economic impact of

climate change policy:

the role of technology and economic instruments

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foreword

Global demand for energy continues to rise, driven by robust economic and population growth. Fossil fuels will continue to play an ongoing major role in meeting global energy demand unless alternative and advanced technologies take their place in the future. Continued reliance on fossil fuels without the adoption of new technologies to meet growing global energy demand is likely to lead to a rapid increase in global greenhouse gas emissions and a corresponding rise in the atmospheric concentration of these gases. Recognition is growing of the critical importance of more energy efficient and cleaner technologies to curb greenhouse gas emissions, while at the same time allowing economies to experience continuing growth.

Given the level of attention being focused on the energy sector and climate change issues nationally and internationally, CSIRO commissioned ABARE to undertake analysis of a series of illustrative global greenhouse gas emission reduction scenarios developed by the Energy Futures Forum. These scenarios range from early to late abatement of greenhouse gas emissions with several advanced technologies including carbon capture and storage. In addition, a further scenario developed by ABARE is described. This report contains the analysis of policy scenarios using ABARE's global trade and environment model.

In this report the important role that improved and new technology will play as part of a solution to global climate change is emphasised. It also explores the role and potential impact of a market based instrument aimed at reducing greenhouse gas emissions in the Australian and global economies.

The analysis reported here examines the technology mix and demand and supply changes that most cost effectively meet specified emission reduction targets. No account is taken here of any benefits from avoided climate change. Analysis to be released later by the Energy Futures Forum will explore potential climate impacts of the emissions pathways outlined here.

BRIAN S. FISHER
Executive Director

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abbreviations and acronyms

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ANSTO	Australian Nuclear Science and Technology Organisation
APPCDC	Asia Pacific Partnership on Clean Development and Climate
ASEAN	Association of South East Asian Nations
BHP	Broken Hill Proprietary Company
CCS	carbon capture and storage
CFC	chlorofluorocarbon
CIS	Commonwealth of Independent States
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EFF	Energy Futures Forum
EIA	Energy Information Administration
EMF	Energy Modeling Forum
EMF21	Energy Modeling Forum 21
EU25	European Union 25
g	grams
GDP	gross domestic product
GHG	greenhouse gas
Gt	gigatonne (billion tonnes)
GTEM	global trade and environment model (ABARE)
Gtoe	gigatonne of oil equivalent
GW	gigawatt
GWP	global warming potential
HCFC22	hydrochlorofluorocarbon 22
HFC	hydrofluorocarbon
HFC23	hydrofluorocarbon 23
HHV	higher heating value
IEA	International Energy Agency
IEEJ	Institute of Energy Economics, Japan

IGCC	integrated gasification combined cycle
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
kW	kilowatt
kWh	kilowatt hour
LHV	lower heating value
METI	Ministry of Economy Trade and Industries (Japan)
Mt	megatonne (million tonnes)
Mt CO_2-e/ US$b	megatonne of carbon dioxide equivalent per United States billion dollars
Mtoe	megatonne of oil equivalent
MW	megawatt
NGCC	natural gas combined cycle
OECD	Organisation for Economic Cooperation and Development
PFC	perfluorinated carbons, per-fluoro compound, perfluorated carbon
ppm	parts per million
SRES	Special Report on Emissions Scenarios
t CO_2-e	tonnes of carbon dioxide equivalent
TWh	terawatt hour
US$/t CO_2-e	US dollars a tonne of carbon dioxide equivalent
US$b	United States billion dollars

glossary

abatement	reduction of greenhouse gas emissions
anthropogenic	attributable to human activity
atmospheric concentration of greenhouse gases	a per unit volume measure of the amount of greenhouse gases present in the Earth's atmosphere
bottom up model	an economic model using an engineering based approach, with detailed cost and performance data for specific technologies and services
carbon capture and storage (CCS)	the capture of carbon dioxide from power generation plants or other sources with subsequent permanent storage in geological sites – in this report, CCS does not include ocean storage
carbon dioxide (CO_2)	the principal anthropogenic greenhouse gas
carbon dioxide constraint	a limit on the total amount of carbon dioxide that can be emitted – the constraint may take a variety of forms including a tax or a quantitative restriction
carbon dioxide equivalent (CO_2-e)	the conversion of non-CO_2 greenhouse gases into CO_2-e units based on their global warming potential (GWP), relative to carbon dioxide, over a 100 year time horizon – GWPs from the IPCC Second Assessment Report (1996a) are used in GTEM to calculate CO_2-e.
carbon intensity of fuels	a measure of the amount of carbon dioxide emitted per unit of combusted fuel
carbon leakage	a process whereby emission intensive production moves from countries (regions) under a carbon constraint to countries (regions) without such a constraint – as a result, emissions abatement in one region is offset by increased emissions elsewhere
efficiency (thermal) of generation	the ratio of electricity produced to each unit of fuel used – usually expressed as a percentage and in terms of LHV or HHV
emissions intensity	emissions per unit of output – in this report, it is defined as megatonnes of carbon dioxide equivalent per billion US dollars worth of total global product (or gross domestic product, GDP), denoted by Mt CO_2-e/US$billion

flue gas	exhaust gas produced as a result of combustion activities
fossil fuel	fuel extracted from a hydrocarbon deposit that was derived from living matter in the remote geological past – petroleum, coal and natural gas
fugitive emissions	greenhouse gas emissions not resulting from the combustion of fossil fuels, but rather from the mining, transport, storage and distribution of fossil fuels
gigatonne	one billion tonnes
greenhouse gas (GHG)	any gas in the atmosphere that absorbs and re-emits infrared radiation – major greenhouse gases include carbon dioxide, water vapor, methane and nitrous oxide
global warming potential (GWP)	an index that describes the warming potential of a unit mass of a well mixed greenhouse gas, relative to that of carbon dioxide, which is given a GWP of 1
higher heating value (HHV)	a standard measure of the efficiency of an electricity generation plant and equivalent to gross calorific value – the quantity of heat energy released when a fuel is burned completely in oxygen, and the products of combustion are returned to ambient temperature and pressure (see also lower heating value)
hydrogen	colorless, odorless, flammable gas
levelised generation cost	the discounted sum of fuel, operating and investment costs, 'levelised' or 'averaged' over the expected lifetime of the capital investment
lower heating value (LHV)	a standard measure of the efficiency of an electricity generation plant and equivalent to net calorific value – corresponds to the number of heat units liberated per quantity of fuel burned in oxygen, minus the latent energy contained in water vapor (exhaust gas) that is produced when hydrogen (from the fuel) is burned. The thermal efficiency of a coal fired plant based on LHV is typically 2–3 per cent higher than its thermal efficiency based on HHV; the thermal efficiency of a gas fired plant based on LHV is typically 10–15 per cent higher than its thermal efficiency based on HHV (Saddler et al. 2004) (see also higher heating value)
non-Annex B countries	countries that are not listed in Annex B of the Kyoto Protocol – that is, countries not committed to meeting any emission reduction targets under the Kyoto Protocol
primary energy consumption	equal to the consumption of commercial energy (excluding biomass in non-OECD countries) in its initial form after production or import

pulverised coal (PC)	an electricity generation plant that combusts pulverised or milled coal at high temperatures, raising high pressure steam and generating electricity in a steam turbine
renewable electricity	electricity derived from natural processes that theoretically cannot be exhausted – for example solar, wind, hydropower, geothermal and biomass
sequestration	the storage of carbon dioxide in terrestrial, geological or ocean sites
total final energy consumption	the sum of energy consumption by all end use sectors, including industry, transport, agriculture, residential, commercial, public services and nonenergy use

summary

- In this report a range of illustrative scenarios developed by the Energy Futures Forum (EFF), together with an additional ABARE scenario, are analysed. These scenarios were designed to examine the economic impacts and associated emission reductions arising as a result of alternative climate change policies with a particular focus on technology options and carbon taxes. The scenarios provided by the EFF include early and late abatement action, differential abatement targets for Australia and varying levels of access to technologies including carbon capture and storage, and nuclear power (table A).
- A scenario designed by ABARE to complement the EFF scenarios and to provide some additional insights is also included. It involves the analysis of greenhouse gas abatement by an international coalition comprising OECD countries, the Russian Federation and other economies in the Commonwealth of Independent States (CIS) plus China and India.
- In all of the scenarios analysed in this report, atmospheric concentration of carbon dioxide (CO_2) is assumed to be stabilised at 575 parts per million (ppm) in 2100. Except for two scenarios, a globally harmonised carbon tax is used to ensure that the required level of abatement is achieved. Other greenhouse gas emissions, including methane and nitrous oxide, are assumed to adjust in response to the carbon tax.
- For practical purposes, given the framework of analysis, a carbon tax or an emissions trading scheme would lead to similar results, other things unchanged. As a consequence, the analysis has been undertaken using a carbon tax instrument.
- The carbon taxes projected for various scenarios in this study should be viewed as the taxes required to achieve the predetermined emissions goal. In reality, a given carbon tax may not achieve a predetermined emissions target and it would be necessary to adjust the chosen carbon tax rate frequently over time to meet the emissions target. The projected carbon taxes are imposed at the point of emissions to the atmosphere without adjusting for existing energy related taxes. Within the modeling framework used in this study, for a given emissions target, the projected carbon taxes will be similar to the likely price of a permit (for an equivalent amount of emissions) under an emissions trading scheme.
- The results of this study indicate that the targeted level of abatement assumed here can be achieved at least cost with an 'all countries' coalition if all countries have access to a broad portfolio of technologies, including nuclear power and carbon capture and storage technologies for electricity generation (scenarios 2a, 2b, 2c, 3, table B). However, the political feasibility of such an 'all countries coalition' is highly questionable.
- To achieve the same global emissions outcome, the required carbon tax under an international coalition comprising the Asia Pacific Partnership on Clean Development and Climate (APPCDC) countries plus the rest of the OECD member countries, the Russian

Federation and the remaining economies of the CIS is estimated to be five times larger than the likely carbon tax under a global coalition at 2050 (scenario 3 vs scenario 2a, table B).

