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CLIMATE CHANGE GETTING IT RIGHT



About this paper

Growth 59: Climate Change – Getting it right

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About CEDA

CEDA (the Committee for Economic Development of Australia) connects leaders of Australian organisations to promote Australia's economic development.

CEDA's activities: CEDA holds more than 250 events, seminars and chief executive roundtables each year, and publishes a range of research papers.

CEDA's mission: CEDA's research and forums identify and explore issues that influence the nation's long-term economic and social development.

CEDA's reach: CEDA draws its members, which number around 1000, from businesses, universities, governments and the not-for-profit sector. During 2006 CEDA's economic and business events attracted more than 21,000 people.

CEDA's independence: CEDA advocates policy in the national interest, rather than lobbying on behalf of special interest groups. It is staunchly non-partisan. CEDA's funding comes from membership, events, grants and sponsorship.

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contents and **contributors**

Foreword	3
David Byers CEO CEDA	
1. Introduction	10
By John Freebairn	
Climate science	
2. Warming up	16
What we know about climate change By Graeme Pearman	
3. Climate models	24
Measuring and forecasting climate change By Ronald Prinn	
Economics and governance	
4. Reviewing Stern	34
Lessons for Australia By Robert Mendelsohn	
5. Beyond 2012	42
Where global policy is heading after Kyoto By Brian Fisher and Anna Matysek	
6. Climate change and India	52
A perspective from the developing world By Jyoti Parikh	
Policy response and technology	
7. The carbon tax	66
An alternative to carbon trading By Robert Shapiro	
8. Managing price and targets	76
Why a hybrid policy is better for Australia By Warwick McKibbin and Peter Wilcoxon	
9. Castles in the ground	86
The prospects for carbon capture and storage By Peter Cook	

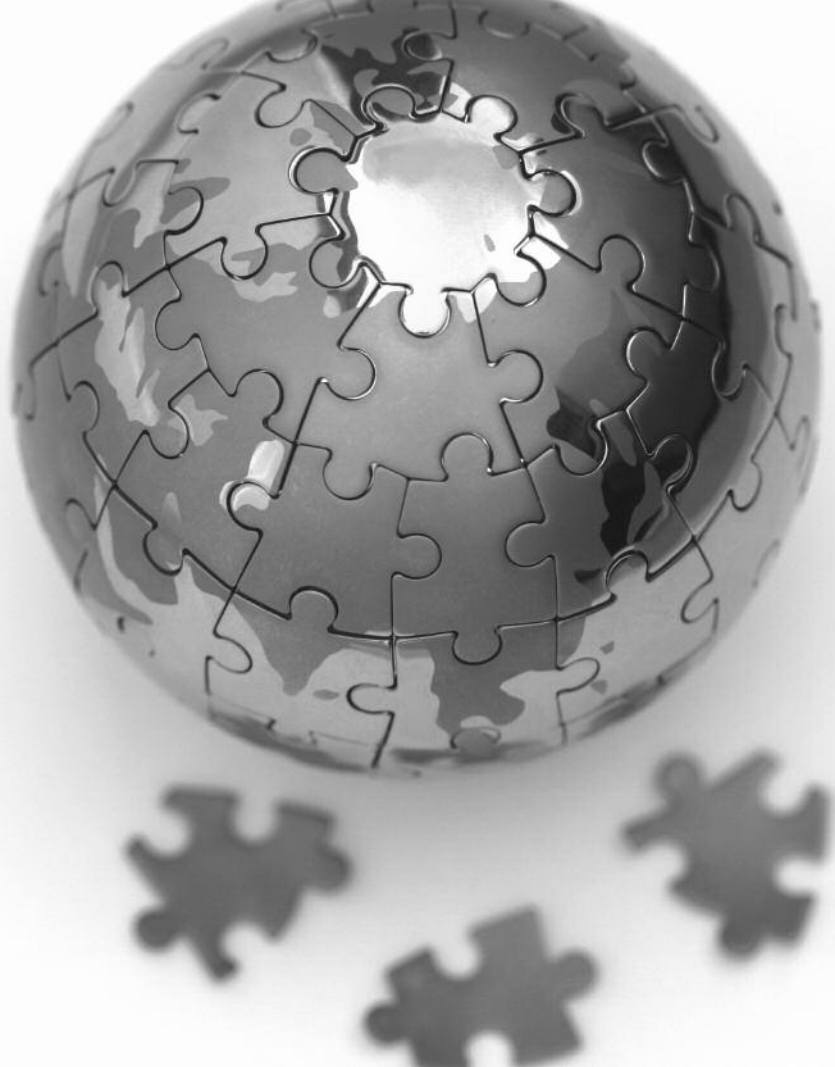
foreword



CEDA's continuing mission is to promote intelligent analysis and vigorous debate on our biggest national challenges. Right now, no issue needs this more than climate change. *Climate Change – Getting It Right* aims to stimulate a better understanding of this important issue. As the UK Better Regulation Commission says in its response to the Stern Report, the issue is “too important to get it wrong”.

In one sense, the current Australian climate change debate suffers from too much certainty. It suffers from analysts on every “side” of the issue who exaggerate the certainty of their case. Yet despite the growing acceptance that climate change could pose serious risks to future generations, projections of climate change necessarily rely on assumptions about the future. As in any exercise of prediction, there are uncertainties – in the science as well as the economics.

We certainly cannot wait for perfect knowledge before taking action. As John Freebairn points out in his introduction to the collection, the prospect of climate change from greenhouse gas emissions calls for risk management strategies. Knowledge is imperfect in many areas of human decision-making. Public policy has tools for making decisions in conditions of risk and uncertainty. These general rules apply equally to climate change issues.



Dealing with climate change, however, is complicated by a number of factors – the broad range of greenhouse gas emission sources, the strong current linkage between energy usage and economic growth, and the long time scales over which climate change must be considered. Warwick McKibbin points out that policies enacted today may not have noticeable effects on the climate until 50 years or more into the future. On top of this, climate change presents one great additional challenge: to deliver the best policy response across all the world’s major economies. In the words of *The Economist* magazine, “climate change is one of the hardest policy problems the world has ever faced”.

So what should we do? Several of our authors point out the most important tools for addressing climate change are markets, prices and investment in low emission technologies on an unprecedented scale. These tools will spur human ingenuity to respond to the challenge.

In this collection, CEDA has accessed the thinking of some of the top experts from not just Australia but around the world. We thank them all for their contributions.

We also thank our large group of trustees who over the past year have pointed to climate change as an issue CEDA should address. This includes 300 trustees who helped us produce our list of Australia’s “big issues” in mid-2007 – a list in which climate change ranked in the top four alongside water supply, the world economy, and

population and migration issues. And our international counterpart organisations around the world have been an important source of advice about the global debate.

Any CEDA publication is the result of work by many individuals, but I would like particularly to recognize the contribution of Professor John Freebairn, of the University of Melbourne, who has been a source of valuable advice at several points in the project, as well as contributing the introductory chapter. We also appreciate the dedication of our editor for this project, Minh Bui Jones, who has steered its evolution over many months and reached across the world to bring forth leading international perspectives.

I would also like to thank our generous group of research sponsors: the Australian Petroleum Production and Exploration Association (APPEA), PB (formerly Parsons Brinckerhoff), ExxonMobil, Leighton Contractors, TRUenergy and Xstrata Coal. Through the willingness of these organisations to support debate, CEDA is able to continue its national mission.

A handwritten signature in black ink, appearing to read "David Byers". The signature is fluid and cursive, with a long horizontal stroke at the end.

David Byers
Chief Executive Officer, CEDA

sponsors' messages



PB

Stuart Glenn Managing Director

Climate Change – Getting it Right is an important publication that seeks to progress understanding on the subject of climate change.

As our knowledge of climate science continues to improve we can no longer ignore mounting evidence that our planet is warming. The recently released Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) confirms that the Earth's climate is warming from human activity. Our actions over the past two centuries have guaranteed that our generation and those of the future will live in an environment between 1.8 and 6.4°C hotter than today.

CEDA's report deals with some of the uncertainties that exist around potential climate change impacts by carefully considering both science and economics. It is designed to assist government and business to better manage the potential risks associated with climate change. Its timing is perfect as we need to make some brave and urgent decisions with regards to public policy and investment in our physical and financial infrastructure. We can no longer afford to be mere spectators to what is certainly one of the most significant issues facing us today.

As engineers, planners, designers and managers we have a moral obligation to enhance our communities and environments to leave behind a beneficial legacy. We must strive to deliver best practice solutions through sustainable initiatives that protect our environment, grow our economy and promote social equity while remaining flexible to long-term needs. There are no excuses for further procrastination and the time for action is now. Stephen Pacala and Robert Socolow wrote in *Science* as long ago as 13 August 2004, "Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problems for the next half-century".

I applaud CEDA's initiative in preparing this research report and for bringing world leaders in the climate change debate to Sydney for this important exchange of ideas. In doing so I also invite each of you to join me on this journey and transition from indecision to realtime action, not only securing a better future for our individual organisations, but more importantly for our future generations.

About PB

PB is one of the world's leading planning, environment and infrastructure firms. We employ more than 12,000 people worldwide, working with our clients to reach their desired project and program outcomes.

Whether it's hands-on problem-solving or pure research, PB professionals contribute their ideas, talents and energy to assist public and private sector clients to plan, design and build infrastructure that meets human needs while respecting the environment.

We combine our core capabilities in design, planning and management with new approaches to project delivery. With experience in various financing arrangements, including PPPs, alliances and design-build-finance, we can respond effectively and flexibly to project challenges.

PB delivers practical solutions, and we build lasting relationships with our clients. We are proud that the majority of our work comes from repeat purchase, and that our clients consistently rate us "best practice" for technical delivery and client service.

Through our contribution to the sustainable development of infrastructure, PB seeks to create a beneficial legacy designed to enhance the lives of people and communities.



APPEA

Belinda Robinson Chief Executive

Climate change and the greenhouse effect are considered by many to be two of the greatest environmental, social and economic challenges facing the world today. As the world struggles to comprehend the magnitude of these challenges and develop appropriate strategies, Australian industry is working hard to develop new low-emission technologies, reduce its greenhouse footprint and further develop energy supplies that make a practical low-emission difference to Australia, our region and the world.

Like most Australians the upstream oil and gas industry is committed to working towards profitable, safe, environmentally and socially responsible operations. To this end the industry works with governments of all political hues to achieve credible industry actions and greenhouse policies to reduce greenhouse gas emissions in a way that minimises the cost burden to the Australian community.

The way Australia continues to respond to the greenhouse gas challenge is one of the key issues facing all existing and promising energy industries as well as all of those who consume energy either at a household level or in business. The way to move forward to ensure that the actions we take both locally and globally are both appropriate and effective, is to continue to improve our understanding of climate change science, critically and objectively examine all options for action, establish policies that deliver emission reductions in a cost-effective way and encourage new and emerging technologies.

There is an appetite for change and if there is a time to act with determination, courage, knowledge and wisdom, that time is now.

APPEA welcomes this report by CEDA and commends it for the contribution it will surely make to Australia's role in tackling this most pressing global issue.

About APPEA

APPEA represents the collective interest of the oil and gas exploration and production industry in Australia. APPEA has 65 full members that collectively account for 98 per cent of Australia's total oil and gas production. APPEA also represents 110 associate member companies that provide a range of goods and services to the industry.

APPEA assists its member companies by working with the state, territory and Australian governments to implement policies that promote investment and maximise returns to the Australian community from the development of the nation's oil and gas resources. It aims to secure the right conditions so that member companies can operate their businesses in a safe, environmentally responsible and profitable manner.

Reliable, secure and competitively priced energy is crucial to our everyday lives in Australia. Within this framework, oil and gas plays a key role in meeting many of our energy needs. At present, petroleum (oil and gas) accounts for more than 50 per cent of Australia's primary energy needs – this is expected to increase into the foreseeable future.

The industry has a very positive role to play in reducing the world's greenhouse footprint – natural gas as a fuel, particularly in power generation can, in the very short term, create improved emissions outcomes in Australia and, through the export of liquefied natural gas (LNG), can contribute to an improved global outcome. The world's largest commercial carbon storage project is currently being developed by the Australian gas industry at a cost of over \$1 billion.

Just as importantly, the industry creates significant wealth for the country, including through the employment of many Australians, underpinning the revenue collections of governments to the tune of \$8 billion and generating valuable export revenue for the Australian economy. A strong, vibrant and growing upstream petroleum industry is essential to the ongoing health of Australia's economy, social fabric and environment.

sponsors

ExxonMobil

ExxonMobil Australia

Mark Nolan CEO

ExxonMobil is proud to be a sponsor of the CEDA International Climate Change Research Report *Climate Change – Getting it Right*. Climate change is an issue of serious concern to governments, communities, corporations and individuals around the world.

Given the link between energy use, living standards and greenhouse gas emissions, it is vital that we all approach the issue in an open and constructive manner through reports such as this.

Climate remains today an extraordinarily complex area of scientific study. The risks to society and ecosystems from increases in CO₂ emissions could prove to be significant - so despite the areas of uncertainty that do exist, it is prudent to develop and implement strategies that address the risks, keeping in mind the central importance of energy to the economies of the world.

This includes putting policies in place that start us on a path to reduce emissions, while understanding the context of managing carbon emissions among other important world priorities, such as economic development, poverty eradication and public health.

The desire of people in the developing world for a better quality of life will be the key driver of global energy demand growth and, therefore, growth in greenhouse gas emissions in the coming decades. For this reason action aimed at curbing emissions must enable the supply of energy needed to improve living standards.

Exxon Mobil Corporation and its subsidiaries around the world are focused on taking action – reducing energy use at our facilities; deploying energy-efficient technologies across our global operations; working with partners to improve our customers' fuel efficiency; and investing in research to foster development of global energy technologies with significantly reduced greenhouse gas emissions.

Addressing climate risks is an important challenge. A thoughtful and considered approach is needed if today's policies are to effectively deliver benefits.

We welcome the contributions of the leading world experts CEDA has organised in this Research Report as Australia, and other countries work to formulate climate policy.

About ExxonMobil

The ExxonMobil group of companies in Australia has had a significant role in the development of Australia's petroleum resources with a business history stretching back more than 110 years.

We are Australia's largest integrated oil and gas company with a total investment of over A\$16 billion. Our activities cover production of oil and gas, petroleum refining and marketing of fuels (including natural gas), lubricants, bitumen and chemical products.



Leighton Contractors

Peter McMorrow Managing Director

The debate in respect to human-induced climate change is clearly over.

At Leighton Contractors we recognise that we have an ethical responsibility to manage our greenhouse emissions. However, in addition to any moral imperative, climate change also poses a serious business risk while creating opportunities for business growth and change.

As a major Australian infrastructure provider and miner, we are uniquely positioned to provide leadership in addressing climate change. By engaging our employees, professional partners and suppliers, we not only seek opportunities to reduce our emissions and improve our energy efficiency, but also to influence change within the industries in which we operate. We will use our engineering and project management capabilities, together with our innovative approach, extensive resources and global networks to capitalise on opportunities in emerging markets.

Through our membership of the Australian government's Greenhouse Challenge Plus and Energy Efficiency and Opportunities programs, we have committed ourselves to measuring, monitoring and publicly reporting our greenhouse gas emissions. We also provide detailed information about our progress towards sustainability within our annual publication *Sustain*.

To ensure our climate change initiatives have the largest possible impact, our Climate Change Strategy focuses on change in four key areas: our company, projects, offices and homes. This approach will encourage and enable all people who work with Leighton Contractors to have the opportunity to make a positive contribution to addressing this local and global issue.

"We believe the decisions we make today can and should enhance our tomorrow".

About Leighton Contractors

Leighton Contractors is a dynamic, vibrant business which provides a range of services throughout Australia and New Zealand. Our clients and partners include some of Australia's highest profile blue chip companies, as well as technical specialists, financial institutions, and government bodies.

With diverse capabilities in construction, mining, telecommunications, industrial engineering, and infrastructure investment - our expertise, experience and innovative thinking allow us to provide industry leadership across the areas in which we operate.

Our people value working closely with clients, contractors and other community and commercial stakeholders to achieve mutual benefits. We have a "can do" culture which, together with our experience and focus on sustaining long term relationships, ensures we are able to adapt to individual client requirements, market changes and industry cycles.

Sustainability for us means that our business is long lasting, consistently profitable and corporately responsible. It is not just about results and business performance - it is also about the way we do business, and the way that we live our values. Our values underscore our culture and guide the way in which we relate to our people, business partners, environment, and communities.

The size of our business, the talent and experience of our people, and our network of business relationships mean that we have unprecedented opportunities to enhance people's lives. But actions speak louder than words and so we strive to ensure our everyday decisions and behaviours contribute to creating a sustainable future.

sponsors



TRUenergy

Richard McIndoe Managing Director

Consensus amongst business, government and community leaders today is that “business as usual” will almost certainly expose us to the irreversible and catastrophic consequences of climate change.

Uncertainty prevails when it comes to the best scientific, technological and economic options for action. This is intensified by the reality that we have only a short window of opportunity in which to implement substantial, sustainable change.

As one of Australia’s leading energy generators and retailers, TRUenergy faces a more difficult challenge than most to reduce its greenhouse emissions intensity. Despite this, we have adopted a leadership position, publicly committing to a prescribed carbon reduction strategy. With a supportive emissions trading framework, TRUenergy will deliver a 60 per cent reduction in its emissions by 2050, based on a sequence of interim emissions reductions milestones.

Implementation of this strategy will create opportunities for TRUenergy to reshape its business, through the adoption of new technologies and practices with the greatest potential to reduce emissions at least cost to our business and our customers.

Our hope is that others will see the immense value in pursuing a similar approach. TRUenergy welcomes this research report and the open platform it will provide for ongoing, informed debate. By helping to expand a collective understanding of both the risks and opportunities presented by climate change, we are confident that other business, government and community counterparts will demonstrate decisive leadership, and adopt comprehensive action plans comparable to our own.

Only then will we be able to successfully make the transition to a carbon constrained economy.

About TRUenergy

TRUenergy is one of Australia’s largest integrated energy businesses. Currently, we service over 1.2 million customer accounts, supplying electricity and gas to residential and small and large businesses across Victoria, South Australia, New South Wales, the ACT, Tasmania and Queensland.

Our business spans energy generation, retailing and portfolio management, providing a strong integrated platform from which to harness further growth. TRUenergy’s \$5 billion portfolio of assets includes Yallourn power station and adjacent mine in Victoria’s Latrobe Valley, Hallett power station in SA, a master hedge agreement that delivers sole rights to electricity from Newport and Jeeralang power stations in Victoria, the Iona gas storage facility near Port Campbell in Victoria, and a number of long-term agreements with upstream gas suppliers and renewable energy suppliers including hydro, wind and biomass. TRUenergy also has a 33 per cent interest in the SEAGas pipeline, a 685-km natural gas transmission pipeline between Victoria and SA.

We are also constructing Australia’s most efficient gas-fired generation facility, near Wollongong, NSW. When complete, TRUenergy Tallawarra will emit 70 per cent less emissions than traditional coal-fired power stations.

As a substantial investor, generator and retailer in the Australian energy sector, TRUenergy recognises its responsibility to take a lead role in the development and implementation of effective carbon reduction solutions. Based on the assumption that an effective national carbon trading scheme will be introduced, our Climate Change Strategy is our blueprint for achieving such reductions, committing us to emissions reductions across our portfolio by 60 per cent by 2050.

TRUenergy is a wholly-owned subsidiary of the CLP Group, which is listed on the Hong Kong Stock Exchange and has a market capitalisation of approximately A\$22 billion. CLP operates a vertically integrated electricity generation, transmission, distribution and retail business in Hong Kong, and invests in electricity businesses in Australia, India, China, Taiwan and Thailand.



Xstrata Coal

Peter Coates Chief Executive

As Chief Executive of Xstrata Coal, the world's largest exporter of thermal coal, it is my pleasure to present the following *Climate Change – Getting it Right* report.

The report outlines the views of some of the world's leading academics, scientists and industry professionals about the need for a globally sustainable and economically viable response to the impacts of climate change.

CEDA has brought these voices together for an impressive and timely discussion of how Australian industry, government and the scientific community can and must continue to work together towards achieving solutions that will not only reduce our country's greenhouse emissions, but also ensure we can continue economic growth and meet our increasing energy needs.

As demonstrated in these pages, together we face an enormous task. We are challenged by International Energy Agency forecasts of a 70 per cent increase in global energy demand by 2030, threats of security of gas and oil supplies and the need to replace almost the entire fleet of ageing power stations around the world. The Chinese coal industry, today producing 2.4 billion tonnes per annum, is growing at the rate of about 200 million tonnes per year and the majority of Kyoto Protocol signatories are unlikely to meet their targets. The task also requires the deployment of low emission technologies, including clean coal and the development of a new international treaty to replace the Kyoto Protocol, one which effectively includes all major emitters from both the developed and developing world.

There is a commitment for change and a willingness to get on with the job. Australian industry is continuing to make dramatic moves towards a future supported by all parts of the energy mix: fossil fuels, renewables and nuclear. We will need all forms of power generation if we are to achieve an economically responsible and sustainable energy model.

I hope you will find this report an engaging start for future work and discussion.

About Xstrata Coal

Xstrata Coal is the world's largest exporter of thermal coal and one of the largest producers of hard coking coal. Headquartered in Sydney, Xstrata Coal has interests in more than 30 operating coal mines throughout Australia, South Africa and the Americas.

Xstrata Coal believes it has both a right and a responsibility to proactively engage with government, industry, the scientific community and the community at large, to help find a sustainable and financially viable solution to the issue of climate change. For this reason, Xstrata Coal is committing millions of dollars to various initiatives across the globe to realise the deep cuts in greenhouse gas emissions that are not only required, but are achievable.

These include being part of international consortia and providing millions of dollars in financial support to two of the world's significant low emission technology demonstration projects – oxy-fuel at CS Energy's Callide A plant in Queensland and the FutureGen project in the United States; a major contributor to Australia's \$1 billion COAL21 Fund, a voluntary coal industry fund for the development, demonstration and commercialisation of clean coal technology in Australia; participation in the development and implementation of a large scale CO₂ storage demonstration project in Victoria; methane drainage trials at underground operations at the Bulga Coal complex in New South Wales; power generation plants using methane from Xstrata Coal's Oaky Creek (Qld) and Teralba (NSW) sites; a business-wide energy efficiency program; and being part of Australia's Greenhouse Challenge Plus program.

Xstrata Coal is a commodity business of Xstrata plc, a global diversified mining group listed on the London and Zürich stock exchanges, with its headquarters in Zug, Switzerland.

introduction



JOHN FREEBAIRN is a Professor of Economics at the University of Melbourne. His first degree was from the University of New England, and he completed a PhD at the University of California, Davis. Professor

Freebairn began his career with the NSW Department of Agriculture, and then moved to academia with appointments at ANU, LaTrobe and Monash universities, and in 1984 and 1985 was Research Director with the Business Council of Australia. In 1996 he joined the University of Melbourne. At Melbourne he was Head of the Department of Economics from 1997 to 2003, and Director of the Melbourne Institute for two years to

April 2007. His research interests are in applied economic policy analysis, with current interests in taxation reform options, unemployment and water markets. Some of the results of his research have been published in international and Australian economics journals. Professor Freebairn has undertaken commissioned research for the Commonwealth and state governments and for business organisations, and he has been a member of two government inquiries on the wine industry and state taxation.

ction



The prospect of climate change calls for devising and implementing risk management strategies. There are uncertainties about the science of climate change, the economic costs and benefits of different mitigation and adaptation options, domestic and global policy reactions, the future path of technological changes, and social attitudes to different policy options. However, imperfect knowledge is prevalent in most of the decisions facing governments, businesses and households, and there are well known strategies for making decisions under uncertainty. As regards climate change, interest lies in the choice of government policy interventions to reduce the flows of greenhouse gas emissions, and in risk management decision options for businesses, households and governments to adapt to changes in temperature, rainfall, storms, sea levels and other dimensions of climate change.

Science has made considerable progress in understanding climate as a result of extensive investments in

measurement and modelling. Clearly, there are areas of disagreement and uncertainty, as is inevitable for this and for other areas of scientific inquiry. Even so, there is an extensive body of validated research pointing to the key role of human activity in causing the climate changes, and in providing probabilistic estimates of future changes in climate.

Data shows an increase in average temperatures since around 1950, and a near doubling in the stock of greenhouse gases over the last two centuries. The Intergovernmental Panel on Climate Change (IPCC) in its *Fourth Assessment Report* issued in early 2007, summarised in the chapters by Graeme Pearman and Ronald Prinn, concludes from extensive modelling studies that there is a 90 per cent probability that the increase in temperatures can be attributed to human activities, and particularly the burning of fossil fuels and agricultural practices.

The CO₂-to-climate-change link involves a long-term global stock-flow process. CO₂ emissions from any part of the globe, both natural and anthropogenic, accumulate as an increase in the global stock of CO₂. In turn, climate models in their simplest structure assume that a larger stock of greenhouse gases allows a larger inflow of infrared energy from the sun and a lower outflow, with the effect of raising temperatures at the surface and lower atmosphere. The temperature increases vary across the continents. In turn, the temperature changes alter rainfall patterns, the frequency of extreme weather events, and other characteristics of the natural environment, but less is known about these other dimensions of climate change.

The available models have been used to prepare probabilistic estimates of the stock of greenhouse gases and of climate into the future decades and centuries, in different scenarios of greenhouse gas flows. For example, Prinn contends that if the world follows stringent policies to restrain the stock of greenhouse gases to about 550 parts per million of CO₂ equivalent (about double the pre-industrial revolution level), average surface temperature will rise by a median of 2.4°C from 1990 to 2100, but with a 95 per cent confidence interval of 1.0 to 4.9°C, using an MIT model. Pearman reports similar probabilistic forecasts from the IPCC.

More specific projections of climate change for Australia are examined by Pearman. Warmer temperatures, less rainfall for southern Australia, more intense storms and increases in sea levels are expected. These climate changes will directly alter the decision contexts for management of water, food and agriculture, ecosystems and tourism, industry, buildings and other infrastructure and settlements, with flow-on effects to almost all areas of the economy and society. More information on climate change projections at quite detailed geographic levels, and more information on potential climate change adaptation strategies, for example, in agriculture and water supply and demand, to lower the costs of adaptation, will be necessary and a valuable investment.

Reducing the flow of greenhouse gas emissions to stabilise the stock of greenhouse gases, especially in the context of a rapidly expanding global economy, will require substantial changes in human behaviour, both on the demand side and on the production side. Households can reduce their draw on fossil-fuel-intensive products by as much as 20 per cent in many ways, as has been illustrated by the responses to the sharp increases in oil prices in the mid-1970s, the early 1980s, and over the last few years. Adjustment options include smaller and more fuel-efficient vehicles, less energy-intensive household appliances, and better designed and managed homes.

Dramatic greenhouse gas reduction options on the supply side are implicit in many current proposals, particularly if the flow of emissions is to be reduced by 50 per cent or more. These include carbon sequestration and “clean coal”, nuclear, renewable forms of stationary

energy and biofuels for transport. In his chapter, Peter Cook, outlines developments in the area of carbon sequestration. He notes that large-scale systems are still untried and that the cost of electricity may double or more. Although nuclear energy is a proven supplier in other countries, notably France where it provides over 70 per cent of supply, concerns about the storage of waste materials and security make this option as much a political as an economic challenge for Australia. While there are good prospects for increasing the supply of electricity from solar, wind, geothermal and other renewable sources, under current technology their costs are high relative to coal and gas (e.g. see Prime Minister’s Task Force, 2007) and few, including Prinn, see them contributing more than 10 to 20 per cent of total electricity needs. At current costs, biofuels are expensive relative to crude oil. Further, once we go beyond the use of waste products, expansion of the supply of biofuels quickly runs against the constraint of limited available arable land and its competing uses for food production and environmental conservation. All these areas have the potential for great technical advances over the coming decades.

Reducing the flow of greenhouse gas emissions to stabilise the stock of greenhouse gases, especially in the context of a rapidly expanding global economy, will require substantial changes in human behaviour ...

Even without dramatic supply-side greenhouse reduction strategies, businesses directly involved in the burning of fossil fuels and the wider business sector, using electricity and transport as inputs, have many opportunities to improve efficiency and reduce the carbon content per unit of product. These options include changes in the input mix, redesigned and new buildings, and a vast range of more energy-efficient production methods.

Technological change holds the key to both the mitigation costs of reducing greenhouse gas emissions and the adaptation costs of adjusting to climate change for households and businesses. Explicit and higher carbon prices will provide enhanced incentives and rewards for private investment in R&D. While we can expect with some confidence gains in technology in the future, the magnitude of the gains, their timing and their specific areas are very much guesswork.

Economic factors

Key economic issues in the climate change debate include global pollution, long time lags between the costs and benefits of mitigation, and the extent of uncertainty of greenhouse gas abatement and external cost functions. Each of these economic issues is integrally related to and dependent upon the science of climate change.

Greenhouse gas emissions are a classic example of an external cost that is a result of market failure. Producers and consumers of, for example, electricity and road transport using fossil fuels as an input consider the private or market costs of labour, equipment and materials in producing the electricity and transport and the private benefits of the electricity and transport consumed in deciding on how much to produce and consume. However, both the producers and the consumers ignore any costs caused by the greenhouse gas emissions as they add to the stock of greenhouse gases. Ignoring these external costs means too much electricity and transport is produced and consumed, and with too carbon-intensive methods, from the society assessment that takes into account the external pollution costs as well as the private costs.

An appropriate policy response to the external costs of greenhouse gas emissions and climate change would seek a lower level of emissions. Ideally, we seek levels where the marginal costs of emissions mitigation equals the marginal benefits of lower costs spent on adaptation to climate change. This level is not just a technical issue per se of a particular flow of greenhouse gas emissions, for example, 1990 rates as specified in the Kyoto Protocol, or a particular stock of greenhouse gases, for example, stabilising at 550 parts per million of CO₂ equivalent.

Further, with changes in technology, population, economic development, and other factors about which we have imperfect knowledge, the socially optimum level of emissions and climate change will also change over time. In particular, as argued in Mendelsohn's chapter (and implicitly in McKibbin and Wilcoxon's paper), the socially optimum rate of emissions reduction would be an increasing function of the stock of greenhouse gases (because of higher climate change adaptation costs). This points to a policy strategy of starting with a relatively generous emission target (or lower carbon tax) and building it up over time, rather than a one-size for all time.

A key characteristic of the climate change policy mitigation problem is the differences between the timing of the costs and benefits. Costs today to reduce emissions and climate change are an investment to reduce future costs of climate change adaptation. To compare the costs on the current generation with the benefits for future generations a discount rate (or price of time) should be used to convert future period dollars to today's dollar values.

Robert Mendelsohn, in his chapter, addresses these issues via a critical assessment of the Stern Report to the UK Treasury in 2006. Stern argues that setting a target

for the stock of greenhouse gases at around 550 parts per million of CO₂ equivalent would save climate adaptation costs from about 2050 onwards equivalent to between 5 and 20 per cent of GDP at a loss to GDP from now onwards at about 1 per cent of GDP.

Mendelsohn argues that Stern both overestimates the costs of climate change and underestimates the costs of mitigation. He is particularly critical of the use by Stern of a low discount rate of 1.7 per cent, rather than the real interest rate of 4–6 per cent commonly used in deciding levels of other investments to benefit future generations in education and physical infrastructure. Mendelsohn argues for a much more moderate reduction of greenhouse gas emissions than Stern.

Even though there is much uncertainty and legitimate debate about the magnitudes of the marginal cost and benefit functions for greenhouse gas emissions and climate change, there is a growing consensus that some climate mitigation is a desirable risk management strategy. Imperfect knowledge occurs in most other private and public investment decisions. Establishing a price on greenhouse gas emissions would provide explicit incentives for R&D to reduce future mitigation and adaptation costs, and it would provide a guide for the household and business sectors with which to choose investments in appliances, equipment and buildings that save on carbon.

Global policy

Effective policy toward greenhouse gas emissions and climate change requires a global policy approach with the involvement of as many countries as possible. However, as Brian Fisher and Anna Matysek describe in their chapter, we live in a world of independent national governments and a weak international governance structure. In the absence of a cooperative agreement there is an incentive for individual countries – not just the small ones but also the United States and China – to free-ride on the climate mitigation policies of other countries. By free-riding a country avoids all the costs of greenhouse gas mitigation but still shares in some of the benefits of reduced climate change. To achieve a global social optimum it is necessary that various governments reach and sustain a cooperative policy strategy to restrict greenhouse gas emissions.

The many barriers to global cooperation and the underlying reasons for the limited progress so far are canvassed by Fisher and Matysek. To take one example, developed countries and developing countries have quite different perspectives on what is a fair and acceptable cooperative global system for reducing greenhouse gas emissions. As exemplified by the Kyoto Protocol and discussed in the chapter by Shapiro, most of the developed countries are happy with a cap-and-trade system of tradable permits, and with an initial allocation of permits to current polluters (the grandfather system). Contrary

to this position, the developing countries argue that the developed countries, through the Industrial Revolution, have both improved their living standards and contributed to most of the growth of the global stock of greenhouse gases; so why should they bear a large part of the mitigation costs? Instead, they propose that permits be allocated on a per capita formula, a policy option explored by Jyoti Parkih. At this stage of international negotiations both sets of countries are far from reaching an agreed position. Fisher and Matysek are doubtful that a cooperative global agreement will be reached within the next 20 years. Rather, they concede that individual countries, and in many cases groupings of like-minded countries, will embark on independent climate mitigation schemes.

Mitigation instruments

Given a decision by governments to intervene to reduce the levels of greenhouse gas emissions, what policy instruments should be used? The options include a carbon or emissions tax, a cap-and-trade or system of tradable permits (with options on how the permits are initially distributed), regulations and subsidies for R&D and for products and processes that involve less pollution.

There is general agreement that the market-based tax and tradable permit systems are more desirable, although governments seem reluctant to move away from regulations and subsidies. The comparative advantage of the market-based instruments is that they place an explicit cost or price on pollution-intensive products and production processes. In turn, the carbon price provides incentives and rewards to all households and businesses to explore all the possible options for finding low-cost ways to reduce greenhouse gas emissions.

There are important similarities and differences in the tax and tradable permit options. Both internalise to household and business decisions the external cost of consumption and production activities which generate greenhouse gas emissions. In a world of perfect knowledge the market price of tradable permits for a given cap on greenhouse gas emissions would correspond with the emissions tax rate. In practice, though, we have imperfect knowledge of the pollution marginal abatement cost function, and the function shifts with technology, the level of economic activity, seasonal conditions, and so forth. In this realistic world, as explained in the chapters by Shapiro and by McKibbin and Wilcoxon, there are subtle but very important differences between the two systems. A system of tradable permits provides for certainty to pollution reduction, but with variation of and uncertainty about the market permit price (as illustrated with the European market for CO₂ permits and the US market for SO₂ permits). By contrast, the tax option gives certainty on the cost of greenhouse gas pollution emissions, but with variable and uncertain outcomes for

the quantity of emissions. In this context, McKibbin and Wilcoxon seek to gain the better properties of both options with a combination long-term tradable permit and short-term carbon tax system.

Shapiro makes the case for using a carbon tax system, such as those of Sweden and Denmark, rather than a tradable permits system. In addition to the stability of the cost surcharge for pollution, he argues that a tax system has greater ease and integrity of administration, particularly in developing countries, and it has a greater potential acceptance for reaching a desirable cooperative global agreement.

An important question not yet fully explored is, who ultimately bears most of the cost of an emissions tax or a tradable permit? In the first instance, business pays the tax cheque to the government and sees the opportunity cost value of a tradable permit. However, just as is the case with other taxes, the additional expenses to businesses change decisions which then change market prices and quantities. The final economic incidence of the additional expenses of greenhouse-gas-emitting activities is passed to the seller or buyer side of the market, which is less responsive (or price elastic) to market price. Given that most of the activities that generate greenhouse gas emissions are manufacturing industries, where constant per unit production cost is a common characteristic over a long-run perspective, almost all of the cost increase of greenhouse gas mitigation policy interventions will be passed forward to consumers as higher prices.

An important question not yet fully explored is, who ultimately bears most of the cost of an emissions tax or a tradable permit?

The fact that most of the costs of greenhouse gas emissions reduction will be passed forward to consumers as higher prices has several important policy implications. It cautions against the idea of giving tradable permits to existing businesses as a necessary bribe for their participation, as has happened in the European Union scheme. Rather, the final distributional outcome recommends a system of auctioning tradable permits, or a carbon tax, with government revenue being the initial beneficiary. Households faced with higher prices and cost of living will seek some compensation. Compensation can come from tax reductions and social security payment increases funded from the extra government revenue. The alternative of workers seeking a compensating wage increase has the potential to initiate an unintended round of inflation, which would be harmful to the economy.

Conclusion

Given the imperfect knowledge of both the science and economics of climate change, there is a growing consensus that sensible risk management calls for government policy intervention to mitigate the flow of greenhouse gas emissions and for businesses and households to prepare and invest in climate change adaptation strategies. There is agreement that the principal policy intervention should involve placing a price on carbon to support changes on both the consumption and production sides and to encourage necessary investment in R&D. Many argue the case for a gradual ramping-up of the carbon tax or aggregate emission target over time. Unresolved policy areas are the emission levels at which marginal benefits and costs of mitigation equate, and the choice between a carbon tax, cap-and-trade system, or a hybrid system. A critical unresolved issue is the development of mechanisms to secure the cooperative agreement of most countries to combat the global greenhouse pollution problem, with general agreement that the Kyoto Protocol format will not suffice.

warming up

What we know about climate change

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Abstract

Current peer-reviewed literature concludes that the Earth has warmed over the past century and that much of this warming has been due to the accumulation of greenhouse gases in the atmosphere. The cause of this accumulation has been human activities, the combustion of fuels, changing land-use and agriculture. This warming has now manifested itself in changes to details of climate: rainfall, winds, storminess, sea level, deglaciation, and so on. Impacts of these changes have been observed on human and natural ecosystems around the world. The science anticipates a further warming of around 2–4°C through this century with a wide range of concomitant effects. Both adaptive and mitigative actions are necessary to deal with these changes and limit dangerous changes into the future.

Introduction¹

The Earth's climate has always varied over periods of hundreds of thousands to millions of years (Overpeck 1995). This has been largely due to changes in the levels of energy arriving from the sun as the relevant position of the Earth and other planets has varied. The sequence of cooling events, ice ages, that occurred through the last million years resulted from the precession of the Earth on its axis, which caused both a reduction of total radiation arriving from the sun and a change in the distribution of that radiation between the two hemispheres (Hays, Imbrie



PHOTO: ISTOCK

and Shackleton 1976). In turn, the cooling events changed the biology of the Earth and physical conditions of the ocean, leading to reductions in the amount of greenhouse gases in the atmosphere, in particular, carbon dioxide, methane and nitrous oxide (and presumably water vapour). These changes amplified the effects that would have occurred due to the planetary changes themselves.

The fact that the temperature of the planet is dependent on the level of these gases in the atmosphere has been recognised for more than 100 years (Arrhenius 1896). Indeed, together with the different distances from the sun and reflective properties of their surfaces, they are understood to be the main explanation for the different temperatures of Earth and its neighbouring planets (IPCC 2001). Thus, for a long time it has been understood that changing the level of these gases in the atmosphere would lead to planetary climate change.

By the middle of the 20th century questions were being raised about whether carbon dioxide levels in the atmosphere might be increasing. At that stage no high-precision measurements of carbon dioxide existed (Plass 1956). During the 1960s and 1970s such measurements were commenced at a number of dedicated observatories around the world (Pales and Keeling 1965; Beardsmore and Pearman 1995; Pearman Hyson and Fraser 1983). It was soon clear that carbon dioxide levels were increasing in the atmosphere. But why?

Spatial and temporal analysis of a growing number of mutually comparable measurements around the globe, coupled with new observational and theoretical understanding of atmospheric and oceanic mixing, isotopic composition of the gases, and high precision measurements of changing oxygen concentrations, led to a growing understanding of the role of human emissions. A greater time perspective followed the development of techniques for retrieving ancient air trapped in glacial ice for the study of the concentration of these gases prior to the commencement of modern measurements (Pearman, Etheridge, de Silva and Fraser 1986; Etheridge, Steele, Langenfelds et al. 1996).

Measuring the climate

Through the 1970s and 1980s, following on from the development of numerical weather forecasting models, a number of research groups around the world started using such models to investigate the likely impact of changes in the chemical composition of the atmosphere on the climate. The weather forecasting role enabled new physical and dynamical processes to be included in models and tested against the observed behaviour of the climate system on a daily basis. Throughout, observations of the Earth systems improved, particularly with the wider inclusion of satellite imagery. Improving knowledge of the various processes that make up these

systems allowed the simultaneous integration of equations representing these processes in computer representations of the climate. Today they are realistic enough to represent most of the key features of the observed climate and are well validated against observations of the climate.

