected to have a strong future in this scenario.

At the same time, it is expected that this rising permit price, the results of programs such as Solar Cities and funding for research, development and innovation in renewable technologies such as geothermal, solar thermal and solar photovoltaic, will also be delivering favourable trends in deployment of such technologies at commercial scale. Wind power is expected to reach its maximum technical penetration in the market, while costs may struggle to remain competitive. Energy storage technologies, including through effective use of the stored hydro-electric potential in the Snowy Mountains and Tasmania, can be expected to be available on a commercial basis to support the intermittent nature of solar and wind. The marrying of such technologies to demand that matches its availability will reflect a more comprehensive approach to infrastructure planning. This phase may see the validation of the potential for technologies such as biochar and algal conversion of carbon dioxide as a form of recycling. Market developments around vehicle fuels and motor technologies will strongly influence whether such biomass material realises greater value as a liquid transport fuel or for stationary electricity generation.

Figure 20.10 indicates a range of cost forecasts for different technologies to illustrate that very different outcomes on the energy mix are possible as these forecasts are confirmed or rejected.

Figure 20.10 Electricity generation technology cost chart



Notes: USC = ultra-supercritical; IGCC = integrated gasification combined cycle; IDGCC = integrated drying gasification combined cycle; CSS = carbon capture and storage; CCGT = combined cycle gas turbine.

Source: Energy Futures Forum (2007), IEA (2008), Wright (2007) and industry submissions.

The impacts of rising energy prices, capital replacement cycles and complementary measures to deploy cost-effective energy efficiency changes will accumulate in this phase driven primarily by the increasingly stringent emissions trading scheme trajectory, taking some considerable pressure from the supply side.

20.3.3 Phase 3—emergence

In the third phase of the transformation, the energy sector will move close to a position of zero carbon emissions. The balance of supply and demand that will achieve this outcome will ultimately be determined by the economics of technology developments, which cannot be forecast with certainty. The transport sector will also be based largely on this zero-emissions electricity generation supply for both public and private transport.

The success of near-zero emissions coal technologies will mean that new fossil fuel plant will continue to be coal, while Australia continues to gain as an exporter from the ongoing high global gas prices. Gas is likely to be most valuable to countries for which near-zero emissions coal technologies are neither physically nor economically feasible.

The development of storage technologies, the reduction in solar costs driven by larger-scale deployment and ongoing technology innovation is expected to combine with geothermal energy to begin to replace fossil fuels as the long-term solution to our energy needs. Near-zero emissions coal technology will have carried out its primary role and will remain a significant energy source for some time. An alternative possibility could be for successful development of biosequestration technologies. Such a development could deliver a more favourable and long-term future for coal in the energy sector, competing with renewable energy technologies as resources and geography dictate.

As in the earlier phases, Australia will be in the fortunate position of being able to monitor the global competitive dynamics of coal, gas, nuclear and renewable technologies to its advantage.

20.4 Key economic impacts

The three phases of the energy transformation will be dependent on many variables, including the global fuel dynamics outlined in section 20.2.1.

These and many other parameters—some domestic and others international; some affecting supply, others demand—will all combine to influence the rate of change experienced in Australia.

The supplementary draft and final reports will examine these issues in further detail and will present this analysis in the context of the modelling undertaken by the Review.

20.5 Risks to the transformation

20.5.1 Inertia

In recent years, there has been much discussion regarding new, integrated coal gasification technologies, featured in such projects as ZEROGen in Australia and FUTUREGen in the United States. These projects are large in both complexity and cost and have struggled to make real progress. Further, this complexity is partly responsible for the generally held view that clean coal technologies will not be commercially viable until after 2020.

While such projects remain critical for the longer term, the work of the Review suggests that this time frame is unrealistically long. Having considered the economics of the technologies, the urgency of making major inroads into our emissions, and the other fuel cost pressures, the Review concludes that there is a strong case for accelerated work on the retrofitting of technologies applied in existing plants. This could facilitate the capture of carbon dioxide from such plants, even if it does not involve complete capture. In some areas, such developments could also be associated with carbon capture and storage from gas-fired plant, at least in the medium-term.

There is a compelling case for Australia to play a major role in accelerating the international research effort on carbon capture and storage (see Chapter 17 and Box 20.3)

20.5.2 Second-guessing the market

There is a risk that Australia is not bold enough to proceed on the basis that a market-based emissions trading scheme, supported by mechanisms to remove defined market failures, as proposed by the Review, offers the most effective and efficient solution. This hesitancy could arise from the Australian distrust of markets, deeply rooted in its business and community sectors. It may also arise from anxiety that the cap and trade system will not drive new technologies, even with the support for research, development and commercialisation of new technologies proposed in this draft report. There will be pressure from interests that stand to lose from high permit prices for caps on price that would compromise the emissions reduction objectives. Political resistance to the implications of carbon pricing on prices for some products may drive demands for truncation of sectoral coverage.

The Review is confident in its advice that Australia will meet its mitigation goals with least risk and lowest cost if it holds firmly to a comprehensive, market-oriented emissions trading system as its primary mitigation instrument.