> The broader (direct and indirect) economic costs per unit of abatement (measured in terms of the potential global output lost per unit of emissions abated) under the smaller

A key scenario assumptions

	scenario 1	scenario 2a	scenario 2b	scenario 2c	scenario 2d	scenario 3
Targeted global abatement of CO_2 at 2050 a (relative to the reference case)	35%	40%	40%	40%	40%	40%
Introduction of climate change policy action	Late action: global participation commencing in 2030	Early action: global participation commencing in 2010	Early action: global participation commencing in 2010	Early action: global participation commencing in 2010	Early action: global participation commencing in 2010	Early action: for developed /transition countries b 2010; delayed action for developing countries c 2020
Differentiated abatement target for Australia	No	No	No	No	Yes: 50% below 1990 levels of CO_2 equivalent emissions by 2050	No
Availability of CCS, globally	Yes	Yes	No	No	Yes	Yes
Availability of nuclear power in Australia	No	No	No	Yes	Yes	No d
A 70% across the board reduction in trade barriers by 2025, globally	Yes	Yes	Yes	Yes	Yes	Yes
Do energy prices change following the introduction of a climate change action?	Yes	Yes	Yes	Yes	Yes	Yes

a Excludes CO_2 emissions from bunkers. **b** Includes the Russian Federation and the remaining economies of the Commonwealth of Independent States (CIS). **c** Includes India and China. **d** A variation to this assumption is made in a sensitivity analysis to identify the likely impacts of Australia's access to nuclear power. CCS = carbon capture and storage technologies in electricity generation. CO_2 = carbon dioxide.

international coalition are estimated to be about twice as much as the 'global coalition' equivalent, at 2050 (scenario 3 vs scenario 2a, table B). This is because, under the smaller international coalition, economic growth in many of the nonparticipating countries is above their projected reference case levels and hence their emissions increase (a process known as carbon leakage) thus making the overall abatement task more difficult for coalition countries.

> It is important to have a wide range of technologies that either currently exist or are realistically achievable within the coming decades in order to attain the concentration target assumed in this study in a cost effective way (scenarios 2a, 2b, 2c, tables B, C). For energy generation and use, for example, technology options may include adopting technologies that provide enhanced efficiency in the intermediate and end uses of energy, shifting from fossil fuel based electricity generation toward renewables and nuclear power, as well as implementing carbon capture and storage technologies for electricity generation.

> Unilateral action to achieve deep cuts in Australia's emissions is estimated to cost the Australian economy significantly more than not undertaking that action and offers no perceptible additional benefits to the rest of the world – neither in economic terms nor in terms of global environmental benefits (scenario 2d vs scenario 2a, table C). Even under a high carbon tax regime as modeled under the smaller international coalition (scenario

B key projections for the global economy under alternative scenarios, 2050

		scenario					
		1	2a	2b	2c	2d	3
'Global' carbon tax	2005US$/t CO_2-e	59	75	119	119	74	399 (347) a
Abatement of all GHGs relative to the reference case	%	34	39	39	39	39	37
Total global product	2005US$b	161 337	160 004	158 662	158 666	159 889	157 219
Change in total global product relative to the reference case	%	–1.7	–2.6	–3.4	–3.4	–2.6	–4.3
Overall economic costs per unit of abatement	2005US$/t CO_2-e b	99	128	167	167	132	227
Change in total primary energy consumption relative to the reference case							
– coal	%	–42	–42	–64	–64	–42	–54
– oil	%	–10	–13	–17	–17	–13	–18
– gas	%	–13	–15	–31	–31	–15	–22
– total	%	–8	–9	–12	–12	–9	–9

a The carbon tax within the parentheses of US$347/t CO_2-e emissions applies to India and China, while US$399/t CO_2-e is the carbon tax that applies to the OECD member countries and the Russian Federation and the remining economies of the CIS (all prices are in 2005 US dollar terms). **b** Loss in total global product (in 2005 US dollar terms) per tonne of CO_2-e abated. CO_2-e = carbon dioxide equivalent emissions. GHG = greenhouse gas emissions measured in CO_2-e terms.

3), Australia is projected to be less worse off when compared with the 'deep cut' abatement regime analysed in the report (scenario 2d). Output from key energy intensive industries, nonferrous metals and noncoal energy (oil and gas), is projected to fall by 75 per cent and 60 per cent respectively in scenario 2d, relative to the reference case at 2050. Activity in the agriculture sector would also decline significantly, with output falling by 44 per cent relative to the reference case at 2050.

> 'Late action', based on a plausible expectation that renewed emphasis on a technology solution to climate change would result in the development and diffusion of cleaner and more cost competitive technologies beyond 2050, is estimated to cost the global economy (as well as the Australian economy) substantially less than any 'early action'

C projections for the Australian economy under alternative scenarios, 2050

		scenario					
		1	2a	2b	2c	2d	3
Carbon tax a b	2005A$/t CO_2-e	77	99	157	157	623	525
Abatement of CO_2 only relative to the reference case	%	38	46	41	41	71	68
Abatement of all GHGs c relative to the reference case	%	36	43	39	39	68	64
Gross domestic product	2005A$b	2 629	2 609	2 591	2 593	2 389	2 454
Change in gross domestic product relative to the reference case	%	–1.7	–2.5	–3.2	–3.1	–10.7	–8.3
Overall economic costs per unit of abatement b d	2005A$/t CO_2-e	152	184	257	247	499	411
Change in real wages relative to the reference case	%	–4.1	–5.1	–7.5	–7.3	–20.8	–17.4
Change in total primary energy consumption relative to the reference case							
– coal	%	–33	–31	–61	–62	–59	–53
– oil	%	–7	–9	–12	–12	–32	–26
– gas	%	–12	–14	–26	–27	–52	–46
– total	%	–7	–7	–10	–9	–20	–18
Change in output, by sector relative to the reference case							
– agriculture	%	–1	–2	–3	–3	–44	–32
– coal	%	–22	–22	–38	–38	–32	–14
– electricity	%	–14	–14	–22	–21	–23	–22
– other energy (oil and gas)	%	–14	–14	–29	–29	–60	–55
– nonferrous metals	%	–22	–24	–39	–37	–75	–74
– other manufacturing	%	1	1	2	2	7	4
– services	%	–1	–1	–1	–1	–6	–4

a The projected carbon tax for Australia differs from that for the rest of the world under scenario 2d because of Australia's differentiated emissions reduction target. Under scenario 3, the projected OECD carbon tax rate applies to Australia. **b** Converted at the 2005 exchange rate of A$1 = US$0.76. **c** GHG = greenhouse gas emissions measured in CO_2-e. **d** Total loss in gross domestic product (in 2005 Australian dollar terms) per tonne of CO_2-e abated. CO_2-e = carbon dioxide equivalent emissions.

involving the use of existing technologies (scenario 1 vs scenario 2a, tables B, C). This is because 'early action' would require early retirement of 'lumpy capital' in emissions intensive sectors, such as electricity, and also because of the higher abatement task before 2050 under 'early action' scenarios compared with the 'late action' scenario.

- The key to achieving such a desirable outcome would be to develop a well focused and internationally coordinated technology strategy for the enhanced development, adoption, diffusion and transfer of energy efficient, cleaner technologies. This would involve governments taking a proactive approach to pursue possible technology 'push' policy measures (such as research and development policies, setting industry technology standards, etc.) as well as to reinvigorate energy research through effective public–private partnerships. In the long run, both technology 'push' policies and technology 'pull' policies (such as carbon taxes, emissions trading schemes) would be needed to effectively address climate change related issues.
- It is important to recognise the current scientific uncertainties surrounding the nature and extent of future climate change and the likely impacts thereof. Hence, a sensible approach to climate change must involve a reasonable balance between multinational action to mitigate future emissions to meet given concentration or temperature change targets and the necessary adaptation policy measures to cope with any unavoidable potential climate change impacts.
- The analysis conducted here explores the most cost effective way of meeting the given emission reduction targets. The targets are achieved by a combination of changing technologies and fuel mixes as well as changes to the demand for energy and changes in the supply and demand for other goods induced by changing prices (taxes). The analysis reported here does not examine the possible changes associated with climate change. Research to be released later by the Energy Futures Forum will explore the possible impacts of climate change that may be associated with the emissions pathways reported here.

1

introduction

CSIRO commissioned ABARE to analyse a range of illustrative greenhouse gas emission reduction scenarios that were developed by the Energy Futures Forum (EFF). The main purpose in this report is to provide quantitative analysis of the scenarios provided by the forum. The scenarios analysed include a reference case and a variety of scenarios representing alternative policy responses to climate change provided by the forum. The report also includes a scenario designed by ABARE to complement the EFF scenarios and to provide some additional insights. It involves the analysis of greenhouse gas abatement by an international coalition of countries, including OECD countries, the Russian Federation and other members of the Commonwealth of Independent States (CIS), plus China and India.