By the mid-1980s the climatological research community had developed sufficient understanding and modelling capability that they were confident there existed significant potential for human activities to change the climate of the Earth and that these changes could have wide-reaching consequences (WMO 1986). It is salutary to recall that at the time there was no convincing evidence that warming had occurred, but given the natural variability of global temperature and the expected rate of warming, it was projected that warming would become evident around the year 2000. And this it did.

A number of consequences followed. On the political side, the United Nations Framework Convention on Climate Change (UNFCCC) was established with the intent of “avoiding dangerous anthropogenic interference with the natural climate system” (UNFCCC 2006b). The rapid rate at which new knowledge about climate change was accumulating meant that there was a need for frequent overviews and a way to connect these with policy development. As a result the Intergovernmental Panel on Climate Change (IPCC) was established in 1988.²

The panel

The IPCC periodically draws together the accumulated peer-reviewed literature and produces assessments of the current status of climate change science specifically for use by policymakers in the public and private sectors. The panel has conducted four of these assessments – in 1990, 1996, 2001 and most recently in 2007.

To illustrate the effort and complexity the assessments entail, consider the recently released *Fourth Assessment Report* (IPCC 2007b, 2007c, 2007d). It was released in three volumes, each of about 1000 pages of text representing respectively the science about the fundamental causes of climate change; the impacts, adaptation and vulnerability associated with that change; and the opportunities for mitigating change through modifications to the global energy systems. For Working Group I alone there were 750 authors (42 Australians), who referred to more than 6,000 peer-reviewed articles, of which approximately half were published since the last assessment in 2001. For each working group report, a summary, specifically targeted at policymakers, was prepared in draft form by the scientists and modified with input from non-scientists representing governments and industry (available at the same website). The following brief descriptions of the observed and anticipated changes to the Earth's climate are based on the findings of the *Fourth Assessment Report*. A *Synthesis Report* will also be published later in 2007 by the panel.

Current knowledge

Greenhouse gases: Data from a global observational network and from ice-core analyses show clearly that the concentration of carbon dioxide, methane, nitrous oxide and several chlorofluorocarbon gases in the global atmosphere far exceed those at any time in the last 650,000 years. Each of the first three of these gases showed decreases during the ice ages. At no stage were concentrations as high as at present. Equally important, research on the cycling of these gases in the atmosphere and exchanges with the oceans and biosphere show that the increase of carbon dioxide is primarily due to the combustion of fossil fuels – coal, oil and natural gas – and of nitrous oxide and methane due to a combination of agricultural activity and land-use changes. The key chlorofluorocarbon gases are entirely man-made, and did not exist in the atmosphere prior to the 1930s. Their concentrations are now slowly decreasing as a result of global intervention to decrease their emissions under the Montreal Protocol on ozone-depleting substances.

Temperatures: Over the past century global surface temperatures have risen by $0.74 \pm 0.18^\circ\text{C}$ with 11 of the last 12 years ranking in the 12 warmest years since recordings began around 150 years ago. This warming is now observed through the bulk of the atmosphere, with cooling observed, as expected, at the highest altitudes. Warming is also observed through the depths of the oceans, in some places now to a depth of 3.5 km. The warming has meant that the summer period in the northern hemisphere has extended 12.3 days over the last century, and by as much as 1.5 months in northern regions of Eurasia and North America. It is concluded that the warming is “unequivocal”.

There are two relatively direct consequences of this warming. The first is that snow cover has decreased in most regions, especially in spring and summer. Retreat has been observed on most of the glaciers around the world where observations have been made. The Arctic sea-ice has declined by 2.7 ± 0.6 per cent per decade and around 10 per cent over the last decade. Its thickness has reduced by almost half over the past several decades.

The *Fourth Assessment Report* concluded that it is very likely (>90%) that greenhouse gas increase has caused most of warming since the mid-20th century and that it is extremely unlikely (<5%) warming was caused by natural variability. A review of significant published literature concluded that these are effects of human activities and that such effects are at least five times greater than those due to solar output change. Mainstream science recognises that the climate of the Earth has varied over geological timescales and has expended significant effort to test the idea that the current warming can be attributed to natural rising concentrations of greenhouse gases.

Oceans: The second consequence of the general warming of the planet is that as the oceanic water has warmed it has expanded, leading to sea-level rises of on average

around 20 cm over the past century or so and at a rate of 1.9 ± 0.5 mm yr⁻¹ from 1961 to 2003. As carbon dioxide has dissolved in the surface waters this has led to acidification, which, averaged over the global oceans, has resulted in an increase of acidity of 0.1 pH unit so far.

Impacts: In addition to changes to the global climate system, many regional changes have been observed in the physical and biological systems, influenced by climate. For the physical systems these include such things as changes to glacial lakes, ground instability, enhanced early summer run-off, coastal erosion, and so on. For biological systems, they include earlier times of leaf-unfolding and seasonal greening, bird migration, egg-laying, shifts in the ranges of plants and animals, and so on.

Current projections

Projections of what future climate might look like depend on two key uncertainties. First, how well is the real climate system represented by the climate models? Second, how much will the concentration of greenhouse gases change over coming decades? Uncertainties in the modelling have been significantly reduced since the last report of the IPCC in 2001. For the first time, a large number of models (23) from research groups around the world have been used. These models contain improved representation of the physics and dynamics of climate, have been run in computers many more times than before, usually with greater computing power than ever before, and with better validation and inter-comparison.

Greatest uncertainty lies with the fact that it is not possible to know just how the global community will source and use energy in the future; to what extent the climate change issue will modify what might have otherwise been trajectories for future energy use. The following summary of projected global change includes ranges of uncertainty that include societal response (IPCC 2007a).

In summary, the expected climatological changes are as follows:

Mean temperatures

- 2025: 0.6–0.7°C *Higher over land/high latitude*
- 2095: 1.7–4.0°C

Extreme temperatures

- More frequent, intense *Longer-lived heat waves*
- Decrease in frost days *Mid to high latitudes*
- Increased growing season *Mid to high latitudes*

Mean precipitation

- Increase in high latitudes
- Decrease subtropics/mid latitudes

Extreme precipitation

- Intensity of events to increase
- Longer periods between events (sub-tropics/mid latitudes)

Tropical cyclones (hurricanes, typhoons)

- Increased peak wind and precipitation
- Overall less frequent; geographic shifts uncertain

Mid latitude storms

- Fewer with a poleward shift (several degrees); increased wind speed and wave heights

Snow and ice

- Snow cover and sea-ice extent decrease
- Glaciers and ice caps lose mass
- Loss of Arctic sea ice as early as mid 21st century

Carbon cycle

- Loss of carbon dioxide absorption efficiency
- Greater atmospheric accumulation of carbon dioxide

Sea level

- By the close of this century, 0.19–0.58 m
- Limited knowledge of potential additional increase due to melting of ice floes

Ocean acidification

- 0.14–0.35 pH units in 21st century
- Southern Ocean exhibits undersaturation with consequences for marine organisms

Australian climate

While the IPCC assessments provide significant guidance as to the potential changes to climate conditions in Australia, this analysis is understandably limited. In the past, the Climate Impacts Group of CSIRO periodically provided interpretations of how climate change may impact across the regions of Australia (Whetton 2001). Recently this group, together with other members of the Australian climate research community, including the Bureau of Meteorology and several universities, captured the results from the climate models used in the *Fourth Assessment Report* and conducted more detailed analysis with regards to relevance for Australia. This work will be published in November 2007 (CSIRO and Bureau of Meteorology 2007).

In essence, what these researchers have done is to examine modelled projections for all 23 international climate models used by the IPCC and evaluated these results by the degree of model agreement, the overlap of changes resulting for all alternative emissions scenarios and the capacity of those models to represent the Australian climate. This made it possible, with the assumptions inherent in this approach, to attach probabilities to changes projected; something that adds to the utility of the results.

Temperature: Warming is expected in Australia across the nation on average at a rate similar to the global mean warming; slightly greater in inland than coastal regions. This is expected to significantly shift the frequency of occurrence of extreme temperature events:

TABLE 1

POTENTIAL CHANGE TO SOME KEY AND VULNERABLE ECOSYSTEMS IN AUSTRALIA WITH THE WIDER QUALITATIVE IMPLICATIONS FOR THE ECONOMY.

VULNERABLE SYSTEMS	CLIMATIC DRIVERS OF CHANGE	IMPACTS	ECONOMY
Eastern Australian Alps	Reduced precipitation and snow cover	Shortened winter season. Loss of plant species, increase of shrubs and loss of herbs	Threats to built environment and biodiversity. Impact on ski industry viability /costs and tourism
Eastern Queensland	Coastal impacts of sea-level rise and storm intensity	Losses to infrastructure and coastal amenity	Tourism implications. Infrastructure costs and insurance risk
Kakadu	Salt-water intrusions	Displacement of freshwater wetlands with mangroves.	Biodiversity and tourism implications
Murray Darling Basin	Reduced river flow	Enhanced competition for water for natural flows, irrigation and town water supplies.	Higher cost of water. Loss of agricultural production and biodiversity
Queensland wet tropics	Coastal impacts of sea-level rise and storm intensity	Species extinction, loss of coral reefs, coastal flooding and infrastructure damage	Tourism implications. Infrastructure costs and insurance risk
Southwest Western Australia	Drying	Water shortages, fragmentation of ecosystems	Loss of agriculture production or enforced changes. Loss of species diversity
Sub-Antarctica islands	Warming and de-glaciation	Loss of key species and rapid changes to ecosystem assemblages	Loss of biodiversity

Source: Based on the IPCC *Fourth Assessment Report*, Working Group II, Chapter 11.

- Number of frost days to decrease, number of days exceeding 35°C to increase with consequent impact on human health (direct and through impacts on disease vectors), heating and cooling demands, fruit setting and vernalisation of seeds.
- Melting snow cover with impacts likely on stream flow, hydroelectricity supply and the snow-skiing industry.
- Increased evaporative demand exacerbating rainfall losses, although evaporation rates are also dependent on factors such as wind speed.
- Impact on phenological development of plants and behaviour/migration of animal species.
- Impact on crop production; also dependent on other factors such as soil moisture and ambient carbon dioxide concentrations.
- Impact on the frequency of coral bleaching and threats to the survival of those ecosystems

Rainfall: It is projected that there will be a decrease of annually averaged rainfall across all regions, but not necessarily for all seasons. This is a much more confident projection for regions south of latitude 30°S with intensification and poleward movement of the high-pressure ridge that dominates Australia's climate. Together with higher temperatures, this suggests the general loss of overall moisture in soils and run-off across the continent. There remains less certainty concerning the intensification of monsoon activity for particular parts in the north of the country. Current rainfall increases in the monsoon region, particularly the northwest, may relate to aerosol (dust)

increases in South-East Asia enhancing the temperature difference that drives the Australian monsoon and these may not persist as Asian economies improve (Roystayn, Cai, Dix et al. 2007). There is no conclusive evidence of strengthening or otherwise of the El Niño intensity or changes in frequency of occurrence. Currently the most likely projection for El Niño is a continuation of variations, but superimposed on a generally warmer and dryer climate.

As with temperature, the impacts of rainfall changes may be mostly due to changes in extreme events. Storms associated with low-pressure systems, particularly those originating over oceans, are likely to be more intense as a result of greater moisture levels from warmer surface conditions, leading to stronger winds, higher sea-level surges and precipitation. This applies to depressions passing south of the continent, those off the east coast that impact on New South Wales and southern Queensland or tropical cyclones.

Thus scientists are expecting less rainfall on average, but when it occurs it will be in more intense events. The consequence of this may be far more damaging run-off and flooding, coastal inundation, siltation of dams and estuaries, less effective utilisation of water by agricultural and natural ecosystems and problems for capture of irrigation, insurance risk and potable supplies.

Sea level: Global sea levels are expected to rise through the century by between 20 and 60 cm. This is generally regarded as a conservative figure given that the projections largely exclude the potential for de-glaciation of Greenland and parts of Antarctic adding to expected rise from thermal expansion due to the warming of ocean waters. The current

sea-level rise has already impacted on the island nations such as Tuvalu and the islands off Bougainville. Such changes are anticipated to further destabilise communities on other islands including the Torres Strait Islands, as well as cause inundation of low-lying regions of northern Australia and southern Papua New Guinea. Such changes have the potential to raise national security, humanitarian and migration issues (Dupont and Pearman 2007).

Sea-level rises will be regionally varied, and the science is improving in quantifying these differences, leading to both assessment of the risk of inundation and sandy beach erosion. But the biggest threats may relate, again, to extreme events, with the coincidence of a generally higher sea level, more intense atmospheric low-pressure systems that cause sea levels to rise beneath them, and higher winds. These potentially threaten non-linear growth in the magnitude of inundation and storm damage to low-lying coastal developments such as beach and canal estates of northern NSW and southern Queensland. This has significant implications for the appropriateness of current building codes and insurance risk.

Miscellaneous: There remain many other features of the climate system that are projected to change in Australia with global warming. They include changes to cloudiness and radiation levels, to humidity, the frequency of hail storms, the permanency of winter snow in alpine regions, wind speeds and so on.

Vulnerability of ecosystems: The complexity of changes in this range of climatological features, both geographically and temporally, leads to significantly different regional exposure that must be assessed to anticipate local risk and plan for adaptive responses.

A number of key ecosystems in Australia have been identified as potentially vulnerable. Table 1 briefly identifies these and the reasons for exposure/impacts, and suggests potential connections to economic consequences. This is not meant to be a comprehensive or detailed analysis, but illustrative of the way in which many sectors of the economy may be exposed to risk. This risk needs to be understood and managed. Management of this risk can proceed with current knowledge, but will be built on greater certainty as more research on physical and economic consequences is completed.

Adaptation to climate change will be required across all community sectors. The complexity and potential invasiveness of climate change suggests that substantial new research is needed to equip the community in the development of management strategies. The following list is not comprehensive but illustrates some of this complexity:

Water

- Improved demand management
 - Human behaviour, water efficiency
- Recycling
 - New infrastructure for storm water and waste
 - Societal acceptance

- De-salination
- Re-evaluation of value of water resource for:
 - energy generation and storage
 - food and fibre production
 - ecosystem protection and tourism
 - potable supplies

Ecosystems

- National park changes, extensions, management
- Management and protection of specific species
- Migration opportunities of species

Food

- Agriculture management processes
 - Planting, cultivation timing and methods
 - New agricultural species
 - Genetic selection of water-efficient species
- Potential opportunities/threats in changed global markets

Coastal systems

- Revised building regulation for coastal structures
- Revised land-use options
- Coastal land protection such as sea walls
- Changed insurance risk

Industry

- Risk assessment of existing strategies for industrial investment and options
- Most vulnerable in coastal and river flood plains, linked to climate-sensitive resources

Settlement and society

- Societal support for poor communities nationally and internationally
- Emergency strategies for flood/bush fire events
- Strategies for:
 - environmental refugees
 - international environmental disasters
 - political management of winners and losers
 - changing insurance risk

Health

- Hazard monitoring/warning for extreme events
- New exposure/health management tools related to changing vectors, infections and international exposure
- National contribution to extreme events of human health in less developed countries (fire, floods, storms, droughts, water-related disease).

Mitigation options

There are very few who argue that it is a good idea to allow the planet to warm indefinitely. However, by just how much should emissions be reduced, just how quickly and by whom? These are the key questions.

To meet current global demands for energy, some 8,000 million tons of carbon is annually emitted into the atmosphere from the combustion of fossil fuels (oil, natural gas and coal). Conservatively, this level of emissions could grow ten-fold through this century (based on anticipated population growth rates, desired growth in

per capita energy and economic aspirations, and assuming that this energy will be derived from conventional fossil energy sources using today's technologies).

The prime mechanism for removing carbon dioxide from the atmosphere on a semi-permanent basis is dissolution into the ocean surface and transport into the deep ocean. This mechanism is capable of transferring about 2,000 million tons of carbon each year. If we are to stabilise atmospheric concentrations of carbon dioxide and therefore, eventually, global temperatures, we need to target emissions reduction of around 80 per cent. This is a physical limitation of the real world that we cannot avoid. But questions revolve around how quickly we must get to this level and how to achieve such reductions.

No single approach or technology is likely to deliver the changes required and thus, over the past decade, discussions have focused on the so-called wedges or portfolio approach to strategies for energy futures.³ Here, a jurisdiction considers a wide range of energy sourcing and use including energy efficiency, enhanced gas, advanced nuclear, wind, solar, bio-fuels, geothermal, carbon capture and storage, and so on.

The value of this approach is that it builds in resilience in the face of current uncertainty. Examination of these technological options reveals that their future value is not certain because we do not know with confidence:

- how the economics will unfold in the world of increasing energy demand and/or carbon prices, changing levels of resource availability, changing scales of energy production or technological innovation;
- the rate at which each technology can be implemented on a scale that can make a substantial contribution to both meeting energy demand and emissions reduction; and
- the public acceptance of the technology and thus the future political will to implement changes.

When uncertainty like this exists it is paramount that resilience is maintained through diversity and that the temptation of "picking winners" should definitely be avoided.

The analysis of the IPCC *Fourth Assessment Working Group III Report, Mitigation of Climate Change*, concluded that over coming decades there will be a great opportunity for economically viable emission stabilisation or even emission reductions while meeting global energy demands. This arises from the almost universal finding in industry, commerce, governments and domestic sectors that current energy efficiency is extremely poor and cost-effective improvements in the order of 20 per cent are available often with a payback on investment of one year.

The report also concluded that the cost of substantial reductions of emissions to reach targets of stabilisation of atmospheric concentrations at 550 and 650 ppm (parts per million) of carbon dioxide were in the range of 0.6 per cent and 0.2 per cent of GDP respectively by 2050.

It points out that the impact of annual growth of GDP is thus generally less than 0.1 per cent in the average year. It even suggests that in part this lost growth would be offset by collateral benefits such as improved human health. Such findings are consistent with the conclusions of the Stern Report (HM Treasury 2006), and in Australia, of the Australian Business Roundtable (Insurance Australia Group 2006), AGL-WWF (2006) and those of an as yet unpublished report on options for Victorian energy futures conducted by Australia 21.⁴ These reports also indicate improved employment opportunities in a diversified energy economy.

How quickly should this be done? To answer this we need to assess the risks associated with allowing the planet to warm by different amounts. There is little agreement about this. The EU has set a target of 2° warming, being the limit beyond which further warming would constitute potentially dangerous warming. Others argue that such a target is not prudent enough, given the potential for tipping points (wildcards) to be reached that facilitate non-linear, rapid and non-retrievable change, such as the breakdown of Greenland ice sheet (e.g. Hansen, Sato, Ruedy et al. 2007). There exists a possibility that improved knowledge or observed changes will cause demand for tighter controls on emissions. In the meanwhile, public understanding of the potential impact of a change in global-mean temperature of say 1°C is confused by the daily exposure of local fluctuations that far exceed this. A change of temperature of 2–4°C represents 40–60 per cent of the change that took place from the middle of the last ice age (when sea levels were 80 m lower, almost half the Earth was covered with ice and natural ecosystems were massively different from today) until recently. We are looking at comparable changes taking place this century.

Another issue is one of equity. Even if a globally acceptable degree of warming and thus emissions reductions had been agreed upon, one that reflects the inequities of exposure of developed versus developing countries and their differentiated capacity to adapt, how would we share the burden of emission reduction? Australia might argue that it will not undergo emissions reduction unless China does the same, but this will hardly be seen as equitable by the Chinese, where per capita emissions are no more than 20 per cent of the average Australian. In any case it is arguably more equitable to consider the ratio of accumulated emissions over the past century, which is really a more reasonable assessment of relative impact on warming. This would skew even more an equitable share of emissions reduction towards Australia and other developed nations.

Australian emissions are a small part of the global emissions and thus any mitigation on our part might be regarded as inconsequential. Australia's annual emissions in 2004 were equivalent to about 528 million tons of carbon dioxide (UNFCCC 2007). In the same year, the UK's were marginally larger at 655 million tons, and

Canada marginally greater at about 758. The Netherlands emitted 218 tons, Poland 388, Ukraine 413, Spain 427, France 562, and Italy 582 tons. All of these individual nations and others could argue that their contributions are too small to be significant.

Conclusion

An assessment of the current peer-reviewed literature concludes that the Earth has warmed over the past century and that much of this warming has been due to the accumulation of greenhouse gases in the atmosphere. The cause of this accumulation has been human activities, the combustion of fuels, changing land-use and agriculture. This warming has now manifested itself in changes to details of climate: rainfall, winds, storminess, sea level, deglaciation, and so on. Impacts of these changes have been observed on human and natural ecosystems around the world. The latest IPCC report anticipates a further warming of around 2–4°C through this century with a wide range of concomitant effects. Both adaptive and mitigative actions are needed to deal with these changes and limit dangerous changes into the future.

ENDNOTES

- 1 Throughout this chapter citations are provided as an introduction to the literature but are not intended as a comprehensive bibliography.
- 2 More detail on the Intergovernmental Panel on Climate Change is available at <http://www.ipcc.ch/about/about.htm>.
- 3 The most widely applied use of this approach is based on work from Princeton University and Socolow, Hotinski, Greenblatt and Pacala 2004
- 4 See <http://www.australia21.org.au/futures.htm>

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climate forecasting models

Measuring and forecasting climate change

3

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Summary

This chapter reviews the key scientific, economic and policy issues that, taken together, provide a significant impetus for lowering greenhouse gas emissions to mitigate future climate change. First, I briefly discuss the current evidence for climate change, then discuss detection of the human influence on climate that is so important to policy. I then review the models of human and natural processes that are used to predict future changes in climate with an emphasis on the modelling system developed at the Massachusetts Institute of Technology (MIT). Next I address the uncertainty in current climate forecasts using the MIT model. This is followed by a review of the risks to humans and natural ecosystems that arise from allowing very significant future global warming to occur. I then review some economically viable technological pathways for meeting future global energy needs while lowering greenhouse gas emissions. After this, I briefly address the major policy options and their costs. Finally, I comment on the unresolved issues in climate science that need future resolution.

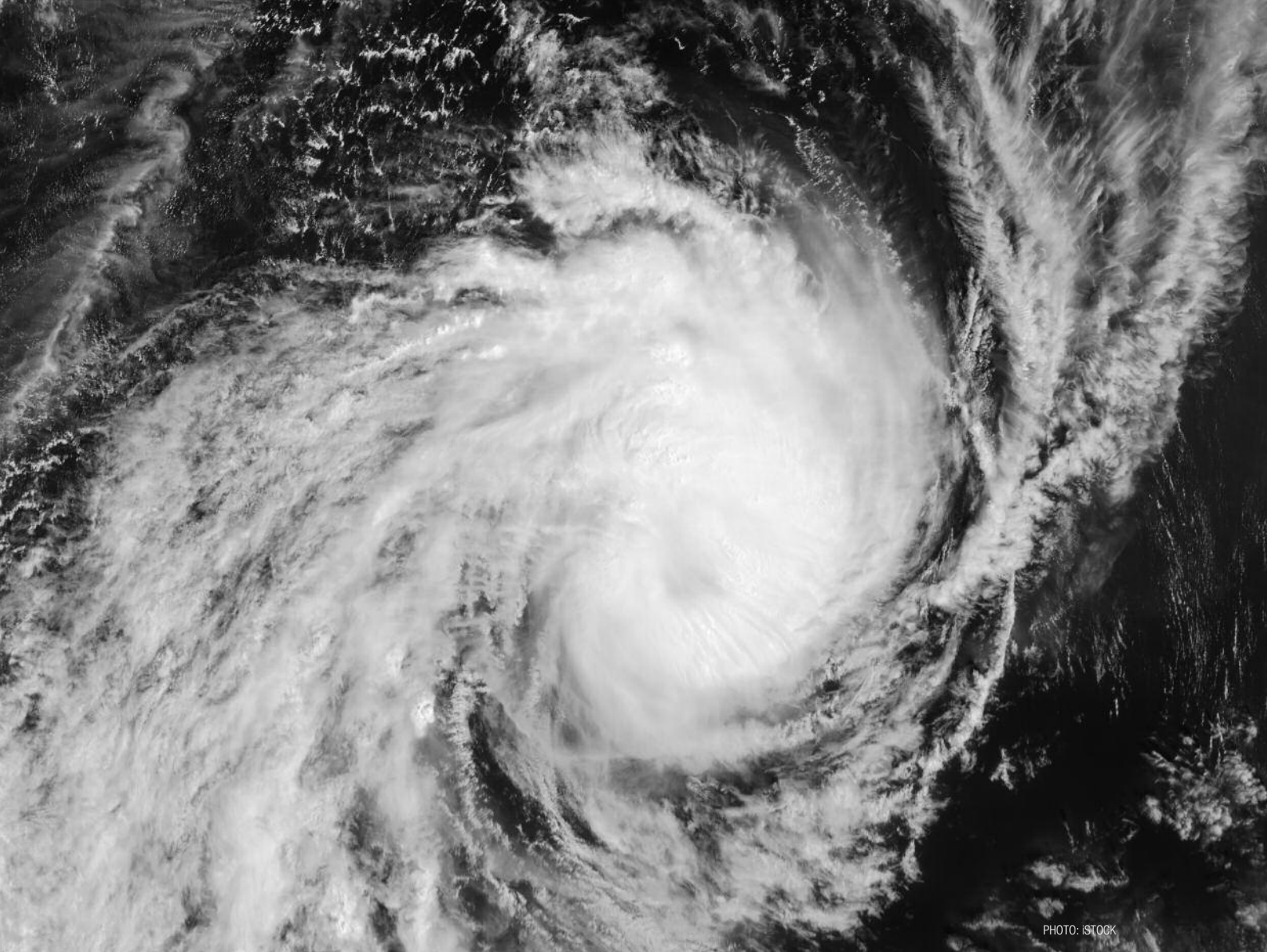


PHOTO: ISTOCK

Introduction

It is important to distinguish between changes in the weather and changes in the climate. Weather patterns evolve on time scales of hours to a year or two without any need for changes in climate. Climate is usefully defined as the average of the weather we experience over a 10- or 20-year time period. Long-term temperature, rainfall and sea-level changes are typical measures of climate change, and these changes can be expressed on a local, regional or global scale. When the global average temperature changes we call that global warming or cooling.

Any imbalance between the energy the Earth receives, largely as visible light from the sun, and the energy it radiates back to space as invisible infrared radiation, will drive global warming or cooling depending on the sign of the imbalance. The greenhouse effect is a warming influence caused by the presence in the air of gases and clouds that are very efficient absorbers and radiators of this infrared radiation. The greenhouse effect is opposed by substances at the surface (such as snow and desert sand) and in the atmosphere (such as clouds and colourless sulphate aerosols), which efficiently reflect sunlight

back into space and are thus a cooling influence. Water vapour is easily the most important greenhouse gas, but this gas typically remains in the atmosphere for only a week or so. Water vapour and clouds are handled internally in climate models. Concerns about global warming revolve around longer-lived greenhouse gases, especially carbon dioxide. The concentrations of carbon dioxide and many other long-lived greenhouse gases (methane, nitrous oxide, chlorofluorocarbons, lower atmospheric ozone) have increased substantially over the past two centuries due totally, or in large part, to human activity. When the concentration of a greenhouse gases increases (with no other changes occurring), it temporarily lowers the flow of infrared energy to space and increases the flow of infrared energy down towards the surface; this raises temperatures at the surface and in the lower atmosphere. Significantly slowing the rate of surface temperature rise is the uptake of heat by the world's oceans. However, warming of the oceans then causes sea levels to rise. It is important to note that as a result of this delaying action of the oceans we are already committed to future warming due simply to the long-lived greenhouse gases already in the atmosphere.

An authoritative review of the direct observations of recent climate change has been provided in the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC), whose summary for policymakers and background reports were released earlier this year (Solomon et al. 2007). They conclude, “warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.” They also conclude,

“at continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones.”

There is no doubt in my mind, based on this report and the extensive underlying literature, that climate is already changing in very significant ways. However, how much of this is due to human activity?

Human influence

If the observed global patterns of climate change over, say, the past 50 to 100 years are shown to be consistent with those predicted by reliable climate models which include the human influences, but not consistent with the patterns predicted when the human influences are neglected, then we can legitimately conclude that there is a human influence on climate. In this exercise, the predictions which neglect human influence are taken as a measure of the natural variability of climate and are thus used to represent the “noise” out of which the human-caused “signal” must arise for a definitive detection. The imperfections of current climate models make them less than ideal tools for defining natural variability and uncertain predictors of the climate response to human forcing. There are other difficulties associated with the inadequacies in climate observations and poor knowledge of past levels of aerosols and their quantitative effects on sunlight reflection.

Based substantially on a multi-model exercise of the above type, the IPCC Fourth Assessment has concluded that there is a greater than 90 per cent chance that most of the observed increase in globally averaged temperatures since the mid-20th century is due to the observed increase in anthropogenic greenhouse gas levels (Solomon et al. 2007). Some of the arguments for this strong conclusion are visibly captured in Figure 1, reproduced here from the IPCC report.

The observed 1906–2005 temperatures are shown at the global and continental scales and are compared to two bands; one band shows the range of multi-model simulations without anthropogenic forcings (i.e. the “noise”), while the other shows the range with these forcings (i.e. the “signal”). The separation of these two

bands during recent decades, and the fact that the observations follow the “forced” band much more closely, argue that the “signal” of human influence has arisen from the “noise”. The conclusions about human influence by the IPCC Fourth Assessment provide a substantial impetus for lowering future greenhouse gas emissions, even if the probability is not quite 90 per cent.

Climate forecasts

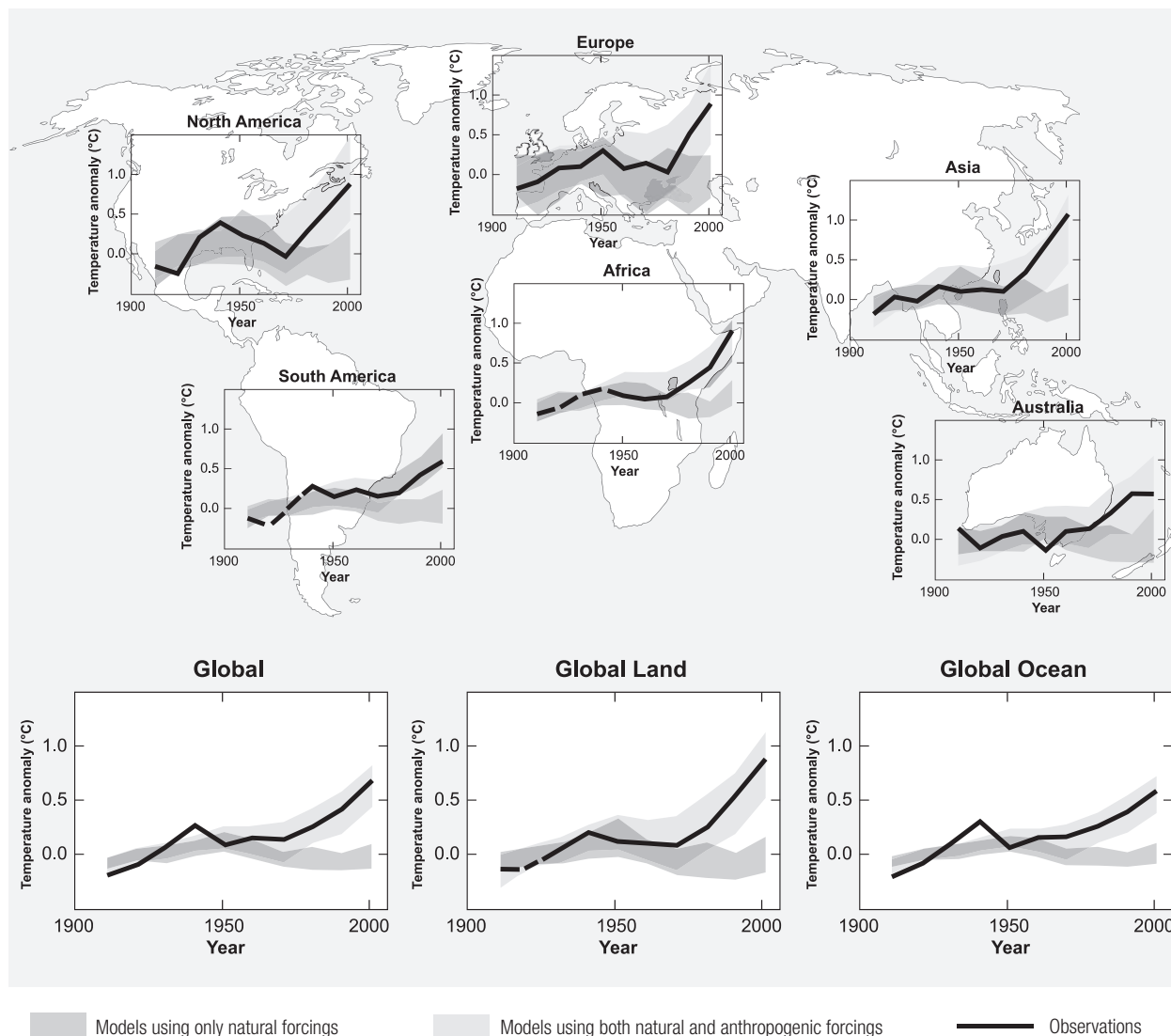
It is the forecasts by scientists of significant warming over the next century under the assumption of growing future greenhouse gas emissions that have especially driven public concern about climate change. These forecasts are made using computer models that attempt to simulate with some, but not complete success, the behaviour of clouds, water vapour, long-lived greenhouse gases, atmospheric and oceanic circulation, and many other essential climate processes on regional and global scales. These models are remarkable in their complexity and, despite their limitations, are invaluable tools for scientific research.

To effectively inform policy development and implementation, it is essential to integrate and understand the diverse human and natural components of the problem. Climate research should focus on predictions of key variables such as rainfall, ecosystem productivity and sea level that can be linked to estimates of economic, social and environmental effects of possible climate change. Projections of emissions of greenhouse gases and atmospheric aerosol precursors should be related to the economic, technological and political forces at play. In addition, such assessments of possible societal and ecosystem impacts, and analyses of mitigation strategies, should be based on realistic representations of the uncertainties of climate science. At the Massachusetts Institute of Technology (MIT), we have developed an Integrated Global System Model (IGSM) to address some of these issues and to help inform the policy process. The IGSM consists of a set of coupled sub-models of economic development and associated emissions, natural biogeochemical cycles, climate, air pollution, and natural ecosystems (Figure 2). It is specifically designed to address key questions in the natural and social sciences that are amenable to quantitative analysis and are relevant to climate change policy (Prinn 2004).

Emissions of chemically and radiatively important trace gases accompany critical human endeavours such as energy and food production. The prediction of global anthropogenic emissions in the MIT program is based on a regionally disaggregated model of global economic growth. Specifically, the Emissions Prediction and Policy Analysis (EPPA) model incorporates the major relevant demographic, economic, world trade and technical forces involved in this process at the national and international levels. This allows for treatment of a shifting geographical distribution of emissions over time and changing mixes of emissions, both of which affect atmospheric

FIGURE 1
GLOBAL AND CONTINENTAL TEMPERATURE CHANGE

Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings from the IPCC Fourth Assessment (Solomon et al. 2007). Decadal averages of observations are shown for the period 1906–2005 (solid black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage of observations is less than 50 per cent. Dark gray shaded bands show the 5–95 per cent range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Light grey shaded bands show the 5–95 per cent range for 58 simulations from 14 climate models using both natural and anthropogenic forcings.



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chemistry. The EPPA non-energy sectors include services, energy-intensive products, other-industry products, transportation and food processing. The energy sectors include coal, crude oil, tar sands, shale oil, refined oil products, biomass liquid fuel, natural gas, coal gasification, electric (fossil, hydro, nuclear), solar and wind, biomass, natural gas with combined cycle, and integrated coal gasification with sequestration. The agriculture sectors include crops, livestock and forestry.

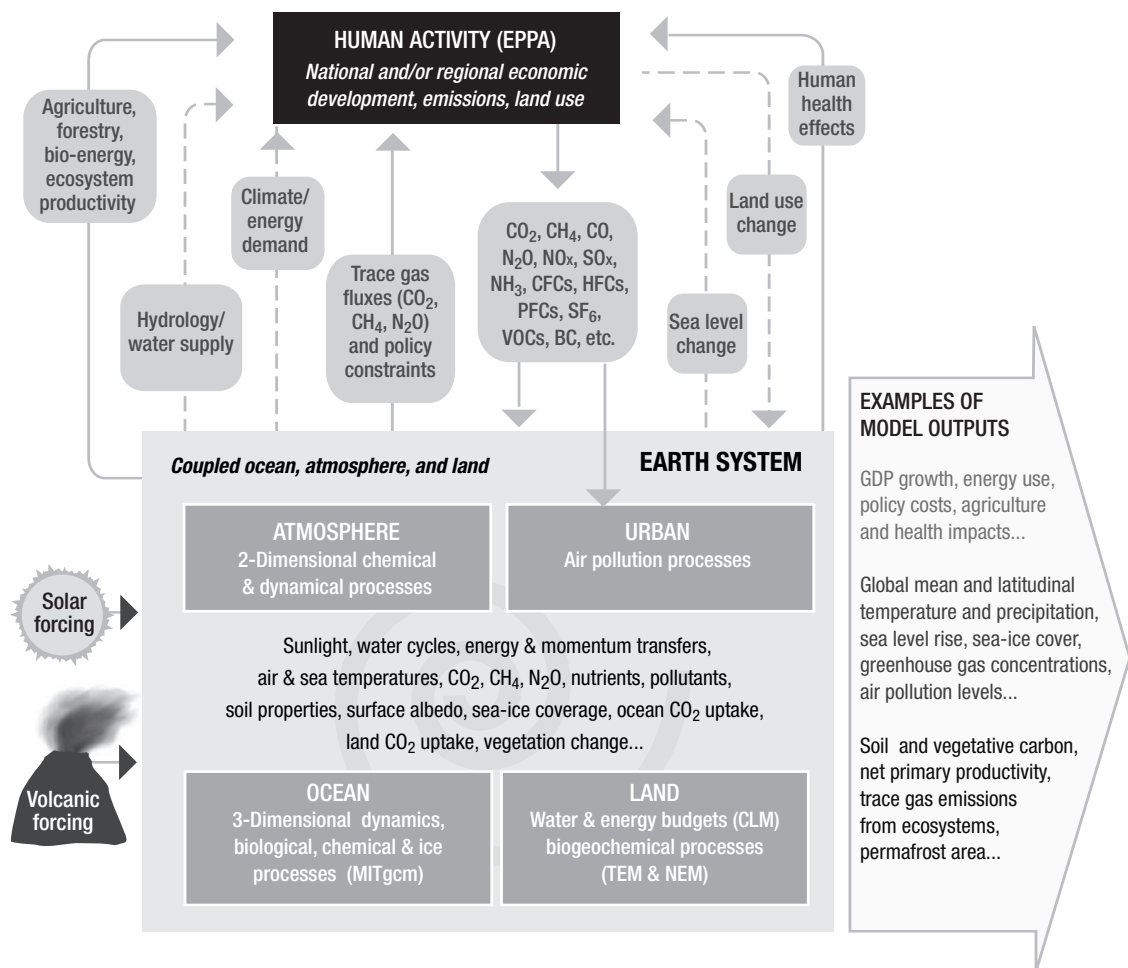
Natural emissions of trace gases must also be predicted, and for this purpose the natural emissions model takes

account of changes in both climate and ecosystem states in wetlands and soils around the world. This model of natural emissions is coupled to climate and land ecosystems models, which provide the needed explicit predictions of temperature, rainfall and soil organic carbon concentrations.

This combination of anthropogenic and natural emissions then drives a coupled atmospheric chemistry and climate model. The essential components of this model are chemistry, atmospheric circulation and ocean circulation. The atmospheric chemistry component is modelled

FIGURE 2
MIT INTEGRATED GLOBAL SYSTEM MODEL VERSION 2

The schematic diagram depicts the current framework and processes of the MIT Integrated Global System Model Version 2 (Sokolov et al. 2005; MIT 2007). Feedbacks between the component models that are under development are shown as dashed lines.



in sufficient detail to capture its sensitivity to climate and different mixes of emissions, and to address the effects on climate of policies proposed for control of air pollution and vice-versa. For the atmosphere and ocean components, a computer has yet to exist that can adequately resolve the important small-scale eddies on a global scale for thousands of century-long calculations. Thus, simplified treatments of these circulations are included in the version of the model used for the Monte Carlo uncertainty and multiple policy applications discussed in the next section. Linking these complex models together leads to many challenges, well illustrated by the failure of essentially all existing coupled ocean-atmosphere models (including ours) to simulate current climate over the globe very accurately without adjustments to the air-to-sea fluxes of heat, water and (sometimes) momentum that indicate deficiencies in the model formulations of air-sea interactions (Solomon et al. 2007).