20.5.3 Reform fatigue

The energy sector has been on a path of continual reform since the mid 1990s, and that journey is not yet complete. These reforms are consistent with the aims of the emissions trading scheme and, in cases such as removal of retail price regulation, may be important in facilitating it. However, there is a risk that the added complexity may introduce unexpected confusion or delays. It will therefore be important that an effective linkage is created between the energy market and emissions reduction reforms, through the agenda of the Ministerial Council on Energy of the Council of Australian Governments.

20.5.4 Short-term instability

It is likely that the energy market will experience wholesale price volatility in the short term as the impact of the pre-existing cost pressures, the emissions constraint and the full policy suite works its way through the economy. Price volatility can be an important and essential feature of an effective market. It is therefore important that governments and their regulators work closely with industry to monitor the causes and effects of any such price volatility, and allow the normal mechanisms of the market to operate. Adverse effects of price fluctuations on the living standards of low-income Australians should be managed through fiscal arrangements outside the markets for electricity or emissions permits.

20.5.5 Insufficient people and/or inadequate skills base

The depth and breadth of the transformation described in this chapter carry significant implications for human resource requirements. The transformation will be happening as the economy in general, and the resources sector in particular, are suffering from an acute skills shortage in engineering, management, finance, and a range of trades. Keeping a strong focus on appropriate education and training will be an important element in the success of the transition to a low-emissions Australian energy sector.

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20A Stationary energy compensation

As discussed in Chapter 15, it has been suggested to the Review that 'compensation' should be made to owners of energy-intensive businesses where the profitability and asset values could be significantly diminished by the introduction of the emissions trading scheme. That chapter set out several arguments that would put a relatively low priority on such claims. This appendix addresses this issue in more detail for the electricity generation sector, where the concern has been most acute.

Position	Review response
Equity There will be an immediate and significant reduction in asset value caused by the introduction of an emissions trading scheme. The asset owners should be compensated for this loss, which is disproportionate to that of the rest of the economy. The expected reduction in future profitability as it impacts the real loss of asset value should be offset.	The electricity pool market in the National Electricity Market is designed to efficiently reflect marginal costs and their changes in the spot wholesale market. In any market, all else being equal, a change in marginal costs that is not borne by competing energy sources will lead to a loss of asset value. The National Electricity Market is likely to crystallise any loss most directly and immediately. The relative position of electricity generators differs considerably. Taken with other forces on energy prices, this means that the absolute and relative position of a generator under 'business as usual' or with an emissions trading scheme in place, in the context of what they might have expected, is far from clear. The results of economic modelling will assist in the quantification of these impacts, but in their nature they cannot be defined with a high level of confidence in advance. The societal benefits of financial compensation by way of free allocation of permits or cash are problematic. Governments do not, as a matter of course, compensate asset owners when environmental or social externalities are internalised. As the Review stated in its Emissions Trading Scheme Discussion Paper: 'The claims of shareholders in this sector for special consideration on equity grounds should be assessed by government alongside the equity claims of others.'

Position	Review response
Sovereign risk Generators have had a right to emit carbon dioxide and this right is being taken away by a policy change. In these cases, the Australian Government does and should compensate the holders of the right.	This is not a sovereign risk issue, but a policy risk, exacerbated by the breadth of the policy intervention. Governments always retain the absolute right to vary policy, and industry is generally cognisant of the risk. There is no basis for or claim that a right to emit was issued. Government does not generally compensate for loss of asset value because of the internalisation of an environmental externality. Past cases where a taken right was removed without compensation include policy changes applying to asbestos and tobacco.
Transition continuity The introduction of the emissions trading scheme will be one of the most significant policy changes that the Australian economy has ever seen. The transition will require the full involvement of the existing generators. Also, the owners of the existing generation assets are most likely those that will be needed to invest in low- and zero-emissions technologies; indeed some have already shown a willingness to do so. That willingness will be compromised in the absence of compensation for loss of asset value that will wipe out equity value and a substantial proportion of debt.	Although there may be risks to prices through market behaviour, the absence of alternative electricity generation supply is expected to provide sufficient incentive for the existing generation plants to run to the extent required by the market. The needs of the retail market for supply and the incentives that the forward permit price will provide to invest in mitigation will tend to encourage ongoing operation. It is not clear how financial compensation would reduce residual risk of generator unavailability during the transition period, or affect their on-going business decisions . The owners of existing assets have been important participants in the energy market, and it is acknowledged that failure to secure compensation of the nature and extent sought may cause them to decide against future investment in that market. However, it is expected that a clearly communicated and credible policy response to climate change will provide significant investment opportunities and that these will be attractive to an adequate range of both new and existing investors.