ABARE's dynamic general equilibrium model of the world economy, GTEM (global trade and environment model), is used to simulate the scenarios. GTEM is well suited to projecting the macroeconomic and sectoral outcomes under the various scenarios. GTEM has been widely used to analyse a broad spectrum of climate change related issues in recent years. The most recent GTEM applications in climate change related issues include Fisher et al. (2006) and Matysek et al. (2006).

The analytical framework used in this study is described in the following chapter, while the reference case is set out in chapter 3. The policy scenarios are outlined in chapter 4 and the GTEM modeling results, comparing the policy scenarios with the reference case, are presented for both the global and Australian economies in chapter 5.

2

analytical framework

GTEM is a recursively dynamic general equilibrium model developed at ABARE to address policy issues with long term, global dimensions, such as climate change. A detailed description of the theoretical structure of GTEM is contained in Pant (2002). Other ABARE documents that describe further model developments can be found on ABARE's web site (www.abareconomics.com). More recent developments relating to the analytical framework are set out in Matysek et al (2006), including the cost assumptions for the advanced technologies used in transport and electricity generation. The version of GTEM employed here does not take into account the possible impacts of climate change or possible feedback from climate change to the economy.

The projections in this report are derived from GTEM version 6.1. Compared with GTEM version 5, additional features of the present version include: the explicit modeling of electricity and heat and associated generation efficiencies of existing and new capacity; the modeling of 'other transport' by explicitly specifying four different technology types for road transport; and the expansion of the emissions coverage to include carbon dioxide emissions from international bunkers and emissions of high global warming potential (GWP) greenhouse gases – HFCs, PFCs, SF_6 and global CFCs. Changes to the modeling of fertility and labor participation rates in the population module have also been made in GTEM version 6.1.

HFC = hydrofluorocarbon

PFC = perfluorocarbon

SF6 = sulfur hexafluoride

CFC = chlorofluorocarbon.

In GTEM the terms 'sector' and 'industry' are used interchangeably.

The GTEM version 6.1 database is adapted from the GTAP 6.0 database (www.gtap.agecon.purdue.edu/databases/v6/default.asp), and corresponds to the year 2001. There are 87 regions, 67 commodities and five primary factors explicitly identified in the database. For this study, the database is aggregated to the 18 regions, 21 commodities and four primary factors, shown in table 1. It is assumed that each commodity is produced by a single sector. The current aggregation explicitly represents all fossil fuels and key energy intensive sectors, including electricity and transport.

carbon capture and storage (CCS)

In some of the scenarios analysed in this report, CCS technologies are assumed to be available to coal and gas fired electricity generation plants in all regions of the world. Subject to storage availability and installation rates, electricity producers adopt a least cost combination of generating technologies with and without CCS. That is, adoption of CCS commences if the cost of capturing and storing a unit of carbon dioxide is less than or equal to the emissions penalty that would otherwise be paid (see Fisher et al. 2006 and Matysek et al. 2006 for a detailed discussion of the modeling of CCS technologies in GTEM).

The additional cost of generating electricity with CCS technology comprises a capture cost and a transport and storage cost. Capture costs are initially assumed to be US$25 and US$30 a tonne of carbon dioxide captured from coal and gas fired electricity generation plants respectively. Transport and storage costs and storage potentials have been adapted from Hendriks, Graus and van Bergen (2004), who provide estimates of the costs and storage potentials in eighteen regions.

A lagged adjustment equation has been employed to prevent industries from responding to price signals immediately. The adoption rate of CCS technologies is such that, if there is sufficient storage capacity, 90 per cent of the steaming coal or gas fired electricity industry will have adopted CCS technology twenty years after the technology becomes economically feasible, with around two-thirds of the industry adopting the technology after ten years.

Since capturing carbon dioxide requires energy, the amount of electricity produced from a unit of fuel by an electricity generation plant using CCS technology is lower than from the same plant without CCS. The reduction in electricity output per unit of fuel from electricity generation plants that use CCS technologies is called an 'energy penalty'.

1 aggregated GTEM regions, commodities and primary factors

regions	commodities	primary factors
Australia	agriculture	capital
Brazil	forestry and fishing	labor
Canada	brown coal	land
China **a**	coking coal	natural resources
Chinese Taipei	steaming coal	
European Union 25 **b**	oil	
India	gas	
Indonesia	other minerals	
Other ASEAN **c**	food	
Japan	wood, pulp and paper	
Mexico	petroleum and coal products	
OPEC	chemicals, rubber and plastic	
Korea, Rep. of	nonmetallic mineral products	
Russian Federation	iron and steel	
Other CIS **d**	nonferrous metals	
Southern Africa	other manufacturing	
United States	electricity **e**	
Rest of world	water transport	
	air transport	
	other transport	
	other services	

a Including Hong Kong. **b** European Union 25 comprises Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Hungary, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and United Kingdom. **c** Other ASEAN (Association of South East Asian Nations) comprises Brunei, Cambodia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor Leste and Viet Nam. **d** Other CIS (Commonwealth of Independent States) comprises Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyz Republic, Moldova, Tajikistan, Turkmenistan, Uzbekistan and Ukraine. **e** Includes heat energy where identified separately in IEA (2004a,b).

In this analysis, energy penalties of 14.5 per cent and 10.7 per cent are assumed for every unit of electricity generated using coal and gas fired CCS technology respectively. That is, installation of CCS technology by coal fired generation plants reduces the quantity of electricity generated from a unit of coal by 14.5 per cent (alternatively, 17 per cent more coal is required to produce a unit of electricity). It is assumed that 90 per cent of carbon dioxide emissions are captured by plants with CCS technologies.

The costs, energy penalties and capture efficiency assumed in this analysis are consistent with current estimates as discussed in Matysek et al. (2005). Large scale deployment of CCS technologies and consequential 'learning by doing' would be likely to lead to systems with lower costs and energy penalties and improved capture efficiencies. In this analysis, it is assumed that once cumulative experience with CCS technologies reaches 5 gigatonnes of carbon dioxide captured, capture costs decline by 10 per cent for every doubling in cumulative capacity. This rate of cost decline is modest compared with learning rates discussed in the literature.

Because the installation of CCS technology in this framework is only economic if there is a penalty on the carbon dioxide emitted by electricity generation plants, in the present analysis there is no uptake of CCS technology in the absence of such penalties in the reference case.

emissions modeling in GTEM

The GTEM version 6.1 emissions database includes estimates of seven anthropogenic greenhouse gases – combustion and noncombustion carbon dioxide, methane, nitrous oxide, HFCs, PFCs, SF6 and CFC emissions. Most major emissions sources and sectors are represented in GTEM. However, emissions from agricultural residues, and methane and nitrous oxide from combustion and some industrial processes are not modeled in GTEM, although nitrous oxide emissions from transport are included.

All greenhouse gases and their sources are modeled in GTEM separately. However, these gases in GTEM are expressed in carbon dioxide equivalent terms, based on their global warming potentials over a one hundred year time horizon, as recommended by the Intergovernmental Panel on Climate Change (IPCC 1996a).

For the 2001 emissions database for matching sources and regions identified in GTEM, the methodology described in Hester and Ahammad (2002) is used. Additional data on high GWP gases were sourced from the US Environmental Protection Agency through the Energy Modeling Forum (EMF) 21 modeling group on non carbon dioxide greenhouse gases. Table 2 shows the estimated global emissions, by gas, from various sources in GTEM for 2001.

There are five energy commodities in GTEM – brown coal, coking coal, steaming coal, (natural) gas, and petroleum and coal products (table 1) – that are responsible for producing carbon dioxide when combusted. In GTEM, changes in emissions from fossil fuel combustion are assumed to change proportionately to the quantity of fossil fuel consumed. Fuel combustion emissions from international bunkers, although not assigned to any particular region, are assumed to change proportionately to the weighted average fuel consumption of regions supplying international transport services.

In line with the IPCC recommended methodology, emissions from fertiliser use by agricultural industries are assumed to change proportionately to the quantity of fertiliser consumed, while methane emissions from paddy rice are proportionate to the area harvested (IPCC 1996b). As recommended by contributors to the EMF21 modeling exercise, emissions from liquid waste are assumed to change in line with population growth, while solid waste emissions in OECD regions except Japan are linked to population growth, and to per person real GDP in Japan and non-OECD regions. Similarly, emissions of the non CFC high GWP gases move in line with the EMF21 recommended methodology, where emissions move according to changes in per person real GDP, but are capped to the per person emissions of a reference region. In line with IPCC/TEAP (2005), global CFC emissions are assumed to fall to 1651 and 338 Gt CO_2-e in 2002 and 2015, respectively. After 2015, CFC emissions are assumed to continue the same rate of decline as a result of their continued phasing out and reduction in stores. All other emissions change in proportion to industry output.