To attain the necessary computational efficiency for uncertainty studies, while retaining plausible treatments

of key climate processes, we use a longitudinally averaged statistical-dynamical climate model that is two-dimensional (2D), but that also resolves the land and ocean surfaces (LO) at each latitude (and so is referred to as the 2D-LO model). It is capable of reproducing many characteristics of the current zonally-averaged climate, and its behaviour and predictions are similar to those of coupled atmosphere-ocean three-dimensional general circulation models (GCMs). By utilising this climate model we are able to incorporate detailed atmospheric and oceanic chemistry interactively with climate, with sufficient detail to allow study of key scientific and policy issues. However, to better address ocean circulation, the latest version of the IGSM includes a low-resolution three-dimensional (3-D) ocean model. This model can simulate changes in the rate of the deep oceanic overturning (thermohaline) circulation that is a key process in the oceanic uptake of heat and carbon dioxide (Sokolov et al. 2005). In common with several other 3-D ocean models, this one shows a detrimental slowing down of the thermohaline circulation with rapidly rising

carbon dioxide levels that constitutes a positive (accelerating) feedback on global warming (Scott et al. 2007).

Urban air pollution has an impact on global chemistry, and thus on climate. Air pollution is a problem in a steadily growing number of giant cities worldwide. The emissions of chemicals important in air pollution and climate are often highly correlated due to shared generating processes, such as combustion. Also the atmospheric lifecycles of air pollutants and some climatically important species (e.g. CH₄ and sulfate aerosols) both involve the photochemistry of the atmosphere. This photochemistry removes about 3.7 petagrams (gigatons) per year of reactive trace gases from the atmosphere, which is similar to the total mass of carbon removed annually from the atmosphere by the land and ocean (Prinn, 2004). To help unravel the interactions, the IGSM contains an urban-scale air chemistry module to simulate the chemical reactions occurring in large cities. This enables the simultaneous consideration of control policies applied to local air pollution and global climate. It also provides the capability to assess the effects of air pollution on ecosystems, and to predict levels of irritants relevant to human health, such as ozone, in the growing number of mega-cities around the world.

The coupled chemistry/climate model outputs then drive a Terrestrial Ecosystems Model (TEM), which is capable of predicting vegetation properties including the difference between carbon uptake by plant photosynthesis and carbon loss by plant respiration (net primary production or NPP), land-atmosphere carbon dioxide (CO₂) fluxes, and soil composition. TEM outputs then feed back to the climate model, chemistry model, and Natural Emissions Model (NEM). Finally, the NEM, which predicts wetland and soil emissions of methane (CH₄) and nitrous oxide (N₂O), is driven jointly by outputs from the TEM and climate models, and in turn provides inputs to both the atmospheric chemistry and climate models. Fundamental ecosystem biogeochemical processes in 18 globally distributed terrestrial ecosystems are included in the ecosystem model. This model, with its significant biogeochemical and spatial detail, also enables us to study how changes in climate and atmospheric composition affect ecosystems, and the relationships between ecosystems and chemistry, climate, natural emissions and agriculture.

The IGSM is arguably unique in its combination of scientific and economic detail, climate-atmospheric chemistry-ecosystem feedbacks and computational efficiency. At the same time I must caution the reader to keep in mind that the various components of the IGSM do contain simplifications when interpreting its climate projections. The climate system contains a number of nonlinearities, feedbacks and critical thresholds that are not present in the IGSM, or most other models (Rial et al. 2004). These omissions, however, are not expected to be important until after the year 2100.

How good are the forecasts?

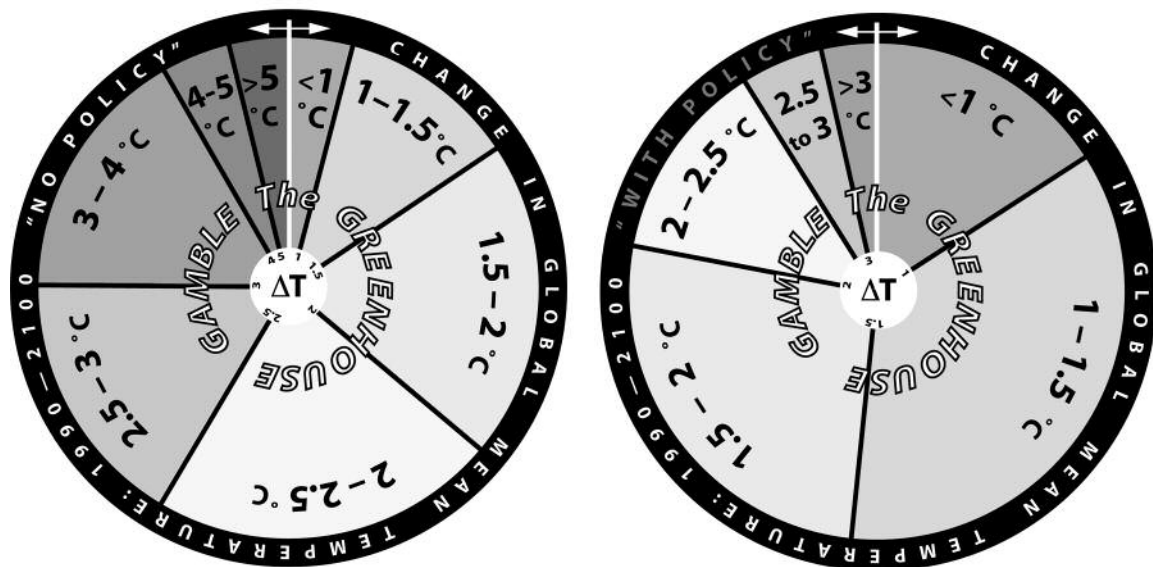
Quantitative assessments of uncertainty in climate projections are very useful for helping decision-makers evaluate how well policies might reduce the risk of climate impacts. As noted above, through a combination of judicious choices and compromises, the IGSM contains detailed process-resolving models for the relevant phenomena that are coupled in a computationally efficient form. With this computational efficiency comes the capability to perform uncertainty analyses using very large ensembles of multi-century model runs, to identify and understand important feedbacks between model components, and to compute sensitivities of policy-relevant variables (e.g. rainfall, temperature, ecosystem state) to assumptions in the various sub-components in the coupled models.

The IGSM 2D-LO physical climate model is flexible, which enables it to reproduce quite well the global behaviour of more complex climate models. This flexibility allows for analysis of the effect of some of the structural uncertainties present in existing models, especially those associated with the critical climate processes involving clouds, aerosols and the deep ocean overturning (thermohaline) circulation. The MIT estimates of these key climate model uncertainties are constrained by observations of the climate system (e.g. Forest et al. 2006). The MIT study also includes uncertainties in projecting anthropogenic emissions of all climatically important gases and aerosols using the EPPA model. These uncertainties include parameters associated with labour productivity growth, autonomous energy efficiency growth and the relationships of emissions to energy, industrial and agricultural activity. These EPPA parameters are derived from relevant data and expert judgement about variables that influence key economic projections.

We have used several hundreds of runs of the IGSM together with quantitative Monte Carlo uncertainty techniques to carry out a detailed uncertainty assessment of future climate change (Webster et al. 2003). Two hypothetical cases – no explicit climate policy and a stringent policy – were assumed in our calculations of the probability of changes in the mean global surface temperature, sea level and many other variables between 1990 and 2100. The stringent policy keeps atmospheric greenhouse gas levels in the year 2100 in the median case to just below 550 parts per million (ppm) of CO₂ equivalent (which is about twice the pre-industrial CO₂ level). Atmospheric levels of greenhouse gases other than CO₂ are converted into the equivalent levels of CO₂ that would have same climate forcing as the non-CO₂ gas in these calculations (Webster et al. 2003). The median projection in the study assuming no mitigation policies shows a global average surface temperature rise from 1990 to 2100 of 2.4°C, with a 95 per cent confidence interval of 1.0°C to 4.9°C. For comparison, the recent Fourth Assessment Report of the IPCC reports a range for the global mean surface temperature rise by 2100 of 1.1 to 6.4°C for six assumed emission scenarios.

FIGURE 3
PROBABILITIES OF WARMING

The probabilities for various amounts of global average warming between 1990 and 2100 calculated from two multi-hundred sets of IGSM forecasts are projected onto two wheels (Webster et al. 2003). The left-hand wheel is for “no policy” and the right-hand wheel is for “policy” (see text).



To be useful, the results of an uncertainty study like this need to be communicated with clarity to the public and policymakers. In fact, the average person on the street is very familiar with the problems of dealing with uncertainty – they just do not describe it with probabilities. Anyone who bets on horses, plays cards or roulette is gambling with significant knowledge about the odds of various outcomes. Similarly, people have become comfortable with these issues when it refers to their health – if your doctor informs you that you have high bad cholesterol levels and your chances of a heart attack are significantly greater than average, you are surely persuaded to take steps to lower these levels. With this in mind, I share with you one way that I (and my MIT colleagues) have found quite effective in communicating the value of climate policy despite the uncertainties (MIT 2007). We call it the greenhouse gamble, a variant on the “wheel of fortune”. Figure 3 shows the probabilities of various amounts of warming from the above MIT study projected onto two wheels.

If there are no significant efforts to curb greenhouse gas emissions, the “no policy” wheel shows about one chance in four of greater than 3°C warming between now and 2100. Most climate scientists regard such an amount of warming as very dangerous. The “policy” wheel, that keeps greenhouse gas levels below twice their pre-industrial levels, indicates that the odds of exceeding 3°C warming drop dramatically. Imagine that you are playing the greenhouse gamble and have \$100,000 in winnings. To end the game and collect your money you must finally spin one of these two wheels. If you land on

any of the sectors of the wheel corresponding to warming exceeding 3°C you lose, say, \$10,000 of your winnings. You can spin the “no policy” wheel for free, but must pay to spin the “policy” wheel with its much lower odds of losing your money. The \$10,000 in this game represents an (arbitrary) penalty for the damages caused by dangerous climate change and the money you are willing to give up represents the cost of mitigating policy. The key question is: how much of your \$100,000 would you be willing to give up in order to spin the “policy” wheel?

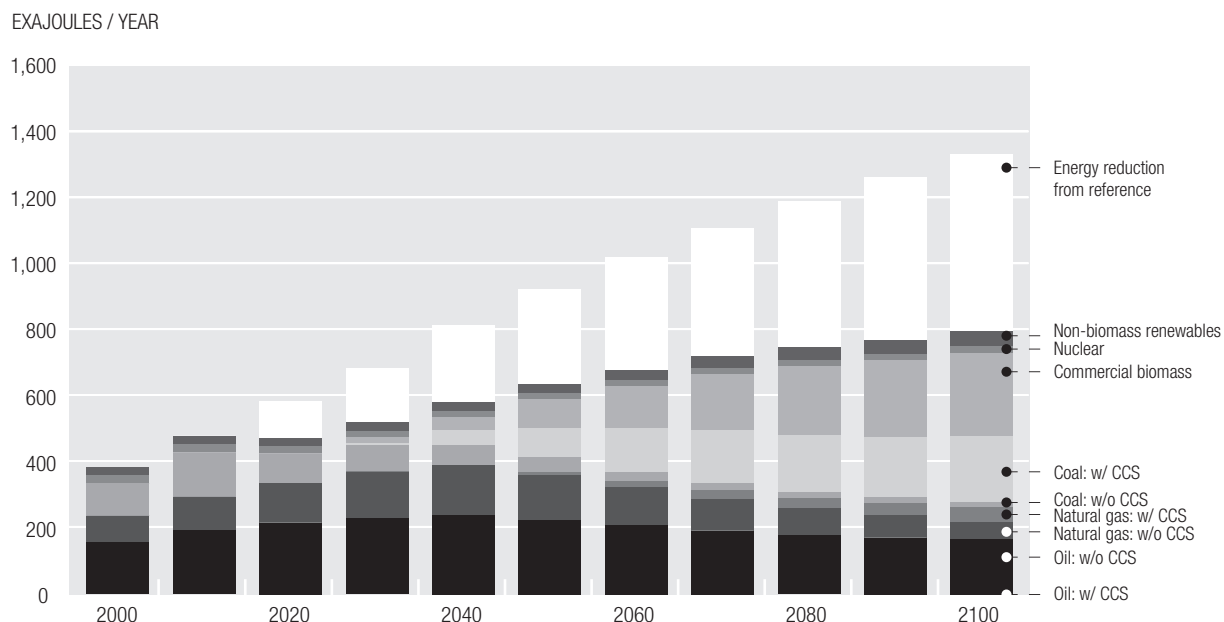
The fact that the “no policy” wheel does not rule out the possibility of very little warming (e.g. less than 1°C) is not a sound argument for inaction. The existence of some probability for small amounts of warming is countered by comparable probabilities for dangerous amounts of warming. I emphasise that the exact odds of various amounts of warming depicted in the two wheels are not as important as the qualitative differences between them. Indeed, more recent research at MIT (Forest et al. 2006), and other work reported in the *IPCC Fourth Assessment* (Solomon et al. 2007), implies that the probabilities of large amounts of warming may be underestimated in these wheels.

What are the risks?

In the MIT “no-policy” case, the projected warming of the Arctic and Antarctic regions is about 2.5 and 1.8 times greater, respectively, than the global average warming quoted above (this uneven warming is evident from past observations, is well understood on physical

FIGURE 4
GLOBAL PRIMARY ENERGY CONSUMPTION BY FUEL FOR GREENHOUSE GAS STABILISATION'

Global Primary Energy consumption by fuel for a policy achieving stabilisation of greenhouse gases with CO₂ held to 550 ppm CO₂ (the all-gas increase in radiative forcing above pre-industrial limited to 4.7 W/m²) as calculated in the MIT IGSM (Sokolov et al. 2005) and presented in the Climate Change Science Program study (US CCSP 2007). Nuclear growth is restricted. CCS refers to carbon dioxide capture in power plants and geological sequestration. Energy demand reduction from the no-policy reference is achieved through increased efficiency in transportation, buildings and manufacturing.



grounds and seen in essentially all other climate model simulations). The calculated warming in the “no-policy” case is also accompanied by projected sea-level rises of 0.2 to 0.84 metres due to warming (and hence expanding) oceans and melting of mountain glaciers. A review of forecasts from a large number of other more comprehensive climate models carried out in the *IPCC Fourth Assessment* reveals qualitatively similar asymmetry in warming, and sea level rises of 0.18 to 0.59 metres (1990–2095) depending on the emission scenario used. Because they do not include the possibility of significant melting of the Greenland and Antarctic ice sheets, these sea-level rise estimates are conservative.

The great vulnerability of coastal and polar regions to global warming is very evident from the above conclusions and many others in the literature. Together, the Greenland and West Antarctic ice sheets contain the equivalent of 12 meters of sea level rise. In this respect, it is important to note that the *IPCC Fourth Assessment* (Solomon et al. 2007) concluded “the last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 meters of sea level rise.” Arctic tundra and frozen soils (which contain the equivalent of about 80 years of current fossil fuel carbon emissions that could be released on melting (Sabine et al. 2004)), and Arctic summer sea ice cover (i.e. already decreasing and is a polar cooling mechanism because it

reflects sunlight to space (Solomon et al. 2007)), are also very vulnerable in a warming world.

Increases in heat waves and high latitude precipitation are among many other expected consequences of global warming. Also needing consideration are some expected benefits of warming; for example, increases in the length of the growing season in cold regions. Recent research has suggested a significant connection between increasing sea surface temperatures and the duration and wind speeds in typhoons and hurricanes (Emanuel 2005). If further research confirms this the increased storm damages, which typically rise as the cube of the wind speed, could be very costly. There are many other thresholds and vulnerabilities in the climate system which, added to those discussed above, make it prudent to attempt to limit the amount of future global warming by lowering greenhouse gas emissions (Rial et al. 2004).

Technological pathways

In order to attain stabilisation of atmospheric greenhouse gases, with CO₂ held to a level of 550 ppm, a significant shift in energy production towards low-carbon and zero-carbon emitting technologies must occur, as well as a decrease in energy demand through gains in efficiency of energy use. The exact technology mix that evolves depends on very uncertain assumptions about the future availability of individual technologies and their costs and

public acceptability. Typical projections using the IGSM with no explicit climate policy show global primary energy use rising from about 400 exajoules per year (13 terawatts) currently to 1350 exajoules per year (38 terawatts) in 2100. Oil, coal and gas provide about 87 per cent of present-day energy.

An example of a projection to 2100 using the IGSM with a policy that attains the needed stabilisation while assuming that nuclear is restricted (due to concerns about safety, radioactive waste disposal and nuclear proliferation) is shown in Figure 4, drawn from a US federal study of stabilisation scenarios (US CCSP 2007). Compared to the current-day energy mix, coal in conventional electric power plants is displaced by coal with CO₂ capture and storage (sequestration) in deep geological reservoirs (especially saline aquifers). The demand for low CO₂-emitting liquid fuels for transportation leads to a very large, renewable bio-fuels industry (especially cellulosic ethanol and bio-diesel) as the use of oil for this purpose steadily decreases in the last half of the 21st century. Allowing more nuclear growth (not shown) cuts back on the use of coal, with CO₂ capture and sequestration, as the primary source of electric power. While non-biomass renewable energy sources (wind, solar, hydro) approximately double over the depicted time period, they do not attain the scales needed to contribute very large amounts to the global energy supply. The most dramatic contribution to attaining atmospheric greenhouse gas stabilisation is made by relatively low-cost gains in energy efficiency in transportation, manufacturing and buildings that drive down projected energy demand in 2100 by about 550 exajoules per year (18 terawatts). The value of an exercise like that depicted in Figure 4 is not that the results represent an accurate forecast. Rather, its value lies in illuminating the importance of carefully considering the required large scales of the dominant low-emission energy technologies, and their assumed availability, relative cost and public acceptability.

Policy costs

A wide variety of alternative potential policies exist that can be applied to realise greenhouse gas reductions. Market-based approaches achieve reductions by creating economic incentives for the desired action, in effect by placing a price on a unit of greenhouse gas emissions. Both emission taxes and cap-and-trade approaches can be considered market-based if proposals do not also mandate use of specific technologies or emission limits for individual entities. A tax is usually set by a governmental entity and requires specific payments for emissions and therefore provides an incentive to reduce them. A cap-and-trade system sets a cap on total emissions, creates emission permits summing to this total, and then distributes them either for free (i.e. “grandfathering”) or by auction. The system allows trading of permits among the emitting entities, thus establishing a market price for them. The revenues from the auction or tax can be used

to reduce other taxes in the economy (e.g. on labour or capital) or to fund tax credits for energy efficiency or technology research and development. Both taxes and emission permits can be applied downstream (final fuel users), upstream (fuel producers or importers) or mid-stream (fuel retailers, utilities and so on). Non-market mechanisms include technology-specific mandates (e.g. ethanol quotas, electricity portfolio standards) and efficiency standards (e.g. automobile fleet-average mileage). These mechanisms have the advantage of relative simplicity but the disadvantage that they entail, in effect, the premature choosing of winning and losing technologies, create distortions influencing the un-regulated energy sectors, and are not easily managed to achieve the needed emissions reductions, especially when compared to the cap-and-trade approach.

We urgently need to improve the accuracy of estimates of the impacts of climate change on natural and human systems in order to better calibrate the policy response.

The results from the application of the IGSM to a price-based approach adopted globally to achieve the 550 ppm CO₂ target in Figure 4 indicate world carbon prices (in year 2000 US\$) around \$75 per ton in 2020, \$245 per ton in 2050 and \$1740 per ton in 2100 (US CCSP 2007). For calibration, a \$100 per ton carbon price (or equivalently a \$27 per ton CO₂ price) applied in 2005 would lead to about a 15 per cent increase in the cost of wellhead natural gas, a 20 per cent increase in the cost of crude oil, and a 170 per cent increase in the price of utility coal. These estimates do not include the significant depression of producer prices due to the imposed carbon price, which would lower the percentage cost increase seen by consumers. The above carbon prices for the 550 ppm target correspond to reductions in gross world product (GWP) in the IGSM of about 2 per cent in 2050 and 7 per cent in 2100. These burdens are bearable, and other models that presume greater availability of low-emission or zero-emission technologies project significantly lower carbon prices and hence lower GWP reductions.

Conclusion

It is important to note that it matters very little where the long-lived greenhouse gases are emitted and that, according to our emissions projections (Webster et al. 2003; Sokolov et al. 2003), very substantial emissions reductions will ultimately require participation by all nations, not just the currently rich countries. Another important point is that the predicted warming in 2100 is

sensitive to the total emissions up to that time, but relatively insensitive to the temporal pattern of the emissions. Higher emissions in the near term can therefore potentially be offset by lower emissions later on.

We urgently need to improve the accuracy of estimates of the impacts of climate change on natural and human systems in order to better calibrate the policy response. In this area the research is less mature, but we need to better understand and quantify these effects. Some of these effects can be potentially mitigated or avoided by adaptation; specifically impacts on human health, agriculture, forestry, water supply and quality and flood-prone coastal and riverine settlements. Unfortunately, natural terrestrial, coastal, and oceanic ecosystems may not be able to adapt. The environmental impacts of future potential renewable energy sources operating at the multi-trillion watt scales needed for them to make a significant contribution to future total energy demand (e.g. billions of acres of land for bio-fuels, many millions of wind turbines) also need to be addressed. Quantitative studies of all of these issues will require significant improvement in the accuracy of climate predictions at the national and regional level. Accurate quantification of impacts is essential to define the appropriate balance between the costs of policies to lower greenhouse gas emissions and the impacts avoided by these policies.

I close by emphasising that we cannot wait for perfection in either climate forecasts or impact assessments before taking action. The severity of the risk is obvious from the fact that scientists cannot presently rule out the rapid warming forecasts. Also, the long-lived greenhouse gases emitted today will last for decades to centuries in the atmosphere. Added to this is the multi-decade period needed to change the global infrastructure for energy and agricultural production and utilisation without serious economic impacts.

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reviewing Lessons Stern

Lessons for Australia

4

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Summary

Although the Stern Review is sometimes cited as an authoritative account of the economics of climate change, it is more of an advocacy paper for aggressive short-term abatement than a balanced economic analysis. The Stern Review makes four assumptions to support capping greenhouse gas concentrations at 550 parts per million (ppm). First, it examines the cost of its preferred policy only against doing nothing at all. It does not consider more efficient policy alternatives. Second, it chooses a very low discount rate to try to hide the long lag between mitigation costs and climate benefits. Third, it exaggerates climate damages, looking at only the worst-case scenarios. Fourth, it takes a very optimistic view of the cost of abatement, assuming a rapid rate of prolonged technical change will make mitigation inexpensive. Consequently, the Stern Review is not a balanced assessment of the costs and benefits of climate change and the recommended policy of aggressive near-term abatement is most likely a terrible waste of resources. Australia's Garnaut Climate Change Review should be careful to avoid these same biases.



PHOTO: AAP

Introduction

The debate about climate change has long been heated. Some industry advocates have argued that regulations would bankrupt the economy, while opposing environmental advocates talk about worst-case scenarios. While these views capture a small sliver of the truth, they by and large distort the complex reality of climate policy. Against the background of this rhetoric the announcement by Her Majesty's Treasury that it was undertaking an economic analysis of climate change raised high expectations. At last an esteemed public agency was going to capture the important insights of economics and bring them to bear on greenhouse policy. The agency would carefully weigh the costs of abatement against the damages of global warming. It would understand the important role that energy- and land-use play in the economy and yet at the same time recognise the global importance of a stable climate. The agency would also understand the important role that time plays when costs far precede benefits. Finally, the agency would strike a moderate course in the best interest of society.

Unfortunately the *Stern Review on the Economics of Climate Change* (Stern 2006) did not live up to this expectation. Laden with internal politics, the Stern Review appears to be more of an advocacy for a predetermined policy than a balanced assessment of the costs and benefits of climate change. DEFRA, the environmental agency for the United Kingdom, was already leaning towards a policy that would stabilise concentrations of greenhouse gases in the atmosphere to 550 ppm (Hadley 2005). This would limit warming to just 2.0°C above current temperatures, a level these scientists felt would avoid harmful climate impacts (Hadley 2005). The problem facing the Stern Review was how to conduct an economic analysis that would support such a policy choice. By contrast, most economic studies done to date suggest that a much higher target is more efficient (e.g. Nordhaus 1991; Manne et al. 1995; Pearce et al. 1996; Plambeck et al. 1997; Nordhaus and Boyer 2000; Tol 2002). The additional trillions of dollars of abatement costs needed to reach the 550 ppm target would far exceed the tens of billions of dollars of reduced damages

associated with a 650 ppm target. Economic analyses suggested that more moderate policies allowing stabilisation at higher levels of greenhouse gases would be better for society. They would cost far less and would lead to only small increases in climate damages.

In order to advocate for this much stricter target the Stern Review made four sets of assumptions. First, it did not compare its preferred policy to the efficient policies promoted in the economics literature, so it was not apparent how inefficient its policy was. Second, it assumed that the discount rate was very low, so that it would appear worthwhile to spend money today to avoid damages in the very distant future. Third, it presented the worst possible case for climate damages. Consequently, it overestimated the benefits of its policy. Finally, it chose the most optimistic estimate of abatement costs and thus underestimated the true cost of its policy. Relying on these four assumptions, it made the best economic case possible for aggressive near-term abatement. However, this is clearly a case of advocacy and not balanced assessment.

The economics

It is important to begin with the basics of climate change. The contribution of greenhouse gases comes largely from burning fossil fuels and land-clearing. It takes a long time for nature to process these gases and remove them, so they accumulate in the atmosphere (IPCC 2007). That is, the amount we emit each year exceeds what nature can remove, so there is a bigger stock of these gases in the atmosphere every year. The gases warm the planet by preventing heat from escaping (IPCC 2007). There is a lag of about 30 years between emission and final temperature changes because the oceans are the long-term transport mechanism and it takes a long time to heat them up (IPCC 2007). Several factors are expected to change in response to the warming, including increased precipitation and sea-level rise. Ecosystems will likely shift poleward because of warming. Other factors may also change, including precipitation patterns, hurricanes and climate variability, but less is known about these changes (IPCC 2007).

The basic economics of climate change is that society can reduce emissions by spending resources on abatement. Reducing emissions will eventually lead to less warming in the future. If warming causes future damages the reduction in emissions will lead to a reduction in damages. What society must weigh up is how much to spend now to avoid damages well into the future. The objective is to determine an abatement path that minimises the present value of the sum of abatement costs plus climate damages (Nordhaus 1991). The present value is the value today of consequences that occur in the future. Future effects are discounted back using a discount rate (a price of time). For most decisions by society, the discount rate is the interest rate. Taking future values and bringing them back to the present is a matter of convenience, since we know what current

values are. However, the analysis could have just as easily calculated a future value taking current costs into the future by assuming that current expenditures grow at the discount rate into the future. The important point is that the discount rate adjusts for time so that impacts occurring in different time periods can be compared. This is important to the greenhouse debate because the benefits of abatement cost expenditures (reduced future damages) are long delayed, making them less valuable.

Because greenhouse gases remain in the atmosphere for a long time, a ton of emissions, after a long lag, causes a stream of damages far into the future. The efficient economic solution is to abate until the marginal cost of abatement is equal to the present value of this stream of marginal damages. By equating the marginal cost of abatement to the stream of future marginal damages, society can determine the path that minimises the present value of the sum of abatement costs and climate damages. Because marginal damages depend on the stock of pollution, the efficient path is not a steady state but rather a dynamic policy. As the stock grows, the marginal damage increases. So the efficient path calls for more abatement over time (higher marginal costs of abatement). The efficient abatement path starts moderately and becomes more aggressive each decade (Nordhaus 1991).

In applying these basic principles to climate change, the literature has come to surprising agreement about what the efficient path should look like. The efficient abatement policy should begin with a universal but moderate reduction of greenhouse gases. The near-term marginal cost or price of greenhouse gases should be around US\$2 to US\$8 per ton of CO₂ (Nordhaus 1991; Manne et al. 1995; Pearce et al. 1996; Plambeck et al. 1997; Nordhaus and Boyer 2000). Of course, some authors, using high climate damages and low discount rates, advocate higher values (Cline 1992; Titus 1992). But more recent studies of the impacts of climate change suggest that, with adaptation, climate damages are smaller than previously thought (Mendelsohn et al. 2000; Mendelsohn and Williams 2004; Mendelsohn 2005; Mendelsohn et al. 2006; Tol 2002). These more recent damages estimates suggest near-term values at the low end of the range.

In the future, however, all authors agree that the marginal cost of abatement should increase. These much higher future abatement levels would eventually stabilise the concentrations of greenhouse gases in the atmosphere. However, most of the economic literature implies that the efficient stabilisation concentration would be much higher than 550 ppm. This is partly because raising the target by 125 ppm would reduce the present value of the abatement cost by half (Nordhaus 2007). It is also due, however, to the evidence that raising concentrations from 550 ppm to 675 ppm is not expected to increase the present value of climate damages very significantly (Mendelsohn et al. 2000; Mendelsohn and Williams 2004; Mendelsohn et al. 2006; Tol 2002).

Society is made better off by relaxing this constraint and allowing more near-term emissions. Whether 650 ppm is the most efficient target or 750 ppm is not clear; the economics literature has moved towards these higher values.

Comparing alternatives

The Stern Review advocates that society should begin to rapidly reduce greenhouse gas emissions in order to stabilise concentrations at 550 ppm. The economics literature, in general, promotes less ambitious targets. If the Stern Review was a balanced assessment, it would have compared its preferred alternative with the recommendations of the economics literature. The Stern Review never makes this direct comparison between its 550 ppm stabilisation program and the 650–750 ppm stabilisation programs in the economics literature. Instead it compares the mitigation cost of the 550 ppm stabilisation program to the climate damages of doing nothing at all for 200 years. By presenting this red herring of no policy, the Stern Review attempts to make the near-term aggressive policy look good. However, the comparison carefully ignores even better choices.

It is difficult to defend the near-term aggressive abatement policies of the Stern Review against better alternatives. A direct comparison of the 550 ppm target to the 650 ppm or 750 ppm targets reveals that it is too costly, given the small gain in climate protection that it offers. The 550 ppm target requires that society begin spending hundreds of billions of dollars per year on abatement immediately. The higher stabilisation programs, in contrast, give society more time. Abatement can start modestly and then ramp up in future decades. This not only postpones the abatement costs (lowering the present value), but it also allows technological improvements to occur before society invests heavily in mitigation programs. The difference between the 550 ppm and 650 ppm programs is likely to amount to trillions of dollars of mitigation costs. In contrast, the additional climate damages caused by allowing concentrations to rise from 550 ppm to 650 ppm are likely to be relatively small (Mendelsohn et al. 2000; Mendelsohn et al. 2006; Mendelsohn and Williams 2004; Tol 2002). The additional climate damage is likely to be only one-tenth of the mitigation costs. The additional abatement cost of the 550 ppm program is not worth the reduction in climate damages.

The discount rate

The Stern Review assumes that the discount rate should be very low (1.7 per cent). The discount rate is the “price of time”. It measures the value of a dollar of consumption in one time period versus a future one. In general, the discount rate should be equal to the market interest rate. People can choose to save or borrow using the market rate of interest. For example, you can borrow money from a bank to buy a car or house, given the price

of a loan. Or you can invest in your retirement by buying bonds or stocks that earn a certain rate of interest. The Stern Review rejects using this long-term market interest rate (4–6 per cent), allegedly because of ethical concerns for the future. The Review is concerned that the market interest rate does not give future consequences enough weight (or gives current consequences too much weight).

The Stern Review claims that using the market interest rate would unfairly burden future generations. It is important to examine this assumption carefully because it is inconsistent with society’s treatment of time in every other decision. Although the inherent excuse for the low discount rate is equity between generations, the Stern Review acknowledges that per capita income will grow at 1.6 per cent (in fact, if per capita income growth was lower, the Review would have advocated an even lower discount rate). That means future generations will be richer than the current one. Nonetheless, the Review thinks it is appropriate that the current generation reduce its standard of living to increase the welfare of the next generation. However, the Review fails to see the long-term implications of using a low discount rate. Not only must the current generation sacrifice for future generations, but each future generation must sacrifice for generations to come. Every generation is consequently made worse off by forcing the discount rate to be less than the market rate of interest. The only equitable quality of this artificially low discount rate is that every generation is made equally worse-off. Of course, making every generation worse off is not a desirable strategy.

In every other decision of whether to save or spend, society uses the market rate of interest. But in this climate decision the Stern Review advocates using a much lower rate. This is important in climate policy because the benefits of mitigation expenditures are delayed for many decades. If the delay is ignored, the benefits appear to be larger. But if the delay is recognised the benefits of mitigation become quite small relative to the costs. Using a low discount rate for climate policy, but not for every other available investment for society, distorts the cost benefit analysis in favour of mitigation.

Benefit assessment

The Stern Review gives the impression that 550 ppm is the highest acceptable level of greenhouse gases. Sir Stern argues that higher concentrations would exceed a tipping point and lead to dangerously high levels of damages. Although Sir Stern is entitled to his opinion, there is no empirical support of a tipping point, much less that it is 550 ppm. To the contrary, the empirical literature reveals that the temperature response function of vulnerable sectors is hill-shaped. Countries that happen to be in relatively warm locations will immediately be hurt by warming as it pushes them down the hill. Countries at the top of the hill will hardly be affected by warming as the response function is flat near the top. Countries that are

currently in cool locations will benefit from warming. Warming will consequently produce both benefits and damages across the globe. At first, benefits will be at least as large as damages, and so there will be no net global impact. Only when concentrations rise above 550 ppm will damages first become larger than benefits. Greenhouse gases will not be net harmful until after concentrations exceed 550 ppm. As they accumulate in the atmosphere they will steadily become more harmful. Consequently,

Countries near the equator are likely to suffer the bulk of climate damages, especially damages to agriculture. Polar countries will largely gain from warming, and temperate countries will hardly be affected.

there is no tipping point for greenhouse gases.

If there is no tipping point it becomes essential to measure the benefits of mitigation. In this case, the benefits of mitigation are the climate damages avoided. The third set of assumptions made by the Stern Review concerns the measurement of climate damages. The Stern Review appears to take the worst possible estimate of every single climate impact and present it as though it is a central estimate. For example, it assumes that market impacts (damages to agriculture, forestry, energy, water and coasts) are equal to 5 per cent of GDP annually. Market damages are currently imperceptible. There are few analyses that argue market damages can reach 5 per cent of GDP by 2100 (Nordhaus 2006a is an exception). Most early studies of climate impacts estimated that market damages would go from zero to only about 1 per cent of GDP by 2100 (Pearce et al. 1996). More recent studies that include adaptation predict that market damages are likely to range from 0.1 to 0.5 per cent of GDP by 2100 (Mendelsohn et al. 2000; Mendelsohn et al. 2006; Mendelsohn and Williams 2004; Tol 2002). The Stern Review has overestimated the expected present value of market damages by between 15 to 60 times.

These impacts will not be distributed evenly across the planet. Countries near the equator are likely to suffer the bulk of climate damages, especially damages to agriculture. Polar countries will largely gain from warming, and temperate countries will hardly be affected. Large countries, such as Australia, may see different effects in different regions. The northern and western regions, for example, are likely to be damaged by warming, but the southeastern coast may be relatively unaffected.

Cost projections

The Stern Review also estimates that non-market damages are equal to 5 per cent of GDP annually. Non-market damages include the loss of species, health effects from air pollution, heat waves and vector-borne diseases, and the reduction of some ecosystems. Although all of these effects are real, they have not been quantified in monetary terms. There is simply no evidence that the magnitude of these effects is even as large as the market effects. Further, many of these effects can be reduced with adaptation programs. The consequences of vector-borne diseases can be moderated with public health and medicinal programs. Heat-wave impacts can be reduced with temporary public shelter programs. Endangered species and ecosystems can be protected with enhanced conservation programs. The cost of these adaptation efforts are relatively small compared to the size of expected market damages. It is likely that the non-market damages assumed in the Stern Review are wildly overstated.

The Stern Review also argues that hurricanes will eventually cause damages equal to 5 per cent of GDP because of global warming. Hurricanes currently cause damages equal to about 0.7 per cent of GDP (Nordhaus 2006b). It is very possible that hurricanes will have more power in the future from warmer oceans and therefore cause more damage (Nordhaus 2006b; IPCC 2007). However, it is not clear how much more damage hurricanes will cause. Based largely on the huge losses associated with Hurricane Katrina, the Stern Review assumes that the aggregate damages from hurricanes will grow exponentially over time. The Stern Review claims that by 2200 hurricane damages will be equal to \$95 trillion a year. Although it is clear that more powerful storms cause a lot more damage, there is no scientific evidence to support Stern's damage projection. For example, the projection does not fit the years following Hurricane Katrina, where instead of damages continuing to increase, they have actually fallen.

The Stern Review also argues that climate damages affecting poor people should be given more weight. Because the bulk of climate damages are likely to be borne by poor, low-latitude rural inhabitants (Mendelsohn et al. 2006), equity weights would increase climate damages substantially. Equity weights thus imply more abatement. However, if countries that emit greenhouse gases are concerned about impacts to poor victims, they should provide compensation to the victims, not equity weighting. The poor would be much better off with direct compensation rather than with increased abatement. Spending compensation funds on equity weighting, and therefore abatement, is making poor people worse off – allegedly in their name.

Despite these many complaints about how the Stern Review measured climate damages, there are two positive features about the Stern Review that distinguish it from earlier studies. First, the Stern Review looks to 2200, whereas the rest of the literature goes no further than

2100. Although 2100 looked pretty distant to the first climate studies that began in 1990, it is now almost 20 years later and extending the analysis further into the future makes sense. Of course, far future events are not likely to have a large impact on current policies (unless your discount rate is too low), but they may be very informative about how the dynamic policies will unfold over the long run. For example, looking to 2200 may identify a stabilisation policy that is not evident by 2100. Of course, the further into the future one looks, the more uncertain everything is.

A second redeeming feature of the Review is that it highlights uncertainty. The Stern Review went to great lengths to explore the uncertainty surrounding climate impacts by 2200 if there were no control policies. They conducted an analysis of both the scientific and economic uncertainties. Of course, this is in some ways a purely academic exercise, since it does not make sense for society to do nothing about climate change for 200 years. However, the exercise does reveal that far future effects could take on a wide range of values if emissions are left unchecked.

Abatement costs

The final important set of assumptions that the Stern Review makes concerns abatement costs. One of the most pressing problems with a target of 550 ppm is that it calls for immediate and costly abatement. There is little time to reduce emissions if concentrations are to be stabilised at a level just a little higher than current values. The stated target of 550 ppm requires that 2050 carbon dioxide emissions must be 25 per cent below today's emission levels. Greenhouse gas emissions would be cut gradually at first and then sharply by 2050. However, the Review assumes that the global economy continues to grow at 1.9 per cent. Consequently, without abatement greenhouse gas emissions will rise to 56 gigatons (GT) of CO₂ (from the current rate of 23 GT) by 2050 and to 96 GT by 2100. Emissions in 2050 will consequently have to fall from 56 to 16 GT to meet the targeted 25 per cent reduction from the current level. By 2050 there must be a 70 per cent reduction in potential emissions. After 2050 emissions will have to stay at 16 GT despite the growing economy.

Pacala and Socolow (2004) claim that such deep cuts in emissions are technologically possible through a combination of energy technologies and non-carbon emissions reductions. Although the Review does not commit itself to a specific program, it relies heavily on their example of using a broad set of approaches. The reductions in emissions in the energy sector would be achieved by adding renewable energy sources (wind, solar, and biofuels), nuclear power, carbon recapture (from fossil fuel burning), and increased energy efficiency. The Review claims that reductions in non-energy sectors would be met through a combination of eliminating deforestation, encouraging reforestation, burning

waste for energy in place of fossil fuels, and reducing agricultural emissions.

The Review assumes the most optimistic estimates of the cost of these programs. First, it assumes that the mitigation will be universal, with every country in the world participating. Second, it assumes that the mitigation programs will be efficient, equating marginal cost across all countries and all sectors of the economy. Third, it assumes that the programs will be efficiently designed over time, although the discount rate used in the Review will make that impossible. That is, the assumed low discount rate will push too much abatement too soon and will substantially raise the present value of the cost of the program.

The Review is also optimistic about each of the abatement technologies. For example, carbon recapture (removing carbon dioxide from smokestacks) is not yet a proven technology. It is not clear what it will cost in practice. It may not even be effective. There may be no way to store the vast quantities of carbon dioxide removed from smokestacks safely for long periods of time. If this stock of carbon dioxide finds its way back into the atmosphere, the abatement program will only have delayed emissions, not stopped them. Carbon recapture is currently a risky alternative.

There may be no way to store the vast quantities of carbon dioxide removed from smokestacks safely for long periods of time.

However, if carbon recapture is taken off the list of alternatives, most of the coal, tar sands and dirty oil in the world could not be extracted while still meeting the 550 ppm target. It would have to be left in the ground. The carbon regulations would make the stocks worthless. The Review does not place a value on this loss. It assumes that the price of fossil fuels will not be affected by regulations. It measures the cost of regulations as the difference between using renewable energy and fossil fuels at their current prices. By failing to value the lost fossil fuels (the fall in their price), the report grossly underestimates the cost of regulations.