Position	Review response
Investor confidence Major write-downs in assets will both drive up the cost of capital for new investment and delay timely future investment. This could create another source of threat to supply. There will at least be a diminution in investor confidence at a time when it may be most needed to support this artificially created market. If there is no compensation for a disproportionate loss due to a policy change, investors will add a significantly higher risk premium on the basis of possible future policy changes in the face of something as uncertain as climate change. Companies do make judgments on market and policy risk in physical markets, and even financial markets with a physical basis, but there may be an argument that the carbon market is not in this category.	The review acknowledges that providers of existing capital through equity or debt markets will view with considerable concern the magnitude of the asset loss that will crystallise from the introduction of a price on emissions. There is little information to indicate how such entities have been factoring an emissions price into their decisions on existing and new assets over the last decade or so, although it would be surprising if the issue had been ignored. The fact that the industry has been citing uncertainty on climate change policy as a deterrent to new investment would suggest that it has been recognised for some years. State and federal policies to address climate change have been on the agenda for some years. The federal government's 2004 statement 'Securing Australia's Energy Future' advised that 'investors should have regard to the government's policy objective of reducing Australia's greenhouse signature in the longer term'. While the materiality of the impact of this policy is likely to be significant, policy changes that adversely affect asset values without compensation are not unusual. In such circumstances, the credibility of the policy change and the clarity with which it is structured and communicated will be critical in providing appropriate certainty for future investors.
Price volatility Generators faced with such a large loss of asset value and with considerable market power, at least in the short term, will be compelled to exercise that power to recover as much as they can of the loss through higher wholesale electricity prices. This could be very much greater and more volatile than anything previously seen in the National Electricity Market.	It is likely that the changes associated with the introduction of the emissions trading scheme will lead to higher prices and possible that it will lead to more volatile prices. While such price signals will create a strong incentive for new lower-emissions plant and for in-plant changes to reduce emissions, the drivers for such price volatility will not be diminished through financial compensation. Economic logic and the experience of the EU scheme indicate that free permit allocation to generators does not mitigate price changes.

Position	Review response
Threat to reliability The cost impost on existing coal generators will threaten their operational viability. At one level, there will be more forced outages due to constrained operating and maintenance expenditure. At another level, there is a risk that an existing coal generator will be shut down in the face of imminent bankruptcy.	There would seem to be low risk of a precipitous loss of electricity supply. If there is no alternative, lower-emissions source of power, the existing generators will get the benefit of the higher price. The major challenge is to change plant to a different mode of operation, and this will most likely lead to higher operating costs. The energy and financial markets adjustments should provide protection against any threat to reliability of supply. However, the complexity of the impact of the emissions trading scheme price on the detailed positions of generation plants at the unit level, means that nothing can be taken for granted. A free allocation of permits will be of value to the owner, but will not affect the short-run marginal cost of the generator, who will value these permits at the market price. The merit order of generators in the National Electricity Market will be directly changed by the reality and size of the price that the market sets on carbon emissions and will continue to change as the price varies. Any interference with this dynamic would increase the costs of adjustment.
Reversal of previous assurances The previous government and the states-based national emissions trading taskforce had indicated that compensation for disproportionate loss would be made in the form of a one-off, once-and-for-all allocation of free permits.	While the reports of the National Emissions Trading Taskforce (2007) and the Task Group on Emissions Trading (2007) did make such recommendations, neither became a policy position of any state or federal government, and no evidence has been provided to the Review to suggest that subsequent decisions have been based on such recommendations.
Complexity is no excuse Potential complexities in designing a compensation methodology—for example, through free permit allocation—should not stand in the way of the arguments in favour of compensation.	The Review has concluded that auctioning is preferable to free allocation as an overall mechanism of permit release into the market. Complexity is only one argument against free allocation. As well as having lower implementation and transaction costs, auctioning of permits is supported by the design principles of credibility, simplicity and integration with other markets.

LIST OF FIGURES AND TABLES

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LIST OF SHORTENED FORMS

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
APEC	Asia–Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
BoM	Bureau of Meteorology
CDM	Clean Development Mechanism
CFCs	chlorofluorocarbons
CGE	computable general equilibrium
CO_2-e	carbon dioxide equivalent
CO2CRC	Cooperative Research Centre for Greenhouse Gas Technologies
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCC	Department of Climate Change
EFF	Energy Futures Forum
GDP	gross domestic product
GEF	Global Environment Facility
GGAS	New South Wales Greenhouse Gas Reduction Scheme
GIAM	global integrated assessment model
GSP	gross state product
GTEM	global trade and environment model
HCFCs	hydrochlorofluorocarbons
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
LPG	liquefied petroleum gas
MMRF	Monash Multi Regional Forecasting
MRET	Mandatory Renewable Energy Target
NASA	National Aeronautics and Space Administration
NEMMCO	National Electricity Market Management Company
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
R&D	research and development
SRES	Special Report on Emissions Scenarios of the IPCC
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute
WTO	World Trade Organization

Units of measurement

Gt	gigatonne (one billion metric tonnes)
kWh	kilowatt hour
Mt	megatonne (one million metric tonnes)
MWh	megawatt hour
PJ	petajoule (10^{15} joules)
ppm	parts per million
TJ	terajoule (10^{12} joules)

GLOSSARY

Definitions are taken from the Intergovernmental Panel on Climate Change (IPCC) wherever possible. A list of sources is provided at the end of the glossary.