2 global emissions, by gas and source, 2001 GTEM

	source	Mt CO_2-e
Carbon dioxide		**25 243.8**
	Electricity	9 485.7
	Transport	5 619.5
	Cement	832.3
	Aluminium production	38.0
	Fugitive mining	146.9
	International bunkers	813.5
	Other	8 307.9
Methane		**4 863.4**
	Fugitive mining	1 380.2
	Livestock	1 867.3
	Rice	335.1
	Waste	1 280.8
Nitrous oxide		**2 130.3**
	Transport	154.4
	Adipic and nitric acid	138.0
	Livestock	716.8
	Fertilisers	1 121.1
High GWP gases		**2 245.4**
	HFC23 (from HCFC22 production)	88.0
	Other HFCs (substitutes for ozone depleting substances)	170.7
	PFCs	80.1
	SF_6	54.3
	CFC	1 852.4
Total		**34 483.0**

As discussed in Matysek et al. (2005), there are opportunities to reduce methane, nitrous oxide and noncombustion carbon dioxide emissions per unit of output from the majority of emitting industries through the adoption of known technologies and/or alternative management practices. In GTEM, these abatement opportunities are represented by emissions response functions. Many of the methane abatement technologies are a function of gas or electricity prices since captured methane can be used to generate electricity or be pumped directly into a natural gas pipeline. Accordingly, changes in reference case prices of gas or electricity may stimulate the adoption of emissions capturing technologies. It is assumed that adoption of emissions reducing technologies is not reversible, and hence, once adopted the technologies permanently reduce the per unit emissions from that source.

carbon tax: a market based instrument for emissions reduction

Under all climate change policy scenarios presented in this report, the objective is to reduce the global emissions of carbon dioxide to some predetermined levels (for details on scenarios, see chapter 4). The policy instrument used to achieve the emissions goal under these scenarios is a carbon tax. Except in two scenarios, the carbon tax is considered to be globally harmonised.

In this report, the carbon taxes projected for various scenarios should be viewed as the taxes on greenhouse gas emissions that are necessary to achieve the predetermined emissions goals subject to the underlying modeling assumptions. In reality, a given carbon tax, unlike emissions trading, may not guarantee a particular emissions target. It may be necessary to adjust the tax rate frequently to meet the agreed emissions target under a national or international commitment. This is to deal with the incomplete information and inherent uncertainties about future emissions sources, abatement technologies as well as the future economic environments (for example, future inflation) within which the carbon tax policy will operate; see Tietenberg (2000).

Also, for modeling purposes, the projected global taxes are imposed at the point of emissions to the atmosphere, without adjusting for existing energy or environment taxes. It should be noted that such an unadjusted global carbon tax system would fail to provide a common price signal to emitters around the world and hence, would not guarantee a level playing field for all participants (Pant, Tulpulé and Fisher 2004; also see Babiker, Metcalf and Reilly 2003). Furthermore, the tax policy design issues as well as the issues relating to compliance costs and revenue constraints that policymakers must consider are not taken into account in the current modeling.

However, for a given emissions target within the current modeling framework, the projected tax will closely approximate the price of a permit (for an equivalent amount of emissions) under a tradable emissions permit scheme.

3

reference case

The reference case aims to reflect a world scenario in which technological development and government policies progress along their known paths, with the exception that there would be significantly less trade barriers, and no implementation of any significant greenhouse gas emission reduction policies. For this study, the Energy Futures Forum provided input into the development of some aspects of the reference case. The reference case employed here is similar to that in Matysek et al. (2006), with the exception that globally all trade barriers are reduced by 70 per cent from their 2001 levels across the board by 2025.

In the reference case, population levels peak in many developed economies as a continuation of below replacement fertility rates results in an aging and eventually declining population. Global population, however, continues to rise over the projection period 2001–50 as a result of expanding populations in most developing nations.

A reasonably optimistic future is assumed for economic activity, with most developing economies overcoming internal problems and experiencing strong growth over the projection period. An increase in income, along with moderate growth in population, results in substantial increases in energy consumption. Despite rising energy demand maintaining upward pressure on fossil fuel prices and continued efficiency improvements in low emission energy sources, fossil fuels remain the dominant source of energy over the projection period. It is assumed that there are no substantial government policies acting to constrain their use.

These factors contribute to a reference case where global greenhouse gas emissions increase by about 144 per cent between 2001 and 2050, with a significant share of emissions growth coming from developing regions including China and India. Projected emissions in this reference case are slightly higher than the corresponding projections in Matysek et al. (2006) because of the Energy Futures Forum's assumption of significant trade liberalisation globally. In Matysek et al. (2006), global greenhouse gas emissions are projected to increase by about 142 per cent over the projection period.

population growth

Population growth is an important determinant of greenhouse gas emissions through its relationship to economic growth and energy consumption. World population is expected to grow by approximately 0.93 per cent a year to 2030, to reach 8.08 billion (table 3) from approximately 6.17 billion in 2001. World population growth is then projected to slow considerably (to 0.41 percentage points a year) to reach 8.76 billion in 2050. This slowdown in population growth occurs as fertility rates in most regions fall to, and in some cases below, replacement levels over the projection period. Population levels are expected to peak in some developed regions within the next fifty years and then experience a decline – Japan will be the first, with its population peak expected to occur in 2009.

Fertility rates are assumed to drift gradually to regional fertility targets that are determined exogenously based on various factors, including expectations of income. For this analysis, to 2050, fertility rates are assumed to drift gradually to 1.7 children per woman in developed regions, 1.8 children per woman in developing Asia and Latin America and 2.0 children per woman in other regions. The assumed easing of China's one child policy in 2016 is expected to stabilise China's population at just over 1.5 billion by 2050.

Growth in world population is driven by population momentum in key developing regions, particularly India which has a historically high fertility rate and therefore a demographic bias toward a relatively young population age structure. Australia's population growth is based on the Australian Bureau of Statistics' medium variant fertility rate, migration and life expectancy assumptions, that result in the population increasing to just over 28 million by 2050 (ABS 2005).

3 populations, by region – GTEM reference case

	2001	2030	2050
	million	million	million
Australia	19.4	25.5	28.1
Brazil	174.0	222.3	234.3
Canada	31.0	38.0	39.5
China	1 291.8	1 520.3	1 529.9
Chinese Taipei	22.7	24.8	24.8
European Union 25	452.8	454.9	425.8
India	1 033.1	1 433.4	1 557.5
Indonesia	214.3	275.9	285.9
Other ASEAN	313.6	432.0	468.3
Japan	127.2	120.0	106.1
Mexico	100.4	134.0	142.0
OPEC	201.8	332.6	403.4
Korea, Rep. of	47.1	51.0	47.4
Russian Federation	144.8	123.1	106.9
Other CIS	138.3	142.3	129.9
South Africa	49.1	54.5	58.3
United States	288.0	364.1	397.8
Rest of world	1 522.1	2 330.3	2 775.2
World	6 171.5	8 078.9	8 761.1

economic growth, labor supply and productivity growth

As economies grow and per person gross domestic product rises, demand for energy intensive goods and services, such as electricity and transport, increases.

In GTEM, gross domestic product (GDP) growth is based on historical data for 2001 to 2005. For a select group of regions, short run GDP projections to 2011 have been drawn from ABARE's own macroeconomic assumptions. For other regions, GDP projections for 2006 have been taken from International Monetary Fund projections (IMF 2005). Beyond these projections, GDP growth projections are calculated based on expected labor productivity growth and labor supply growth.

Regional labor productivity growth (growth in output per worker) is an exogenous input into the model and is derived from expectations about investment rates, technology development and technology transfer. Regional labor supply growth rates are determined by the population projections and detailed workforce participation rate growth paths that are implemented in GTEM, by gender and age. Changes in participation rates over time are based on expectations about policy change, social attitudes, economic development and the impact of rising aged dependency ratios. For example, rising aged dependency and increases in

4 average annual growth in gross domestic product – GTEM reference case

	2001–10	2010–30	2030–50	2001–50
	%	%	%	%
Australia	3.2	2.4	2.2	2.5
Brazil	3.2	4.2	3.7	3.8
Canada	2.9	2.3	2.0	2.3
China	8.4	5.4	4.0	5.4
Chinese Taipei	4.1	3.0	1.8	2.7
European Union 25	1.8	1.8	1.5	1.7
India	6.6	5.8	4.8	5.5
Indonesia	4.9	5.0	3.9	4.5
Other ASEAN	5.2	4.1	3.3	4.0
Japan	1.8	1.4	1.1	1.3
Mexico	3.1	4.1	3.0	3.5
Rest of OPEC	4.5	4.8	4.1	4.4
Korea, Rep. of	4.5	3.0	1.7	2.7
Russian Federation	5.4	3.3	2.8	3.5
Other CIS	7.7	4.6	3.2	4.6
South Africa	3.7	3.4	3.4	3.5
United States	3.2	2.8	2.5	2.8
Rest of world	4.1	4.3	3.9	4.1
World	3.2	3.0	2.8	3.0

life expectancy in many developed economies are expected to result in participation rates for older people increasing slowly back toward 1950 levels. Other key assumptions are that, in developed and rapidly developing economies, female participation rates continue to increase and young people continue to delay their entry into the workforce to pursue higher levels of eduction.

Despite slowing global population growth, world economic growth is expected to grow at about 3 per cent a year between 2001 and 2050 (table 4), compared with 2.5 per cent a year between 1990 and 2001 (IMF 2005). Underlying this economic growth is the expectation that development of new technologies over the projection period continues. Developing economies are assumed to experience strong productivity growth as they continue to open their economies to foreign investment and benefit from technology transfer. In addition, it is also assumed that energy and agricultural resource supply constraints are minimal and that global health continues to improve.

economic growth projections for Australia

Economic growth in Australia averaged around 3.3 per cent a year between 1990 and 2001. This strong economic growth was underpinned by relatively high labor productivity growth. Competition policy and other microeconomic reforms played a key role in Australia's productivity increases.