With current technology, an aggressive near-term mitigation program would be expensive. The current cost for a 70 per cent reduction in carbon emissions is estimated to be about \$400/ton of CO₂ (Anderson 2006, p. 44). Multiplying this average cost by the 40 billion tons of CO₂ emissions per year would cost \$16 trillion per year. Given that global GDP in 2050 is expected to be \$110 trillion, this amounts to an energy abatement program that would cost 15 per cent of global GDP by 2050. This does not even include the additional cost associated with cutting another 10 billion tons of CO₂ in the non-energy sectors.

The Review argues that the cost of abatement would be closer to 1 per cent of GDP (\$1.1 trillion/year). It contends that technological change will drive these costs down from what they would cost today. In addition, it assumes that if people and firms are mandated to buy new abatement and energy technologies, the costs will automatically fall. By 2020 the report hypothesises that the costs of reaching the 2020 target will be only 3 per cent of GDP, and by 2050 the annual costs will be only 1 per cent of GDP. The Review has effectively assumed that the cost of abatement falls by over 5 per cent every year. Although it is reasonable to assume that there will be some rate of technology improvement, it is not clear that abatement costs can fall at this rate per year for 50 years. It is not likely that technical change can reduce the costs as fast as the Review has assumed. Using the most recent models available, the estimated present value cost of achieving the 550 ppm target is more likely to be between \$3 and \$10 trillion (Richels et al. 2007).

The Stern Review also likely underestimates the environmental impacts of alternative energy sources.

It is likely that the report has underestimated the costs of adopting many forms of abatement. For example, engineering studies (Greene and DeCicco 2000; Lovins 2007) argue that cars can be made more fuel efficient at virtually no additional cost by simply making them lighter, smaller and less powerful. However, consumers are willing to pay substantial sums for cars with more space, power and comfort. Regulations that forbid these choices would have high welfare costs, even if they had low out-of-pocket costs. The Stern Review also argues that there are substantial energy savings possible in buildings. Again it is not clear what sacrifices these savings would require of residents in terms of reduced space and comfort. It is also not clear how quickly improvements in buildings can be instituted. Given the long lifetimes of existing buildings and the high expense of retrofitting, it may take many decades before society can realise the potential energy savings in buildings.

The Stern Review also likely underestimates the environmental impacts of alternative energy sources. Burning ethanol raises ozone and particulate levels and saves little carbon. Burning municipal waste leads to high levels of particulates because the heterogeneous waste flows cannot be burned efficiently. There are few remaining sites for new hydroelectric dams that do not have serious environmental costs. Doubling the number of nuclear plants raises questions of safety and nuclear waste disposal. No new nuclear plants have been built in the United States for several decades.

There are also serious potential problems associated with using large quantities of land for renewable energy. The biofuel sector would need an additional 500 million hectares of land to make a substantial contribution to energy. However, there are only 1.2 billion hectares of cropland in the world (World Resources Institute 2005). This large increase in the demand for land for biofuels would make arable land scarce. This would cause the price of cropland to increase, increasing the price of crops. Not only would this increase the cost of the biofuel program, it also raises questions about whether the program would affect food security. There would be increased pressure to convert forest land to agriculture. This would make other components of the abatement program more expensive, such as efforts to halt deforestation and increase reforestation.

Lessons from Stern

The Australian Labor Party recently commissioned the Garnaut Climate Change Review to examine the impacts of climate change and climate change policy on Australia. What lessons should the Garnaut Review take from the Stern Review? First, it should compare plausible alternative policies so that governments can see what their choices are and what these choices imply. Presenting only one policy leaves policymakers with no perspective. Specifically, the Garnaut Review should examine stabilising greenhouse concentrations not just between 450 to 550 ppm, but also at a range of higher values. Second, the Garnaut Review should be careful to use realistic discount rates. Climate policy should be evaluated using the same criteria that Australia uses to evaluate other important public investments such as health, education and infrastructure.

Third, the Garnaut Review should not only discuss mitigation, it should also address adaptation. Helping people adapt is an important component of climate change policy. If people adapt, the damages from climate change will be a lot smaller than early analysts believed. Adaptation does not imply that mitigation is unnecessary, but it does imply that society can afford less mitigation and that it has time to implement effective mitigation policies.

Fourth, the Garnaut Review should be careful about representing uncertainty. Selecting the worst possible case or the best possible case does not serve society. Authors can talk about worst and best cases, but they must do so in the context of the expected outcome of a given policy. Distorting the facts may get a policy passed or rejected but it will never lead to good government.

Finally, the Garnaut Review should recognise that Australia has unique characteristics that should influence its climate change policy. For example, Australia has a large supply of coal which will be very vulnerable to any restric-

tions on carbon emissions. Australia, especially its northern and western parts, is already hot, which means that higher temperatures may be particularly harmful. On the other hand, southeastern Australia is temperate, which means that climate impacts may be milder in that region.

Conclusion

In summary, the Stern Review has gathered together an argument for near-term aggressive abatement. The argument hinges on using very low discount rates, overstating the damages of climate change and underestimating the abatement costs. Even with this distorted impression of the economics of climate change, the Review is careful not to compare its preferred policy to more efficient strategies. It is a very good advocacy paper for aggressive near-term abatement.

Overall, the Review is not a balanced review of the economics of climate change. It does not examine the efficient policies promoted in the economic literature. It does not present a balanced view of the costs and benefits of climate policy, underestimating costs and overestimating benefits. Furthermore, it hides the important role that time plays in climate decisions, given the long lag between mitigation expenditures and resulting climate benefits. When viewed in perspective, the Stern Review of the Economics of Climate Change becomes an exposition of why aggressive near-term abatement is poor policy. Developing a moderate abatement program will be difficult enough. However, one advantage of beginning with a moderate program is that it will be easier to start. The initial sacrifice will be small and the overwhelming feeling that at last something is being done should carry the program through.

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beyond policy 2012

Where global policy is heading after Kyoto



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Summary

The international community has sought to find a policy solution to climate change under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC). Despite the great efforts made, it has not yet been possible to find a global solution that is acceptable to all major emitters. The main reason for this is the vast differences in national circumstances, not only between developed and developing countries, but also between OECD countries. In addition, there has been a presumption that international emissions trading is the policy instrument of choice, given its acceptance as part of the Kyoto Protocol. However, trading will only be effective with proper compliance and governance regimes in place. It is clear that such regimes do not exist throughout Annex I countries, let alone more generally across the world.

At the recent APEC Leaders meeting in Sydney APEC members agreed to work constructively toward a comprehensive post-2012 agreement, but it is clear that a global regime will not be in place in the next 20 years. In the near term climate change policy will be characterised by country and regional agreements. Australia will introduce a domestic emissions trading scheme. The effectiveness of this scheme will depend on its design features, but ultimately the reversal of the growth in global greenhouse gas emissions will require the adoption of new energy technology on an unprecedented scale. This will require not only a policy shift in developed countries, but participation by developing countries in a way that accommodates their aspirations for economic growth and addresses concerns about energy security and local pollution.

Introduction

Global greenhouse gas emissions are expected to grow substantially over the coming decades, along with the continued reliance on fossil fuels. As scientific understanding of the climate change problem has improved, it has become increasingly clear that substantial emissions reductions will be required to avoid further climate change.

The level of difficulty of the task is clearly illustrated by reference to Table 1, which was compiled by the Intergovernmental Panel on Climate Change (IPCC 2007, p.15). Inspection of the table shows that in order to limit the global mean temperature increase (compared to pre-industrial levels) to between 2.0° and 2.4°C in future, global carbon dioxide emissions would probably have to peak between the years 2000 and 2015 and then decline steeply thereafter. There is no evidence that emissions are on such a trajectory – in fact, global emissions are continuing to grow strongly. It is already more likely that, subject to the science, the present global emissions pathway will result in at least 3°C warming.

The nature of the emission reductions being discussed in some parts of the world go well beyond mitigation efforts at the margin, involving major energy system transitions and significant economic costs. To achieve this in a way that does not stifle economic development, particularly in the developing world, is a challenge of unprecedented proportions. Technological change on a massive scale will be necessary. And this needs to be backed up with institutional frameworks and financial incentives to bring the technologies into play. The proposition is often advanced that the only thing required to solve the global climate problem is to introduce a price on carbon. Proponents of this view argue that once the price is introduced the market will do the rest. But is this an over-simplification?

The international community has sought to find a policy solution to climate change under the auspices of the UNFCCC. However, despite the great efforts made to date, the international community has not found a global solution acceptable to all major emitters. The main reason for this is the vast differences in national circumstances, not only between developed and developing countries, but between OECD countries themselves. In addition, there has been a presumption that international emissions trading is the preferred policy instrument, given its acceptance as part of the Kyoto Protocol. However, trading will only be effective with proper compliance and governance regimes in place. It is clear that such regimes do not exist throughout Annex I countries, let alone more generally across the world.

The political realities of the climate issue are such that a coordinated, global, market-based approach to greenhouse policy is unlikely to involve key developing countries such as China and India for decades to come. As such, a more regionalised, piecemeal approach to climate policy is likely to evolve in the face of increasing public pressure. The early

stages of this have already been seen emerging by way of the EU emissions trading scheme and various US state-based targets and proposed initiatives, as well as the agreement on both sides of federal politics that Australia will introduce a domestic emissions trading scheme before the end of the first Kyoto commitment period. In the face of this evolving political reality, reversing Australia's decision not to ratify the Kyoto Protocol would seem an error of judgement and run counter to Australia's economic interests. Environmentally speaking, Australia's ratification of Kyoto would have, at best, nil effect on global emissions and at worst, result in emissions leakage to developing countries that could exacerbate climate change.

Institutions and conventions

There are a wide range of institutions and processes associated with attempts to deal with the climate change problem at the international level. At the broadest level, the Millennium Development Goals, the World Summit on Sustainable Development and the Johannesburg Plan for Implementation and the United Nations Commission on Sustainable Development have links to the climate change agenda in the context of energy supply and poverty reduction. Other international institutions, including the UN General Assembly, the OECD and the International Energy Agency, the World Bank and its regional affiliates, and the G8 Dialogue on Climate Change are important in providing support for both policy development and implementation.

However, the key international agreements in the climate change context are the UNFCCC and its Kyoto Protocol. At the regional level, discussions under the auspices of agreements such as the Asia-Pacific Partnership on Clean Development and Climate (AP6) and more recently, APEC, are also increasingly important.

The UNFCCC

The United Nations Framework Convention on Climate Change entered into force on 21 March 1994 and provides the overarching framework for intergovernmental efforts to deal with climate change. The UNFCCC has been ratified almost universally, with a membership of 189 countries, including the European Economic Community (EEC).

The ultimate objective of the Convention and its subsidiary instruments is the stabilisation of greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, Art. 2). Key principles (Art.3) under the Convention include: i) intergenerational equity; ii) consideration of mitigation and adaptation costs for developing countries; iii) the precautionary principle, which, tempered by cost-effectiveness, should be the basis for action; iv) sustainable development, recognising that

TABLE 1

CHARACTERISTICS OF POST-TAR (THIRD ASSESSMENT REVIEW) STABILISATION SCENARIOS^a

CATEGORY	RADIATIVE FORCING (W/M ²)	CO ₂ CONCENTRATION ^b (PPM)	CO ₂ -EQ CONCENTRATION ^c (PPM)	GLOBAL MEAN TEMPERATURE INCREASE ABOVE PRE-INDUSTRIAL EQUILIBRIUM USING "BEST ESTIMATE" CLIMATE SENSITIVITY ^{d,c} (°C)	PEAKING YEAR FOR CO ₂ EMISSIONS ^d	CHANGE IN GLOBAL CO ₂ EMISSIONS IN 2050 (% OF 2000 EMISSIONS) ^d	NO OF ASSESSED SCENARIOS
I	2.5–3.0	350–400	445–490	2.0–2.4	2000–2015	–85 to –50	6
II	3.0–3.5	400–440	490–535	2.4–2.8	2000–2020	–60 to –30	18
III	3.5–4.0	440–485	535–590	2.8–3.2	2010–2030	–30 to +5	21
IV	4.0–5.0	485–570	590–710	3.2–4.0	2020–2060	+10 to +60	118
V	5.0–6.0	570–660	710–855	4.0–4.9	2050–2080	+25 to +85	9
VI	6.0–7.5	660–790	855–1130	4.9–6.1	2060–2090	+90 to +140	5
						Total	177

^a The understanding of the climate system response to radiative forcing, as well as feedbacks, is assessed in detail in the AR4 WGI Report. Feedbacks between the carbon cycle and climate change affect the required mitigation for a particular stabilisation level of atmospheric carbon dioxide concentration. These feedbacks are expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms. Therefore, the emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated.

^b The best estimate of climate sensitivity is 3°C [WGI SPM].

^c Note that global mean temperature at equilibrium is different from expected global mean temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150.

^d Ranges correspond to the 15th and 85th percentile of the post-TAR scenario distribution. CO₂ emissions are shown so multi-gas scenarios can be compared with CO₂-only scenarios.

SOURCE: IPCC (2007, P.15).

economic development is necessary to enable mitigation; and, v) promotion of open international economic systems and repudiation of unjustifiable restrictions on international trade, including on measures taken to combat climate change either unilaterally or otherwise.

The Convention clearly distinguishes between and establishes distinctly different commitments for developed country parties (those included in Annex I of the Convention) and developing country parties. For the purposes of the Convention there are many countries included in the “developing” country grouping that have per person incomes well in excess of many countries included in Annex I. The first anomaly in this respect is that South Korea and Mexico (both members of the OECD) are not listed in Annex I and therefore, under the Kyoto Protocol, were not allocated emissions reduction targets. In addition, for the purposes of the Convention, countries such as Singapore are considered to be “developing”.

Article 4 of the Convention establishes “common but differentiated responsibilities” for parties. Parties included in Annex I are required to “adopt national policies and take corresponding measures on the mitigation of climate

change ...” (Article 4.2a). Actions of Annex I parties are reviewed periodically as required by Article 4.2b. Articles 4.3, 4.4 and 4.5 commit developed country parties to provide funding, technology and know-how to assist developing country parties to meet their commitments under the Convention and in particular to adapt to climate change.

The effect of this division between the developed and developing country parties that is enshrined in the Convention has led to legal and political blockages to the negotiations over possible future commitments to reduce emissions by countries in the “developing” country grouping. In passing, it is worth noting that the 2007 APEC Leaders Declaration on Climate Change reflects the language of the Convention in its observation that, “The future international climate arrangement needs to reflect differences in economic and social conditions among economies and be consistent with our common but differentiated responsibilities and respective capabilities.”

The Kyoto Protocol

The Kyoto Protocol entered into force on 16 February 2005 and has been ratified to date by 169 countries and the EEC. Parties to the Convention that are not parties to the Protocol (such as Australia and the United States) are able to participate in meetings of the parties as observers (Article 13).

The Protocol builds on the UNFCCC by establishing legally binding targets and timetables for the reduction of greenhouse gas emissions by countries listed in Annex B. Annex B to the Protocol is effectively those countries listed in Annex I to the Convention less Turkey (some countries' names changed between the agreement of the Convention and the Protocol as a consequence of the reorganisation in Eastern Europe). As noted above, the specific listing of countries in Annex I and Annex B means that not all industrial countries have emissions reduction targets under the Protocol.

The structure of the Convention and the provisions of the Protocol make it difficult for developing country parties to take on emission reduction targets that are formally recognised under the Convention, even if they wish to do so. For example, taking into consideration the wording of Article 10 of the Protocol, the G77 and China rejected outright the voluntary emissions reduction target offered by Argentina prior to COP4.

Article 3.9 specifies that consideration of emission reduction commitments for parties included in Annex I for the second and subsequent commitment period shall be initiated at least seven years before the end of the first commitment period (2008–2012). In accordance with that provision CMP1 (in 2005) began the process by establishing the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG).

Success and failure

Reflecting international concern about the possible effects of climate change, the great majority of national governments are parties to the UNFCCC. The Kyoto Protocol to the Convention is the most significant outcome of the international negotiations on climate change response policy so far.

As a result of the Convention and the Kyoto Protocol, international awareness of global climate change has been greatly heightened over the past decade. The Convention has provided a forum for exchange of information and ideas. A range of non-binding actions have been promoted and techniques for measuring and reporting emissions have been developed.

However, 13 years after 155 countries originally signed the Convention, and thousands of person-years of negotiating effort later, the plain facts are that the Protocol will not curb global greenhouse gas emissions or move anywhere close to stabilisation of atmospheric concentra-

tions of greenhouse gases in the atmosphere. In particular, the repudiation of the Protocol in March 2001 by the US, currently the single largest emitter of greenhouse gases in the world, significantly reduced the potential emissions reductions the Protocol could achieve. However, the policy framework has several other significant shortcomings as outlined by Bodansky (2001):

- The Protocol has an elaborate architecture, meaning it requires substantial institutional support to ensure that parties meet their targets.
- There are a very large number of players in any UN negotiation that have a diverse range of interests and often conflicting agendas. Progress is therefore cumbersome and slow as a result of politics and difficult logistics.
- The Kyoto Protocol does not involve a mutual exchange of promises among parties. Rather, commitments have been made by a specific group of parties according to rules negotiated by all the parties, including those to whom group commitments do not apply. Developing countries participated fully in the negotiation process, yet were specifically absolved from taking on emission reduction commitments.
- The negotiations have often been conducted in a divisive atmosphere that has strained international relations, and is hardly conducive to progress when so much depends on collaboration.
- Article 3.1 of the Convention states that, "Parties should protect the climate system ... in accordance with their common but differentiated responsibilities and respective capabilities ... developed country Parties should take the lead ..." Developing countries have interpreted this to mean that developed countries must reduce their emissions before developing countries will take on any emission reduction commitments of their own.
- Article 4.7 states that developing country commitments "will depend on the effective implementation by developed country Parties of their commitment under the Convention related to financial resources and transfer of technology ..." Coupled with the reference in Article 3.1 to "respective capabilities", this has been used to underpin the developing countries' argument that they cannot take on mitigation unless and until developed countries provide the resources to increase their capacity to do so.
- Developing countries argue that they cannot afford to divert resources to mitigation activities as development will always be the priority. This is, of course, a reasonable argument, but enshrining this and related principles in the Convention has inevitably led to many unproductive hours of north-south debate in the negotiations. Thus, under the current framework, not only is there no emission abatement required by developing countries, but finding a way forward for their future engagement is extremely difficult.

- A significant number of countries not included in Annex B currently have per person incomes well in excess of some countries that have taken on targets under the Protocol, further undermining any sense of fairness in the Convention.
- Emissions trading will only be effective with proper compliance and governance regimes in place. It is clear that such regimes do not exist throughout Annex I countries.

In addition, it is unclear how the legally binding targets implemented under the Kyoto Protocol for Annex B countries can be enforced given that agreement on a second commitment period appears less and less likely at each subsequent Conference of Parties (COP) negotiation.

At COP11 in 2005, a process was initiated to consider future action on climate change. This discussion, known as the “Dialogue on long-term cooperative action under the Convention”, is an open and non-binding process. The discussions are “without prejudice to any future negotiations, commitments, process, framework or mandate under the Convention, to exchange experiences and analyse strategic approaches for long-term cooperative action to address climate change”. The dialogue is scheduled to conclude at COP13 in December 2007. However, it seems unlikely that the process will be a catalyst for rapid agreement on a global emissions reduction regime.

Alternative frameworks

AP6

The Asia Pacific Partnership on Clean Development and Climate (AP6) is an international, non-treaty agreement between Australia, China, India, Japan, South Korea and the US to cooperate on the development, deployment and transfer of clean technologies to promote energy security, reduce national air pollution and curb emissions, while simultaneously promoting economic growth and poverty reduction. The agreement was launched on 12 January 2006.

The objectives of the agreement are to develop, deploy and transfer existing and emerging clean technologies to meet increased energy needs and explore ways to reduce greenhouse gas emissions without hurting economies, while building human and institutional capacity to strengthen cooperative efforts and seek ways to engage the private sector.

The Partnership has established eight international working groups comprised of government and private sector representatives in the areas of: i) cleaner fossil energy; ii) renewable energy and distributed generation; iii) power generation and transmission; iv) steel; v) aluminium; vi) cement; vii) coal mining; and viii) buildings and appliances.

One advantage of the Partnership is that it provides a forum in which to engage the key developing economies of China and India, along with the US, in a dialogue on energy security and air pollution with climate change co-benefits. It also involves just six countries in negotiations rather than 189, but these six countries account for almost 50 per cent of the world’s greenhouse gas emissions, energy use, GDP, and population. As such, this small group of countries could still make a substantial contribution to averting climate change if the appropriate actions were taken.

However, the Partnership has been criticised for its lack of binding targets, with some parties labelling the agreement nothing more than a public relations ploy. Such criticisms miss the importance of engaging the large, developing country emitters outside the process that is taking place under the UNFCCC. The same point should also be made about the importance of the recent climate dialogue within APEC in this regard. It is, however, true to say that negotiations under both AP6 and APEC will need to include substantive agreements with respect to cooperation on technology R&D and transfer if emissions reductions are to be made as a result of these dialogues.

Bilateral agreements

One option that has gradually been gaining momentum for future efforts is bilateral agreements that facilitate and promote cooperation between concerned countries to achieve national interest goals that are also consistent with beneficial climate change outcomes. These agreements could cover a number of areas, including facilitating foreign direct investment in alternative or more energy efficient technology; facilitating investment flows that assist in dealing with adaptation to climate change; facilitating investment flows that generate capital structures more consistent with meeting domestic pollution reduction objectives; providing assistance in adopting economic reforms that result in reduced greenhouse gas emissions; providing capacity-building assistance to strengthen legal and regulatory environments and facilitate technology transfer and development through, for example, protection of intellectual property rights; liberalising trade flows to ensure production is taking place in regions that employ resources most efficiently; and sharing scientific and economic data and exchanges of relevant climate and technological expertise.

The European Union (EU) has already concluded separate agreements with India and China. The EU agreement with India aims to promote the development of cleaner technologies, while the agreement with China is aimed at the development of low carbon technologies.

Bilateral agreements such as these avoid the demanding global negotiating and legal framework since a large international bureaucracy is not required to enforce actions.

Negotiating effort can be focused where it brings results rather than being dissipated by side issues and obstructionism. The network of bilateral relationships that form could be multilateralised at some later date, and this might be a natural evolution if there were found to be mutual benefits, for example, an Australian agreement with the US might link into agreements between the US and China and between Australia and China.

Multilateralising such agreements should not prove a complex process. Unlike trade agreements, which can be difficult to multilateralise on account of rules of origin, for example, climate agreements would suffer no such impediment. For example, environmental standards agreements achieved under bilateral partnerships are not only legally enforceable under the WTO, but multilateralising such arrangements may actually augment economic efficiency. This is because production could be made more uniform in a market that operates under a harmonised standard than would be the case in a differentiated regulatory environment.

Potential outcomes

Historically, the EU has been an environmental leader on the issue of climate change. At the February 2007 EU Council meeting it endorsed a unilateral target of a 20 per cent reduction on 1990 levels by 2020 (Council of the European Union 2007, p.13). In addition, at the same meeting, the EU indicated that it is willing to commit to a deeper cut by 2020 (30 per cent against the 1990 level), provided that other developed countries commit to a similar target and that the economically more advanced developing countries “adequately contribute according to their responsibilities and respective capabilities” (Council of the European Union 2007, p.13).

In an announcement on 13 March 2007 the United Kingdom went beyond the EU commitment and announced its own target of a 60 per cent emissions reduction by 2050 and a 26–32 per cent reduction target by 2020 (Department for Environment Food and Rural Affairs 2007). It is anticipated that these targets will be enacted in legislation thus becoming legally binding.

This approach by the EU is very similar to that adopted during the Kyoto negotiations, that is, announce a stringent target for themselves and then attempt to persuade others to follow. However, as mentioned above, there is no indication of any progress on formally involving developing countries and therefore the stance of key developed countries outside the EU will remain uncertain.

The stance of the G77 and China has not changed. They continue to state, with justification, that their key priority is economic development and poverty eradication.

There is a growing body of opinion that substantial progress will be made in the international negotiations if a Democrat president is elected in the US at the end of

2008. However, it is unclear how such an event would influence the international negotiating dynamic. The previous Democrat administration took a similar approach to the negotiations as that adopted by the EU but was unable to achieve domestic consensus on the introduction of the necessary measures within the US, given a lack of binding targets for large, developing country emitters. This is not to suggest that the US will remain unmoved in the face of any progress in the international climate negotiations. However, it seems most likely that US domestic policy will need to evolve and that the direction this takes will determine what the US is likely to accept in multilateral negotiations. For the foreseeable future, it seems that public opinion in the US suggests a Democrat administration is more likely to sway in the direction of domestic regulations than subscribe to an international emissions trading framework.

This approach by the EU is very similar to that adopted during the Kyoto negotiations, that is, announce a stringent target for themselves and then attempt to persuade others to follow.

The foregoing discussion leads to two sets of questions:

- If it is believed that the way forward on tackling climate change is under the Framework Convention and its Kyoto Protocol, then the key question is how to engage developing countries within that framework to achieve emissions reductions.
- If it is considered that negotiations under the UNFCCC have reached a stalemate, then the key questions are what alternative or complementary measures should be adopted and how to engage developing nations, especially China and India, while maintaining momentum in the developed countries.

Engaging developing countries

The dialogue ends with its report to COP13. It seems unlikely that developing countries will change their stance on binding commitments. Therefore, the new negotiating mandate agreed at COP13 in Bali is likely to be much less ambitious than hoped, for example, by the EU, and this will call into question the direction of the negotiations on an extension of the Kyoto Protocol into a second commitment period.

The inherent difficulties in the negotiations and the lack of institutional frameworks in the vast majority of developing countries to support sophisticated market

mechanisms such as international emissions trading leaves project-based mechanisms as the only meaningful way of engaging developing countries in the medium term under the Convention.

The success of project-based mechanisms hinges on the provision of financial assistance from developed countries, such as occurs under the Clean Development Mechanism (CDM). However, significant progress must be made in furthering the scope and extent of CDM projects if substantial reductions in emissions are to occur under this mechanism. In any event, the maintenance of the CDM as an operational mechanism provides a possible source of emissions credits for any domestic emissions trading schemes that might be introduced in Annex I countries.

This suggests that any international regime adopted post-2012 should allow for the possibility of linking any UN recognised market-based unilateral domestic emissions trading scheme to any project-based scheme that succeeds the CDM.

Beyond Kyoto

It seems likely that if action on climate change must involve global cooperation before anything is done, then little action will be taken in the foreseeable future. This view questions the effectiveness of the UNFCCC, which relies on consensus among 189 countries, for every major decision taken.

Aside from the Framework Convention negotiations, there are several other models for cooperation that may hold greater promise. In particular, a fruitful model for cooperation would appear to be a series of bilateral and multilateral agreements between countries in the area of technology development and deployment. Such an approach would overcome the immediate necessity for a global agreement if emission reductions could be achieved by just a few of the larger emitters.

One sub-global approach is in its infancy under the auspices of the AP6. Part of the AP6 process involves research and development of various categories of technology, with different countries focusing on different technologies that are particularly suited to their domestic circumstances. For example, China and Australia are co-chairing the taskgroup on cleaner fossil energy, with the aim of identifying areas for collaborative efforts to accelerate research and demonstration of prospective technologies in order to reduce their costs and ultimately improve deployment. Under this model, technology outcomes would be shared across all partnership countries. One crucial issue to resolve under this approach is how to deal with intellectual property. It is widely recognised that progress will be slow in terms of involving the private sector in any research initiatives without appropriate intellectual property incentives.

Another potential sub-global approach could be drawn out from the results achieved on vehicular emissions under

the Californian efficiency standards legislation. Under this approach, markets for emissions-intensive products could be analysed to identify where there may be a concentrated market that could potentially influence global manufactures through environmental legislation. An extension of this approach is sector-by-sector agreements, although these are subject to difficulty when the operating environment of companies varies greatly across countries (for example, as is the case in the aluminium smelting sector).

A further approach might be for multinational private sector companies with energy-intensive interests to collaborate on technology. To ensure that such actions were not contrary to anti-trust legislation around the world it would probably be necessary for governments to sponsor such collaboration.

Mitigation and technology

The following discussion is drawn from a study undertaken by ABARE (Matysek et al. 2006) that updates an earlier report written for the inaugural meeting of the AP6 (Fisher et al. 2006). Analysis was undertaken on the potential mitigation that could be achieved over the course of the next few decades if all available best practice technologies and practices were deployed across a range of energy-intensive sectors, including electricity, transport, cement, aluminium, wood, pulp and paper, iron and steel and fugitive sectors. Several scenarios were examined in which the accelerated deployment of technology was assumed to occur either only across AP6 countries or globally. In addition, the importance of carbon capture and storage (CCS) technologies was considered.

The analysis showed that while the accelerated global deployment of technological best practice and forced uptake of CCS in key regions can limit growth in future greenhouse gas emissions by as much as 26 per cent relative to reference case levels at 2050, more substantial action will be required if future emissions are to decline and atmospheric concentrations of greenhouse gases are to be stabilised.

Deployment of best practice technologies across all of the considered sectors and CCS utilisation within only the AP6 countries delivered substantially less mitigation potential. Mitigation potential in the absence of the forced uptake of CCS technologies from 2015 on all new coal and gas fired electricity generation in the US, Australia and Japan and from 2020 in China, India and the Republic of Korea, was even lower again, resulting in around an 11 per cent reduction in emissions relative to the reference case by 2050.

It is evident from these results that to achieve deep cuts in emissions of the magnitude discussed by Stern (2006), for example, an expansion in available technologies across sectors and activities that greatly exceeds the degree of technological change considered in the ABARE report (and hence best possible outcomes under the AP6)

would be required, and that it would be necessary to have in place complementary mechanisms that lead to the deployment of such technologies. This finding is confirmed by Edmonds et al. (2007).

More advanced technologies that allow for the decoupling of greenhouse gas emissions from economic growth would be required in the long term to achieve such reductions in emissions. Management strategies and technologies for adaptation will therefore also be important in mitigating the impacts of climate change that will arise in the future.

In order to make more advanced technologies commercial within the timeframes being considered, major new investments in research and development are crucial. The presence of a price on carbon in various regions will not be sufficient to bring these advanced technologies to commercialisation: not only will the carbon prices under these circumstances be different across countries (since the schemes are not coordinated in any way and differences in countries' structural composition will ensure differences in marginal abatement costs), but it is also likely that the price will be relatively low (to avoid substantive negative impacts in countries adopting unilateral climate policy). As such, although a carbon price will act as a signal to emitters to begin pricing emissions in their investment decisions, it is likely that initial pricing schemes will act as an incentive only to draw the relatively low-cost technology options off the shelf, but not to act as an incentive to the more expensive development and commercialisation of advanced technologies that are still a long way from deployment. However, as stated previously, if deep cuts in emissions are to take place these technologies will also be required. For this, public expenditure will be required in large amounts to contribute to private sector development of new technologies, otherwise hurdle rates will remain insurmountable.

Although global spending on energy R&D has been stable for the past decade, after falling for the previous two decades, energy R&D expenditure is still declining relative to the size of the global economy (Edmonds et al. 2007). This trend will need to be reversed immediately if the technology necessary to stabilise greenhouse gas concentrations is to become available while allowing the global economy to continue to grow. Given the small size of Australia's economy, there are limits to the availability of government funding for the development of large-scale, expensive technologies. This reinforces the case for bilateral or multilateral cooperation and co-funding of projects between countries with similar resource base and technological interests.

There are a large number of conditions that must be met to ensure that economic agents make rational choices about their greenhouse gas mitigation strategies. Crucial among these is that carbon is priced and that carbon prices behave predictably over time. Pricing

carbon in one trade-exposed economy without taking account of policies elsewhere in the world is likely to lead to serious distortions in investment in energy-intensive industries. This inevitably leads to attempts to design unilateral trading schemes in a way that will "protect" trade exposed industries. Such arrangements can never be perfect and inevitably lead to economic losses as a consequence of rent-seeking and uncertainty.

In addition to pricing carbon, a number of other pre-conditions must be met to ensure that individuals and firms are in a position to respond to calls to reduce greenhouse gas emissions. First, Edmonds et al. (2007, p. 23) point out that "Long-term, consistent financing for technology development and demonstration is also essential. Much of the support for the early stages of this process will likely come from the public sector or other means of collective action."

Second, any policy mechanisms in place should ensure that carbon from all sources is priced in an equivalent way. In particular, carbon emissions from land-use change, carbon offsets from sequestration and carbon emissions from the combustion of fossil fuels should all be priced equally.

... although a carbon price will act as a signal to emitters to begin pricing emissions in their investment decisions, it is likely that initial pricing schemes will act as an incentive only to draw the relatively low-cost technology options off the shelf ...

Third, the temptation to call for all sectors to make equal proportionate reductions in their emissions should be strongly resisted. The marginal cost of abatement varies across sectors and emission reductions should be undertaken in each economy where it is most cost-effective to do so. For example, it is likely to be more costly to reduce one tonne of emissions in a modern jet aircraft fleet than it is to reduce one tonne of emissions in the residential housing sector.

Finally, even if markets for carbon are established they will only operate effectively if the necessary institutional arrangements are in place to support them. For example, an emissions trading scheme must be supported by an effective monitoring and enforcement regime. Confidence in the market will be undermined if the title to a tonne of carbon is not assured or if those selling permits are not making equivalent reductions in their emissions. Geo-sequestration of carbon will not be

undertaken by private firms unless the necessary legal frameworks have been established to deal with the liability associated with guaranteeing that the sequestered carbon stays *in situ* over the coming millennia.

Conclusion

There is a growing body of evidence to suggest that if dangerous climate change is to be averted, substantial action must be taken to reduce global emissions. However, despite many years of negotiations under the UNFCCC and the Kyoto Protocol, the international community is a very long way from achieving a global framework that will make the required mitigation inroads over the next few decades.

One of the key reasons for this lack of progress, despite all best efforts, is that individual countries have very different priorities and political imperatives. This divide is particularly stark between developed and developing countries. However, given that the climate problem cannot be solved in the absence of key developing countries such as China and India, it is crucial that ways be found to engage these increasingly large emitters in any future policy architectures.

Although international emissions trading has long been portrayed as the best possible policy approach, the serious shortfalls that continue under the Kyoto Protocol indicate that this may not be a feasible approach to pursue beyond 2012. In addition to the difficulties associated with engaging developing countries, it is not even clear that the necessary institutional frameworks exist in many Annex B countries to properly support a monitoring and enforcement regime compatible with a viable international emissions trading scheme.

Despite these difficulties, many countries, including Australia, have either introduced or signaled that they will introduce, emissions trading schemes. Some commentators believe that governments can relax once a domestic emissions trading scheme is introduced. However, contrary to popular belief, unilateral schemes in small countries like Australia will do little on their own to solve the global climate problem. Effort needs to be made to coordinate such schemes with mitigation efforts by other major emitters. In addition, ongoing attention needs to be paid to complementary institutional arrangements.

The unprecedented scale of technology development and deployment that will be required over the coming decades suggests that a priority area is the development of agreements that focus on technology R&D and widespread deployment of resulting innovations.

At present the scale of technology R&D is not commensurate to the task at hand. Governments should urgently address this issue to stem the historic downward trend in energy R&D expenditures. The long lead times,

spill-over effects, high risk and intellectual property constraints associated with new developments all suggest that there may be an incentive for countries with similar resource bases or interests to collaborate and subsequently enjoy the benefits of any innovations.

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climate change perspective **india**

A perspective from the developing world

6

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Summary

The race is on to find a post-Kyoto international framework, which ends in 2012. Whatever replaces Kyoto will only be effective if it is undertaken as a parallel effort and not instead of the United Nations Framework Convention on Climate Change (UNFCCC), which has been painstakingly created. The UNFCCC has not only ensured the participation of a large number of countries year after year, but also has a framework that could be built upon and expanded with various programs, like a carbon emissions trading scheme. This paper discusses various alternatives for a post-Kyoto regime. It focuses on a three-tier system, a proposal that considers per capita global average emissions as a reference point. It also briefly discusses the Asia-Pacific Partnership on Clean Development and Climate (AP6), in which Australia is playing a leading role. These issues are discussed in the context of the developing countries, especially as they relate to their needs and capabilities. The paper ends with a look at some of the strategies and policies for carbon emissions reduction in India.



PHOTO: ISTOCK

Introduction

Fifteen years ago, in the Brazilian city of Rio de Janeiro, 178 countries gathered to discuss how to face the threats of climate change. In an unprecedented consensus at the highest level, they agreed to sign the UNFCCC, which eventually led to the Kyoto Protocol. In 2012 the Kyoto commitment period ends and new ideas are desperately needed for the Conference of Parties (COP) meeting of climate change signatories in December at Bali, Indonesia. So far progress in greenhouse gas reductions has been very slow. On the other hand, progress has been achieved in terms of general acknowledgement and awareness of the problem, and the development of important policies.

In 1992 the world was divided into Annex I and non-Annex I countries. It could be argued that this division was based on per capita emissions. For example, Belgium and the Netherlands, although small in size and population, are in Annex I, while China and India are not. One could say that consideration was given to poor countries due to their GDP level or standards of living. Joseph E. Aldy suggests that per capita emissions are implicit in the UNFCCC. As he explains, “In a per capita emissions allocation scheme, for example, an aggregate quantity of greenhouse gas emissions would be set, then allocated among all [participating] countries according to population.” Also, Ross McKittrick and Mark C. Strazicich (2006) argue that “the range of future emission scenarios can be narrowed substantially by switching attention from total to per capita emissions”.

FIGURE 1**COMPARISON OF EMISSIONS OF NON-ANNEX I AND ANNEX I COUNTRIES: TOTAL (MT) AND PER CAPITA (T)**

NON-ANNEX 1 COUNTRIES	TOTAL (MT)	PER CAPITA	ANNEX 1 COUNTRIES	TOTAL (MT)	PER CAPITA
Saudi Arabia	325	13.6	Italy	462	7.9
Korea	462	9.6	Spain	330	7.7
South Africa	343	7.5	France	387	6.2
Iran	369	5.5	Switzerland	44	5.9
Malaysia	136	5.5	Sweden	52	5.8
Venezuela	128	4.9	Portugal	60	5.7

FIGURE 2**INDIA, CHINA, USA, AUSTRALIA, EU, WORLD**

REGION/COUNTRY	GDP PER CAPITA (2000\$)	CO ₂ /POP (T Co ₂ / Capita)	CO ₂ Emissions (b) (MT of CO ₂)	CO ₂ GDP (KG CO ₂ 2000\$)	CO ₂ GDP (PPP) (KG CO ₂ 2000\$ PPP)
India	538	1.02	1,103	1.90	0.35
China	1,461	3.66	4,769	2.50	0.66
United States	36,414	19.73	5,800	0.54	0.54
Australia	22,543	17.53	354	0.78	0.59
European Union	18,578	8.21	4,048	0.44	0.35
World	5,713	4.18	25,752	0.73	0.49

Alternative ideas

Now the situation has changed, and discussions on new alternatives are underway. For example, new groups are being considered: the Asia-Pacific Partnership on Clean Development and Climate (AP6); Annex1+BRICS (Brazil, Russia, India, China and South Africa); G8+5 (five consisting of Brazil, China, India, Mexico and South Africa). A move to bring large non-Annex I countries into Annex I based on total emissions is on. But these initiatives do not conform to the UNFCCC, which is implicitly consistent with the principle of CO₂ emissions per capita. These new alternatives will be effective if they are undertaken as a parallel effort and not instead of UNFCCC. The UNFCCC has been painstakingly created. Commitments to this framework have been shown year after year in COP meetings. New international frameworks with such consensus are hard to create. The UNFCCC has not only ensured the presence of a large number of countries year after year, but also has a framework that could be built upon and expanded with various programs, like protocols that permit carbon markets and so on.

In these last 15 years, many non-Annex I countries (NACs) have increased their carbon dioxide emissions per capita. Using the statistics of countries' effluent given by the International Energy Agency (IEA 2006), one can see that in the top 10 emitting countries of the world, on a per capita basis, there are six NACs, essentially the OPEC countries. In the top 30 we find 14 NACs, in

addition to oil-rich countries, including Taiwan, Singapore, Hong Kong, Korea, Israel and Kazakhstan. In the top 50 there are 21 NACs including the above and Mediterranean countries. (The IEA only gives figures for CO₂ emissions and not all greenhouse gas emissions.)

A move to bring large non-Annex I countries into Annex I based on total emissions is on.

Figure 1 compares Annex I countries and selected NACs in terms of their total and per capita emissions. We find that some NACs have both higher total and higher or similar per capita emissions than Annex I countries. One can see that countries such as Norway, France, Spain and Sweden have lower per capita emissions than these NACs (see Figure 3). Should they not, then, begin to think of reducing emissions? Applying the principle of equity, some of the NACs should have greater obligations, and consequently a transition mechanism is needed. The NACs selected for inclusion in Figure 3 have emissions higher than those of India and Brazil put together.

Figure 2 shows the relative position of India with respect to other countries and global totals or per capita averages. It can be seen that only India and China are way behind the developed countries.