Terms in a definition that appear elsewhere in the glossary are italicised.

abatement Activity that leads to a reduction in *greenhouse gas* emissions.

abrupt climate change The nonlinearity of the *climate system* may lead to abrupt *climate change*. The term 'abrupt' often refers to time scales faster than the typical time scale of the responsible *forcing*.

adaptation Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

adaptive capacity The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

additionality Reduction in emissions by sources or enhancement of removals by sinks that is additional to the reduction would occur in the absence of an incentive provided through a program.

adverse selection Situations where features of a market result in the market being dominated by poorer-quality goods. Adverse selection results from *information asymmetry.*

aerosols A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 micrometre (a millionth of a metre) that reside in the atmosphere for at least several hours. Aerosols may originate from natural processes or human activities. Aerosols may influence climate either directly by scattering and absorbing radiation, or indirectly by modifying formation, the optical properties and lifetime.

afforestation Planting of new forests on lands that historically have not contained forests.

albedo The fraction of *solar radiation* reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo, the surface albedo of soils ranges from high to low, and vegetation-covered surfaces and oceans have a low albedo. The earth's planetary albedo varies mainly through varying cloudiness, snow, ice, leaf area and land cover changes.

Annex B countries/Parties Industrialised countries and economies in transition countries listed in Annex B to the *Kyoto Protocol* that have emissions reductions targets for the period 2008–12.

Annex I countries/Parties Industrialised countries and economies in transition listed in Annex I to the United Nations Framework Convention on Climate Change. They include the 24 original OECD members, the European Union, and 14 countries with economies in transition.

anthropogenic Resulting from or produced by human beings.

atmosphere The gaseous envelope surrounding the earth.

atoll Rings of coral reefs that enclose a lagoon. Around the rim of the reef are islets called 'motu' with a mean height above sea level of approximately two metres.

Bali Roadmap The key decisions agreed at the 2007 Bali Climate Change Conference, charting the way for the UN negotiations on a post-2012 UN climate agreement. The Roadmap comprises the Bali Action Plan establishing a new negotiating track under the *UNFCCC*, the *Kyoto Protocol* negotiations on second *commitment period* targets, and other decisions.

biochar A charcoal product made through anaerobic combustion of biomass (for example farm or wood waste) at high temperatures. Gas released during this process can be used to produce energy, while biochar can be applied as a fertiliser.

biosequestration The removal of *greenhouse gases* from the atmosphere through biological processes, such as growing trees.

bounded rationality The theory that individuals and firms may not be able to always make perfect or optimum decisions, due to gaps in their knowledge or cognitive abilities. Bounded rationality contrasts with the assumption often used in economics that individuals and firms always make perfect decisions.

business as usual An estimate of future patterns of energy consumption and *greenhouse gas* emissions that assumes that there will be no major changes in attitudes and priorities.

carbon budget The amount of carbon (or emissions, expressed as *carbon dioxide equivalent*) allowed to be released over a number of years, by a given party or parties.

carbon cycle The term used to describe the movement of carbon in various forms (for example, as carbon dioxide or methane) through the atmosphere, ocean, plants, animals and soils.

carbon dioxide equivalent (CO_2-e) A measure that allows for the comparison of different *greenhouse gases* in terms of their potential influence on the climate system.

- Carbon dioxide equivalent concentration (measured in parts per million (ppm)) is the concentration of carbon dioxide that would lead to the same *radiative forcing* as a given mixture of carbon dioxide and other greenhouse gases.
- Carbon dioxide equivalent emissions (often measured in gigatonnes of carbon) is the amount of carbon dioxide emissions that would cause the same integrated *radiative forcing*, over a given time horizon, as an emitted amount of a well-mixed greenhouse gas. The equivalent carbon dioxide emission is obtained by multiplying the emission of a well-mixed greenhouse gas by its *global warming potential* for the given time period.

carbon dioxide fertilisation Increasing plant growth or yield by elevated concentrations of atmospheric carbon dioxide.

carbon sink or **reservoir** Parts of the *carbon cycle* that store carbon in various forms.

carbon–climate feedback See *feedback*.

Clean Development Mechanism (CDM) A flexibility mechanism under the *Kyoto Protocol.* The CDM allows *Annex I countries* to meet part of their obligation to reduce emissions by undertaking approved emissions reduction projects in developing countries. Emissions reductions under the CDM can create tradable permits, called certified emission reductions or CERs.

climate change A change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.

climate sensitivity A measure of the *climate system*'s response to sustained *radiative forcing*. Climate sensitivity is defined as the global average surface warming that will occur when the climate reaches equilibrium following a doubling of carbon dioxide concentrations. Models predict a wide range of climate sensitivities due to differing assumptions about the magnitude of *feedbacks* in the climate system. The 'effective' climate sensitivity reflects the warming occurring in the short term, and takes into account climate feedbacks at a particular time.

climate system A highly complex system consisting of the atmosphere, the water cycle, ice, snow and frozen ground, the land surface and plants and animals, and the interactions between them. The climate system changes over time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, variations in *solar radiation* and human influences such as the changing composition of the atmosphere.

climate Climate in a narrow sense is usually defined as the average weather or, more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