Toward 2050, Australia's labor productivity growth is assumed to move gradually from the high levels achieved in the past decade. On average, Australia's labor productivity is assumed to increase at an annual rate of 1.9 per cent between 2001 and 2050. This compares with an historical average annual growth of approximately 1.75 per cent between 1970 and 2000 (Treasury 2002).

Australia's labor supply growth is projected to decline from an annual rate of 1.2 per cent between 2001 and 2010 to around 0.4 per cent between 2030 and 2050. This projected decline in labor supply growth mainly reflects an expected fall in fertility rates and an aging population, which more than offsets the effects of assumed moderate increases in migration and participation rates toward 2050.

tariffs

The past international trend of tariff reductions across industries throughout the world is expected to continue in the future. Underlying this assumption is strong world economic growth and political stability that greatly enhance the living standards globally and reduce opposition to the removal of tariffs. It is assumed that by 2025 all trade barriers in terms of export/output subsidies and import tariffs have been reduced by 70 per cent across the board and across the globe. This assumption of significant trade liberalisation is made to reflect the views of the Energy Futures Forum participants.

energy consumption

Global primary energy consumption is projected to grow significantly over the period, from 9 gigatonnes of oil equivalent (Gtoe) in 2001 to 22 Gtoe in 2050 (table 5). The majority of this growth is projected to take place in developing regions. This occurs because developing economies experience higher growth in population and income per person and developed economies continue to switch away from energy intensive industries toward service based industries. Combined energy consumption by India and China increases from 14 per cent of global primary energy consumption in 2001 to 28 per cent in 2050.

5 primary energy consumption – GTEM reference case a

	2001	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Australia	104	122	141	157	176	196
World	8 983	10 892	13 274	15 838	18 818	22 248

a Includes primary energy from nonhydro renewables that are used only in public and/or own industry use electricity and heat production as specified in IEA (2005a,b) – for example, biomass used by private households is not included. If energy from all sources were included, global primary energy consumption in 2001 would be around 10 000 Mtoe (IEA 2005a).

6 fuel shares in total primary energy consumption – GTEM reference case

	coal a	oil	gas	nuclear	hydro b	nonhydro renew-ables c
	%	%	%	%	%	%
Australia						
2001	46.4	32.0	19.5	na	1.4	0.8
2010	42.7	32.8	21.3	na	1.2	2.0
2020	41.5	33.1	21.5	na	1.0	2.8
2030	38.9	33.6	22.2	na	1.0	4.3
2040	37.3	33.0	22.0	na	0.9	6.8
2050	35.6	32.3	21.7	na	0.8	9.5
World						
2001	25.8	39.4	23.4	7.7	3.0	0.7
2010	27.9	36.9	23.8	7.2	3.1	1.2
2020	28.0	36.2	24.4	6.6	3.2	1.6
2030	26.6	36.3	24.4	6.9	3.3	2.6
2040	25.8	35.3	24.8	7.8	2.9	3.3
2050	24.9	34.5	25.1	8.8	2.7	4.0

a Combined brown and black coal. **b** Includes geothermal. **c** Includes biomass, solar, waste and wind. **na** Not applicable.

Over the period to 2050, a global technology switch is expected in favor of low or zero emissions intensity. This occurs in response to, among other things, continued energy security fears and the improved competitiveness of renewable energy sources. Despite this, fossil fuels continue to be the predominant energy sources, with the shares of oil and coal consumption in global energy consumption projected to fall only slightly, from 39.4 per cent to 34.5 per cent and 25.8 per cent to 24.9 per cent respectively over the projection period (table 6).

In Australia, energy consumption is projected to expand by about 1.3 per cent a year to 2050. Coal rather than oil is the dominant energy source in Australia, primarily as a result of Australia's abundance of cheap coal reserves. Nonhydro renewables (such as wind, solar and biomass) powered generation are projected to increase the importance of renewables in the energy mix in response to expected improvements in the relevant technologies and cost competitiveness. However, in 2050 these technologies are expected to still only contribute less than 10 per cent of Australia's total primary energy consumption.

Detailed assumptions relating to reference case energy efficiency in key sectors are set out in Matysek et al. (2006).

electricity generation

Electricity generation output is disaggregated by technology type. Seven technologies for electricity generation are identified in GTEM: brown coal, black coal, petroleum, gas;

nuclear, hydro, and nonhydro renewables based technologies. The main components of nonhydro renewables are biomass, waste, wind and solar.

electricity technology share assumptions

In the GTEM reference case used in this report, the shares of various technologies in electricity generation between 2001 and 2020 are determined exogenously using projections from IEA (2002, 2004c), IEEJ (2004) and various government organisations. These shares reflect a wide range of factors, including relative fuel prices, energy endowments and levels of development, policy concerns about energy security and types of new power plants currently being constructed.

Both coal and oil fired generation and nuclear power are expected to lose significant share to gas fired generation and nonhydro renewables by 2020. Gas fired generation is expected to increase significantly within the first twenty years as a result of the commercialisation of natural gas combined cycle power plants that can achieve generation efficiencies of over 50 per cent. National plans by many governments currently outline an expansion of gas fired electricity generation to lower the cost of electricity and improve energy security and emission intensity. In China it is assumed that the share of electricity generated by gas increases from 1.2 per cent in 2001 to 8.2 per cent in 2020. Between 2001 and 2020, global electricity generation derived from gas is expected to increase by 143 per cent, whereas global electricity generation derived from coal is expected to increase by 73 only per cent. Oil fired electricity generation grows by only 2 per cent as energy security concerns results in little development of new oil fired electricity plants.

The global share of nuclear power in electricity generation is expected to fall significantly by 2020 as a result of little expansion and the retirement of old plants in developed economies under current nuclear programs, with the exception of the Republic of Korea and Japan. In the Republic of Korea and Japan, energy security and addressing the various environmental concerns help to overcome opposition to increasing nuclear capacity in the near term. In the Republic of Korea, substantial growth in new nuclear capacity after 2010 increases the share of nuclear power in total electricity generation from 35 per cent in 2010 to almost 50 per cent by 2020. In Japan, eleven new plants are currently planned (totaling 14.7 gigawatts, including three reactors currently under construction). It is assumed that seven of these reactors come into operation by 2015, the remaining two brownfield reactors by 2020 and the two greenfield reactors by 2025 (bringing total nuclear generation capacity up to 61.48 gigawatts in 2025). This is somewhat pessimistic compared with the Ministry of Economy, Trade and Industries (METI) forecasts of having all eleven new reactors online by 2014.

China and India are projected to be the main drivers of new nuclear capacity in the near term and are projected to install an additional 31 and 20 gigawatts of nuclear capacity respectively by 2020. Recent announcements that India is likely to exceed 20 gigawatts of installed nuclear capacity by 2020 (Platts 2005) are not incorporated in this reference case because this is deemed to be a possible outcome of the Asia Pacific Partnership on Clean Development and Climate (Fisher et al. 2006), which is not considered in this reference case.

The GTEM reference case projections for electricity output, by fuel, are presented in tables 7 and 8. As can be seen from these tables, initially after 2020, new hydroelectric generation

7 share of electricity (excluding heat) generated, by fuel – GTEM reference case

	coal a	oil	gas	nuclear	hydro b	nonhydro renew-ables c
	%	%	%	%	%	%
Australia						
2001	78.3	1.3	12.1	0.0	7.6	0.7
2010	73.7	1.2	16.3	0.0	6.3	2.5
2020	72.0	1.1	18.4	0.0	5.2	3.3
2030	67.6	1.1	21.8	0.0	4.8	4.7
2040	66.5	0.7	21.4	0.0	4.2	7.1
2050	65.3	0.5	21.0	0.0	3.7	9.5
World						
2001	38.4	7.7	18.6	17.0	16.9	1.4
2010	40.1	5.3	21.4	14.5	16.2	2.4
2020	38.6	4.5	25.7	12.3	15.6	3.3
2030	36.5	4.9	26.7	12.2	14.6	5.1
2040	35.4	3.6	29.4	13.1	12.4	6.2
2050	33.9	2.7	31.5	14.0	10.7	7.3

a Combined brown, coking and black coal. **b** Includes geothermal. **c** Includes biomass, solar, waste and wind.

8 electricity output generated, by fuel – GTEM reference case

	coal a	oil	gas	nuclear	hydro b	nonhydro renew-ables c
	TWh	TWh	TWh	TWh	TWh	TWh
Australia						
2001	170	3	26	0	16	2
2010	194	3	43	0	16	6
2020	229	4	59	0	16	10
2030	252	4	81	0	18	18
2040	290	3	93	0	18	31
2050	331	3	106	0	19	48
World						
2001	5 963	1 195	2 890	2 638	2 622	218
2010	8 323	1 108	4 436	3 013	3 359	500
2020	10 501	1 217	6 999	3 351	4 233	894
2030	12 585	1 698	9 193	4 210	5 033	1 753
2040	15 360	1 560	12 750	5 666	5 370	2 696
2050	18 302	1 454	17 021	7 562	5 767	3 946

a Combined brown, coking and black coal. **b** Includes geothermal. **c** Includes biomass, solar, waste and wind.

is constrained by assumed economically exploitable capability and, in the longer term, by assumed technically exploitable capability (World Energy Council 2001). Oil fired generation is projected to continue losing market share, as petroleum products are shifted to satisfy demand in other, more profitable, sectors of the economy (see tables 7 and 8). Coal fired generation remains the largest share of global electricity generation throughout the projection period, contributing 33.9 per cent in 2050, closely followed by gas fired generation at 31.5 per cent in 2050.