FIGURE 3
PER CAPITA CO₂ EMISSIONS FOR ANNEX I, AGA AND BGA GROUPS

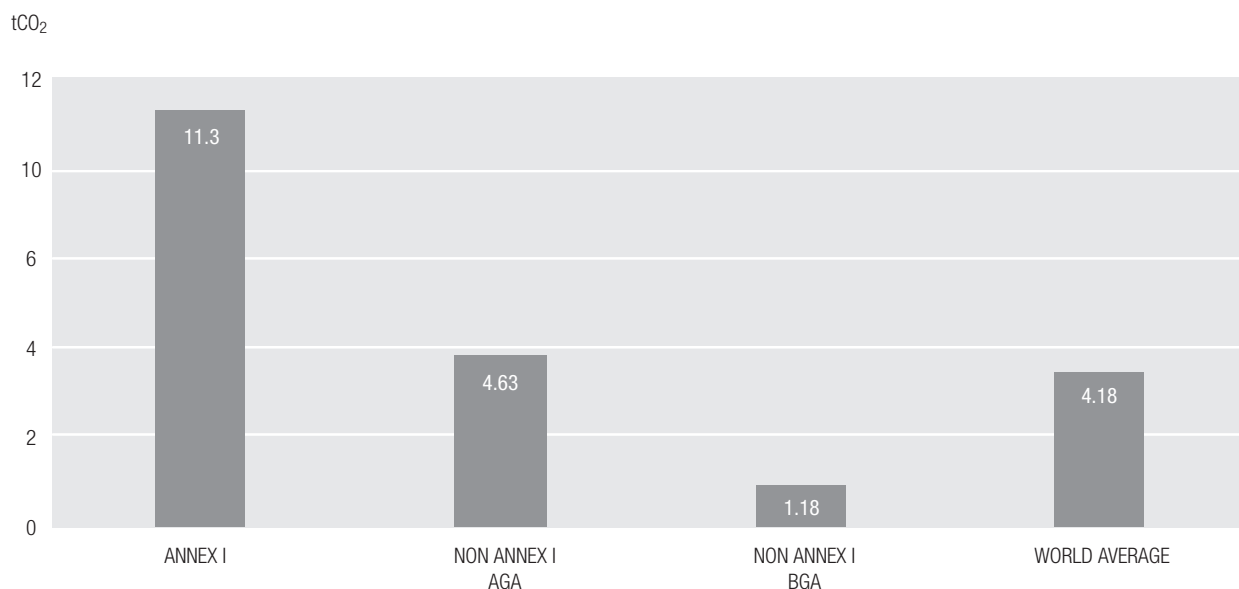


FIGURE 4
EMISSIONS AND POPULATION OF THREE GROUPS OF COUNTRIES (2004)

GROUPS	TOTAL NO. OF COUNTRIES	TOTAL CO ₂ EMISSIONS (MT)	SHARE OF TOTAL CO ₂ EMISSIONS	POPULATION (MILLIONS)	PER CAPITA (T)
Annex I countries	39	14,183	55%	1256	11.3
Non-Annex I countries	97	11,569	45%	4898	2.3
AGA	28	7764	30%	1677	4.6
BGA	69	3804	15%	3220	1.2
Global Totals and average*	136	25,752	100%	6154	4.2

* We have left out nearly 60 small countries with emissions less than 0.4 Mt. Together, they account for 2 per cent of total emissions.

Source: IEA 2006. <http://data.iea.org/ieastore/statistiting.asp>

Three-tier system

One possible way forward would be to introduce a “three-tier system”, which could provide a smooth transition to a more equitable system (Parikh 2005, 2007). The non-Annex I countries would be divided into two groups, those that have emissions above-global average (AGA) in per capita terms, 4.2 t/cap, and those NACs with below-global average (BGA) in per capita terms. Altogether we have three groups: Annex I, AGA and BGA (China is included in the AGA group, as it is already close to the global average and is likely to have surpassed it already or will do so soon).

Figure 3 shows CO₂ emissions per capita difference among the three proposed groups. Annex I countries emit 11.3 t per capita CO₂ emissions (PCE), non-Annex I AGA 4.6 t PCE, non-Annex I BGA 1.2 t PCE. The global average is 4.2 t PCE. It is important to point out that AGA without China is 8 t PCE and are higher than

global average. However, China is included in AGA because it has PCE close to the global average.

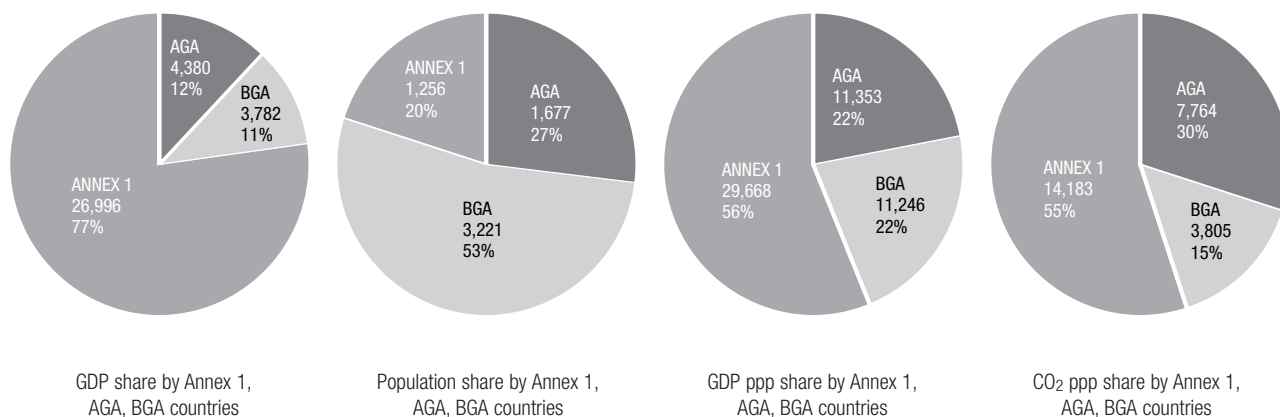
An aggregated picture of the three-tier system (see Figure 4) shows that 39 Annex I countries emit 14,183 million tons (Mt) of CO₂ (55 per cent of the global total), with a population of 1,256 million. Altogether, the 28 AGA countries emit 7,764 Mt of CO₂ (30 per cent of the total), with a population of 1,677 million. The 80 BGA countries, including India, Brazil, Mexico and Argentina, emit 3,804 Mt of CO₂ (15 per cent of the global total), with a population of 3,220 million.

We have left out nearly 60 small countries with emissions less than 0.4 Mt. Together, they account for 2 per cent of total emissions.

The three-tier system is a multilateral initiative, consistent with the UNFCCC fairness principle, equity among the equal emitters and consistent with concerns

FIGURE 5

ANNEX I, AGA, BGA PARTICIPATION IN TOTAL GDP, PURCHASING POWER ADJUSTED GDP, POPULATION AND TOTAL EMISSIONS



about loss of competitive edge among blocks. This mechanism would keep up the momentum generated by Annex I by the next group of NAC. Non-Annex I is split into two blocks – AGA and BGA – in a natural succession to the UNFCCC. (A full list of countries is given in Annexure 1.)

Figure 5 shows Annex I, AGA and BGA participation in total GDP, purchasing power adjusted GDP, population and total emissions. We find that the AGA group is in the middle layer, not only for CO₂ total emissions, but also GDP and GDP ppp (purchasing power parity). It is evident that this group should take more responsibility for reducing emissions as their economies are getting stronger.

However, the three-tier system would not mean that all AGAs should join Annex I, but envisages a separate tier with a separate program. The system anticipates a future in which gradually the global average may go down in, say, 20 years. Moreover, more countries may join, say, Argentina and Mexico, currently at 3.5 t PCE, and India. The BGA tier countries should also know what awaits them and when. We need to think of three groups, where the participation of the middle group (AGA) can be different from the other two (Annex I and BGA), and each group can take on its own responsibilities to contain or reduce emissions.

Small countries should not be left out in a rule-based transition mechanism. Just as Monaco, Liechtenstein and Luxembourg are included in Annex I, Kuwait, Qatar, Singapore and Hong Kong should be included in the AGA group.

What could the AGA countries do? Of course, they have to discuss it themselves, but there are several options. They could remain at 2012 levels or revert by 2020 to 2012 levels, or reduce the CO₂/GDP rates, which are relatively high. The BGA group could also reduce the CO₂ growth rates – not economic growth and

improve the CO₂/GDP intensity. Thereby the system is rule-based; it follows a common but differentiated approach to ensure fairness and is effective because all groups can see what they need to do and when.

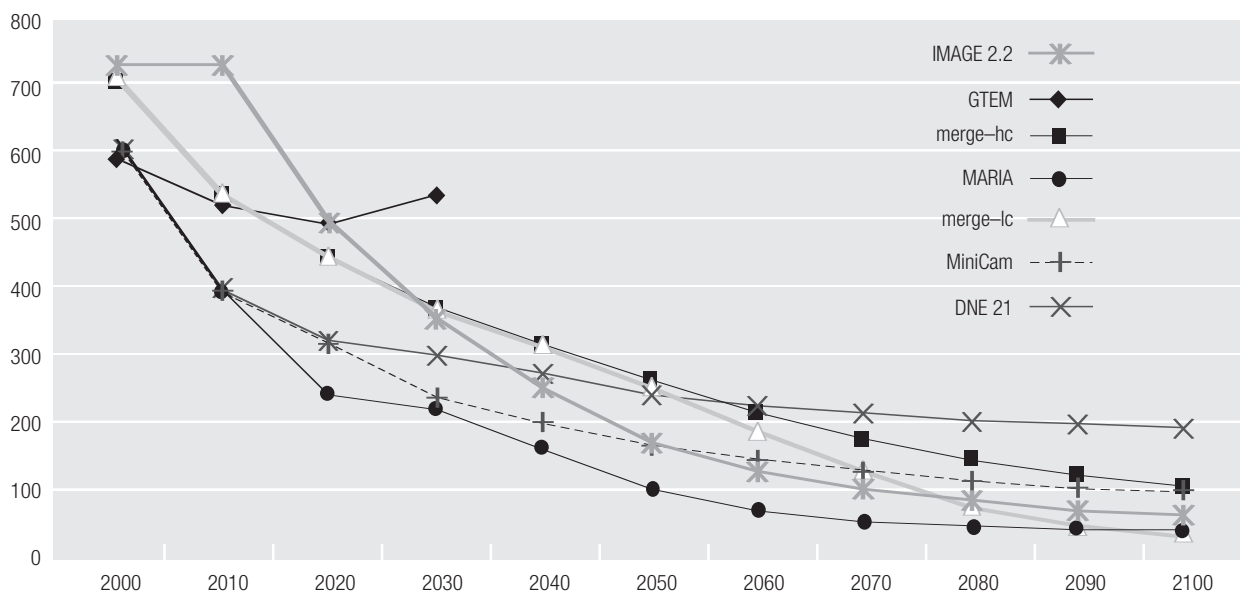
In conclusion, we can say that the per capita global average approach of the three-tier system is consistent with the UNFCCC principle of keeping every country on board and taking into account their common but different responsibilities. This framework is logical and rule-based. However, none of the alternatives will be effective if the high-emitting countries like United States and Australia continue to remain outside the system. In terms of greenhouse gas emissions, each year five Indias worth of CO₂ are added by the US alone, four Indias by China and nearly four by the EU. If India reduces 10 per cent of emissions it will have a cut only 110 million tons. If, on the other hand, the US reduces 20 per cent, it would reduce India's entire output. Even Australia, with its 20 million people, is adding one-third of India's greenhouse gas emissions with a population of one billion. In this context, India's efforts will only have symbolic value on a global scale.

The Asia-Pacific partnership

The Asia-Pacific Partnership on Clean Development and Climate (AP6) was launched in 2006. Its six members (comprising of three developed and three developing countries) are the US, Australia, Japan, India, China and South Korea. It has approved eight public-private sector task forces covering aluminium, buildings and appliances, cement, cleaner use of fossil energy, coal mining, power generation and transmission, renewable energy and distributed generation, and steel. The partners propose that by building on the foundation of existing bilateral and multilateral initiatives they will better cooperate to meet increased energy needs and the associated challenges,

FIGURE 6
REFERENCE CASE CARBON EMISSION PROJECTION FOR INDIA

CARBON GENERATED (IN MILLION METRIC TONS) / GDP (IN TRILLIONS OF 1990 US\$\$)



including those related to air pollution, energy security and greenhouse gas intensities, in accordance with national circumstances. While the AP6 follows a sectoral approach, it does so without financial incentives and with only a few selected countries in the Asia-Pacific region.

India's record

Despite poverty and low per capita emissions, India has been trying to tackle the problem of emissions through various measures:

- emphasis on energy conservation;
- promotion of renewable energy;
- abatement of air pollution;
- afforestation and waste land development;
- economic reforms;
- fuel substitution policies; and
- recycling and reuse.

As a result, the rise of per capita emissions is slower than the rate of GDP growth. I will briefly outline some of the initiatives in India's greenhouse gas emissions reduction program.

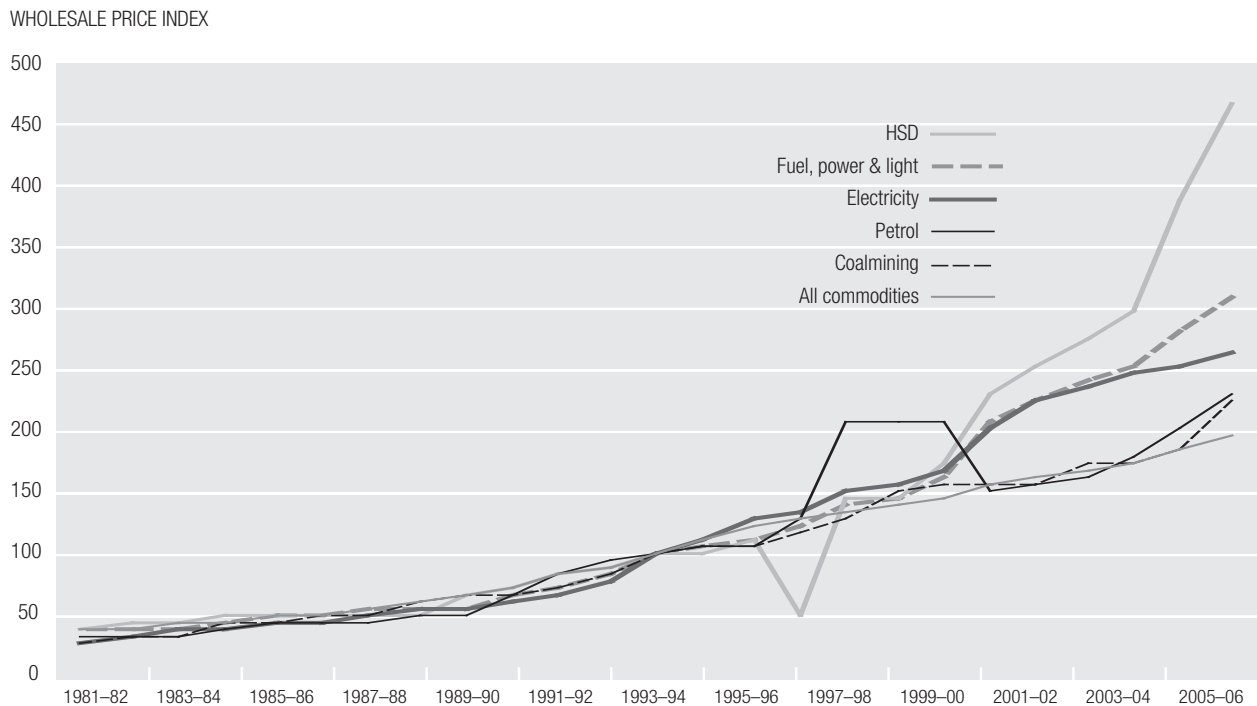
Energy conservation has been emphasised for many decades in view of scarce resources, as well as in order to reduce greenhouse gas emissions. The lack of capital for new projects, scarcity of non-renewable fossil fuels, increased cost of oil imports and concerns about air pollution are the important factors motivating India to

conserve energy. To fill the gap in energy supply, renewable energy sources are being promoted.

A number of organisations have been set up in India to handle energy sector problems. The Petroleum Conservation Research Association aims to explore oil sources and raise production, as well as to reduce oil imports. The Bureau of Energy Efficiency was established for training, research and implementation, and to set standards, introduce labeling systems, so consumers are informed about the choices they make. The Power Finance Corporation has been employed to take care of supply-side efficiency. There are additional organisations, which together with those mentioned form an institutional commitment to solving the problems of the energy sector. The result is that India's energy/GDP intensities are dropping and are on par with advanced nations like Germany, when GDP is adjusted for purchasing power. The 2004 Special Report on Emissions Scenarios contained results from nine international modelling teams, which worked out scenarios for 2100 for various regions of the world. Their results (illustrated in Figure 6) show that India's emissions intensities will continue to drop substantially (Weyant and Parikh 2004).

Several policies have been formulated for air pollution abatement. Most of these measures aim to either avoid or reduce emissions. The main polluters (for example, industries and the transport sector) have been directed to control their pollutants. Several technologies have been provided to keep pollution in check. The introduction of compressed natural gas engines is one example that shows there has been improvement in technology alongside fuel substitution.

FIGURE 7
WPI FOR DIFFERENT ENERGY RESOURCES WRT WPI FOR ALL COMMODITIES



Afforestation and wasteland development are two important ways to check pollution. Efforts have been made by various government organisations, private organisations and NGOs to make the environment as green as possible. Recently, the Green India initiative was launched.

Several economic reform programs have been formulated by the government to avoid and reduce greenhouse gas emissions. The government provides incentives in the form of subsidies for better implementation of such policies. As a result, over time, subsidies on energy are gradually reduced, as can be seen in Figure 7, where the price indices for all energy forms have risen faster than the wholesale price index, especially diesel and electricity, which were previously subsidised to cater to the needs of the poor.

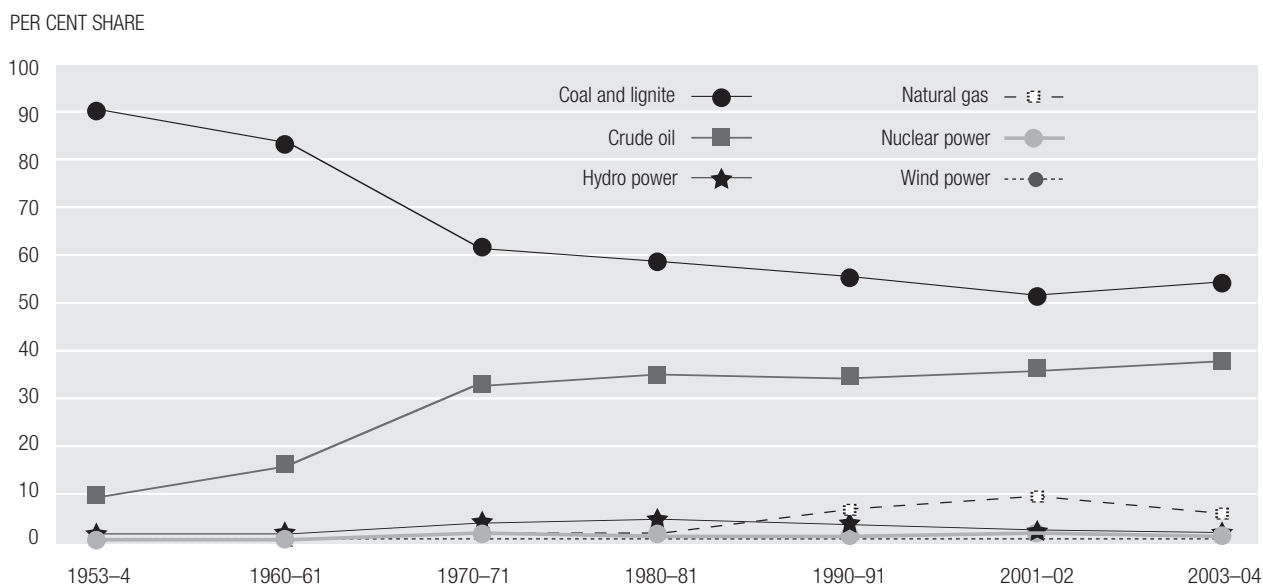
Fuel substitution is another way of reducing greenhouse gas emissions. Renewable sources of energy are promoted to replace scarce fossil fuels. At the policy level, several economic reforms and subsidy removal programs are being launched. Several types of substitution are taking place simultaneously. For instance, biomass, such as fire wood, crop residue and animal dung (referred to as non-commercial energy or traditional energy), which is considered carbon-neutral if it does not lead to deforestation, is increasingly being replaced by fossil fuels such as kerosene and liquefied petroleum gas (LPG). However, sustainable biomass consists of bio-gasifica-

tion, improved stoves, efficient kilns, and new bio-fuels such as biodiesel and ethanol. Other low-carbon technology and renewable energy sources include energy from hydro projects, wind and solar power. Figure 8 illustrates changes in the share of different fuels in India's primary energy supply. It shows that the share of coal and lignite has declined continuously since 1953-54.

Recycling can be a major contributor to resource conservation. Items like cloth, furniture, paper, and bottles are constantly reused or recycled by the majority of Indians, thereby reducing greenhouse gas emissions ...

On the other hand, despite high crude oil prices, the share of oil has remained the same. From 1980-81, the share of natural gas increased until 2001-02. We can also see that mini-hydro and wind energy have not contributed much. However, the use of these renewable resources can be increased, and the share of coal and lignite, as well as crude oil, can be reduced to a significant extent in future.

FIGURE 8
CHANGE IN SHARE OF DIFFERENT FUELS IN PRIMARY ENERGY SUPPLY (%)



Source: Derived by authors from energy statistics. Private communication from Planning Commission, Government of India 2006.

Recycling can be a major contributor to resource conservation. Items like cloth, furniture, paper, and bottles are constantly reused or recycled by the majority of Indians, thereby reducing greenhouse gas emissions, even though there is no binding requirement for India to do so in the UNFCCC.

Conclusion

Climate change is one of the major challenges globally in both the short and long term. India has also many short-term, imminent problems that require attention, such as the 300 million people living below the poverty line and earning less than a dollar a day, 300 million unelectrified households, lack of access to water and sanitation for 500 million, and lack of access to LPG and kerosene for 650 million.

Yet India's 8 per cent economic growth rate allows the addition of new power plants, new coal units, steel plants and cement plants, in which better technologies can reduce potential emissions. The various alternatives for the post-Kyoto period include the three-tier system, CO₂ intensities approach that includes CO₂/GDP, total emissions approach, and a total emissions approach on a regional basis.

Regardless of the approach the UNFCCC members adopt, India's current efforts provide an example at the global level of sustainable development issues and the reduction of the global greenhouse gas emissions. Although the extent to which efforts towards sustainable

development in India will reduce its greenhouse gas emissions is unknown, the strong connections between air and water pollution and greenhouse gas emissions make it extremely likely that emissions will be lower if development proceeds sustainably. The international community can argue that India should reduce greenhouse gas emissions for the global good, but also for its own good, beyond what it gains in reduced climate change impacts.

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ANNEXURE 1
ANNEX1 COUNTRIES

REGION/ COUNTRY	POPULATION (MILLION)	GDP (BILLION 2000\$)	GDP (PPP) (BILLION 2000\$)	CO ₂ EMISSIONS (B) (MT OF CO ₂)	CO ₂ /POP (T CO ₂ / CAPITA)	CO ₂ GDP (KG CO ₂ 2000\$)	CO ₂ GDP (PPP) (KG CO ₂ 2000\$ PPP)
United States	294	10,704	10,704	5,800	19.73	0.54	0.54
Russia	144	329	1,309	1,529	10.63	4.65	1.17
Japan	128	4,933	3,432	1,215	9.52	0.25	0.35
Germany	83	1,953	2,160	849	10.29	0.43	0.39
Canada	32	787	947	551	17.24	0.7	0.58
United Kingdom	60	1,591	1,661	537	8.98	0.34	0.32
Italy	58	1,114	1,496	462	7.95	0.41	0.31
France	62	1,415	1,678	387	6.22	0.27	0.23
Australia	20	456	598	354	17.53	0.78	0.59
Spain	43	656	958	330	7.72	0.5	0.34
Ukraine	47	44	279	305	6.42	6.92	1.09
Poland	38	187	445	296	7.75	1.59	0.66
Turkey	72	229	529	209	2.92	0.91	0.4
Netherlands	16	399	467	186	11.41	0.47	0.4
Czech Republic	10	63	168	119	11.64	1.89	0.71
Belgium	10	246	290	116	11.14	0.47	0.4
Greece	11	135	211	94	8.49	0.7	0.44
Romania	22	47	169	91	4.22	1.95	0.54
Austria	8	205	243	75	9.19	0.37	0.31
Finland	5	132	147	69	13.18	0.52	0.47
Belarus	10	17	63	61	6.17	3.64	0.96
Portugal	11	109	181	60	5.73	0.56	0.33
Hungary	10	55	145	57	5.62	1.03	0.39
Sweden	9	263	262	52	5.8	0.2	0.2
Denmark	5	166	160	51	9.42	0.31	0.32
Bulgaria	8	15	58	45	5.85	2.99	0.79
Switzerland	7	254	226	45	5.95	0.18	0.2
Ireland	4	118	134	41	10.2	0.35	0.31
Slovak Republic	5	24	70	38	7	1.55	0.54
Norway	5	180	176	36	7.91	0.2	0.21
New Zealand	4	62	94	33	8.04	0.53	0.35
Croatia	4	22	50	21	4.63	0.94	0.41
Estonia	1	7	18	17	12.29	2.31	0.92
Slovenia	2	22	38	16	7.81	0.72	0.41
Lithuania	3	15	41	13	3.69	0.84	0.31
Luxembourg	0	22	24	11	24.94	0.51	0.47
Latvia	2	10	25	7	3.13	0.7	0.29
Netherlands Antilles	0	3	3	4	16.79	1.33	1.24
Iceland	0	10	9	2	7.72	0.24	0.25
TOTAL ANNEX1	1,256	26,996	29,668	14,183	11.29	0.53	0.48

ANNEXURE 1
AGA COUNTRIES

REGION/ COUNTRY	POPULATION (MILLION)	GDP (BILLION 2000\$)	GDP (PPP) (BILLION 2000\$)	CO ₂ EMISSIONS (B) (MT OF CO ₂)	CO ₂ /POP (T CO ₂ / CAPITA)	CO ₂ GDP (KG CO ₂ 2000\$)	CO ₂ GDP (PPP) (KG CO ₂ 2000\$ PPP)
China	1,303	1,904	7,219	4,769	3.66	2.5	0.66
Korea	48	613	921	462	9.61	0.75	0.5
Islamic Rep. of Iran	67	126	463	369	5.51	2.92	0.8
South Africa	46	151	468	343	7.54	2.28	0.73
Saudi Arabia	24	215	304	325	13.56	1.51	1.07
Chinese Taipei	23	324	484	255	11.26	0.79	0.53
Kazakhstan	15	27	103	162	10.81	5.95	1.58
Malaysia	25	107	235	136	5.47	1.28	0.58
Venezuela	26	120	145	128	4.91	1.07	0.88
Uzbekistan	26	17	45	126	4.82	7.54	2.8
Former Yugoslavia	21	63	148	114	5.53	1.8	0.77
United Arab Emirates	4	96	96	103	23.86	1.08	1.08
Kuwait	2	43	44	65	26.36	1.49	1.48
Israel	7	121	152	62	9.15	0.51	0.41
Serbia and Montenegro	8	10	22	53	6.5	5.05	2.42
Libya	6	41	34	44	7.58	1.07	1.29
Turkmenistan	5	5	29	39	8.25	7.94	1.36
Qatar	1	22	26	39	49.64	1.72	1.5
Singapore	4	102	109	38	8.97	0.37	0.35
Hong Kong (China)	7	189	195	36	5.27	0.19	0.19
Oman	3	23	36	25	9.97	1.11	0.71
Trinidad and Tobago	1	10	15	22	17.03	2.11	1.52
Bahrain	1	10	14	17	23.68	1.71	1.24
Lebanon	4	20	19	15	4.32	0.77	0.81
Cyprus	1	10	17	7	8.4	0.68	0.4
Brunei Darussalam	0	5	4	5	14.18	1.09	1.25
Malta	0	4	7	3	6.28	0.66	0.36
Gibraltar	0	1	1	0	15.67	0.72	0.76
TOTAL AGA	1,677	4,380	11,353	7,764	4.63	1.77	0.68

ANNEXURE 1
BGA COUNTRIES

REGION/ COUNTRY	POPULATION (MILLION)	GDP (BILLION 2000\$)	GDP (PPP) (BILLION 2000\$)	CO ₂ EMISSIONS (B) (MT OF CO ₂)	CO ₂ /POP (T CO ₂ /CAPITA)	CO ₂ GDP (KG CO ₂ 2000\$)	CO ₂ GDP (PPP) (KG CO ₂ 2000\$ PPP)
India	1,080	581	3,115	1,103	1.02	1.90	0.35
Mexico	104	619	957	374	3.59	0.60	0.39
Indonesia	218	197	722	336	1.55	1.71	0.47
Brazil	184	655	1,385	323	1.76	0.49	0.23
Thailand	64	150	474	207	3.25	1.38	0.44
Egypt	73	117	281	141	1.93	1.20	0.50
Argentina	38	287	469	136	3.54	0.47	0.29
Pakistan	152	86	311	116	0.76	1.35	0.37
Iraq	25	21	27	81	3.20	3.82	2.99
Vietnam	82	41	207	79	0.96	1.91	0.38
Algeria	32	64	196	78	2.41	1.21	0.40
Philippines	82	89	346	72	0.89	0.82	0.21
DPR of Korea	22	11	31	70	3.14	6.67	2.28
Chile	16	88	161	59	3.63	0.67	0.36
Colombia	45	94	300	57	1.28	0.61	0.19
Syria	19	21	62	48	2.57	2.31	0.78
Nigeria	129	52	137	48	0.37	0.92	0.35
Morocco	30	40	118	36	1.19	0.88	0.30
Bangladesh	139	56	239	34	0.24	0.60	0.14
Azerbaijan	8	8	32	29	3.53	3.73	0.92
Peru	28	61	144	29	1.05	0.47	0.20
Cuba	11	29	81	24	2.16	0.83	0.30
Ecuador	13	19	48	22	1.68	1.15	0.46
Tunisia	10	23	71	20	1.99	0.85	0.28
Dominican Republic	9	22	60	18	2.01	0.81	0.29
Yemen	20	11	16	17	0.85	1.59	1.05
Jordan	5	11	23	17	3.07	1.58	0.71
Bosnia and Herzegovina	4	6	25	16	4.17	2.96	0.64
Sri Lanka	19	19	78	13	0.65	0.67	0.16
Bolivia	9	9	23	10	1.16	1.12	0.46
Jamaica	3	9	10	10	3.92	1.22	1.02
Guatemala	12	21	49	10	0.84	0.49	0.21
Sudan	36	15	64	10	0.27	0.63	0.15
Zimbabwe	13	6	25	10	0.75	1.63	0.39
Myanmar	50	12	267	9	0.19	0.76	0.03
Kenya	33	14	35	9	0.27	0.63	0.26
FYR of Macedonia	2	4	12	8	4.03	2.24	0.66
Angola	15	12	31	8	0.50	0.63	0.25
Republic of Moldova	4	2	7	8	1.80	4.50	1.13

BGA COUNTRIES ...CONTINUED

REGION/ COUNTRY	POPULATION (MILLION)	GDP (BILLION 2000\$)	GDP (PPP) (BILLION 2000\$)	CO ₂ EMISSIONS (B) (MT OF CO ₂)	CO ₂ /POP (T CO ₂ / CAPITA)	CO ₂ GDP (KG CO ₂ 2000\$)	CO ₂ GDP (PPP) (KG CO ₂ 2000\$ PPP)
Honduras	7	7	19	6	0.91	0.94	0.34
Ghana	22	6	45	6	0.28	1.01	0.14
El Salvador	7	14	31	6	0.85	0.41	0.18
Cote d'Ivoire	18	10	25	6	0.32	0.56	0.22
Kyrgyzstan	5	2	9	6	1.10	3.39	0.62
Costa Rica	4	18	37	5	1.28	0.30	0.15
Panama	3	13	21	5	1.72	0.41	0.26
Tajikistan	6	1	7	5	0.85	3.79	0.77
Uruguay	3	20	30	5	1.56	0.26	0.18
Ethiopia	70	8	49	5	0.07	0.64	0.10
Albania	3	5	14	5	1.56	1.05	0.34
Botswana	2	6	16	4	2.44	0.67	0.27
Nicaragua	5	4	18	4	0.76	0.94	0.23
Senegal	11	5	18	4	0.36	0.78	0.23
United Rep. of Tanzania	38	12	23	4	0.10	0.32	0.16
Paraguay	6	8	27	4	0.62	0.45	0.14
Armenia	3	3	11	3	1.15	1.21	0.30
Georgia	5	4	12	3	0.68	0.77	0.26
Nepal	27	6	36	3	0.11	0.48	0.08
Cameroon	16	11	32	3	0.18	0.27	0.09
Namibia	2	4	14	3	1.33	0.65	0.19
Benin	8	3	8	2	0.29	0.90	0.29
Dem. Rep. of Congo	56	5	36	2	0.04	0.46	0.06
Zambia	11	4	10	2	0.18	0.53	0.21
Togo	6	1	8	2	0.32	1.33	0.23
Mozambique	19	5	22	2	0.09	0.34	0.08
Gabon	1	5	8	2	1.23	0.32	0.20
Haiti	8	3	14	2	0.19	0.46	0.12
Congo	4	4	3	1	0.23	0.25	0.26
Eritrea	4	1	4	1	0.17	0.97	0.19
Total BGA	3,221	3,782	11,246	3,805	1.18	1.01	0.34

ANNEXURE 1

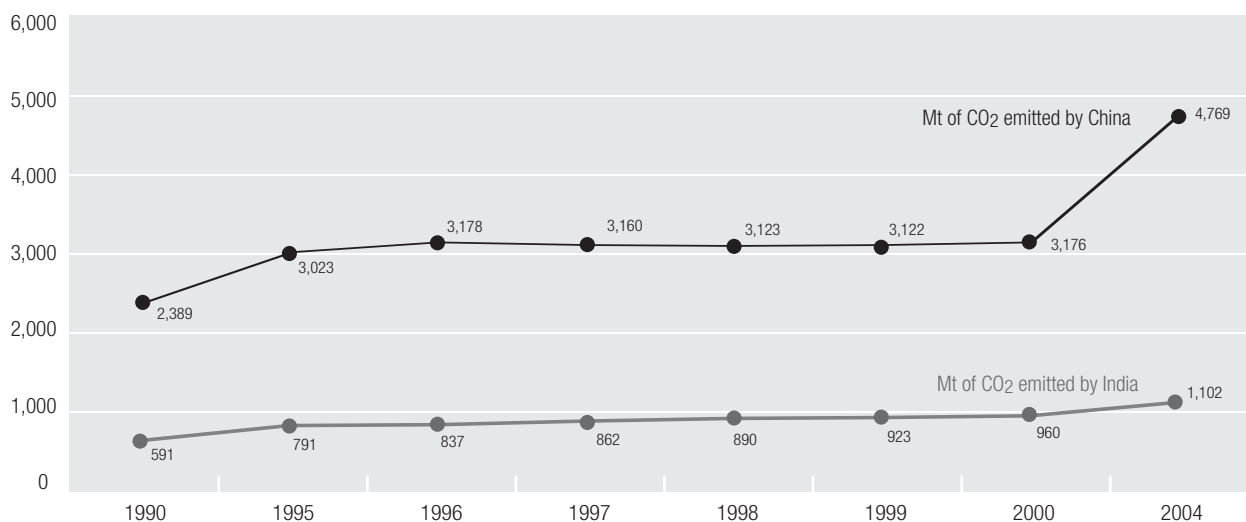
TOP TWENTY TOTAL EMITTER COUNTRIES IN 2004

REGION/ COUNTRY	ANNEX-I COUNTRIES(1) & NON-ANNEX I COUNTRIES(2)	POPULATION (MILLION)	GDP (BILLION 2000\$)	GDP (PPP) (BILLION 2000\$)	CO ₂ EMISSIONS (b) (MT OF CO ₂)	CO ₂ /POP (T CO ₂ / CAPITA)	CO ₂ GDP KG CO ₂ 2000\$)	(CO ₂ GDP (PPP) (KG CO ₂ 2000\$ PPP)
United States	1	294	10,704	10,704	5,800	19.73	0.54	0.54
China	2	1,303	1,904	7,219	4,769	3.66	2.50	0.66
Russia	1	144	329	1,309	1,529	10.63	4.65	1.17
Japan	1	128	4,933	3,432	1,215	9.52	0.25	0.35
India	3	1,080	581	3,115	1,103	1.02	1.90	0.35
Germany	1	83	1,953	2,160	849	10.29	0.43	0.39
Canada	1	32	787	947	551	17.24	0.70	0.58
United Kingdom	1	60	1,591	1,661	537	8.98	0.34	0.32
Italy	1	58	1,114	1,496	462	7.95	0.41	0.31
Korea	2	48	613	921	462	9.61	0.75	0.50
France	1	62	1,415	1,678	387	6.22	0.27	0.23
Mexico	3	104	619	957	374	3.59	0.60	0.39
Islamic Rep. of Iran	2	67	126	463	369	5.51	2.92	0.80
Australia	1	20	456	598	354	17.53	0.78	0.59
South Africa	2	46	151	468	343	7.54	2.28	0.73
Indonesia	3	218	197	722	336	1.55	1.71	0.47
Spain	1	43	656	958	330	7.72	0.50	0.34
Saudi Arabia	2	24	215	304	325	13.56	1.51	1.07
Brazil	3	184	655	1,385	323	1.76	0.49	0.23
Ukraine	1	47	44	279	305	6.42	6.92	1.09
TOTAL TOP 20		4,043	29,042	40,776	20,723	5.13	0.71	0.51

ANNEXURE 2

SUSTAINED GAP BETWEEN CHINA AND INDIA TOTAL CO₂ EMISSIONS DURING 1990–2004

MT OF CO₂



Source: IEA 2002, CO₂ emissions from fuel combustion. 1971–2000. p. II 187 and II. 253

THE carbon tax

alternative

An alternative to carbon trading

7



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PHOTO: ISTOCK

Summary

A solid consensus has emerged among scientists and most public officials around the world that emissions of greenhouse gases from burning fossil fuels, especially carbon dioxide (CO₂), contribute significantly to climate changes which could have very serious, adverse effects. Wherever greenhouse gases originate they affect everyone because they disperse widely in the upper atmosphere and accumulate there for a century. Since every industrialised nation produces these emissions they all need to be part of the global effort to control them.

This paper examines the two most prominent strategies for reducing greenhouse gases: a global system of national caps on the emissions and tradable permits, modelled on the Kyoto Protocol, and global, harmonised, net carbon-based taxes. It finds that cap-and-trade systems can achieve

their emissions targets year by year, but will introduce significant additional volatility in energy prices. These systems also entail substantial administrative complexities and costs, and their emissions goals can be undermined by evasion and manipulation. Carbon taxes are less certain to achieve their emissions targets year by year, but their levels can be adjusted to minimise this deficiency. They are also easier and less expensive to administer, less vulnerable to manipulation and evasion, and provide more reliable incentives to develop and use alternative fuels and more energy-efficient technologies. Based on economic analyses and evidence, we conclude that carbon taxes are the more environmentally effective and economically efficient strategy for addressing climate change.

Introduction

Scientists and most public officials around the world have come to a solid consensus that the greenhouse gases emitted when fossil fuels are burned, especially carbon dioxide (CO₂), contribute to climate changes that will have very serious effects on the planet. These greenhouse gases disperse widely through the upper atmosphere and remain there for about a century, so wherever they originate they affect everyone on Earth. Since every nation with an industrialised economy produces these emissions, a successful effort is needed to control them which must include all industrialised countries. With strong leadership, the world community may be able to come together to address this problem before the limited Kyoto agreement expires in 2012. To prepare, policymakers must very carefully analyse their alternatives, to ensure that the approach finally chosen is the most effective and efficient one available.

In this paper we examine the two leading strategies for reducing greenhouse gases: a global system of national caps on greenhouse gas emissions and tradable permits, based on the emissions targets and timetables created by the Kyoto Protocol (cap-and-trade); and global, harmonised, net carbon-based taxes (carbon taxes). Recent economic analyses and evidence strongly suggest that carbon taxes would be a more environmentally effective and economically efficient way to address climate change than a cap-and-trade system, and provide stronger incentives to develop alternative fuels and more energy-efficient technologies (Nordhaus 2005; Cooper 1998, 2005).

Other policies also affect climate change, especially steps to protect and re-plant tropical forests and to support new technologies that can reduce emissions or their adverse effects on the climate. Reforestation and such scientific advances will have to play important roles in any climate change effort. Forestry measures are the most cost-effective responses available for many Latin American and African countries (Enkvist et al 2007). Moreover, both a strict cap-and-trade program and carbon taxes impose substantial costs on emissions and the energy that produces them, creating incentives to reduce those costs by developing cleaner fuels and more energy-efficient technologies. As a political matter, the higher energy prices required to make progress will be difficult to sustain for longer periods without the prospect of technological advances that eventually can stabilise or even bring down those prices.