CO_2-e See *carbon dioxide equivalent.*

commitment period The period in which countries listed in *Annex B countries* are required to meet their emissions reduction commitments. The first commitment period is 2008 to 2012. The dates of the second commitment period have not yet been agreed.

committed warming Due to the thermal inertia of the ocean and slow processes in ice sheets, biological sinks and land surfaces, the climate would continue to change even if the atmospheric composition were held fixed at today's values. Past change in atmospheric composition leads to a committed climate change. The further change in temperature after the composition of the atmosphere is held constant is referred to as committed warming.

coordination externalities The benefits (or cost) experienced by society that arise from multiple parties working together, beyond those experienced by those parties involved. See also *externality*.

deadweight loss Also known as allocative inefficiency, the loss of economic efficiency that can occur when the equilibrium price and quantity for a good or service is not suboptimal. A deadweight loss is usually due to a distortion in the market which results in over- or under-consumption of a good or service. Distortions that lead to deadweight losses can include monopoly pricing, *externalities*, taxes or subsidies, and binding *price ceilings* and *floors*.

deforestation Conversion of forest to non-forest.

demand–pull To increase the output of new inventions or technologies by stimulating market demand for those technologies.

demonstration and commercialisation Stages in *innovation chain*. Demonstration is an incomplete version of a product, put together with the primary purpose of showcasing the idea, performance, method or features of the product. Commercialisation is the process of introducing a new product into the market.

direct emissions Emissions at the point of final fuel combustion.

discount rate The rate at which future dollar values are discounted to the present. The discount rate allows a comparison of *utility* across generations.

economic welfare The level of real household consumption adjusted for the expenditure required to adapt to climate change. Consumption can be considered a measure of welfare as individuals are assumed to maximise *utility* through their consumption choices.

economies of scale Situations where the cost of producing each unit of a commodity, including services, decreases as the amount of output increases. This often occurs because fixed costs, such as information and equipment, can be spread over more units of output.

ecosystem A distinct system of interacting living organisms, together with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire earth.

efficiency The efficiency of a system describes how well it produces outputs with a given set of inputs. A system is said to be economically efficient if no one can be made better off without making someone else worse off. Governments may intervene to ensure markets are efficient.

El Niño – Southern Oscillation (ENSO) A coupled fluctuation in the atmosphere and the equatorial Pacific Ocean. The El Niño – Southern Oscillation leads to changes in sea surface temperature across the central tropical Pacific Ocean every three to seven years, and leads to changes in rainfall, floods and droughts on both sides of the Pacific. It is characterised by large exchanges of heat between the ocean and atmosphere, which affect global mean temperatures but also have a profound effect on the variability of the climate in Australia.

elasticity A measure of the responsiveness of one variable to another, defined in percentage changes.

emissions (or carbon) **intensity** A measure of the amount of *greenhouse gases*, or sometimes carbon dioxide, emitted per unit of, say, electricity or energy output.

emissions case One of four future emissions trajectories out to 2100 being investigated by the Review: a **no-mitigation case** with no action to mitigate climate change; an **ad hoc mitigation case** representing loosely coordinated mitigation action; an **ambitious global mitigation** case involving emissions reductions that lead to a stabilisation concentration of 450 ppm CO_2-e with an *overshoot* to 500 ppm CO_2-e, and a **strong global mitigation** case with emissions reductions leading to a stabilisation concentration of 550 ppm CO_2-e.

emissions limit The limit on the number of tonnes of *greenhouse gas* that can be emitted under an *emissions trading scheme*. The limit could apply to the whole economy, or to all sectors covered under the scheme (sometimes called an 'emissions cap'). The limit should generally be set below what emissions would be under *business as usual*. A specific time period may be set for which this limit applies.

emissions permit See *permit*.

emissions trading scheme An administrative approach used to reduce the cost of emissions control by providing a market-based and tradable instrument for achieving reductions in emissions. A cap and trade scheme places a limit on emissions allowed from all sectors covered by the scheme. It allows those reducing greenhouse gas emissions to use or trade excess emissions permits to offset emissions at another source. Trading can occur at the intra-company, domestic and international levels.

emissions trading A mechanism by which two emissions trading markets or two countries can buy and sell *emissions permits*.

energy efficiency The ratio of energy required to produce a certain level of a service, such as kilowatts per unit of heat or light. The term energy efficiency sometimes refers to the process of reducing the ratio of energy required to produce a service.

energy intensity A measure of the amount of energy supplied or consumed per unit of, say, *gross domestic product* or sales.

enteric fermentation Part of the digestive process of ruminant animals, such as cows and sheep, that results in the release of methane emissions.

equity A concept of fairness, including the notion that people with a greater ability to pay should pay more than those with a lesser ability to pay.

evapotransporation The sum of evaporation and plant transpiration from the earth's land surface to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil and bodies of water. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapour through its leaves.

exposure The nature and degree to which a system is exposed to significant climatic variations.

externality An externality occurs when the participants in an economic transaction do not necessarily bear all of the costs or reap all of the benefits of the transaction. Positive externalities are sometimes referred to as *spillovers* or spillover benefits.