Developed economies currently with nuclear programs (with the exception of the European Union 25) are assumed to start building new power plants again after 2020 as opposition to further uptake is expected to decline. In many of these regions, the share of electricity generation from nuclear power increases toward 2001 levels by 2050. Nuclear power is also expected to continue to expand in China and India beyond 2020. By 2050, nuclear generation in China and India is projected to be about 39 per cent of total global nuclear electricity generation. Despite such large capacity additions, coal fired generation technologies are projected to still represent around half of total generation in India and China at 2050. In this reference case, Australia is assumed not to develop any nuclear power capacity over the projection period.

Relatively rapid improvements in the cost and performance of nonhydro renewable electricity generation technologies are assumed to continue over the projection period and become more attractive in most regions. Despite these improvements, the continued prevalence of cheap fossil fuels without any stringent constraints on their consumption is assumed to suppress the ability of nonhydro renewable technologies to gain significant market share in most regions.

Globally, electricity generated by nonhydro renewables is projected to increase at an average annual rate of 6.1 per cent a year between 2001 and 2050, increasing their share of total global electricity generation to around 7.3 per cent by 2050. The European Union is assumed to have the highest share of electricity generated using nonhydro renewables (16.1 per cent at 2050), driven largely by continued large subsidies and favorable government policies, particularly in EU15 countries. Australia is expected to have the second largest share of nonhydro renewables (9.5 per cent at 2050).

China's current renewables energy development plan to 2020 has been incorporated into this reference case (http://nyj.ndrc.gov.cn/gjkzsnydh/t20051108_48661.htm). In particular, it is assumed that 290 gigawatts of hydroelectric capacity, together with 30 gigawatts of wind, 20 gigawatts of biomass and 2 gigawatts of solar photovoltaic capacity, are installed by 2020. Assuming these capacity levels, by 2020, China is projected to generate more electricity from renewables than any other region. Despite the significant growth in electricity generated from nonhydro renewables, the declining share of electricity generated by hydro power results in the share of all renewables in global electricity production remaining between 17 and 20 per cent throughout the projection period.

electricity generation costs

Despite a significant improvement in the competitiveness of gas fired electricity generation in the past decade, coal fired electricity generation remained the cheapest form of electricity in 2001 on average (table 9). Over the projection period, coal fired generation improves its competitiveness relative to other fossil fuel energy sources. This occurs because real coal prices are assumed to fall relative to gas and oil prices. Despite nonhydro renewables having the fastest efficiency improvements, the competitiveness of nonhydro renewables only improves marginally as other electricity generation options also experience productivity improvements.

In 2001 in Australia, coal had a greater cost advantage compared with gas and oil, which explains its high uptake. Gas, however, improves its cost competitiveness relative to coal over the projection period (table 10). Compared with average global costs, nonhydro renewables in Australia are more competitive with other technologies as a result of the development and uptake of more efficient processes. This is one reason why Australia's nonhydro renewable share in electricity generation is higher than most other regions.

9 indexes of global electricity generation costs, by technology
2001 coal fired generation price = 1.00

	2001	2010	2020	2030	2040	2050
Coal	1.00	0.92	0.87	0.86	0.85	0.85
Oil	1.83	2.04	1.77	1.68	1.66	1.64
Gas	1.15	1.16	1.12	1.09	1.06	1.05
Nuclear	1.54	1.47	1.44	1.39	1.35	1.33
Hydro	1.46	1.44	1.43	1.45	1.47	1.48
Nonhydro renewables	2.25	2.08	1.94	1.77	1.70	1.66

10 indexes of electricity generation costs in Australia, by technology 2001 coal fired generation price = 1.00

	2001	2010	2020	2030	2040	2050
Coal	1.00	0.93	0.87	0.83	0.79	0.75
Oil	2.16	2.50	2.11	1.97	1.89	1.81
Gas	1.25	1.17	1.07	1.00	0.95	0.90
Nuclear						
Hydro	1.27	1.22	1.17	1.13	1.10	1.07
Nonhydro renewables	1.90	1.72	1.54	1.38	1.27	1.18

emissions

Global greenhouse gas emissions, excluding those from land use change and forestry, are projected to grow by 2.0 per cent a year between 2001 and 2030, with the level of greenhouse gas emissions projected to increase from 34 gigatonnes to 61 gigatonnes

11 total greenhouse gas emissions – GTEM reference case [a]
excluding land use change and forestry

	2001	2010	2020	2030	2040	2050
	Mt CO_2-e	Mt CO_2-e	Mt CO_2-e	Mt CO_2-e	Mt CO_2-e	Mt CO_2-e
Australia	497	560	661	727	790	846
World	34 483	41 825	52 079	61 283	72 156	84 051

a Global greenhouse gas emissions are projected to increase from about 34 Gt CO2-e in 2001 to about 84 Gt CO_2-e in 2050, or by about 144 per cent. Because of the Energy Futures Forum's assumption of significant trade liberalisation globally in this reference case, the projected emissions are slightly higher than the corresponding projections of 142 per cent in Matysek et al. (2006).

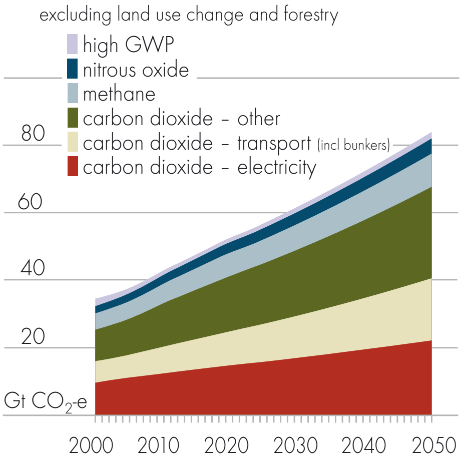
of carbon dioxide equivalent, Gt CO_2-e (table 11). Between 2030 and 2050, emissions growth slows to 1.6 per cent a year as a result of lower global population growth and a continued decline in emission intensity of output. In 2050, global greenhouse gas emissions are projected to be about 84 Gt CO_2-e (figure 1).

Emissions are projected to grow fastest in OPEC and India, at a rate of 3.2 per cent and 3.1 per cent a year respectively between 2001 and 2050. Emissions growth in these regions reflects strong population and per person income growth. China, however, is the largest emitter over the projection period, with cumulative emissions of 644 Gt CO_2-e, which is significantly higher than the next largest emitter, the United States, with the corresponding emissions projected at 493 Gt CO_2-e.

Emissions growth tends to be slower in developed economies, reflecting slower rates of population and economic growth, restructuring away from emission intensive industries and the uptake of less emission intensive technologies and practices. For instance, Japan's emissions grow only by 0.5 per cent year between 2001 and 2050 as a result of falling population and relatively low productivity growth. The Russian Federation, however, has the lowest emission growth between 2001 and 2050, at 0.4 per cent a year, despite relatively high productivity growth. This occurs because the Russian Federation experiences a large decline in population and relatively high improvements in energy efficiency over time.

In 2001, carbon dioxide was the main source of global greenhouse gas emissions, contributing around 73 per cent, followed by methane (14 per cent) and nitrous oxide (6 per cent), with the remainder made up of the various high GWP gases and CFCs. Expansion of the electricity and transport sectors causes the share of carbon dioxide emissions in total emissions to increase to 81 per cent by the end of the projection period (figure 1).

1 global greenhouse gas emissions – GTEM reference case
excluding land use change and forestry



12 share of Australian and world greenhouse gas emissions, by sector – GTEM reference case

excluding land use change and forestry

	2001	2010	2020	2030	2040	2050
	%	%	%	%	%	%
Australia						
Agriculture	18.7	19.0	20.6	20.1	19.2	18.4
Electricity	37.8	37.7	36.3	35.3	34.9	35.0
Transport	16.0	16.4	16.6	17.4	18.3	19.2
Industry	26.3	25.6	25.1	25.6	25.8	25.5
Households	1.2	1.4	1.4	1.6	1.8	2.0
World						
Agriculture	12.8	12.8	12.5	12.4	12.2	11.9
Electricity	27.5	28.8	27.9	27.3	26.8	26.3
Transport	19.1	18.9	19.6	20.7	21.6	22.5
Industry	37.1	36.1	36.7	36.2	36.0	35.8
Households	3.4	3.4	3.3	3.4	3.4	3.5

Note: Electricity emissions are not allocated to end users of electricity; emissions from private vehicles are allocated to the transport sector, not private households.