Both of the two principal policy approaches necessarily result in higher prices for fossil fuels, but in different ways. Carbon taxes raise the price of carbon-based energy directly, predictably and in a constant manner, imposing the greatest costs on those firms and economies that produce the most emissions. In so doing, carbon taxes create direct incentives to reduce carbon-based energy use or substitute cleaner forms of energy, until the cost of doing so is greater than the tax. A serious cap-and-trade program applies no direct charge to emissions up to its

cap, but the cap for the system is set below its current or forecast emissions. Companies and countries whose emissions exceed their caps therefore either have to reduce them either by cutting their energy use or substituting cleaner forms of energy, or by purchasing permits to cover the gap from those whose emissions are less than their own caps. The costs of the permits or the steps taken to cut energy use or use cleaner fuels are passed on in higher prices, so once again countries and firms with higher emissions pay higher prices for energy. However, those price increases are less predictable and will vary month to month depending on the size of the gap.

The critical economic distinction is that cap-and-trade directly controls the *quantity* of emissions, while carbon taxes directly control their *price*.

The two approaches differ in several other important ways. The critical economic distinction is that cap-and-trade directly controls the *quantity* of emissions, while carbon taxes directly control their *price*. The result is that cap-and-trade can produce a designated quantity of emissions, but with much greater potential volatility in energy and energy-related prices, while carbon taxes will produce more certain prices for energy and energy-intensive goods, but greater uncertainty about the quantity of total emissions. These two trade-offs are not equivalent. By regulating the quantity of emissions, a strict cap-and-trade program will drive the price of permits to whatever level is required to bring emissions under its cap. The price of permits and their underlying energy source will rise sharply when emissions increase, because, for example, an industry or country's growth accelerates or the winter weather is colder than expected. This price effect will introduce much greater up-and-down movements in national energy prices, on top of the normal increases and declines in global energy prices. Under a cap-and-trade program strict enough to affect climate change this increased volatility in energy prices will affect business investment and consumption. As the public learns to associate these unexpected price movements with the cap-and-trade system, their support for the effort could erode. As we will see, this price volatility is both evident and substantial in both the emission permits traded under the US acid rain program, the major US example of cap-and-trade, and in the first 22 months of CO₂ permit trading under the European Emissions Trading Scheme (ETS).

A carbon tax does not increase or accentuate the volatility of energy prices because it raises the unit-cost of energy by a constant amount (depending on its carbon

content), regardless of how fast a company, industry or nation's emissions are growing. The predictable cost of a carbon tax facilitates government and business decisions about investments and other steps to reduce emissions and thereby reduce the burden of the tax. While the tax will reduce emissions by raising the relative price of more carbon-intensive fuels (and lowering the relative price of less carbon-intensive alternatives), no one can predict the precise extent of those effects for any particular level of carbon tax, and consequently the tax may be set too low to achieve a particular emissions goal in a given year. However, this shortcoming is more easily offset than the price volatility of cap-and-trade. The environmental costs of greenhouse gases occur over a long term, and in principle a government can raise or lower the carbon tax rate year by year to achieve the long-term emissions reductions it seeks. While some proposals for cap-and-trade systems include provisions to reduce price volatility by auctioning or distributing additional permits when permit prices increase sharply, these provisions address the price volatility after it has already occurred and taken a toll on investment. Moreover, the distribution of additional permits in the face of rising prices may also sacrifice much of the environmental benefits of the cap-and-trade system.

A second important difference is that global carbon taxes have generally comparable effects from country to country, while a global cap-and-trade program usually does not. When slow growth or mild weather reduces the energy use and emissions of a country or an industry it will pay less carbon taxes, but in good times or bad times a uniform net carbon tax will impose comparable costs and provide comparable incentives from country to country to develop and adopt climate-friendly technologies and strategies. By contrast, a global cap-and-trade system creates a range of effects and incentives across countries, depending on the base from which it calculates the emissions targets for each country. Once a cap-and-trade agreement determines that a country's emissions should be reduced by a certain percentage relative to its current emissions or to its emissions in a previous base year, the country may be able to meet its target without taking any steps if its economy slows – or it could take serious measures to reduce emissions and still fail to meet its target because its economy is growing faster than normal.

The third important difference is that cap-and-trade programs are more difficult to administer and more vulnerable to evasion, corruption and manipulation than carbon taxes. The administration of a net carbon tax is straightforward: Each country would apply a tax rate to every energy source, which, after counting the country's current energy taxes and subsidies, would produce the global net carbon tax rate. Each country could also collect the receipts using the same mechanisms it relies on for existing energy or business taxes. Under cap-and-trade, each country first has to create a new system to distribute its national cap among its energy-related

industries and their thousands of companies and plants in the form of permits; then it must set up a monitoring system to track energy production at every site before and after permits are traded.

Cheating also poses a more serious problem for cap-and-trade than carbon taxes. While some companies will try to evade their taxes, the government on the other side of the transaction has a strong interest in discovering and stopping it. Under cap-and-trade, if a company fraudulently understates its energy production and emissions so it can sell permits for some of them, the buyer on the other side of the transaction has no incentive to uncover or reveal the fraud. As a result, Yale economist William Nordhaus (2005) has concluded that "cheating will probably be pandemic" under cap-and-trade.

By creating tradable financial assets worth tens of billions of dollars for governments to distribute and monitor among their industries and plants, cap-and-trade programs also introduce incentives to cheat by corrupt and radical governments. Corrupt governments will almost certainly distribute their permits in ways that favour their supporters and understate their actual energy use and emissions. By doing so they can "earn" billions of dollars in hard foreign currencies trading "excess" permits, and in the process undermine the program's environmental goals. A global cap-and-trade program also has no way to prevent radical governments from using such transfers to finance whatever purposes they choose, whether it is education or domestic oppression, foreign assistance or foreign terrorism. Corrupt and radical states can use carbon-tax revenues for such purposes too, but at least the resources come from their own economies.

Given these drawbacks, cap-and-trade's principal attraction appears to be political feasibility. Many environmental activists assume that a global cap-and-trade program is more achievable than global carbon taxes, because much of the world agreed to Kyoto and most people resist higher taxes. On close analysis, the Kyoto agreement is too weak to signify a meaningful consensus for the kind of strict caps needed to address climate change. This disappointing result reflects three major political compromises that eroded most of Kyoto's environmental potential: 1) its exemption for all developing countries, including major greenhouse-gas producers such as China, India and Brazil; 2) its effective exemption for Russia and the Eastern European countries, and substantial leeway for many Western European countries, based on the selection of the base year from which reductions are calculated; and 3) a system of transfers that would have imposed such disproportionate costs on the world's largest economy, the United States (along with Australia and a few others), that it declined to ratify the agreement.

People and companies in every country resist higher taxes. Yet Sweden and Denmark have applied carbon taxes, or their equivalent, and are now among the most

FIGURE 1

US ACID RAIN PROGRAM: ANNUAL PERCENTAGE CHANGE IN CLEARING PRICES FOR SO₂ PERMITS, 1993–2006

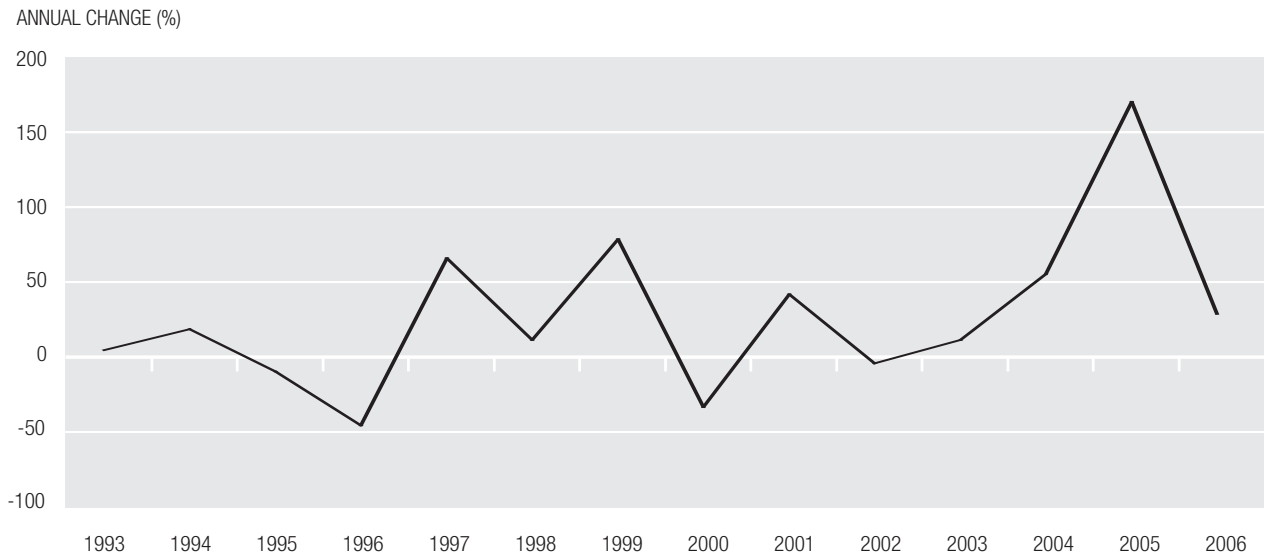
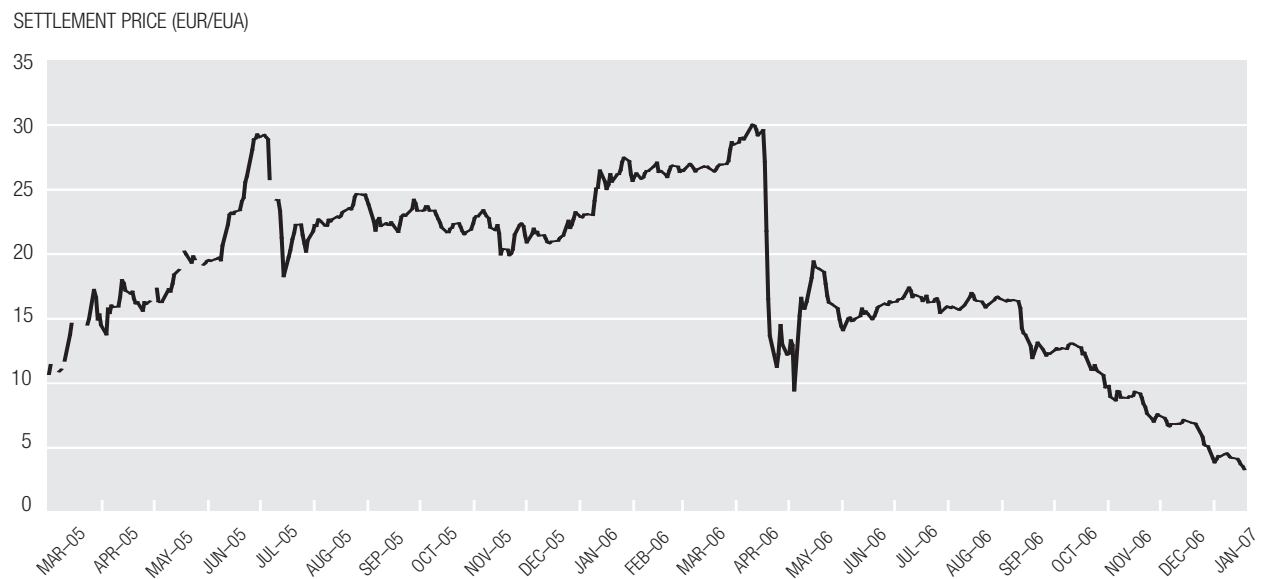


FIGURE 2

EUROPEAN EMISSIONS TRADING SCHEME: DAILY PRICE MOVEMENTS OF CO₂ PERMITS, MARCH 2005–JANUARY 2007



emission-efficient economies in the world. A global carbon tax sufficiently high to affect climate change may also be seen more broadly as politically achievable when governments recognise that they can use its revenues to reduce their existing payroll or corporate taxes or finance popular pension or health-care programs. On balance, if the world community intends to take serious steps to slow and ultimately reverse climate change, the evidence strongly suggests that a global carbon tax would be preferable to a global cap-and-trade system on economic, environmental and even political grounds.

Price volatility

When the world's nations negotiated the cap-and-trade arrangements of the Kyoto agreement in the 1990s, many economists and environmental activists supported the process and its result as a politically acceptable, market-based way of improving the global environment. By the late 1990s, however, researchers identified a number of serious problems with cap-and-trade, and many began to favour carbon taxes as a better alternative. William Nordhaus (2005) recently published a literature review covering recent economic research in this area, and much of the following discussion draws on that review and the research on which it is based.

One serious problem is the well-documented tendency of regulations that directly limit the quantity of something that people need to produce large volatility or swings in the price of what is regulated. A powerful demonstration occurred from 1979 to 1982, when the US Federal Reserve Board shifted from targeting the price of credit (interest rates) to its quantity (monetary aggregates). As demand for credit increased or waned, while the quantity of credit remained strictly regulated, interest rates moved much more sharply than at any time before or after this brief experiment in “monetarism”.

The same price volatility is evident in the leading US instance of a cap-and-trade based environmental regulation, the acid rain program. The program applies cap-and-trade arrangements to major emitters of SO₂ (sulfur dioxide) and NO_x (nitrogen oxide). Recent analysis has found that the trading prices for the SO₂ and NO_x emission permits have ranged from \$66 per ton to as high as \$1,700 per ton, moving up and down by an average of 10 per cent per month and 43 per cent per year, or several times the volatility seen in oil prices or stock-market prices (EPA). Moreover, this volatility has increased in the last three years as permit prices have risen by an average of more 80 per cent a year despite the use a “safety valve” provision under which the US Environmental Protection Agency has auctioned additional permits to temper the volatility.

The European Union’s Emissions Trading Scheme (ETS) for CO₂ emission permits issued under the Kyoto guidelines has also experienced great price volatility. Its permit prices have moved up or down by an average of 10 per cent per month in its first 12 months and 23 per cent per month from March 2006 to January 2007 (European Energy Exchange 2007). From March 2005 to February 2006, permit prices predominantly moved up, increasing by 17 per cent per month in the first four months and an average of 6 per cent per month in the first 12 months. From March 2006 to January 2007, ETS permit prices generally moved down, with average price declines of 23 per cent per month. In contrast to the constant impact of a carbon tax, those sharp declines in permit prices greatly reduce incentives for firms to limit their emissions (IHT 2006).

For this and other reasons, the ETS is failing to reduce overall emissions. In 2005 total CO₂ emissions increased by 0.4 per cent in the EU-25 and by 0.6 per cent among the EU-15, despite the “caps” (European Energy Exchange 2006). Looking ahead, the European Environmental Agency (EEA) projects that the EU is likely to achieve no more than one-quarter of its Kyoto-targeted reductions by 2012, and much of that will reflect credits purchased from Russia or other transitional countries, with no net environmental benefits (Egenhofer, et al. 2006; European Energy Exchange 2006).

Comparable price fluctuations for CO₂ permits under a serious, global cap-and-trade program would have significant economic costs. The largest producers of CO₂

emissions are electricity-generating utilities, especially those powered by high-polluting coal. Under a strict cap-and-trade program, when a particularly cold winter or hot summer occurs or an economy grows faster than trend, CO₂ emissions will rise sharply with electricity consumption. Since the quantity of emission permits would be capped, their price would also rise sharply and be passed on to the consumer as higher electricity prices. The same dynamic would occur in oil and gasoline prices when demand for those fuels rise.

These national-based price movements will not only tend to dampen business investment, especially in energy-incentive areas such as manufacturing, where the additional costs could make the difference between financially acceptable and unacceptable rates of return. More important, unexpected and accentuated energy-price increases publicly linked to a cap-and-trade system could undermine public support for the effort and force governments to roll back or suspend their caps, potentially unravelling the entire program.

Kyoto shortcomings

The Kyoto agreement was signed and ratified by 165 nations, still awaits ratification by two other nations (Croatia and Kazakhstan), and was signed by two more countries that subsequently declined to ratify it (the US and Australia). Despite its broad global support, Kyoto commits only 38 industrialised countries – 36 with the withdrawal of the US and Australia – to take action before it expires in 2012. The agreement covers six emissions – CO₂ (carbon dioxide), CH₄ (methane), N₂O (nitrous oxide), HFC (hexafluorocarbon), PFC (perfluorocarbon) and SF₆ (sulfur hexafluoride).) These 36 countries agreed to achieve specific reductions in their CO₂ and other greenhouse emissions, ranging from 8 per cent below 1990 levels for the EU and 6 per cent below 1990 for Japan, to 10 per cent above 1990 emissions for Iceland. The Kyoto agreement also allows countries and companies to buy and sell rights to produce emissions. Since the cost of reducing emissions differs from plant to plant, industry to industry and country to country, this trading provision creates a market for emission rights that can help to ensure that emission reductions consistent with the overall targets occur where they can be achieved relatively inexpensively.

In addition to price volatility, the Kyoto-based arrangements embody two problems that seriously impair its effectiveness and efficiency, namely, the base year from which its targeted reductions are calculated, and the exclusion of developing nations from the targets. Both aspects were necessary to achieve a political agreement, but together they profoundly weaken the project.

In 1997 the parties to Kyoto designated 1990 as the base year from which it would calculate its 2008–2012 national targets for lower emissions. The choice of 1990 created serious distortions which were well recognised at

the time. First, 1990 was the peak year of economic activity in the Soviet Union and Eastern Europe before their state-directed economic systems unravelled. The World Bank (2006) reports that Russia's economic production slumped from \$385 billion in 1990 (2000 dollars) to \$286 billion in 2002, and its corresponding CO₂ emissions fell from 2.26 million tons to 1.43 million tons. Since Russia's Kyoto target is an 8 per cent reduction from its 1990 levels of 2.26 million tons, the 1990 base year allows Russia to increase its emissions from 1.43 million tons to 2.08 million tons (2.26×0.92) or 45 per cent, and earn an enormous financial windfall by selling its excess tradable permits until its emissions reach that level. According to one estimate, if the 38 nations assigned targets under Kyoto all participated on a strict basis Russia and Eastern Europe could take in about \$40 billion a year (1990 dollars) by selling their excess permits, principally to companies in the US, Australia, Canada and Japan (Nordhaus 2005; Nordhaus and Boyer 2000).

Kyoto's 1990 base year also allows Germany and the United Kingdom, which together account for 80 per cent of the EU-15's targeted reductions, to avoid taking serious steps to reduce their emissions. Following Germany's reunification in October 1990, much of East Germany's out-dated and high-polluting, state-owned industrial plants were dismantled or closed down. As a result, Germany's target of 8 per cent reductions from a 1990 base also became a license to increase emissions. Similarly, the privatisation of British coal mining in 1995 cut coal use in Britain just as its North Sea natural gas operations expanded, allowing Britain to actually increase its emissions and still meet an 8 per cent reduction target calculated from a 1990 base (Aldy et al. 2003).

The 1990 baseline also penalises countries that had already made substantial progress in reducing emissions. The Netherlands, Sweden, Denmark and Japan, which had controlled much of their emissions by 1990, will find it more difficult and expensive to further reduce them and will have to purchase additional permits from Russia and Eastern Europe (Cooper 2001). The Kyoto baseline also penalises the US, Australia, Ireland and few other countries for experiencing strong growth and consequent increases in energy use since 1990 (Canes 2003). For them, the 1990 base year produces 2012 caps which they cannot meet regardless of how much they invest in new technologies and alternative fuels. Instead, they would have to pay Russia and Eastern Europe tens of billions of dollars for their excess permits (Cooper 1998).

Kyoto's prospects for affecting climate change are further undermined by the exemption granted to developing countries, including major sources of CO₂ emissions such as China, India and Brazil. Those and other developing nations agreed to ratify Kyoto only if it imposed no constraints on their economic development, and as recently as 2006 China reiterated its position of never accepting emission caps. These exemptions con-

centrate all of the reductions in 38 countries that produce just over half of all worldwide emissions; with the US and Australian withdrawal, the agreement covers just 30 per cent of global emissions (Nordhaus 2005). The exemptions for developing countries also seriously impair the program's economic efficiency, since about half of the most cost-effective opportunities for reducing emissions would occur as developing economies replace old industrial plant, build new energy infrastructure, and find alternatives to deforestation.

Unsurprisingly, an econometric simulation of the costs and benefits for the world's regions estimates that the benefits will exceed costs only for those countries that are exempt from the costs (Nordhaus 2005). If the US participated, however, it could face net long-term costs of more than \$5 trillion, while Western Europe, Japan, Canada and Australia together would face \$2 trillion in net costs (Aldy et al. 2003).

The designation of those countries subject to Kyoto targets and those which are exempt has no economic or environmental justification. It is not based on a nation's ability to bear the costs, since Kyoto exempts wealthy Middle Eastern states such as Qatar with a per capita GDP of \$43,110, and the United Arab Emirates, Kuwait and Brunei with per capita GDP of more than \$20,000 (World Bank 2006). The exempt countries also include many major producers of greenhouse gases, including several with substantial per capita GDPs such as Singapore, Taiwan, Korea and Hong Kong.

One justification commonly cited is a sense of historical equity – since the developed countries are responsible for most of the current atmospheric stock of greenhouse gases, they should bear the cost. Wealthy countries were largely responsible for the greenhouse gases produced in the 1970s and 1980s. However, by 2002 when Kyoto was approved, six major exempt countries – China, India, Korea, Brazil, Mexico and South Africa – accounted for more than 25 per cent of global CO₂ emissions (World Bank 2006). By 2012, China and those five other large, exempt nations will produce more than one-third of global CO₂ emissions.

The result of the combination of these exemptions and the 1990 base year is that Kyoto will produce little progress on global warming. Even if the US shifted course and participated, and Kyoto's provisions were all strictly implemented and enforced, the program would abate the expected increase in global temperatures between now and 2050 by just 0.02° to 0.28°C (Nordhaus 2005).

The complex trading arrangements of a cap-and-trade program also present problems that tend to degrade its environmental results and increase its costs. Once negotiators determine a global cap and distribute it across the involved nations, each government is free to distribute its nation's permits among its industries and companies as it chooses. Even in a transparent and democratic society, distributing a scarce and valuable benefit through the normal

political process invites pressures that often produce special preferences for influential interests and companies. For example, the German government announced in June 2006 that it would exempt its coal industry, the country's largest greenhouse-gas producer, from its CO₂ caps under the European ETS. In countries without a transparent democratic process – Russia, the Ukraine, and many others – these pressures may go unchecked, and political favouritism and corruption will almost certainly substantially determine how the permits are distributed.

... cap-and-trade programs create new temptations for countries to cheat, because ... "limiting emissions [through caps] creates a scarcity where none previously existed – in essence printing money for those in control of the permits".

The subsequent trading of the permits introduces more problems. To have much effect, a global cap-and-trade program will have to cover hundreds of thousands of installations in scores of countries, and the trades among them will require accurate measurements of the energy production or emissions on both sides of each transaction, before and after the trade. That may be plausible in advanced countries with elaborate, professionalised regulatory systems, but it's considerably less likely in transitional economies such as the Czech Republic and Romania, and frankly implausible in places such as Russia and China. Cap-and-trade systems also have built-in incentives for cheating and corruption, because both buyer and seller can gain by understating their emissions. Even if only the seller cheats by understating its emissions (creating or increasing the permits it can offer for sale), the buyer has no incentive to discover or reveal the fraud.

Finally, cap-and-trade programs create new temptations for countries to cheat, because, as Nordhaus (2005) notes, "limiting emissions [through caps] creates a scarcity where none previously existed – in essence printing money for those in control of the permits". A global cap-and-trade system will include countries ruled by corrupt or radical regimes – as does Kyoto – presumably eager to raise billions of dollars or euros by understating emissions and then trading artificially inflated numbers of excess permits. Under a global-cap-and-trade program, countries such as Iran, Syria and the Sudan might be able to raise international capital by selling permits; and even under Kyoto they can receive credits for clean-energy investments which can be traded like permits to raise funds (Torvik 2002).

Tax relief

The first burden for any tax-based regulatory approach is to minimise its effects on "relative prices", which can make an economy less efficient. The gist of this issue is that whatever is taxed becomes more expensive relative to what remains untaxed, so what consumers and corporations buy and use is no longer determined simply by prices reflecting the costs to produce them. Since taxes of some kind are unavoidable the challenge is to design them so they distort these relative prices as little as possible. Part of the answer is to make the base of the tax broad, so its rate can be low and most people and activities are affected equally. Carbon taxes generally meet this criterion, although not as well as broad income or consumption taxes. Moreover, the economic drawback of raising the price of carbon-intensive products and operations, relative to those which are not, is the environmental purpose of a carbon tax.

Further, a close analysis shows that these traditional concerns about efficiency effects are largely moot for carbon taxes. Efficient markets and correct relative prices depend on a close correspondence between the prices of goods and services and the total costs to produce them. However, economists have long recognised that the pollution created by the production and use of fossil fuels is a cost not captured in the prices of these fuels. These "externality" costs fall on those who happen to live or work close to where the fuel is produced or used, usually in the form of higher health care costs. In the case of greenhouse gases and climate change these costs are borne by almost everyone, but again based not on how much fuel a person uses but on where he or she lives.

A carbon-based tax could capture the externality costs of those pollution emissions and embed them in the market price of fuel, creating what economists call a market-perfecting Pigouvian tax (after Arthur Pigou, the English economist who first wrote about these issues). Using a Pigouvian tax that raises the price of a fuel to reflect its externality costs should improve economic efficiency by better aligning the relative prices of things with all of their costs, especially if the revenues were used to offset the costs borne by those subject to its pollution. While we do not know what precise level of carbon tax would capture all of these costs, a tax which embeds a significant part of those costs should improve the efficiency of prices.

Another economic issue is the degree to which a carbon tax would focus environmental improvements where they can be achieved most cheaply or efficiently. Cap-and-trade programs achieve this by using tradable permits, at least in principle. Carbon taxes also can achieve this form of economic efficiency and without a cumbersome trading mechanism susceptible to base-year distortions, exemptions and cheating. The tax would raise the price of carbon-based energy in proportion to its carbon content, so that countries and companies which can reduce their carbon emissions for less than the incremental cost of the tax can be expected to do so, while those which find that reducing emissions would cost more than the tax will pay it. The

consequent reductions in emissions should be greatest where the costs of achieving them are lowest, within each country and worldwide. Carbon taxes should also create more reliable incentives for companies to develop environmentally-friendly technologies or abatement strategies. The tax would provide “a continual incentive to reduce the costs of carbon abatement”, as one expert has put it (Chupka 2001), because the permanent increase in the cost of carbon-intensive energy would raise the rate of return on the development and use of technologies that reduce the consumption of those forms of energy.

Administrative ease

A global carbon tax regime would still present serious challenges. Significant CO₂-producing countries have to agree on what is to be taxed, the rate, and how to treat other taxes and government spending that may reduce or increase the effective burden of a carbon tax for particular industries. However, it would be unrealistic to expect governments to strip their budgets and tax codes of all preferential treatment for energy companies or energy-intensive manufacturers. Instead, the agreement could set a uniform net carbon tax for countries and create an arbitration body to determine each country's current net carbon tax burden based on its existing fuel-related subsidies, taxes, credit programs and other preferences, plus the additional tax required to achieve a roughly uniform carbon tax level (Victor 2001). These issues are complicated, but technically manageable. The International Monetary Fund (IMF) could review these net carbon tax burdens as part of its annual consultations with countries about their macroeconomic and fiscal policies (Cooper 1998). Panels of experts could resolve technical disagreements on the model of the panels that resolve technical issues in trade disputes before the World Trade Organization.

Once the terms of the tax are established, most countries would apply it at the points where energy is generated or distributed, based on the fuel's carbon content, much as caps and permits are usually distributed at such points. In other respects a carbon tax should be relatively simple and inexpensive to administer and enforce. While cap-and-trade requires additional administrative systems and structures to allocate the permits and monitor their subsequent trades every government has a tax system in place already, and most of them already tax energy.

For all of these reasons a carbon tax regime should be more environmentally effective and less economically disruptive than a cap-and-trade program. This expectation is supported by recent econometric modelling that compared the impact on CO₂ emissions of the Kyoto version of cap-and-trade with and without US participation, and a hypothetical global carbon tax which limited CO₂ concentrations to twice their pre-industrial levels by 2075 (Nordhaus 2005). By 2025 the hypothetical carbon tax would reduce worldwide CO₂ emissions by 17 per

cent compared to their 1990 levels, while Kyoto could reduce those emissions by 12 per cent with US participation and by 3 per cent without the US. By 2045, the carbon tax would bring down emissions by 30 per cent from their 1990 levels, while Kyoto would produce reductions of 15 per cent with US participation and still 3 per cent without the US. By 2075, the hypothetical carbon tax would reduce emissions by fully 40 per cent compared to their 1990 levels, while Kyoto could achieve only a 16 per cent reduction with US participation and less than 4 per cent without it.

Overseas results

In 2005 New Zealand proposed a carbon tax, scheduled to take effect in April 2007, but reversed course in December 2005 after elections increased the influence of minor parties supporting the government but opposed to the tax. Sweden and Denmark have had substantial carbon taxes in place since the early 1990s. While all Western European countries impose significant taxes on gasoline and other transportation fuels, only Denmark and Sweden also apply them to carbon-based energy used by industry. In 2000 their taxes, respectively, were \$67 and \$64 (PPP \$) per ton of CO₂ for coal in industrial uses and \$72 and \$52 per ton of CO₂ for diesel, oil and other fuels used for industrial purposes (Baranzini, Goldenberg and Speck 2000). By contrast, Germany, the UK, Australia, the US and most other advanced economies imposed no taxes on coal used for industrial purposes and modest taxes on other fuels used by industry.

These tax differences play a significant role in differences in their relative emissions. For each dollar (PPP) of GDP, the Swedish economy in 2003 generated 0.221 kg of CO₂ and the Danish economy 0.301 kg of CO₂, compared to an average of 0.460 kg of CO₂ for all high-income OECD economies, 0.380 kg of CO₂ per dollar of GDP in Germany, 0.353 kg in Britain, 0.604 kg in the US and 0.717 kg in Australia (World Bank 2006). These results confirm the vast body of analysis and evidence that carbon-based taxes are a highly effective way to reduce and control greenhouse gas emissions.

The evidence from cap-and-trade systems is less encouraging. The chief example, the ETS, is expected to show little genuine progress on European emissions. As noted earlier, among the EU-15, total CO₂ emissions actually increased by 0.6 per cent in 2005. Nor are the signs heartening for the 2008–2012 Phase 2 of the ETS. As of December 2006, 11 of the EU-25 had failed to submit completed plans for Phase 2 (EU 2006), and analysts found that among those that did comply, most projected higher base emissions than most independent analyses in order to reduce their future burdens (Rathmann, Reece, Phylipsen and Voogt 2006). Further, Climate Action Network Europe, the region's leading umbrella group for environmental organisations, has found that many ETS members have little capacity to monitor or verify the energy

use or emissions of those who hold permits (Rathmann et al. 2006). Finally, as also noted earlier, the EEA has projected that the entire ETS effort is likely to achieve no more than one-quarter of the EU's Kyoto-targeted reductions by 2012 (EEA 2006), with much of those "reductions" reflecting credits purchased from Russia or other countries outside the EU with no net environmental benefits.

Conclusion

As the risks of climate change continue to grow, few countries seem prepared to pay a significant price to reduce their greenhouse gas emissions. The Kyoto agreement was achieved only after ensuring that most nations would pay little or no price for many years, ultimately producing little progress on climate change. The EU's Emissions Trading Scheme, based on the Kyoto targets, will likely achieve even less. Moreover, there are powerful reasons to doubt that a better-designed cap-and-trade system could effectively control global greenhouse gas emissions. The world's major CO₂-producing, developing countries, including China and India, have vowed never to join a cap-and-trade regime. Its complex administrative mechanisms and internal incentives are likely to produce substantial cheating by both companies and some governments. Perhaps most important, the energy-price volatility likely to arise in countries that strictly enforce genuine caps on their emissions could rapidly undermine public support and unravel the system. On balance, an alternative approach based on global, harmonised net carbon taxes, can better contain the risks of climate change, and do so in an economically efficient and politically feasible way.

The task is to persuade the world's major energy producing and consuming countries to adopt harmonised carbon taxes. The first step of simply expanding the public debate to include rigorous environmental and economic analyses of the advantages and disadvantages of carbon taxes and a cap-and-trade regime will be challenging. The current US Congress and President oppose higher energy taxes. On the other side of the world, the Australian Government recently issued a task force report, concluding that emissions trading would be preferable to carbon taxes, but it failed to address the current results from the European Trading Scheme, the environmental effectiveness of Scandinavian carbon taxes or the growing economics literature on the subject (Australian Government 2007). The importance of these matters for every country deserves serious and dispassionate analysis.

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managing price AND

targets

Why a hybrid policy is better for Australia



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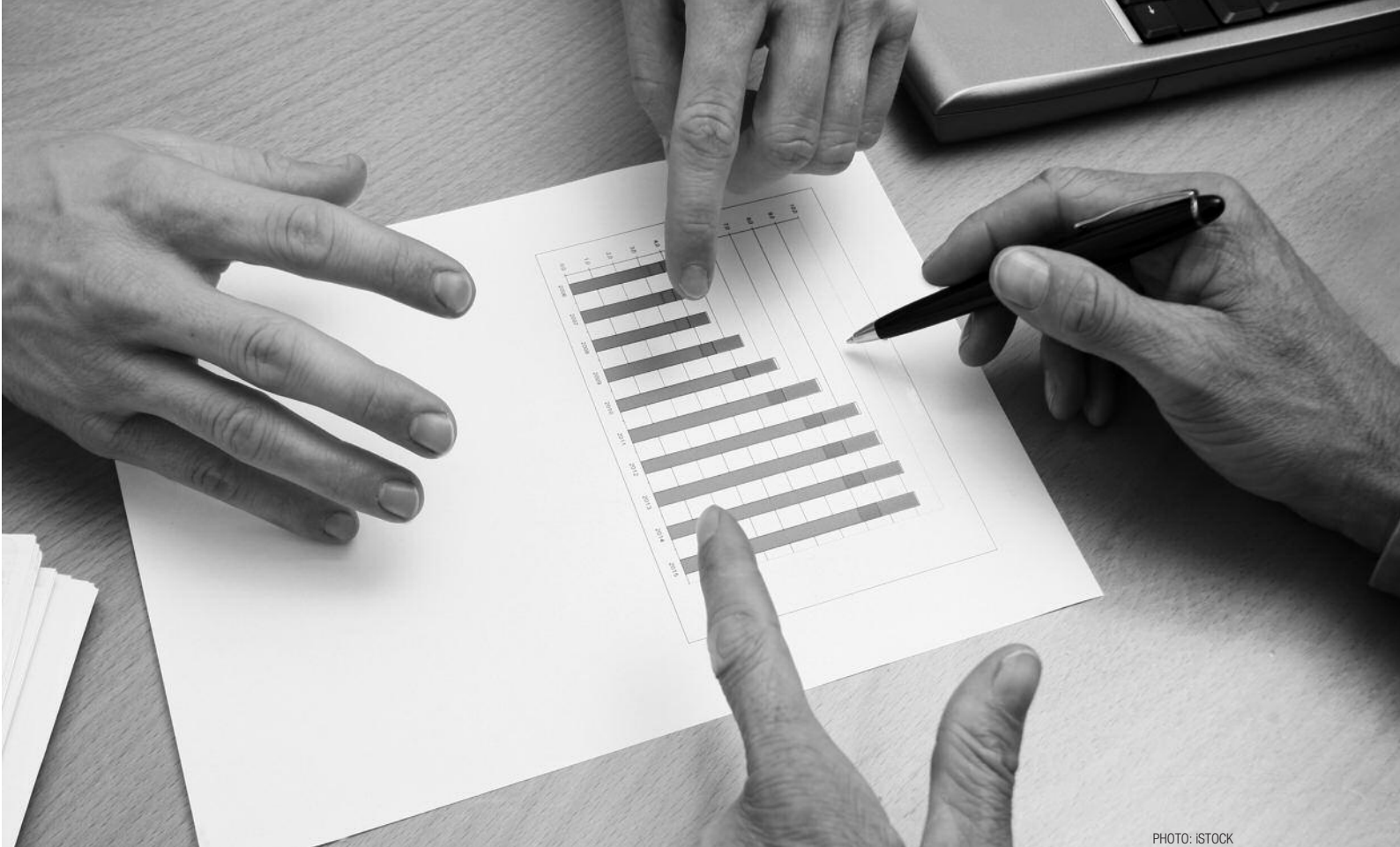


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and use of large-scale intertemporal general equilibrium models. He is a co-author of the Jorgenson-Wilcoxon model, a 35-sector econometric general equilibrium model of the US economy that has been used to study a wide range of environmental, energy and tax policies. He is also a coauthor of G-Cubed, an eight-region, twelve-sector general equilibrium model of the world economy that has been used to study international trade and environmental policies. He has published more than 50 papers and has co-authored two books: one with Warwick McKibbin on the design of an international policy to control climate change, and one with Peter Dixon, Brian Parmenter and Alan Powell on the design and construction of large-scale economic models. Dr. Wilcoxon's past positions include: Associate Professor of Economics, the University of Texas at Austin; Assistant Professor of Economics, the University of Texas at Austin; Visiting Fellow, the Brookings Institution; Visiting Scholar, Harvard University; and Senior Research Fellow, the University of Melbourne in Australia. His research has been funded by the Environmental Protection Agency, the Department of Energy, the US Geological Survey, and the National Science Foundation.

Summary

Promising to reach an emissions target on a precise timetable is a popular approach to climate policy – indeed it underlies the Kyoto Protocol. Despite its popularity, there are many problems with this strategy. A better approach is to specify a target but to allow costs to determine the speed at which the target is approached. This can be achieved using a hybrid of targets and emission fees. This paper summarises the targets and timetables approach to climate policy and how it is usually implemented in cap-and-trade permit markets. However, as a basis for domestic policy or for an international climate regime there are major flaws in this approach. We then present the McKibbin Wilcoxon hybrid approach and compare it to the approach proposed by the Prime Minister's Emissions Trading Task Group.

Introduction

Climate change is caused by anthropogenic emissions of greenhouse gases, principally carbon dioxide, and addressing it will require those emissions to be reduced over time. Many people believe that the best way to reduce greenhouse gas emissions is to specify a target for emissions and a timetable for reducing those emissions. This “targets and timetables” approach seems like common sense and, until recently, has been the basis of most of the climate policy debate in Australia and internationally. The Kyoto Protocol, for example, requires that participating countries achieve specified emissions targets over the period 2008–2012. Unfortunately, many aspects of the targets and timetables approach that look so attractive in theory do not work well in an uncertain world.

Setting targets and timetables seems like commonsense because it's a familiar approach that works well in many day-to-day situations. When driving from one part of the country to another, for example, it's natural to set goals for each day's drive. These goals are achievable because of the relative certainty of the driver's information. As a climate policy, however, a targets and timetables strategy is flawed because climate change involves vast uncertainties, especially in the cost of reducing emissions. Any significant climate policy is largely a venture into unknown territory. Establishing a set of emissions targets to be achieved by specific dates makes no more sense than deciding to drive through a sequence of cities on particular dates without a map, and without knowing the distance between the cities or the obstacles that may lie along the way.

The initial step in a targets and timetables program is to establish a sequence of emissions targets and set a timetable over which the former will be achieved. Once the targets have been adopted there are a number of policies that could be used to achieve them: subsidies for emissions-control devices; direct intervention such as mandating the use of particular devices or technologies for controlling emissions; an appropriate emissions tax; or creating markets in emissions rights based on the target. Economists generally agree that a market-based approach is the lowest cost way to implement an emissions target. In recent years much attention has been focused on so-called cap-and-trade mechanisms, under which total emissions are capped but firms are permitted to buy and sell emissions allowances among themselves. The cap-and-trade approach has many attractive features for conventional pollutants, but it has important liabilities for climate policy. In particular, it does not work well in a world of uncertainty.

In this paper we argue that there is a much better approach to climate policy, one that addresses the inherent uncertainties and provides credible, long-lasting incentives for reducing emissions. It is a hybrid approach that combines the best features of two market-based mechanisms used for controlling other kinds of pollution – emissions taxes and tradable permits.

The second section of this paper, "Policy risks", summarises the reasons climate policy is difficult to formulate and why uncertainty must be at the core of policy design. The following section, on carbon trading, outlines the standard way of implementing the approach of targets and timetables in the form of cap-and-trade emissions trading. The problems with the cap-and-trade approach are outlined in the next section titled "The hybrid blueprint", where it is argued that the appropriate short-term policy for Australia is to abate emissions up to a particular cost, rather than to hit a particular emissions target. This can be done via a hybrid of a permit trading system based on long-term permits and a price-based system with a short-term price cap. In the final section we summarise how a hybrid approach could work in Australia and

compare the approach we proposed (McKibbin and Wilcoxon 2002) with the approach of the Prime Minister's Task Group on Emissions Trading (2007).