feedback An interaction mechanism between processes, where the result of an initial process triggers changes in a second process and that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.

fluorinated gases See *greenhouse gas*.

forcing An induced change to a system.

geo-engineering Technological efforts to stabilise the climate system by direct intervention in the energy balance of the earth to reduce global warming.

geosequestration Injection of carbon dioxide directly into underground geological formations.

global warming potential The index used to translate the level of emissions of various gases into a common measure in order to compare the relative *radiative forcing* of different gases without directly calculating the changes in atmospheric concentrations. The global warming potential represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation. The *Kyoto Protocol* is based on global warming potential from pulse emissions over a 100-year time frame.

greenhouse effect The effect created by the *greenhouse gases* in the earth's *atmosphere* that allow short-wavelength (visible) solar radiation from the sun to reach the surface, but absorb the long-wavelength heat that is reflected back, leading to a warming of the surface and lower atmosphere. The increase in global temperatures caused by higher levels of greenhouse gases in the atmosphere as a result of human activity is often referred to as the 'enhanced greenhouse effect'.

greenhouse gas Any gas that absorbs infrared radiation in the atmosphere. This property causes the *greenhouse effect*. The primary naturally occurring greenhouse gases that can be managed directly by humans are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), all covered by the *Kyoto Protocol*. Water vapour (H_2O) and ozone (O_3) are also important greenhouse gases, but can only be indirectly managed by humans. There is also a range of entirely man-made greenhouse gases, including hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs), which are ozone-depleting substances covered under the *Montreal Protocol*. The fluorinated gases—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) are covered under the Kyoto Protocol. The man-made gases are sometimes referred to as 'halocarbons' (except SF_6), or 'synthetic greenhouse gases'. With the exception of Chapter 3, where a wider range of greenhouse gases are discussed, the term 'greenhouse gases' in this Review relates to those gases covered by the *Kyoto Protocol*. These gases are the focus of most domestic and international policy.

gross domestic product (GDP) An aggregate measure of economic activity, usually for a country.

gross value added The value of output minus the value of intermediate consumption. The term is used to describe gross product by industry and by sector.

halocarbons See *greenhouse gas*.

hoarding Net banking of *permits* by the private sector. That is, permits purchased in excess of current acquittal liability may be held as an asset on a firm's balance sheet and saved for future use.

ice sheet A mass of land ice that is sufficiently deep to cover most of the underlying bedrock, so that its shape is mainly determined by the flow of the ice as it deforms internally and/or slides at its base. Most ice is discharged through fast-flowing ice streams or outlet glaciers, in some cases into the sea or into ice shelves floating on the sea. There are only three large ice sheets in the modern world, one on Greenland and two on Antarctica. During glacial periods there were others.

indirect emissions Emissions associated with the production of purchased electricity, heat and steam.

information asymmetry Situations where one party to a transaction has critical information that another party does not have.

information market failures Market failures relating to problems in the supply, consumption or use of information.

innovation chain A model of innovation that suggests that new knowledge progresses to become commercial technologies through a series of one-way linear stages.

internalise To remedy the presence of an *externality* by ensuring that parties to a transaction bear the costs and benefits of their actions.

inter-temporal flexibility The ability to use *emissions permits* at different points in time, made possible through the flexibility mechanisms of hoarding and lending.

Joint Implementation A *Kyoto Protocol* flexibility mechanism which allows an *Annex B country* to earn emissions reduction units in another Annex B country which can be counted towards meeting the former's Kyoto Protocol target.

Kyoto Protocol An agreement adopted under the United Nations Framework Convention on Climate Change in 1997, and entered into force in 2005. Countries listed in Annex B of the Protocol have committed to meet targets that reduce their greenhouse gas emissions over the period 2008–12, compared with 1990 levels. The Protocol has been ratified by most countries but not the United States.

labour productivity The ratio of labour to output.

lending Lending of *permits* by the authorities to the private sector, which are repaid to the authorities at a future date.

long-lived greenhouse gases The selection of greenhouse gases covered by the *Kyoto Protocol* are sometimes referred to as 'long-lived greenhouse gases' to distinguish them from ozone and water vapour, both of which are removed from the atmosphere relatively quickly

long-wavelength radiation Thermal radiation, or heat, emitted by the earth's surface, the atmosphere and the clouds. It is also known as infrared radiation.

marginal costs The change in total cost that arises when the quantity produced changes by one unit. For example, the average cost of a unit of electricity is the total cost of providing a unit of energy divided by the number of units provided. The marginal cost of a unit of energy is any additional costs borne in providing that additional unit. In some cases marginal costs may be lower than average costs, but if new infrastructure is required to provide an extra unit then marginal costs can be higher.

marginal utility of consumption The additional amount of utility gained from an each extra unit of consumption.

market failure Where a free market does not result in an efficient outcome. Market failures are often used in economics as one of the two justifications for government intervention, along with *equity*.

materiality The relative significance of something, such as information or an event, in affecting the performance of a firm.

mitigation An intervention to reduce the source of, or enhance the sinks for, *greenhouse gases*.