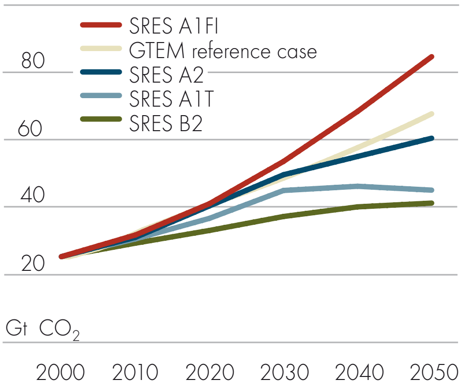
Two key sectors — electricity and transport — accounted for about half of global greenhouse gas emissions in 2001, contributing 27.5 per cent and 19.1 per cent respectively (table 12). In 2050, the global electricity industry is expected to remain the major source of global emissions, although its share in total greenhouse gas emissions is projected to fall to 26.3 per cent in 2050. On average, per person emissions from electricity generation are projected to grow at 1.0 per cent a year. The global transport sector experiences the largest growth in emissions, with its share of total greenhouse gas emissions increasing from 19.1 per cent in 2001 to 22.5 per cent in 2050. This reflects the large expansion of the transport sector (particularly private transport) in many developing countries and the continued use of petroleum products as the dominant fuel input. On average, emissions per person from the transport sector are projected to grow at 1.5 per cent a year.

The agriculture sector's share of global emissions falls from 12.8 per cent to 11.9 per cent over the projection period. The share of emissions from other industries (labeled 'industry' in table 12) falls from 37.1 per cent in 2001 to 35.8 per cent in 2050.

Global carbon dioxide emissions in the reference case follow closely those projected under the SRES A2 scenario (Special Report on Emissions Scenario — see Nakicenovic and Swart 2000) until around 2030 (figure 2). After

2 carbon dioxide emissions – GTEM reference case and SRES scenarios

excluding land use change and forestry



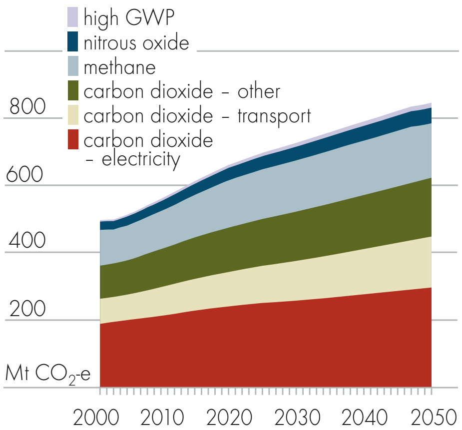
Note: SRES data taken from Nakicenovic et al. (2000).

2030, global carbon dioxide emissions under the SRES A2 scenario begin to diverge from the GTEM reference case as a result of an assumed decline in global economic growth. Global carbon dioxide emissions in GTEM are projected to grow at 2.3 per cent a year between 2003 and 2030. This is considerably higher than the IEA (2005c) projection of 1.6 per cent a year between 2003 and 2030 and is primarily a result of different economic growth and population projections but is comparable to the EIA (2006) projection of 2.1 per cent a year between 2003 and 2030.

emissions in Australia

Australia's greenhouse gas emissions, excluding those from land use change and forestry, are projected to grow on average at 1.3 per cent a year between 2001 and 2030, with the level of greenhouse gas emissions projected to increase from 497 Mt CO_2-e in 2001 to 727 Mt CO_2-e in 2030 (figure 3). Between 2030 and 2050 emissions growth slows considerably to 0.8 per cent a year as a result of a slower population growth and a continued switch away from energy intensive industries.

3 Australian greenhouse gas emissions – GTEM reference case
excluding land use change and forestry



The electricity sector remains the major contributor to total emissions throughout the projection period, although its share falls from 37.8 per cent in 2001 to 35.0 per cent in 2050. This decline occurs as a result of large energy efficiency improvements and a switching away from the use of emission intensive coal fired power generation to nonhydro renewables. The transport sector's share of total emissions increases from 16.0 per cent in 2001 to 19.2 per cent in 2050. This occurs because of the continued reliance on fossil fuels. The shares of agriculture and other industry sectors fall slightly over the projection period.

4

description of alternative policy scenarios

Six alternative policy scenarios are described in this chapter. Of these, the first five scenarios are provided by the Energy Futures Forum. These scenarios are designed to examine the impacts of alternative technology options and/or hypothetical policies aimed at reducing greenhouse gas emissions. The final scenario of this report is included by ABARE to complement the forum scenarios and to provide some additional insights.

The Energy Futures Forum has also provided input into the development of the reference case already discussed in chapter 3, with which the projections under all scenarios are compared. The six alternative policy scenarios described in this section are labeled as scenario 1, scenarios 2a–2d, and scenario 3. A summary of the key assumptions for the alternative scenarios is provided in table 13.

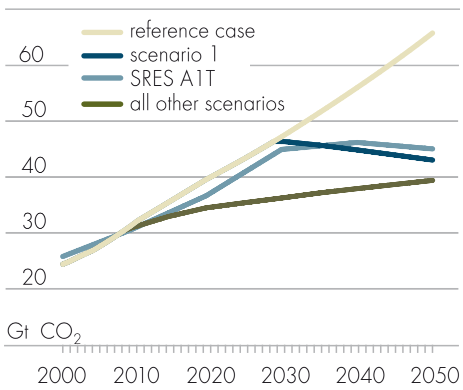
All six alternative scenarios in table 13 are developed so as to set the global economy on emission pathways that are consistent with stabilising the atmospheric concentration of carbon dioxide (CO_2) at 575 parts per million (ppm) in 2100. However, these scenarios differ in terms of the timing of the hypothetical introduction of a policy to contain emissions as well as in technology options to achieve the concentration target. Each individual scenario is described below.

scenario 1

This scenario represents the implementation of a hypothetical global policy action to reduce greenhouse gas emissions, starting in 2030. The emissions pathway of this scenario is similar to the emissions pathway of the SRES A1T scenario (figure 4). In this scenario, global carbon dioxide emissions are targeted such that the global allowable emissions at 2050 will be 43.1 gigatonnes of carbon dioxide (Gt CO_2). This target represents a 35 per cent reduction in global carbon dioxide emissions relative to the reference case (table 13).

The emission abatement target in scenario 1 is assumed to be achieved through the introduction of a globally harmonised carbon tax from 2030. Other greenhouse gas emissions including methane and nitrous oxide are assumed to adjust in response to the carbon

4 **emissions paths – various scenarios**



tax. In this scenario, all global regions (with one exception) have access to all potential abatement technologies modeled in GTEM including the carbon capture and storage (CCS) options for coal and gas fired power generation. The only exception to this technology option assumption is that Australia has no access to nuclear power during the projection period.

13 key scenario assumptions

	scenario 1	scenario 2a	scenario 2b	scenario 2c	scenario 2d	scenario 3
Targeted global abatement of CO_2 at 2050 a (relative to the reference case)	35%	40%	40%	40%	40%	40%
Introduction of climate change policy action	Late action: global participation commencing in 2030	Early action: global participation commencing in 2010	Early action: global participation commencing in 2010	Early action: global participation commencing in 2010	Early action: global participation commencing in 2010	Early action: for developed /transition countries b 2010; delayed action for developing countries c 2020
Differentiated abatement target for Australia	No	No	No	No	Yes: 50% below 1990 levels of CO_2 equivalent emissions by 2050	No
Availability of CCS, globally	Yes	Yes	No	No	Yes	Yes
Availability of nuclear power in Australia	No	No	No	Yes	Yes	No d
A 70% across the board reduction in trade barriers by 2025, globally	Yes	Yes	Yes	Yes	Yes	Yes
Do energy prices change following the introduction of a climate change action?	Yes	Yes	Yes	Yes	Yes	Yes

a Excludes CO_2 emissions from bunkers. b Includes the Russian Federation and the remaining economies of the Commonweath of Independent States (CIS). c Includes India and China. d A variation to this assumption is made in a sensitivity analysis to identify the likely impacts of Australia's access to nuclear power. CCS = carbon capture and storage technologies in electricity generation. CO_2 = carbon dioxide.

scenarios 2a–2d

These four scenarios represent the hypothetical implementation of an alternative global policy action to reduce greenhouse gas emissions, *commencing in 2010*, under different technology options and/or a differentiated abatement target for Australia (scenario 2d).

In all four scenarios, global carbon dioxide emissions are targeted such that the global emissions at 2050 will be restricted to 39.4 Gt CO_2 (figure 4). Again, this targeted emission path is set so as to be consistent with a CO_2 concentration stabilisation target of 575 ppm at 2100. This emissions target represents a 40 per cent reduction in global CO_2 emissions relative to the reference case. Except in scenario 2d, the required emissions abatement is assumed to be achieved by the introduction of a globally harmonised carbon tax from 2010. As is the case of scenario 1, other greenhouse gas emissions, including methane and nitrous oxide, are assumed to adjust in response to the carbon tax under this suite of scenarios.

The distinguishing features of the group 2 scenarios are as follows:

> scenario 2a – it is assumed that all regions have *access to all potential abatement technologies* modeled in GTEM, including the carbon capture and storage (CCS) options for coal and gas fired power generation. However, Australia is assumed to have *no* access to nuclear power during the projection period. The technology option assumption for scenario 2a, therefore, is similar to scenario 1.

> scenario 2b – similar to scenario 2a except that it is assumed that, under scenario 2b, *no region in the world will implement carbon capture and storage technologies* during the projection period. As is the case in scenarios 1 and 2a, Australia is assumed to have *no* access to nuclear power. As such, scenario 2b is designed to assess the importance of the availability of carbon capture and storage on the cost of meeting the given abatement task. This can be undertaken by comparing the model projections for scenario 2a and scenario 2b.