Policy risks

Designing a viable and effective climate policy is very difficult for a number of reasons. First, climate change cannot be entirely prevented, even if worldwide emissions were to cease immediately. The accumulated greenhouse gases from past emissions, largely from industrialised economies, would continue to raise global temperatures for decades to come. Thus, a comprehensive response to climate change will require both mitigation actions – to reduce emissions and decrease the severity of climate change – and adaptation policies to respond to climate change that can no longer be prevented. Second, climate policy is complicated by the extraordinary range of emissions sources, from individuals to major corporations. Third, it is a policy that must cross many jurisdictions – international organisations, national, state and local governments – which makes formulating and coordinating the policy extremely difficult. Fourth, the time scales for climate policy are much longer than most other policy problems. Policies enacted today may not have noticeable effects on the climate until 50 years or more into the future. Finally, the uncertainties surrounding climate change are large, numerous and mostly intractable. There is uncertainty about future emission levels, the impact of these emissions on future carbon dioxide concentrations, how those concentrations affect the timing and extent of temperature change and climate variability (and distribution across regions), what impacts these temperature changes and variability have on ecological systems and the extent of economic damages and economic benefits in different regions at different times. Most difficult of all, climate change could lead to large changes in sea level and other catastrophic events, but the likelihood of these catastrophes is both low and poorly understood. Formulating a policy to reduce the chance of rare but disastrous events is especially challenging.

What should be done given the uncertainty? Fortunately, the conceptual techniques for understanding uncertainty and managing risks are well developed, and they should be at the core of any climate policy. Climate policy should be designed to manage risks, especially taking into account the unusual nature of the risks associated with climate change. For example, the possibility of catastrophic outcomes from climate change needs to be taken into account. It is also necessary to make sure that the costs of mitigation actions are not excessive because there are many other problems competing for society's scarce resources, such as alleviating poverty or controlling preventable diseases. Important trade-offs are involved, hence it is essential to take into account the opportunity cost of the actions taken in policy.

FIGURE 1
PERMIT MARKET EQUILIBRIUM IN LOW- AND HIGH-COST CASES

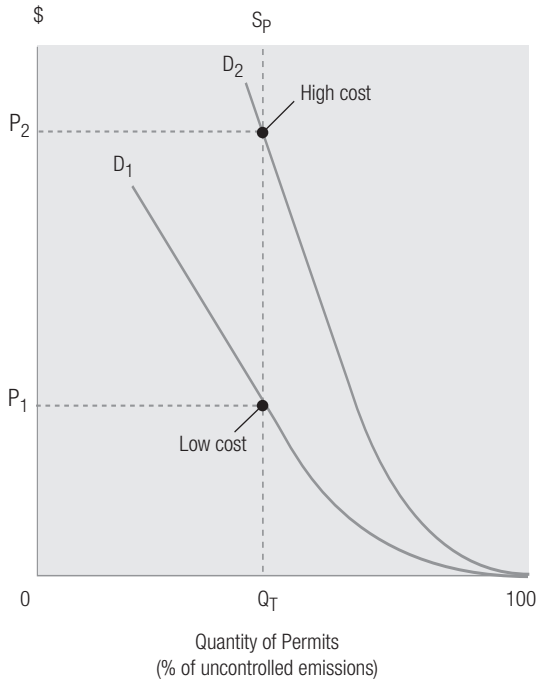
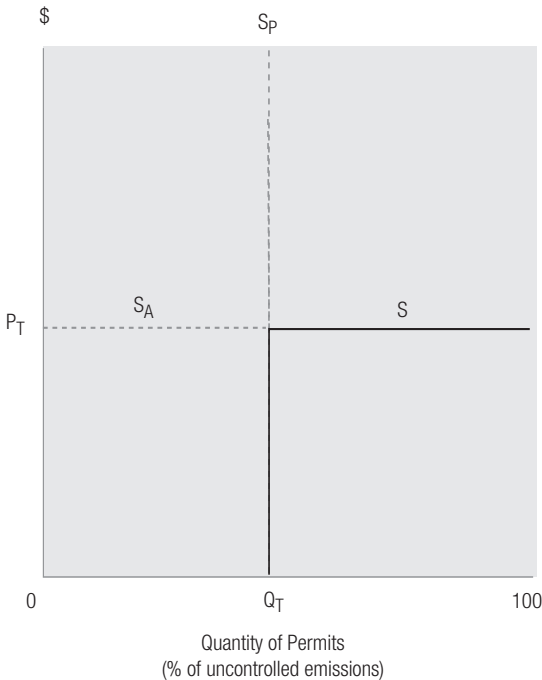


FIGURE 2
SUPPLY OF EACH TYPE OF PERMIT FOR USE IN A GIVEN YEAR



Carbon trading

The idea behind a cap-and-trade permit system is relatively straightforward. A target for emissions is chosen for a given year. Emission permits are then printed and distributed for that year. Legislation is also enacted that requires an emitter of carbon to have permits equal in number to its emissions,

and to specify rules for monitoring polluters and punishing violators (for example, the penalty for non-compliance is often a very high fee). Figure 1 illustrates the resulting market for permits. With a cap on emissions fixed at quantity Q_T , market trading will result in a price that depends on the demand for permits. The demand for permits, in turn, will depend on the marginal abatement costs. The higher the marginal abatement costs, the higher the demand for permits at a given price. In Figure 1, if abatement costs are low the demand for permits will be low. The demand curve might look like D_1 , and the price that the market generates will be P_1 . However, if the marginal abatement costs are relatively high the demand for permits will be given by curve D_2 .

This is a conventional cap-and-trade permit trading system. The strength of the system is that the emissions outcome is known and specified explicitly in the policy: it is the target Q_T . However, the price of an emissions permit (often called the price of carbon) will not be known until after the market clears. Moreover, it will move around with shifts in the demand for permits, and can be highly variable. A conventional permit system works well if there is a clear target that needs to be achieved, such as with a “threshold pollutant” that causes damage only when it exceeds a particular level. In this case the way to reduce risk sharply is to set a clear emission target that is not to be exceeded under any circumstances. However, the system does not work well for pollutants that don’t have thresholds, such as carbon dioxide. For such pollutants there is no clear distinction between safe and dangerous levels; all emissions contribute equally to the problem.

Moreover, what matters for the climate is the concentration of emissions in the atmosphere. It is not the flow of emissions each year but rather the accumulation of these emissions over time that is important. As a result, it is important to achieve any given amount of abatement as cheaply as possible over time. Reaching a precise target at high cost in one year and then achieving the same target at low cost in another year would be inefficient because it is the sum of emissions in the two years that matters. It would be better to do more abatement in the low-cost year and less in the high-cost year. A conventional carbon-trading market performs poorly in this context because it targets the annual flow of emissions rather than the stock. A better policy would be to have a flow of emissions each year that is determined in a manner allowing for cost-smoothing over time. As will be discussed below, the hybrid approach allows exactly that.

Climate scientists generally agree that if global temperatures are to be stabilised there needs to be a substantial reduction in the flow of emissions. Deep cuts in emissions are required to stabilise temperatures. This is why many of the proposed reductions in emissions are quite steep – perhaps as much as 60 to 80 per cent reductions in the flow of emissions by 2050.¹

The hybrid blueprint

A hybrid approach to pollution control, which would combine the best features of emissions taxes and tradable permit systems, was first proposed by Roberts and Spence (1976). A hybrid policy for climate change was first introduced by the authors of this paper in 1997 and has been extended and refined (McKibbin and Wilcoxon 2002, 2007). The hybrid we described back in 1997 was relatively simple. A country wishing to control its carbon emissions would issue a limited number of tradable long-term emissions permits, each of which would entitle the owner to emit one ton of carbon per year. A polluter emitting more than its permit holdings in any given year would be required to pay an emissions fee per ton of carbon in excess. In essence, the policy would present polluters with two mechanisms for compliance: buying permits or paying an emissions tax (or any combination of the two). The emissions fee is often referred to as a “safety value” because it would ensure that the costs of complying with the policy were not excessive. The idea of a safety valve has been adopted in the domestic debate in the United States.² We subsequently refined the proposal into a unified permit system with two classes of permits: the long-term permits described above, and short-term permits good only for one year and sold by the government for a stipulated price. In addition, the approach was extended to allow for differentiation between developed economies by imposing a tight and tightening constraint on developed economies over time but a loose and tightening constraint on developing countries, and adapted to provide stronger incentives for technological innovation.

All versions of the approach would provide a foundation for a global system of emissions control, but the emphasis would be on coordination of national policies rather than on imposition of an overarching international regime. Coordination would focus on achieving a common world price for carbon rather than implementing a rigid system of targets and timetables. An advantage of this approach is that it would build the global system by starting at national level in a few countries and adding greater coordination and additional countries over time. Moreover, it would not require global consensus and would allow individual countries scope to tailor the policy to meet their own national interests. Most importantly, establishing clear, credible policies at the national level will be essential for encouraging the private sector investments in key energy infrastructure that will be needed to address climate change.

Our approach, which we will refer to as the McKibbin-Wilcoxon Blueprint (MWB), has been widely discussed and extensively refined over the last decade. Moreover, elements of it have been adopted in many alternative proposals.³ In the remainder of this section, we present a synopsis of the current version of the MWB proposal.

Long-term permits

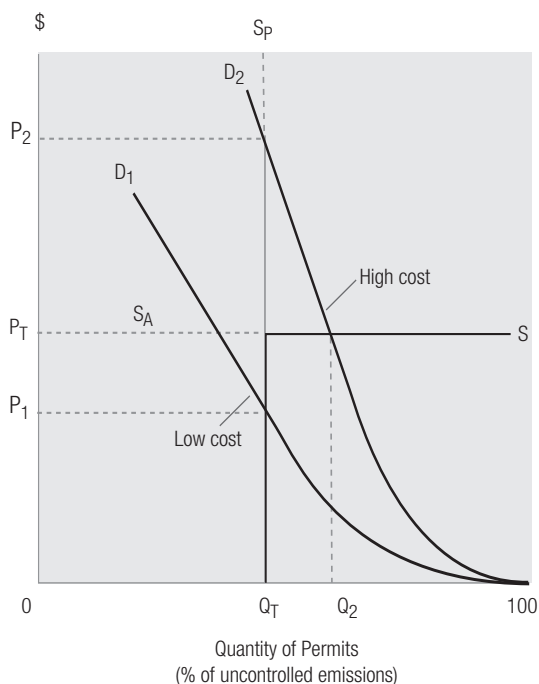
The core of the proposal is to combine a fixed (and declining) supply of long-term permits with a flexible supply of short-term permits that would be valid for only a single ton of emissions in a specified year. For convenience we'll refer to the different types of permits as long-term permits and annual permits. The long-term permits can be thought of as a bundle of short-term permits with differing dates, all packaged together. These long-term permits represent the long-term target for emissions. In practice, the number of long-term permits issued would be less than current emissions and would be declining over time, reflecting the desired target path for emissions. Once issued, the long-term permits could be bought, sold or leased without restriction and each one would allow the holder to emit a pre-specified amount of carbon per year. There would only be a one-off allocation of long-term permits. They could be given away, sold at a set price or auctioned. After the allocation the permits could be traded among firms and households, or bought and retired by environmental groups. Only those activities that emit carbon would require an acquittal of permits at the end of each calendar year. However, anyone could own the permits. The permits would have value because: (1) by law, emitters are required to have an annual permit and there would be fewer available than needed for current emissions; and (2) the number of permits would be diminishing over time, increasing their scarcity value. As a consequence, the owners of long-term permits would form an interest group with a large financial stake in the success of the policy. They would improve the policy's credibility because a large private-sector group with a clear financial interest in the policy would help prevent future governments from weakening or repealing it.

Short-term permits

The other component of the policy, annual emissions permits, would be issued by the government each year for a specified fee, such as \$20 per ton of carbon dioxide. There would be no restriction on the number of annual permits sold, but each permit would be good only in the year of issue. The annual permits give the policy the advantages of an emissions tax: they provide clear financial incentives for emissions reductions but do not require governments to agree to achieve any particular emissions target regardless of cost.

Every year emitters within the country would be required to hold a portfolio of permits equal to the amount of carbon emissions they produce. The portfolio could include any mix of annual permits, long-term permits owned outright by the firm, or long-term permits leased from other permit owners. The implications of this can be seen in Figure 2, which shows the supply of permits available in any year. At a price below P the market price of permits is flexible and determined by demand, given the supply of long-term permits. Once the price rises above P_T

FIGURE 3
MARKET EQUILIBRIUM IN LOW- AND HIGH-COST CASES



the market price is determined by the government cap and the supply of annual permits. Figure 3 shows why this is important. If the marginal cost of abatement is low the market delivers a price of P_1 . If the demand for permits is high, because it is costly to reduce emissions in the given year, then the price is bounded by P_T .

Investment incentive

Although the policy is more complex than an emissions tax or conventional permit system, it would provide an excellent foundation for large, private sector investments in capital and research that will be needed to address climate change. To see why, consider the incentives available to a firm after the policy has been established. Suppose the firm has the opportunity to invest in a new production process that would reduce its carbon emissions by one ton every year. If the firm is currently covering that ton by buying annual permits, the new process would save it \$20 per year every year. If the firm can borrow at a 5 per cent real rate of interest it would be profitable to adopt the process if the cost of the innovation were \$400 or lower. For example, if the cost of adoption were \$300, the firm would be able to avoid buying a \$20 annual permit every year for an interest cost of only \$15. Adopting the process, in other words, would eliminate a ton of emissions and raise profits by \$5 per year.

Firms owning long-term permits would face similar incentives to reduce emissions, because doing so would allow them to sell their permits. Suppose a firm having exactly the number of long permits needed to cover its emissions faced the investment decision in the example

above. Although the firm does not need to buy annual permits, the fact that it could sell or lease un-needed, long-term permits provides it with a strong incentive to adopt the new process. At a cost of adoption of \$300, the firm could earn an extra \$5 per year by borrowing money to adopt the process, paying an interest cost of \$15 per year, and leasing the permit it would no longer need for \$20 per year.

The investment incentive created by a hybrid policy increases with the annual permit fee. For example, raising the fee from \$20 to \$30 raises the investment incentive from \$400 to \$600. That makes sense: if emitting a ton of carbon becomes 50 per cent more expensive every year, the amount a firm would pay to avoid that cost should rise by 50 per cent as well. Raising the annual fee even further would continue to increase the incentive in proportion, provided that the policy remains credible: a \$40 fee generates an \$800 investment incentive; a \$50 fee generates a \$1,000 incentive; and so on.

The critical importance of credibility becomes apparent when considering what would happen to these incentives if firms are not sure if the policy will remain in force. If the policy were to lapse at some point in the future, emissions permits would no longer be needed. At that point any investments made by a firm to reduce its emissions would no longer earn a return. The effect of uncertainty about the policy's prospects is to make the investments it seeks to encourage more risky. Firms will take that risk into account when evaluating climate-related investments and will be willing to pay far less to undertake them as a result. Consider the same investment that would save a firm \$20 a year if the policy is in force, but now suppose the firm believes that there is a 10 per cent chance each year that the policy will be repealed. That may sound like a small erosion of credibility, but it can be shown that it reduces the maximum amount the firm would be willing to pay for the innovation from \$400 to only \$133. The drop in credibility – from 100 per cent confidence in continuation of the policy to 90 per cent – reduces the incentive for investment by two-thirds.

Policy stability

Since the incentives created by the policy increase with the price of an annual permit, a government might try to compensate for low credibility by imposing higher annual fees. For example, suppose a government would like a climate policy to generate a \$400 incentive for investment but firms believe that there is a 10 per cent chance the policy will be abandoned each year. For the policy to generate the desired incentive, the annual permit price would have to be \$60 rather than \$20. That is, the stringency of the policy (as measured by the annual permit fee) must *triple* in order to offset the two-thirds decline in the incentives arising from the policy's lack of credibility. In practice the situation is probably even worse. Increasing the policy's stringency is likely to reduce its credibility further, requiring even larger increases in the annual fee.

FIGURE 4
EMISSIONS AND LONG TERM PERMITS IN AUSTRALIA

EMISSION / ALLOCATIONS

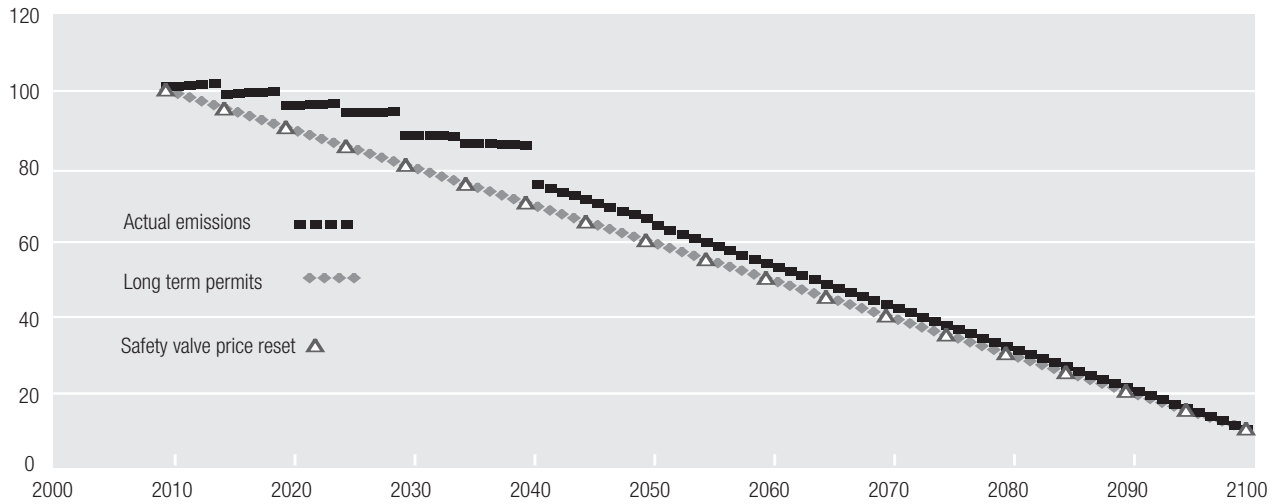
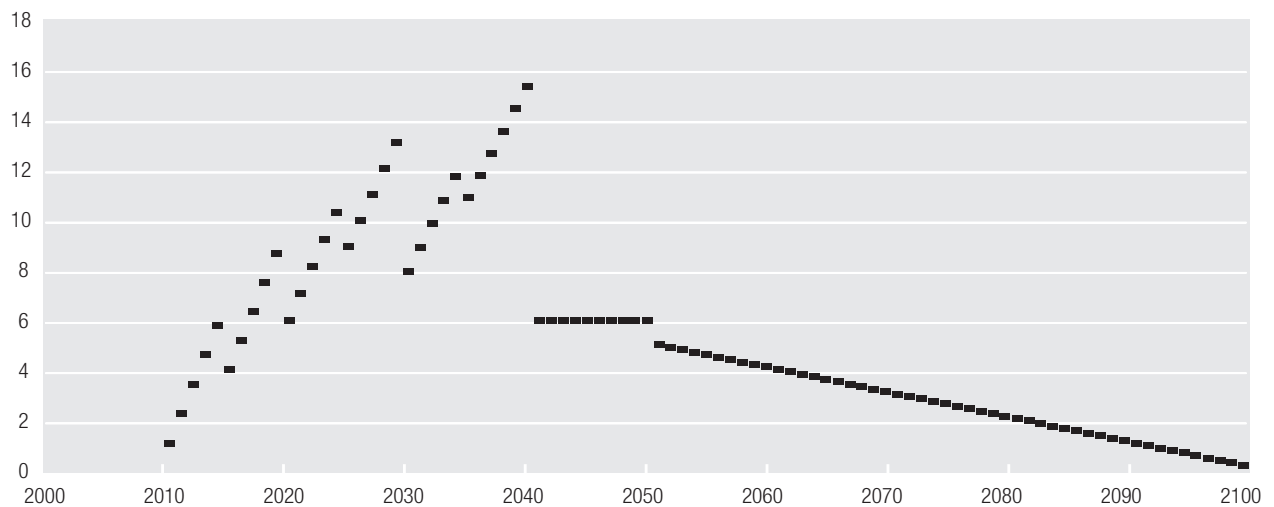


FIGURE 5
ANNUAL PERMIT SALES – AUSTRALIA

EMISSIONS ABOVE TARGET



For example, suppose investors believe it is probable that the government will abandon the policy rises by 1 per cent for each \$20 increase in the annual fee. In that case, maintaining a \$400 investment incentive would require an annual fee of \$70 rather than \$60, which would be accompanied by an increase in the perceived likelihood of the policy being abandoned from 10 to 12.5 per cent. The general lesson is clear and vitally important to the development of an effective climate policy: a modest but highly certain policy generates the same incentives for action as a policy that is much more stringent but less certain. A hybrid policy with a modest annual permit price would generate larger investment incentives than a more stringent, but less credible, emissions target imposed by a system of targets and timetables.

In summary, a hybrid policy combining a fixed supply of tradable long-term emissions permits with an elastic supply of annual permits would be a viable and efficient long-term climate policy at the national level. It would be more credible than many alternatives, especially a carbon tax, because it builds a political constituency with a large financial stake in preventing backsliding by future governments. It thus addresses the inherent difficulty that a democratic government faces in binding future governments to continue carrying out the policy. At the same time, the provision for annual permits allows the hybrid to avoid the inefficiencies and political hurdles that would arise with a conventional system of permits that imposed a rigid cap on emissions. It would provide a strong foundation for investment decisions by the

FIGURE 6
ANNUAL PERMIT PRICE

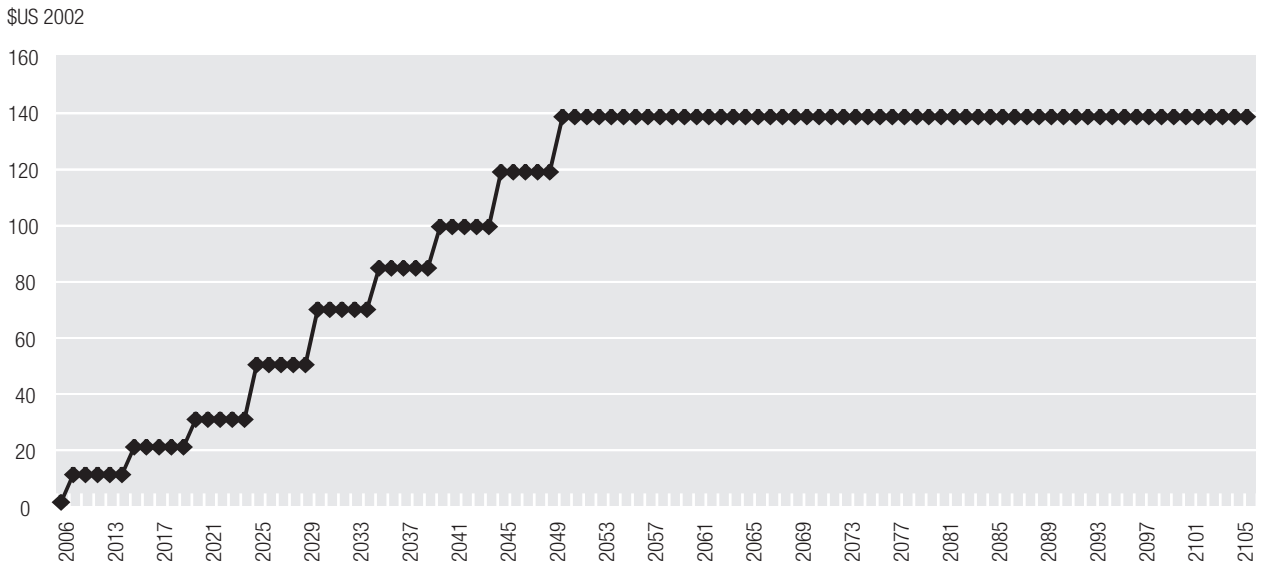
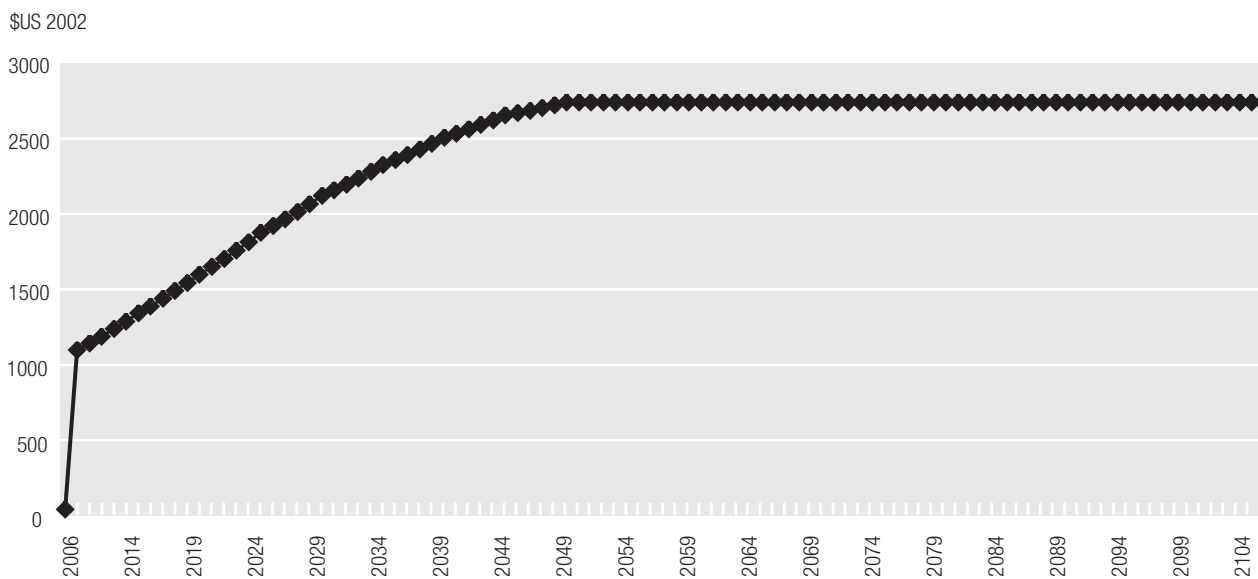


FIGURE 7
STYLISTED VALUE OF LONG-TERM PERMITS



private sector because it would create credible, long-term returns for reducing greenhouse gas emissions.

To illustrate how this would work in practice, one possible scenario is illustrated in Figures 4 through 7. In Figure 4, the diamond line shows a long-run emissions target with emissions normalised to 100 in 2010, then declining to 60 units by 2050, and to 10 units by 2100. This target is also the quantity of long-term permits that are issued in 2010 with each long-term permit giving an equivalent annual permit allocation that diminishes over time. The actual emissions in this scenario might look like the broken line above the target path. The curve implies that the price cap was reached in most years and

annual permits were issued (since the curve lies above the diamond line). The extent of annual permit sales is shown in Figure 5. Figure 6 shows the path of annual permit prices in this particular scenario. The safety valve price in this scenario has been set to follow a step pattern: increasing every five years but constant between the revisions. The price gradually ratchets up until the long-term target is achieved. Figure 7 shows the value of long-term permits each year. This is the expected future value of annual permit prices. It is clear that even a low initial price, when combined with a rising expected future price, can create a valuable long-term permit. This, in turn, creates significant wealth in the present from activities that will reduce carbon emissions in the future.

Carbon trading in Australia

One of the problems of a cap-and-trade permit trading system is that it requires a careful calculation of the cap. Setting a very tight target could, over time, lead to excessive costs being incurred. Setting too loose a target could, over time, result in excessive emissions and a missed opportunity for rapid, low-cost emission reductions. In determining the optimal target for Australia one option would be to use the percentage reduction in global emissions advocated by the Stern Review. However, this approach is likely to be sub-optimal when costs are taken into account. Numerous studies comparing marginal abatement costs show that Australia is relatively high on the list (that is, it has relatively high marginal abatement costs).⁴ Under a global targets and timetables system, international permit trading is usually advocated as a way for high-cost countries to reduce their costs by buying emission reductions from low-cost countries. As a result, the marginal costs of the reduction would be equalised across participating countries. Although marginal costs will be equated, different countries might undertake very different emissions reductions. This key point seems to be ignored in the current policy debate on what unilateral actions countries such as Australia should take, which seems to presuppose equal percentage reductions.

One way around this dilemma is to choose a target without a specific timetable and focus on capping the short-term costs to the economy. This is the approach of the MWB. The long-run target is implemented in the long-term permit market. The cost of getting this calculation wrong in any particular year is limited by the operation of the safety valve, under which the government can print annual permits as needed to cap the short-run price. In a conventional cap-and-trade system the government does not have this capacity and cannot easily smooth out short-run difficulties in achieving the target over time. The only way around this problem is to set a short-time horizon for the emissions target and then renegotiate the target frequently through time. This is indeed the Kyoto strategy. The problem with this approach, however, is that it does not give clear or credible signals about future carbon prices, especially beyond the period of the commitment.

The PM's Task Group

Another approach has been proposed in the recent report by the Prime Minister's Task Group on Emissions Trading (2007). This report is a wide-ranging assessment of climate policy and is far more detailed than the MWB, although the basic idea is the same; that is, to tackle the climate problem by setting a long-run target with a flexible timetable and a short-run safety valve focused on minimising costs through time. However, there are some significant differences in implementation between the two approaches.

The first difference is in the way in which the safety valve is implemented. In the Task Group approach

(TGA), the safety valve is a penalty that emitters must pay to the government if their emissions exceed the permits which they hold. The price effect of this is the same as buying annual permits from the government under the MWB approach. However, under the TGA it is a sanction for bad behaviour, whereas under MWB it is a market transaction in annual permits.

The second difference is that rather than setting a long-run goal for emissions and creating assets that reflect this goal and distributing these assets at the commencement of the trading, the TGA sets a goal and creates bundles of annual permits of different dates, which are distributed as a subset of the bundle. Every five years a decision will be made about whether to issue more permits of different duration to relax the constraints. This is similar to a government financing a fiscal deficit by issuing different duration bonds over time. This strategy of not pre-committing to the long-run target is designed to increase flexibility. However, it also undermines the credibility of the future carbon price which is critical for generating the incentives to develop alternative technologies. It is also not clear why this approach is needed since there would be sufficient flexibility in cost containment through the safety valve.

A third difference is the way in which permits are allocated. The TGA proposes an evaluation of the costs of the scheme to affected emitters, in particular those industries whose export competitiveness is harmed by the introduction of the scheme. These industries would receive an initial allocation based on expected costs. Further allocations may be made depending on future cost outcomes. Other permits of different duration would be auctioned. The new allocation through time would be auctioned. Under MWB all long-term permits are allocated to affected industries as well as consumers who would face higher energy bills. The compensation issue does not need to be as finely calculated because by creating such long-term assets that are claims over future emissions, enough wealth is transferred from future generations to current emitters to provide more compensation than required. This is important since it is difficult to precisely calculate winners and losers, defusing potential for the political coalitions that would form to support or oppose the policy.

The Task Group report is an important step forward, because, like the MWB it proposes an approach that can be developed in individual countries and then joined together with other systems to create a global approach.

Conclusion

The policy debate based on targets and timetables for climate policy is quickly being replaced with more flexible approaches in which the speed of reaching a given target is determined by an assessment of the costs and benefits of taking action. The approach of the Prime Ministerial Task Group on Emissions Trading is clearly in

this new mould. This is an important step because it will reduce the likelihood that countries will commit to a system for carbon reduction only to withdraw when costs appear to exceed benefits. There is a debate currently under way in developed countries such as Japan, Canada and New Zealand that have ratified the Kyoto Protocol but are unlikely to reach their Kyoto targets. It's also taking place in developing countries where emissions are rising sharply despite the Kyoto Protocol. Cap-and-trade in these countries is unlikely to work in the climate area in the next few decades because of the uncertainty about what cap to impose. Thus the approach offered by hybrid policies that combine cap-and-trade approaches with a short-run safety valve mechanism to control costs are more likely to dominate the policy debate beyond the 2012 post-Kyoto period.

Disclaimer

The authors thank Jennifer Gippel for her helpful comments. The views expressed are those of the authors and should not be interpreted as reflecting the views of the trustees, officers or other staff of the Brookings Institution, the Australian National University, Syracuse University or the Lowy Institute.

ENDNOTES

- 1 See the Stern Review (2006).
- 2 See Kopp et al (1997, 1999).
- 3 See the papers in Aldy and Stavins (2007).
- 4 See the Energy Journal (1999).

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The prospects for carbon capture and storage

9



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PHOTOS: BP

Summary

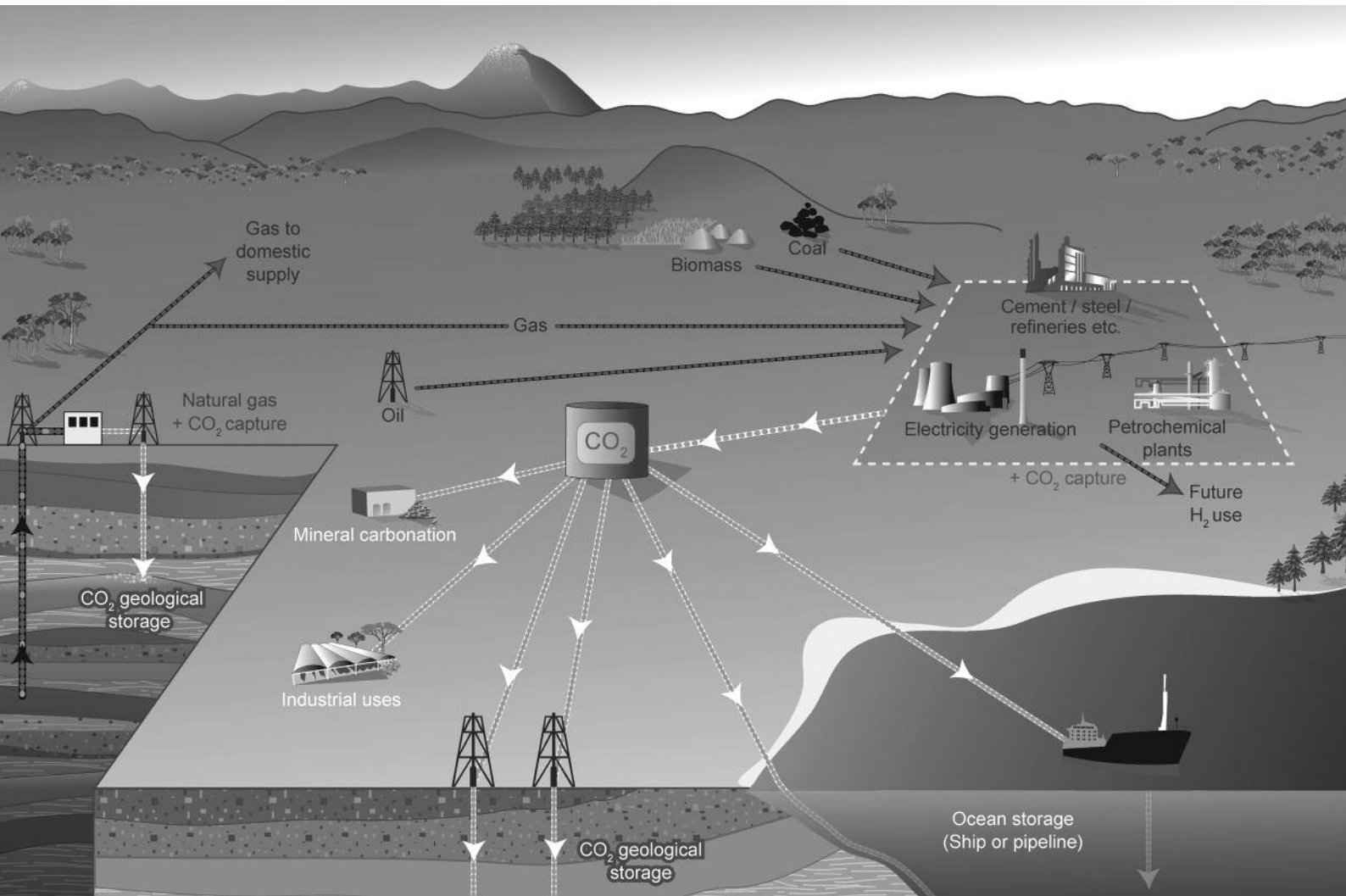
Carbon dioxide emissions and atmospheric concentrations continue to rise. At the same time, projections of world energy demand indicate increasing use of fossil fuels, especially coal. Because of this, there is interest in using carbon capture and storage technologies as a mitigation option, particularly in Australia because of its dependency on fossil fuels for electricity generation and the importance of its fossil fuel exports. Capture options include post-combustion capture (PCC), integrated gasification combined cycle (IGCC) and oxyfuels combustion. Separation technologies include solvent absorption, membranes, adsorption and cryogenics. Carbon dioxide can be stored in the ocean and in minerals, but by far the most likely option is storage in suitable geological locations. Australia appears to have abundant geological storage capacity, particularly in saline formations and to a lesser extent in depleted oil and gas fields, but that capacity is not always close to the CO₂ sources. Storage in coal systems has potential, but more research and development is needed. Australian capture and storage projects are planned for most states.

Acceptance by the community will be dependent in part on cost, but confidence that the technology is safe will be crucial. This will require an effective regulatory regime and appropriate monitoring and verification. For capture and storage to play its part in reducing global emissions, we must aim at large-scale deployment by 2015–2020. Australia could become an early mover in the application of carbon dioxide capture and geological storage.

Introduction

Australia produces only 1.6 per cent of the world's total greenhouse gas emissions, but its industries are energy-intensive, it is a major user of electricity and it has one of the world's highest per capita rates of greenhouse gas emissions. It also has abundant fossil fuel resources, particularly coal and natural gas, which provide low-cost energy and export income. State and federal governments are committed to decreasing Australia's CO₂ emissions, but there is no desire to implement measures that will place a major impost on the economy or result in Australian industry becoming uncompetitive.

FIGURE 1
SCHEMATIC DIAGRAM OF POSSIBLE CCS SYSTEMS SHOWING A RANGE OF CO₂ SOURCES, AS WELL AS TRANSPORT AND STORAGE OPTIONS



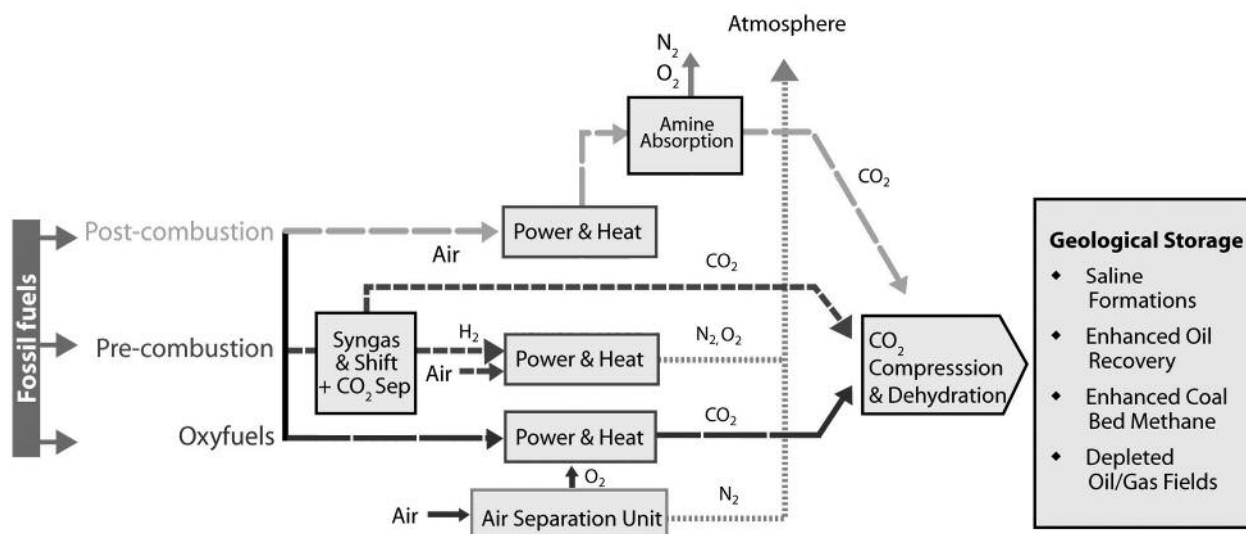
In Australia energy demand is projected to increase by 50 per cent by 2020, requiring at least A\$37 billion in new energy investments, mainly for the provision of base load power. A range of mitigation measures will be required by Australia, including greater energy efficiency, switching to lower carbon-intensity fuels, greater use of renewable energy and carbon capture and storage (CCS). CCS has the potential to enable Australia and other nations to make deep cuts in emissions while maintaining the economic benefits of using much of the existing energy infrastructure (IPCC 2005, p 442).