Montreal Protocol The Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in Montreal in 1987. It controls the consumption and production chemicals that destroy stratospheric ozone, such as chlorofluorocarbons.

network externality When the purchase of a good or service by one individual indirectly benefits others who are also consuming the good or service (see also *externality*).

non-traded Firms or industries that produce goods for the domestic market, as opposed to exporting or being subject to import competition. Non-traded firms will mostly be in a position largely to pass through the *permit* price to domestic customers, unlike firms in the trade-exposed sector, for whom prices are set on world markets.

obligation A requirement to undertake a particular course of action. Parties with an obligation under an emissions trading scheme are legally required to monitor and report emissions, and acquit *permits* equal to those actual emissions during a compliance period. The point in the supply chain where the obligation is placed is referred to as the 'point of obligation'.

offsets Reductions or removals of *greenhouse gas* emissions that are used to counterbalance emissions elsewhere in the economy.

opportunity costs The opportunity forgone in choosing one alternative over another.

overshoot scenario or **profile** A mitigation scenario where concentrations of a *greenhouse gas* (or a mix of greenhouse gases) peak at a higher atmospheric concentration than the eventual target, and then reduce over time to achieve *stabilisation*.

pass-through Firms will attempt to recover costs of the emissions trading scheme (for example, the price of *permits*) by passing them down the supply chain in the form of higher prices. For example, the cost of compliance with the scheme will be applied to liquid fuel at the point of excise, but will be passed through to consumers in higher petrol prices. The proportion of cost pass-through is likely to vary between producers.

peaking scenario or **profile** A mitigation scenario where concentrations of a *greenhouse gas* (or a mix of greenhouse gases) stabilise or peak, and then continue to reduce indefinitely.

permafrost Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years.

permit or **emissions permit** A certificate created under the emissions trading scheme that enables the holder to emit a specified amount of greenhouse gas, generally one tonne of *carbon dioxide equivalent*.

phenology The study of the times of recurring natural phenomena. Examples include the date of emergence of leaves and flowers, and the first appearance of migratory birds.

physiology The study of the mechanical, physical and biochemical functions of living organisms.

price ceiling and **price floor** A price ceiling sets an upper limit on emissions prices; when it is reached, an unlimited amount of *permits* are issued at that price. A price floor sets a lower limit on emissions prices; when the floor price is reached, authorities may intervene to reduce the supply of permits, in order to keep prices at or above the floor.

primary energy Energy in the forms obtained directly from nature, such as black coal, brown coal, uranium, crude oil and condensate, naturally occurring liquid petroleum, gas, ethane and natural gas, wood, hydroelectricity, wind and solar energy.

principal–agent Principal–agent relationships exist where one party (the principal) assigns another party (the agent) to carry out a task for them. Principal–agent problems may occur where the principal cannot ensure that the agent acts in the principal's best interests.

prisoner's dilemma A term from economic game theory, which describes a 'game' or problem in which the cooperative outcome is the superior one, but in which agents (such as countries or individuals) have an incentive not to cooperate. It is named after the situation in which two suspects would receive short sentences if neither informs on the other, and long sentences if both inform on the other. If only one suspect informs on the other, the informant will go free. The best solution for the suspects is the cooperative one (neither informs on the other), but each has an incentive not to cooperate (to inform).

proxy measure A variable that can be measured and used in order to estimate something else that cannot be directly measured.

public good A good that is non-rival and non-excludable. This means, respectively, that consumption of the good by one individual does not reduce the amount of the good available for consumption by others; and no one can be effectively excluded from using that good.

purchasing power parity. A purchasing power parity exchange rate equalises the purchasing power of different currencies in their home countries.

radiative forcing A measure of the influence that a factor has on the energy balance of the *climate system*, and the importance of that factor as a potential *climate change* mechanism. Positive forcing tends to warm the surface, while a negative forcing tends to cool it. Radiative forcing is a measure of change. In this report, radiative forcing values are given in watts per square metre and represent the change between pre-industrial conditions (1750) and 2005.

reference case The evolution of the global and Australian economies and associated *greenhouse gas* emissions to the end of the current century in the complete absence of climate change.

reforestation Replanting of forests on lands that have previously contained forests but that have been converted to some other use.

rents See *resource rents*.

rent-seeking An attempt by an individual or firm to get greater income, without increasing productivity. Rent-seeking benefits the recipient at the expense of others in the economy.

resource rents Economic rent is a surplus value after all costs and normal economic returns have been accounted for. Resource rents refer specifically to the supernormal return from natural resources such as coastal space or minerals.

risk Refers to a situation where enough information is available for decision makers to construct a probability distribution.

secondary market A financial market for trading of *permits* that have already been issued, whether by auction of some other method of allocation. It may also include markets in physical or financial contracts for the future purchase or sale of permits, so-called forward contracts.

sensitivity With respect to the *climate system*, the degree to which the system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (for example, a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (for example, damage caused by an increase in the frequency of coastal flooding due to sea-level rise).

sequestration Carbon storage in terrestrial or marine reservoirs. Biological sequestration includes direct removal of carbon dioxide from the atmosphere through land-use change, afforestation, reforestation, carbon storage in landfills and practices that enhance soil carbon in agriculture.

severe weather event An event that is rare within its statistical reference distribution at a particular place. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called 'severe weather' may vary from place to place. An 'extreme climate event' is an average of a number of weather events over a certain period of time—an average which is itself extreme (for example, rainfall over a season).

solar radiation Electromagnetic radiation emitted by the sun. It is also referred to as short-wavelength radiation. Solar radiation has a distinctive range of wavelengths determined by the temperature of the sun, peaking in visible wavelengths. The intensity of solar radiation reaching the earth varies due to the seasons, the sunspot cycle, and changes to the earth's orbit and the tilt of its axis.

split incentives Describes the situation where there is an incentive for a principal to undertake certain actions (such as to reduce energy use) but the principal cannot act on the incentive because an agent with different incentives makes the relevant decision on their behalf. See *principal-agent*.

stabilisation In the climate change context, keeping constant the atmospheric concentrations of one or more *greenhouse gases* (such as carbon dioxide) or of a *carbon dioxide equivalent* mix of greenhouse gases.

storm surge The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). A storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.

stratosphere The highly stratified layer of the *atmosphere* above the *troposphere* extending from about 10 km (ranging from 9 km at high latitudes to 16 km in the tropics on average) to about 50 km altitude.

streamflows The volume of water flowing in streams, rivers and other channels, often measured at the entrance to storage facilities.

structural adjustment Changes to the allocation of resources (labour and capital) and changes to patterns of activity within the economy, in response to an external driver, such as *climate change* or an emissions price.

substitutes A good or service that can be consumed or used in place of another good or service in at least some of its possible uses.

sunspot cycle The sun exhibits periods of high activity observed in numbers of sunspots (small dark areas on the sun), as well as radiative output, magnetic activity and emission of high-energy particles. The sunspot cycle is a semi-regular modulation of solar activity with varying amplitude and a period of between nine and 13 years.

supply–push To increase the output of new inventions or technologies by putting more resources into research and development.

technological lock-in The state in which persistent biases towards the status quo inhibits the uptake of superior alternative technologies.

temperature reference point or **baseline** Unless otherwise specified, temperature changes discussed in this report are expressed as the difference from the period 1980–99, expressed as '1990 levels' as per the IPCC Fourth Assessment Report (2007). Following the same convention, temperatures over the period 1850–99 are averaged to represent 'pre-industrial' levels. To compare temperature increases from 1990 levels to changes relative to pre-industrial levels, 0.5°C should be added. Projected changes to the end of the 21st century are generally calculated from the average of 2090–99 levels, but are often expressed as '2100'.

thermal expansion In connection with sea level, this refers to the increase in volume (and decrease in density) that results from warming water. A warming of the ocean leads to an expansion of the ocean volume and hence *sea-level rise*.

thermohaline circulation Large-scale circulation in the ocean that transforms low-density upper ocean waters to higher density intermediate and deep waters and returns those waters back to the upper ocean. It is driven by high densities at or near the surface, caused by cold temperatures and/or high salinities, in addition to mechanical forces such as wind and tides.

threshold or **tipping point** The level of magnitude of a system process at which sudden or rapid change occurs. More specifically, a point or level at which new properties emerge in an ecological, economic or other system, invalidating predictions based on mathematical relationships that apply at lower levels.

total factor productivity The ratio of all inputs to output.

trade-exposed, emissions-intensive industries Industries that are either exporters or compete against imports, and produce significant emissions (above a threshold) in their production of goods.

transaction costs Costs associated with a market exchange (which may include indirect costs of market participation, for example, information gathering).

troposphere The lowest part of the atmosphere, from the surface to about 10 km in altitude at mid latitudes (ranging from 9 km at high latitudes to 16 km in the tropics on average), where clouds and weather phenomena occur. In the troposphere, temperatures generally decrease with height.

ultraviolet radiation The high-energy, invisible part of light emitted by the sun. The majority of ultraviolet radiation is absorbed by the layer of ozone in the stratosphere.

uncertainty Where a future possible event is sufficiently unique that no data or information can be used to construct a probability distribution of possible outcomes for it.

United Nations Framework Convention on Climate Change (UNFCCC) An international treaty that sets general goals and rules for confronting climate change. It has the goal of preventing 'dangerous' human interference with the climate system. Signed in 1992, it entered into force in 1994, and has been ratified by all major countries of the world.

upstream point of obligation Designating the point of obligation at a point higher or earlier in the supply chain. For example, the obligation for emissions from petrol can be placed upstream at the point of excise.

utility Personal satisfaction or benefit derived by individuals from the consumption of goods and services.

vector-borne disease A disease that is transmitted between hosts by a vector organism (such as a mosquito or tick—for example, dengue virus).

volumetric control imposing a restriction on the amount of something allowed. For example, a cap and trade *emissions trading scheme* sets a limit on the amount of emissions that may be released over a given time without incurring a penalty. By contrast, an emissions trading scheme with a price control would limit the cost of emissions or *permits*, but not the amount.

vulnerability The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.

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