Carbon capture and storage is the process of capturing carbon dioxide (CO₂) from major stationary sources (such as power stations), transporting that CO₂ (usually by a pipeline) and then injecting it into a sink, which could be the ocean or minerals, or a suitable geological formation (see Figure 1). Other terms used for the process of carbon capture and storage include carbon (or carbon dioxide) capture and geological storage (CCGS), carbon capture and geological sequestration (or geosequestra-

tion), and geological disposal. In short, there is no universal agreement on nomenclature. Europeans favour the term storage. However, storage has the connotation that at some stage the CO₂ will be retrieved, whereas in fact, this is unlikely to be technically or economically feasible in most circumstances. In the United States, the term sequestration seems to be increasingly popular. In this paper, the terms capture, transport and geological or ocean or mineral storage are used and the acronym CCS is used for the overall process.

CCS studies in Australia commenced in 1998 through the work of the Australian Petroleum CRC (Cook et al. 2000) to determine the perspectives for CO₂ storage in Australia. That work clearly showed that CCS was an important mitigation option for Australia, and in 2003 it was decided to establish the Cooperative Research Centre for Greenhouse Gas Technologies (CO₂CRC), which focuses on the research development and demonstration of CCS. This paper outlines some of the outcomes of the work by CO₂CRC and its collaborative organisations.

FIGURE 2
CAPTURE APPLICATIONS (AFTER CO₂ CAPTURE PROJECT AND IEA GHG R&D PROGRAM)



Capturing CO₂

A few industrial processes emit pure CO₂ that can be captured and separated relatively cheaply. Such processes include the manufacture of some fertilisers and natural gas processing. The latter is significant because it provides a relatively pure stream of CO₂ at little additional incremental cost. The reason for this is that frequently CO₂ must be separated from methane to meet sales gas specifications, or to produce liquefied natural gas (LNG). It is also for this reason that some of the earliest CCS projects began around natural gas activities, for example, the Sleipner Project in Norway.

The issue of separation of CO₂ from natural gas is likely to be significant to Australia in the future, as approximately half of our identified natural gas resources have high concentrations of CO₂ and virtually all natural gas used for LNG will need to have some CO₂ removed. Natural gas processing is a potential early mover in the application of CCS in Australia.

Other early opportunities may arise from cement manufacturing (modern plants emit up to 50 per cent CO₂ in the emission stream), and iron and steel plants. In the future, as gas-to-liquid and coal-to-liquids or coal-to-chemical processes become established, there will be an additional major new stream of relatively pure CO₂ that may be suitable for storage.

Much of Australia's anthropogenic CO₂ is emitted from coal-fired power stations. The recovery of CO₂ from power generation plants, which represent the biggest single emission sector (approximately half of Australia's total greenhouse gas emissions), can potentially be addressed by

applying separation technologies to the existing style of plant or by changing the generation technology to simplify the CO₂ capture process. These power-plant applications are referred to as post-combustion, pre-combustion and oxyfuels combustion (see Figure 2).

The issue of separation of CO₂ from natural gas is likely to be significant to Australia in the future ...

Applying CO₂ capture to a typical existing coal-fired power plant is referred to as post-combustion capture, in which the low pressure (1 atmosphere) exhaust gases, currently emitted directly to the air at about 10–15 per cent CO₂, are passed through a separation process that removes CO₂. The current benchmark separation technology is a process called solvent absorption. Post-combustion facilities can potentially be retrofitted to existing power plants or provided as a feature of new plants. There are no existing power stations fully equipped for post-combustion capture of CO₂, but several new stations are proposed and many small units exist. Post-combustion capture on a small scale is proposed for Hazelwood in Victoria, for example.

Pre-combustion capture (Figure 2) can be applied to integrated gasification combined cycle (IGCC) processes. This system operates at high pressures (25–65 atmospheres) making CO₂ separation easier and cheaper. In this type of plant, the fuel is not combusted but reacted at high pressure and temperature to form a synthesis gas

containing CO, CO₂ and H₂, which is then reacted further with water to convert the residual CO to CO₂ and H₂, allowing the CO₂ to be captured and sent to storage. The H₂ is combusted to produce power, with water as the main exhaust to the atmosphere. There are several hundred plants processing syngas in operation around the world at the present time, but they are mainly used in the production of chemicals, with only a few gasifiers used for the production of electricity.

The oxyfuels technology is similar to that used in existing power plants, except that rather than combusting the fuels in air, combustion occurs in an oxygen atmosphere. This removes the nitrogen (that makes up much of the air); hence the CO₂ separation step is simpler. However, pre-combustion air separation to provide pure oxygen is costly and changes are required to the boiler and associated flue gas handling system to accommodate the higher flame temperatures arising from combustion with oxygen. The resultant flue gas is highly concentrated in CO₂.

While the scale of the capture plants required for these power plant applications is larger than any plant currently installed, there appears to be no insurmountable technical challenges to introducing them, but there are cost impediments (see later).

Separating CO₂

Different power generation applications can reduce capture costs. Various separation technologies can also be used.

Solvent absorption is a process in which CO₂ is absorbed into a liquid, typically an amine, although research is underway into the use of ammonia. The gas stream, with the CO₂ removed, is then emitted into the atmosphere. The CO₂-bearing liquid is processed to remove the CO₂, which is then concentrated for storage. The resulting CO₂-free liquid is used again for absorption and the process continues.

Membranes, made of polymers or ceramics, can be used to preferentially separate CO₂ from gas streams (Franco et al. 2006; Ho et al. 2006). This process is commercially used for the separation of CO₂ from natural gas, but has not yet been applied to flue gas applications.

CO₂ can be *adsorbed* from a gas stream onto the surface of a mineral solid, typically a zeolite (Chaffee et al. 2006). The gas stream, with most of the CO₂ removed, is then emitted to the atmosphere while the solid is then purified using changes in either pressure or temperature to remove and concentrate the CO₂ for storage. This technique is used commercially in a number of gas separation processes, including those processing syngas; however, it has not yet been used for flue gases.

Cryogenic/low temperature techniques are based on the use of low temperatures to cool, condense and purify CO₂

from gas streams. It has been applied to moderately concentrated CO₂ streams in the natural gas sector and are being investigated for use in a wider range of applications.

Chemical looping is similar in some ways to the oxyfuels approach in that oxygen is removed from air prior to combustion by reacting it with metal particles in a fluidised bed forming a metal oxide. This captured oxygen, in the form of metal oxide, is then contacted with the fuel, such as natural gas, in a separate fluidised bed, effectively combusting the fuel, releasing energy and producing CO₂ and water. In the process the metal oxide is reduced back to the metal, which is available to be recycled and again reacted with the air. The CO₂ is relatively easily separated with a process similar to that used for oxyfuels.

Transporting CO₂

Unless the source of separated CO₂ lies directly above or adjacent to a site for injection, it is necessary to transport the CO₂ to the injection site, usually by pipeline (Figure 1). To do this, the CO₂ is compressed into a dense fluid prior to transport, and water (and possibly some contaminants) will be removed. In the US, there are several thousand kilometres of CO₂ pipelines, employed to transport CO₂ for use in enhanced oil recovery. In Australia, transportation by pipeline is an accepted and widely used technique for natural gas. Therefore, pipeline transportation of CO₂ is likely to be acceptable to the Australian community. Pipeline transportation of CO₂ in Australia is used in neutralisation of aluminium-rich red muds and in the CO₂CRC Otway Project.

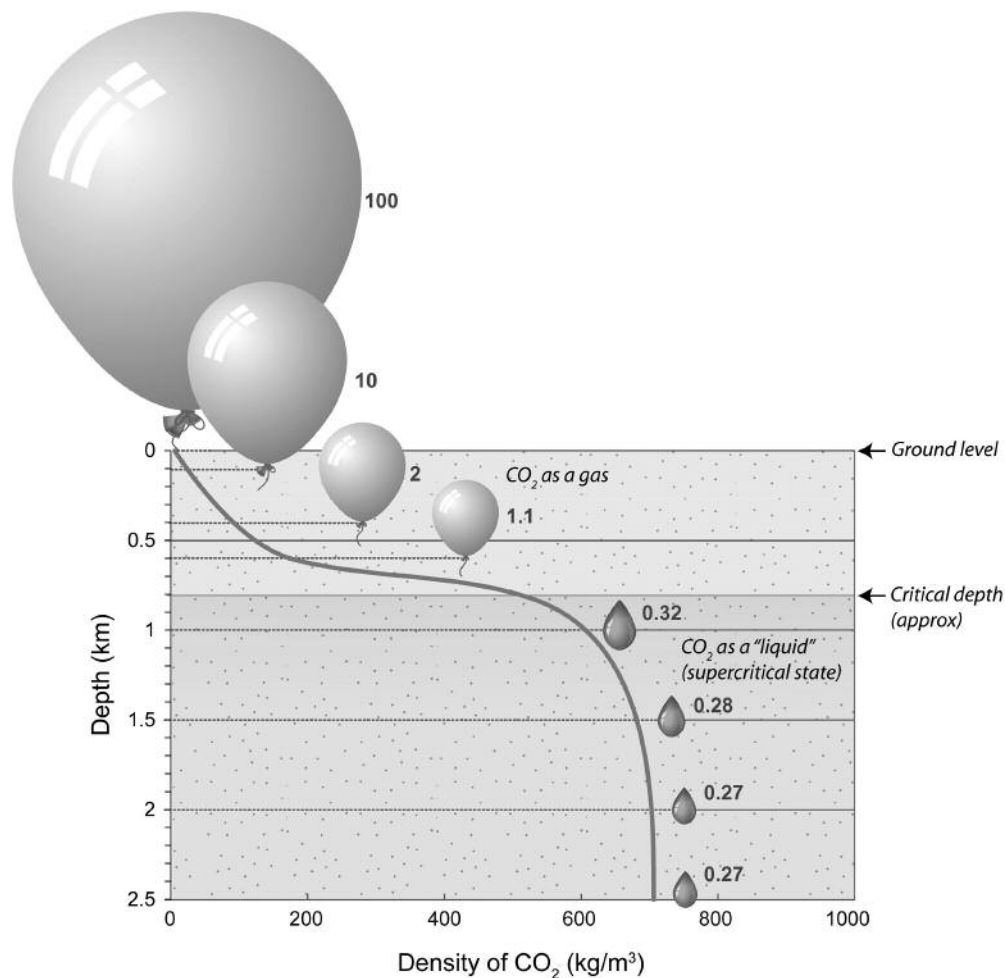
Transportation of concentrated CO₂ by road or rail may be technically feasible for small-scale projects, but is likely to be prohibitively expensive for major commercial projects. In the same way that LNG is transported by ship around the world, it would be technically feasible to transport large quantities of CO₂ from a coastal emission source to an offshore storage site, but the costs of such a scheme are likely to be high.

Storing CO₂

There are three options for long-term storage of CO₂ – ocean storage, mineral storage and geological storage, but of these only geological storage is seen as a viable mitigation option at this time.

Ocean storage involves the injection of captured CO₂ into the ocean at depths of 1000 metres or more, either from a ship or via a pipeline. At intermediate depths, the CO₂ will dissolve in the seawater and become part of the long-term oceanic carbon cycle. At depths greater than 3000 m the CO₂ is denser than seawater and could “pool” in topographic depressions on the sea floor (Barry et al. 2004) to produce a CO₂ lake (Nakashiki 1997). Anthropogenic CO₂ injected into the deep ocean could be isolated from the atmosphere for thousands of years,

FIGURE 3
BELOW A DEPTH OF APPROX 800 M CO₂ IS IN A DE-USE CRITICAL STATE



but would adversely impact on the biota and would also produce a lowering of the pH of seawater, that is, the ocean would become more acidic. For these reasons, there is opposition to the concept of ocean storage from many non-governmental organisations (NGOs) and governments. In addition, there is considerable doubt that it would be allowable under existing international law. Ocean storage is unlikely to be used as a mitigation option in the foreseeable future.

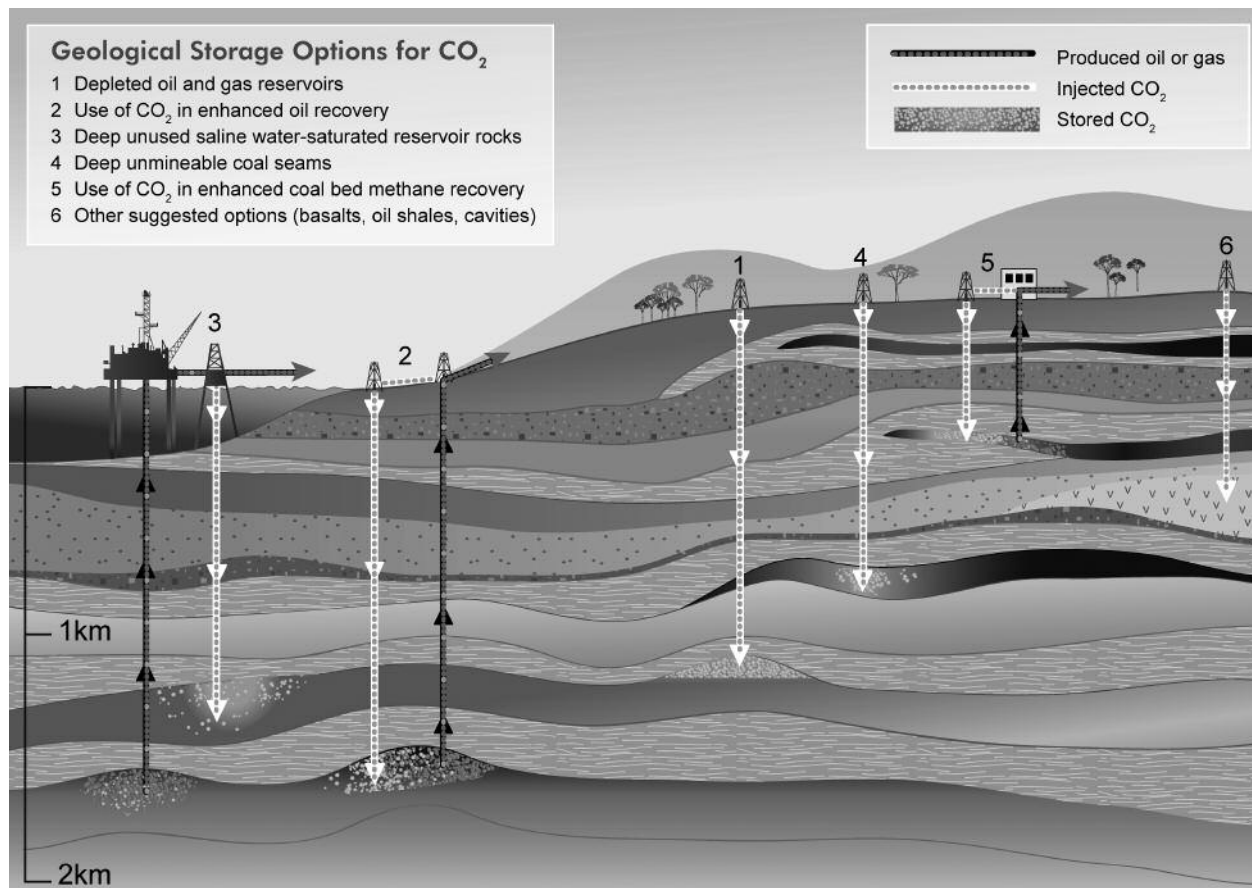
Mineral storage involves the fixation option of CO₂ – when CO₂ is fixed in a solid state – in the form of inorganic carbonates. Minerals such as silicates occur widely geologically, as natural weathering products and as byproducts of industrial processes. The use of CO₂ in order to neutralise red muds (Seifritz, 1990) resulting from the production of alumina and aluminium, is a form of mineral sequestration already used today on a small scale. However, for mineral storage sequestration to have a significant mitigation impact would require very large-scale mining of silicate minerals such as olivine (Goff and Lachner 1998). A combination of the mining operation and grinding of the silicate, coupled with the

capture of the CO₂, results in an energy penalty ranging from 60–180 per cent (IPCC 2005), which for the present makes mineral storage a non-viable mitigation option in most circumstances. Ocean and mineral storage will not be considered any further.

Geological storage is now receiving a great deal of attention as a large-scale mitigation option, with the release of the parliamentary report, *Between a Rock and a Hard Place – The Science of Geosequestration* (House of Representatives Standing Committee 2007) the most recent indication of the level of interest in Australia in this mitigation option.

So how does geological storage work? Prior to storage, the emitted gas stream is concentrated to 95 per cent or more CO₂ and compressed to a dense state, producing a liquid which has a density (depending on the pressure) of around 0.5–0.7 g/cm³ (water has a density of 1g/cm³). Provided the CO₂ is injected to a depth of 800 m or more below the ground it will remain in this dense state, which means that far more CO₂ can be stored than if it were to be injected in a gaseous state (Figure 3).

FIGURE 4
OPTIONS FOR GEOLOGICAL STORAGE OF CO₂



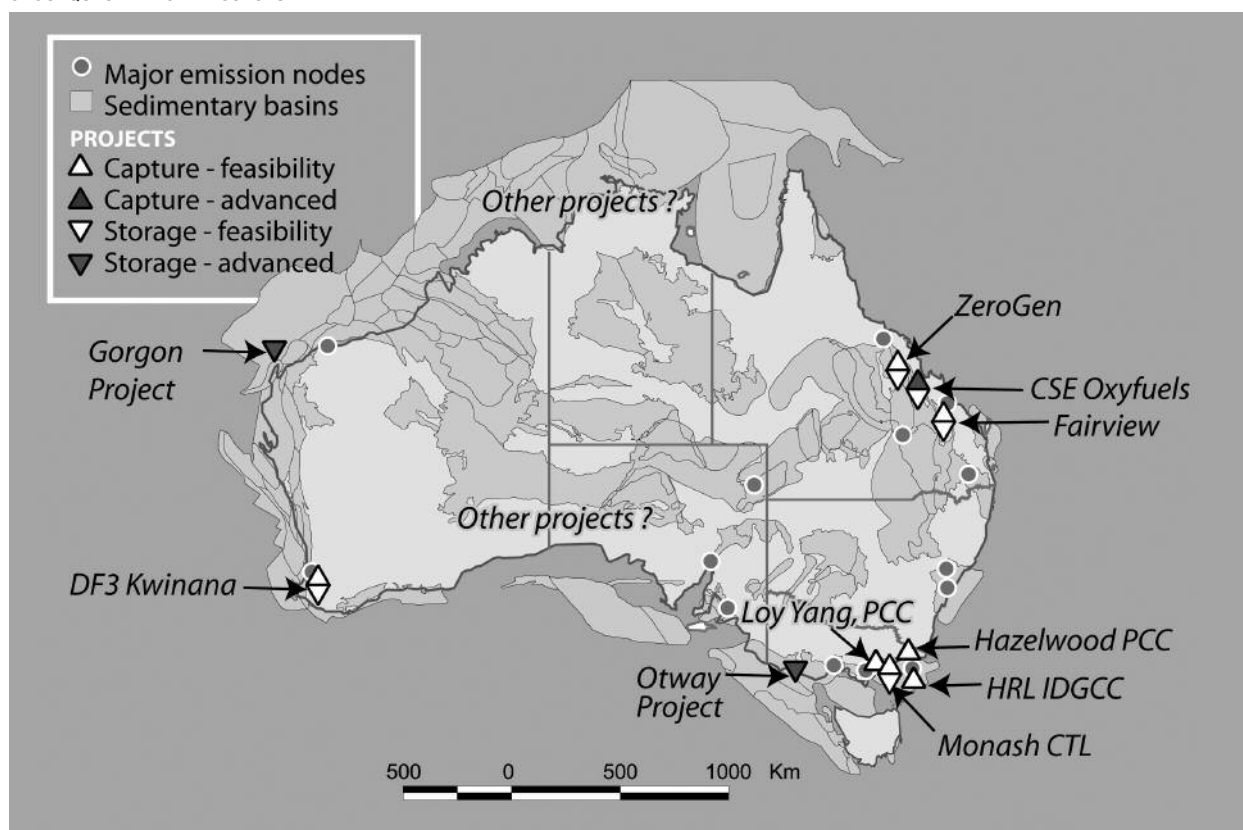
The storage of CO₂ involves keeping the CO₂ secured deep underground in an appropriate geological formation. The ideal characteristics of a storage site involve simple geology; a porous/permeable rock containing saline groundwater, overlaid by an impermeable seal at a depth below the surface of 800 m or more. Expertise in locating such geological formations is well established within the oil and gas industry, and geoscientists and engineers can utilise mature technology to identify and evaluate specific sites for geosequestration potential, as well as to ensure that conditions for safe and effective long-term storage are present.

Depleted oil and natural gas fields (Figure 4), which generally have proven geologic traps, reservoirs and seals, are potentially excellent sites for storage of injected CO₂. Sedimentary basins in Australia where this may be applicable in the future include the offshore Gippsland Basin (Gibson-Poole et al. 2006), existing fields as they become depleted over the next 20 years, and the Western Australian margin in 20 to 40 years, as major gas fields there are depleted. In some circumstances it may be possible to combine geological storage of CO₂ with enhanced oil or gas recovery. This has not been carried out to date in Australia but is worthy of consideration because of the potential to beneficially combine geosequestration with increased production of hydrocarbons.

Australia has very extensive basins with deep saline formations, both onshore and offshore, with a CO₂ storage resource equivalent to many hundreds of years of emissions at the current rate (Rigg et al. 2001). Technical, economic and environmental considerations will need to be addressed to turn this resource into a defined and usable storage reserve. This could markedly decrease the amount of CO₂ that can be stored, but on a national scale it will still be very large. This type of geological formation is also considered to have a high storage potential by the IPCC (2005). Trapping in saline aquifers (Figure 4) involves the trapping then dissolution of CO₂ into the saline formation water. Recent research indicates that as the CO₂ moves through the geological formation, a proportion of it dissolves in the formation water. Modelling has shown that with time, the CO₂-rich water has a higher density which causes downward fingering of the denser CO₂-rich waters into the saline aquifer, resulting in there being a decreased likelihood of any trapped CO₂ leaking to the surface (Ennis-King and Paterson 2004).

CO₂ can also be adsorbed onto the fine organic particles in coal (Faiz et al. 2006), but there are difficulties in injecting the CO₂ into coal because of its typically low permeability. This therefore requires that the permeability of the coal must be enhanced prior to CO₂ injection by the extraction of water and/or coal bed

FIGURE 5
LOCATION OF AUSTRALIAN SEDIMENTARY BASINS, MAJOR SOURCES OF CO₂ AND PROPOSED DEMONSTRATION AND COMMERCIAL GEOSEQUESTRATION PROJECTS.



methane. Coal-bearing formations may be a valuable storage option combined with production of coal-bed methane in areas such as Queensland and New South Wales, but more research is needed to confirm this.

The economics of CCS

The cost of a CCS project is site- and process-specific. For example, where the primary emission stream is CO₂-rich and the storage site is nearby the cost of mitigation may be no more than a few dollars per ton of CO₂. If, however, the emission is low in CO₂ and the storage site is hundreds of kilometres away, then the cost could be A\$100 or more per ton of CO₂, and therefore probably non-viable economically compared to other mitigation options. As pointed out earlier, the cost of capture from a conventional coal-fired power stations is likely to constitute 70–80 per cent of the total cost of CCS. By comparison, the cost of CO₂ capture associated with gas processing, cement manufacture or a coal-to-liquids storage is likely to be only a small proportion of the total cost of the CCS project. A study of the likely cost of CO₂ storage-only projects in Australia (Allison and Nguyen 2002; Allison et al. 2003) indicated a wide range of capital and operational costs, driven primarily by the distance between the source of the CO₂ and the storage site. But with many potential storage projects costing US\$10 or less per ton of CO₂ avoided, that is, prevented

from being released into the atmosphere, at 2002 prices, this price could have doubled over the intervening five years. Not surprisingly, costs of onshore storage projects are generally significantly less than the cost of offshore storage projects.

The IPCC (2005) examined the issue of CCS costs in some detail, but it is difficult to compare the IPCC costs directly with Australian costs for various reasons, including the country-specific cost of equipment, currency variations and the local cost of electricity. However, there is general agreement on two points: the cost of CCS probably needs to be of the order of US\$20–\$30 a ton CO₂ avoided for it to be widely deployed (although this ceiling will change if costs of other mitigation options rise); and the costs need to come down from their present level of US\$60 or more a ton.

The CO₂CRC has undertaken research into low-emission hubs in Australia as a way of achieving economies of scale. These are regions with high concentrations of emission sources which can potentially adopt a coordinated approach to decreasing CO₂ emissions (Hooper et al. 2006). Areas in Australia that offer scope for this approach include the Latrobe Valley in Victoria, Kwinana and the Burrup Peninsula in Western Australia, the Sydney–Newcastle region in NSW, southeast Queensland and the Gladstone–Rockhampton district of central Queensland (Figure 5).

CCS in Australia

A great deal of geosequestration research is underway in Australia, but to date there has been no demonstration of capture or storage technology at a commercially significant scale. This will change shortly. A number of examples of projects and proposed projects are provided below:

CO₂CRC Otway Project

The CO₂CRC (www.co2crc.com.au) will undertake a demonstration of geological storage of CO₂ in the Otway Basin of Victoria (Figure 5), with injection of up to 100,000 tons of CO₂ expected to commence in late 2007 (Cook and Sharma 2006). In summary, the Otway Project involves CO₂ production from a natural gas well, transport by pipeline, injection into a 2 km deep porous/permeable geological formation overlaid by an impermeable seal; and the monitoring and verification monitoring and verification of the behavior of the stored CO₂-rich gas (Figure 6). Unseparated gas will be injected in the first phase of the project. In the second phase the CO₂ will be separated and purified to 97 per cent CO₂ and then injected. Up to 100,000 tons of CO₂ will be injected until 2009 and monitoring will continue until at least mid-2010. The project is one of the most comprehensive storage projects in the world.

ZeroGen

The proposed ZeroGen project (Figure 5) in Central Queensland (www.zerogen.com.au) aims to investigate the viability of integrating coal-based gasification and CCS to produce low emission base-load electricity. This will combine both coal-based gasification and geological storage in deep saline

formations on a commercial scale. A feasibility study is currently underway by the Stanwell Corporation to investigate economic, environmental, social, regulatory and technical considerations alongside the drilling of wells up to two km deep to test storing CO₂ in deep saline formations in the Dennison Trough off Central Queensland.

Monash Project

The Monash Energy project of Anglo and Shell (Figure 5) is planned to be a coal-to-liquids project incorporating geological storage (www.monashenergy.com.au). The Monash Energy project proposes to utilise coal gasification in combination with Fischer-Tropsch synthesis and geological storage for the low-emissions production of a range of transport fuels – initially ultra-low sulphur diesel, but ultimately hydrogen, to support the development of a hydrogen economy. The project will process brown coal from Victoria's Latrobe Valley, in the onshore Gippsland Basin, and will transport and geologically store up to 10 million tons per annum of CO₂ offshore. The project has the potential to act as a catalyst for the development of infrastructure to support the subsequent capture of CO₂ from electricity generation in the Latrobe Valley when more cost-effective technologies have been developed to capture CO₂ from power stations.

Although there are many parts of Australia where suitable rocks for storage exist, they are not always near to these hubs. Some of the potential hubs (e.g. Latrobe) are close to areas that are likely to be suitable for storage. Others such as the Sydney–Newcastle area require further study to determine a suitable storage option.

A low-emission hub strategy would require capturing CO₂ from a variety of sources. Industrial processes most suited include electric power generation, natural gas processing, steel manufacture, furnaces, fertiliser manufacturers, aluminum manufacture, smelters, cement kilns and sugar mills. If a number of these were brought together then economies of scale could be achieved. The costs can vary significantly depending on the situation (Neal et al. 2006), but the Latrobe study indicated that major cost-savings are achievable.

There are good reasons for expecting the costs of capturing CO₂ to fall in the future as technological improvements are made. The 2005 IPCC Special Volume states, "Over the next decade the cost of capture

could be reduced by 20–30 per cent and more should be achievable by new technologies that are still in the research or demonstration phase".

The recent report of the Task Force on Emissions Trading (2007) stated, "On balance, there would be benefits in the Australian Government now setting a post-2012 constraint on emissions", with the preference of the Task Force being for emissions trading based on a cap-and-trade model rather than a carbon tax. The Task Force is strongly opposed to favouring any particular technology, and it is therefore not unreasonable to conclude that CCS will be adopted if it is cost-effective compared to other mitigation options. The only shortcoming with this policy is that for a number of years (perhaps the next decade) there will be a need for government support to encourage deployment of CCS, as it is only through deployment that the cost of CCS can be brought down. Money raised through emissions trading could be used for this purpose, but this would still leave a hiatus between now and 2013 when other funding sources would be required.

Gorgon Project

The Gorgon project (www.gorgon.com.au) of Chevron, Shell and ExxonMobil plans to develop the Greater Gorgon gas fields, located between 130 km and 200 km off the coast of WA (Malek et al. 2004). The gas fields contain about 40 trillion cubic feet of gas, Australia's largest known undeveloped gas resource. However, the natural gas contains up to 14 per cent CO₂, which is stripped out as part of LNG processing. The Gorgon project proposal involves a two-train, 10 million ton-per-year LNG plant and a domestic gas plant on Barrow Island (Figure 5). The geological storage target is the Dupuy Formation located around 2000 m beneath Barrow Island. The total amount of reservoir CO₂ to be re-injected is about 100 million tons.

OxyFuel Project

Eleven Australian and Japanese organisations have formed a consortium to develop a demonstration oxy-fuel combustion plant, with CO₂ capture and geological storage, based on CS Energy's (www.csenergy.com.au) Callide A power station in Central Queensland (Figure 5). This project will be the first of its kind in Australia. The project has two stages: the first stage involves a detailed engineering feasibility study of the technical requirements and costs to convert an existing pulverised-coal fired boiler (Callide A's 30 megawatt unit) to oxy-firing. The second stage will involve establishment of a demonstration plant capable of capturing up to 150,000 tons per year of CO₂ for geological storage over a test period of three to four years.

Kwinana

The Kwinana (DF 3) project of BP and RioTinto was announced in May 2007 (www.hydroenergy.com) with a feasibility study underway into the A\$2 billion project to be located in Kwinana, 45 km southwest of Perth, WA (Figure 5). The project would involve gasification of Collie Basin to produce H₂ plus CO₂, with the H₂ used to generate 500 MW of low-emission electricity. This would be fully integrated with CCS; the most likely area for CO₂ storage is the offshore Perth Basin. Further investigation is required, but the aim would be to capture, transport and geologically store up to 4 million tons of CO₂ a year. A final investment decision on the project will be made by 2011.

Fairview

The Fairview project of General Electric, Santos and Origin is located in southwest Queensland (Figure 5) and will involve construction of a new 100 MW gas-fired power station. CCS will be used on one-third of the CO₂ emissions with the CO₂ injected into nearby coal seams. This in turn will lead to enhanced coal-bed methane production, with the methane being used in the power station.

Whether the cost of geosequestration in Australia will be higher or lower than that of other mitigation options depends on:

- the location of the facility;
- the nature of the facility – whether the emission stream is concentrated or dilute CO₂;
- in the case of power generation whether or not it is required to be “base-load”;
- the extent to which future technology developments bring down costs; and
- the price signal on carbon.

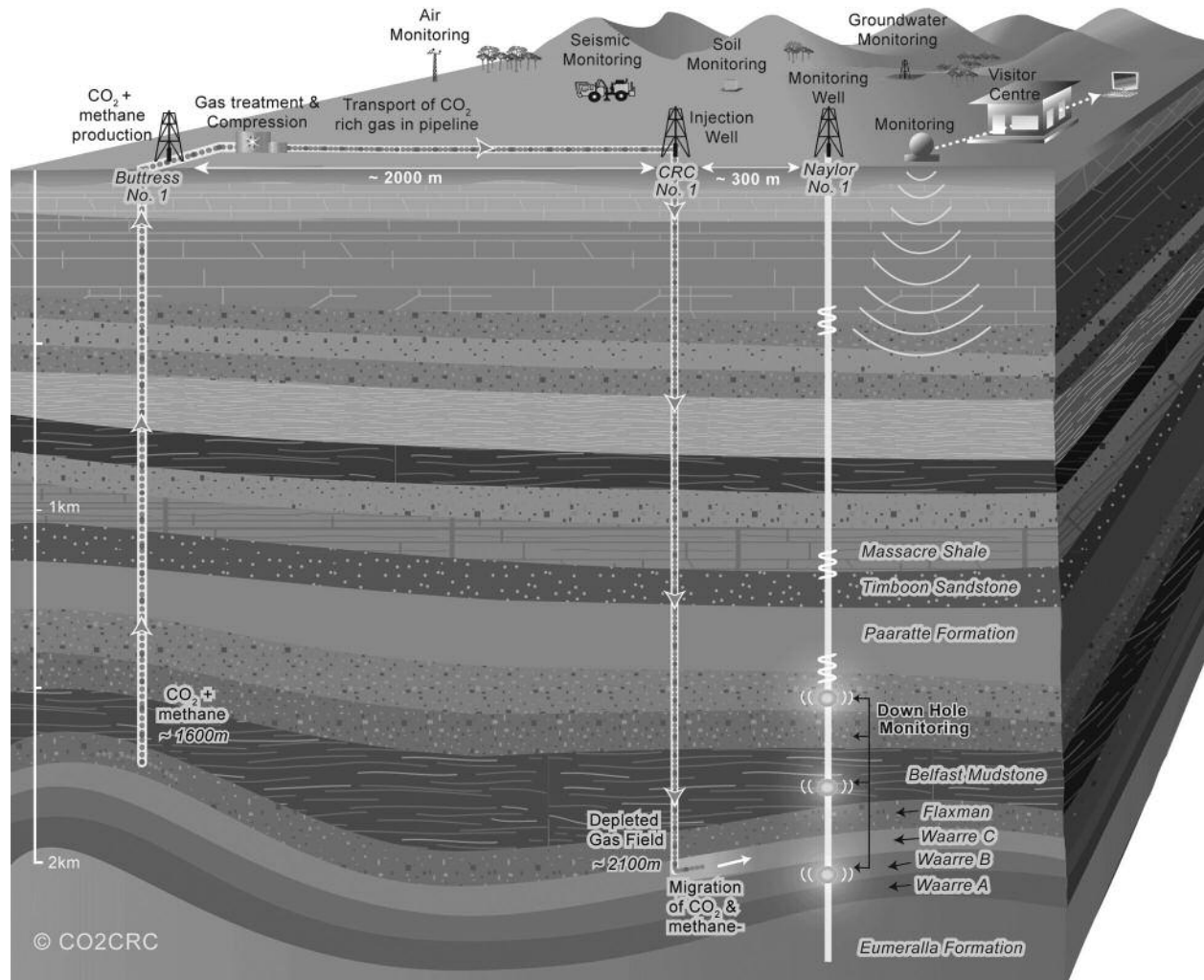
CO₂CRC and other organisations have set a target of around A\$20–\$30 a ton of CO₂ avoided for capture, transport and storage. What does this mean in terms of future energy costs – a key issue for politicians and their electorates? That depends on where one is in the electricity chain. For example, a mitigation cost of A\$40 a ton CO₂ translates into an increase in the cost of electricity at the

generator in the order of 100 per cent; this in turn leads to an electricity cost increase of 50–60 per cent for the large retail customer and perhaps 30–40 per cent for the domestic customer. Given that Australia has relatively low electricity costs by world standards, such a price rise may (or may not) be acceptable to the domestic consumer. But this would obviously have a significant impact on the major consumer who produces an energy-intensive product (such as aluminium) that sells on world markets.

Community acceptance

For the most part, there is little debate about the technical feasibility of CO₂ capture, as it is seen as a relatively normal industrial process that will operate within an existing regulatory framework. However, storage is a new concept and inevitably uncertainties arise in the minds of many people about health and safety. An example of CO₂ leakage frequently cited is that of Lake Nyos in central Africa. In 1986, two million tons of CO₂ gas was released from Lake Nyos in a large-scale degassing

FIGURE 6
SCHEMATIC REPRESENTATION OF THE CO₂CRC OTWAY PROJECT



episode (Kling et al. 1994) resulting in the death of 1,700 people. The question that arises is, could geologically stored CO₂ be similarly catastrophically released? In fact, we know of no mechanism by which such a release could occur from a well-characterised geological storage site. Slow leakage from a site may be a possibility in some circumstances, but even here the view of the IPCC (2005) was that at a well-characterised site, leakage over 1,000 years would amount to 1 per cent or less of the total amount of CO₂ stored. In other words, if 10 million tons of CO₂ was stored at a site the annual leakage might be in the order of 100 tons per annum or less. Experience at the CO₂CRC Otway Project helps to put this into context. As part of its gas-well testing program, CO₂CRC released approximately 100 tons of CO₂ over a period of 40 hours. This is equivalent to 200 times the rate that the IPCC considered to be a maximum leakage rate that would occur from a site holding 10 million tons of CO₂. The only effect was that a mound of solid CO₂ accumulated at the test site, which remained in the paddock for several weeks, before being

removed by truck and deposited in a municipal rubbish dump. This is not to trivialise the importance of addressing the possibility of leakage, but rather to try to put the potential impact into perspective and show that under all normal circumstances CO₂ leakage from a storage site is unlikely to constitute a significant hazard.

Any CO₂ storage site will require monitoring and verification regime. The precise form that this will take is still under consideration and there are few places in the world where comprehensive monitoring and verification has been undertaken. One place where this will be done is the CO₂CRC Otway Project in Western Victoria. There, a comprehensive monitoring network has been established to determine the behaviour and distribution of CO₂ in the subsurface, the near surface, the surface and the atmosphere (Figure 6). A comprehensive set of measurements will make it possible to detect any minor leakage from the storage site and differentiate between any natural CO₂ and the stored CO₂.

At the present time it is possible to obtain insurance for the operational phase of a storage project and perhaps also the early closure stage. What is not possible to obtain is liability insurance for hundreds of years. There has been a great deal of debate on the issue of long-term liability associated with storage sites. There is an understandable reluctance on the part of a company to accept liability for an indefinite term. Similarly, to date governments have shown an unwillingness to accept long-term liability. This stand-off is undoubtedly creating difficulties for project proponents and requires resolution. This will need some creativity, for while it is difficult to see how common law liabilities can be waived, it is equally difficult to see how a company could accept liability extending over hundreds of years. As a minimum, governments should consider accepting long-term liability to encourage demonstration and deployment over the next decade.

Licensing sites

The recent decision to agree to the offshore geological storage of CO₂ under the London Convention is an important step forward in acceptance of geological storage at the international level, re-enforced by a similar decision with respect to the North Atlantic (OSPAR) Convention (London Protocol 2006; IEA 2007).

In an onshore regime the responsibility for geological storage rests with the states. The development of plans for a number of CCS projects is now requiring that states do develop appropriate licensing arrangements. The most advanced storage project is the CO₂CRC Otway Project. This project has been developed in an uncertain regulatory environment in that there no regulations specifically developed for CCS.

Australia is a world leader in seeking to develop an appropriate licensing regime to enable CCS to move ahead, with discussion papers released by the federal government and Queensland. The federal government proposes to use the Offshore Petroleum Act (OPA) as the basis for licensing of offshore storage sites, but as yet the draft legislation has not been released. Use of the OPA for CCS is a pragmatic and potentially a workable approach, but there are some issues that will need to be considered, such as the fact that while storage in depleted oil and gas fields can fairly readily be addressed through an OPA-type approach, this may not be so straightforward for regional saline aquifers. The other issue that arises is the potential impact of CO₂ storage on other resources, particularly oil and gas. This is indeed an important question that requires a risk-based approach while recognising existing property rights, so that the benefit of extracting petroleum can be set in the context of the benefit of storing CO₂.

Conclusion

When questioned, people invariably indicate that they would like to use more renewable energy. But the reality is that projections from the IEA and the IPCC indicate that we will be using more, not less, fossil-fuel based power in the future. CCS represents the only technology we have that would enable us to decrease our emissions, while using more fossil fuels. It would also enable us to continue using much of the existing energy infrastructure. Indeed, the IPCC considers that the inclusion of CCS in a mitigation portfolio will decrease the overall cost of mitigation by a third.

CCS is part of the answer to rising levels of atmospheric CO₂, although it is unclear what proportion of the answer it will provide. But what is clear is that for as long as we use fossil fuels there will be a need for CCS, given that most projections indicate increasing use of fossil fuels, particularly in developing countries such as India and China, which are rapidly increasing their use of coal. However, it would be quite unrealistic to expect developing countries to apply CCS if developed countries have not first shown the way.

How soon should CCS happen? Again it is important to be realistic; premature deployment of CCS could produce very high costs on power (and in the longer term on transport), which would adversely impact upon the Australian economy. Conversely, as pointed out by the Stern Report, we cannot leave it too late. The modelling done by CO₂CRC on the uptake of CCS and its likely impact on CO₂ mitigation suggests that we should aim to have all new power stations with CCS after 2015–2020. All existing power stations should evaluate retrofitting CCS. Beyond that, any new power stations that are currently being proposed should be planning to be “capture-ready” to minimise future retrofit costs and should clearly identify storage options. This is not a formula for delaying action, but a strategy that will lead to early implementation. This would be a challenging target for Australia, and most other countries, but it is one that has to be contemplated if global atmospheric concentrations of CO₂ are to be kept below 550 parts per million by 2100.

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