> scenario 2c – identical to scenario 2b above except that *Australia is assumed to have access to nuclear energy* under scenario 2c. It is assumed that, under scenario 2c, one small nuclear power plant begins operation in Australia around 2020, with the likely capacity expansion thereafter being unrestrained. This scenario thus can be used together with scenario 2b to assess the importance of the availability of nuclear energy in Australia when carbon capture and storage is still unavailable globally.

> scenario 2d – Australia is assumed to reduce its own carbon dioxide equivalent emissions to 50 per cent below its 1990 levels by 2050, while the 2050 global carbon dioxide emissions target remains at 39.4 Gt CO_2. Relative to the projected reference case emissions presented in chapter 3, this implies a 71 per cent cut in Australia's carbon dioxide emissions in 2050, while the global target is a 40 per cent cut in total carbon dioxide emissions in 2050. As for the technology options, the assumption of the global access to carbon capture and storage is maintained under scenario 2d. Also, Australia is assumed to have access to nuclear energy. As in scenario 2c, one small nuclear plant is assumed to start operating in Australia around 2020, with potential expansion taking

place between 2020 and 2050. Scenario 2d is designed to examine the economic impacts of *Australia unilaterally undertaking deep emissions cuts* while the global abatement task remains unchanged at the scenario 2 group level.

scenario 3

This scenario is designed to represent a situation where only OECD countries, the Russian Federation and other members of the CIS plus China and India undertake emissions abatement action to achieve a given global emissions target. Under this scenario, the global carbon dioxide emissions path is targeted, as in the case of the scenario 2 group, such that at 2050 global emissions will be contained at 39.4 Gt CO_2 (figure 4). The chosen emissions path is consistent with the carbon dioxide concentration stabilisation target of 575 ppm at 2100. The member countries of this hypothetical international coalition (except China and India) are assumed to implement an abatement policy action in terms of a harmonised carbon tax from 2010. For the purpose of this analysis, it is also assumed that China and India will join the coalition in 2020 with the introduction of a small carbon tax domestically, which is to be increased incrementally such that these two developing countries fully move toward a harmonised carbon tax for the coalition as a whole around 2070, when the tax rate will be the same for all coalition members.

It is assumed that the scenario 2a technology options are maintained under scenario 3, allowing for the uptake of carbon capture and storage (CCS) technologies globally and *no access to nuclear energy for Australia* during the projection period to 2050. However, in order to identify the likely impacts of the availability of nuclear power in Australia under the coalition, a sensitivity analysis regarding Australia's nuclear power assumption was carried out. As such, this alternative technology assumption for scenario 3 (allowing Australia's access to nuclear power) is identical to that under scenario 2d.

In all these greenhouse gas emission reduction scenarios, trade barriers are left at their reference case levels throughout the projection period. Furthermore, all energy prices are assumed to adjust in response to the relevant greenhouse gas emission reduction policies considered above.

brief scenario descriptions

For brevity, the scenarios in this report are labeled as follows:

scenario 1	late action with a full range of abatement technologies
scenario 2a	early action with a full range of abatement technologies
scenario 2b	early action without carbon capture and storage technologies
scenario 2c	early action without CCS but with Australia's access to nuclear
scenario 2d	early action with a deep cut in Australia's emissions
scenario 3	an international coalition for greenhouse gas abatement.

5

analysis of scenario projections

A quantitative analysis of the range of alternative greenhouse gas emission reduction scenarios described in chapter 4 is presented in this chapter. ABARE's global trade and environment model (GTEM) is used to analyse these scenarios. The GTEM simulation results for the world economy and Australia are discussed with a particular focus on the following key variables:

- carbon tax level
- gross domestic product (GDP)
- sectoral distribution of emissions abatement
- primary energy consumption and its composition
- electricity generation and its technology portfolio.

The GTEM simulation results are expressed, unless otherwise stated, as deviations from the corresponding levels in the reference case (see chapter 3). In reporting the projected levels for certain variables (for example, carbon tax and GDP), global values are expressed in 2005 US dollar terms, with the corresponding variables for Australia expressed in 2005 Australian dollars (converted at the 2005 exchange rate of A$1 = US$0.76).

scenario 1 – late action with a full range of abatement technologies

Under scenario 1, it is assumed that a globally harmonised carbon tax is introduced in 2030 and the global abatement task is set so as to reduce carbon dioxide emissions to around 35 per cent below the reference case level at 2050 using a range of technologies, including carbon capture and storage (CCS) technologies for electricity generation. Australia is assumed to have no access to nuclear power throughout the projection period to 2050.

global projections

overall impacts

The key global results for scenario 1 are presented in table 14. The carbon tax under this scenario is projected to rise from a low level in 2030 to US$36 per tonne of carbon dioxide equivalent (CO_2-e) at 2040 and then to US$59/t CO_2-e in 2050. With a rising carbon tax, the emission intensity of the global economy is projected to fall over time. Also, emissions intensity is projected to fall relative to the reference case – from 0.51 Mt CO_2-e/US$b in the reference case to 0.34 Mt CO_2-e/US$b in 2050 under scenario 1.

In 2050, total global product is projected to fall by about 1.7 per cent relative to the reference case level (table 14). As can be seen from table 15, countries with relatively low

14 global carbon tax, abatement and total global product – scenario 1

		2040	2050
Carbon tax	2005US$/t CO_2-e	36	59
Total abatement	Gt CO_2-e	15.7	28.9
Total global product a	2005US$b	123 975	161 337
Emission intensity	Mt CO_2-e/US$b	0.46	0.34
		deviation from the reference case	
		%	%
Greenhouse gas emissions (CO_2-e)		–21.8	–34.4
Total global product a		–1.07	–1.75

a Total global product is the global equivalent of gross domestic product (GDP).

carbon intensities such as Japan and Korea are projected to experience smaller declines in GDP (measured as deviation from the reference case) than the corresponding global average of about 1.7 per cent, as these economies benefit from a competitive advantage over their more carbon intensive rivals. In contrast, countries with high dependence on fossil fuels in domestic consumption and/or exports experience significant GDP losses relative to the corresponding reference case levels at 2050– namely, the Russian Federation (–5.3 per cent), 'other' CIS (–4.5 per cent), OPEC (–3.5 per cent) and Indonesia (–2.8 per cent). Other countries that are projected to incur substantial GDP losses (relative to the reference case) include today's fast growing economies such as China, South Africa and India.

15 change in gross domestic product, by region – scenario 1

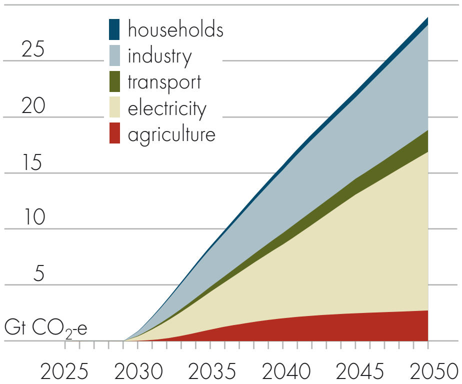
relative to the reference case

	2040	2050
	%	%
Australia	–0.99	–1.75
Brazil	–0.85	–1.22
Canada	–0.70	–0.99
China	–2.55	–3.59
European Union 25	–0.62	–0.86
India	–1.76	–2.89
Indonesia	–1.47	–2.84
Other ASEAN	–0.71	–1.31
Japan	–0.15	–0.11
Mexico	–0.29	–0.43
OPEC	–1.92	–3.54
Korea, Rep. of	–0.48	–0.59
Russian Federation	–2.87	–5.27
Other CIS	–2.54	–4.51
South Africa	–1.89	–3.49
United States	–0.58	–0.84
Rest of world	–1.16	–1.98

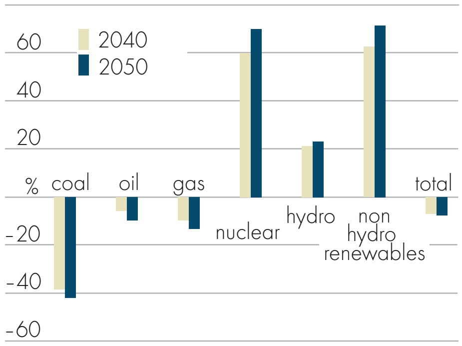
sectoral abatement

Under scenario 1, the electricity sector is projected to be the single largest contributor to global abatement, accounting for about 49 per cent of total global abatement in carbon dioxide equivalent terms at 2050 (figure 5). This is achieved by substantial uptake of CCS technologies as well as through technology switching from fossil fuels to renewables based electricity generation. Other industries (labeled as 'industry' in figure 5) are also projected to offer significant emissions abatement opportunities. Abatement from industrial sources occurs through energy substitution within industries in response to the increased costs of fossil fuels as well as through the scaling down of output of particularly emissions intensive industries.

5 **global emissions abatement, by sector – scenario 1**



6 **change in global primary energy consumption, by fuel – scenario 1**
relative to the reference case



impacts on global primary energy consumption

With the introduction of a carbon tax under scenario 1, global primary energy consumption is projected to fall by about 8 per cent relative to the reference case at 2050, with consumption of the most emissions intensive fuel, coal, falling by 42 per cent relative to the reference case (figure 6). The consumption of other fossil fuels (oil and gas) is also projected to fall relative to the reference case. Although gas is significantly less emissions intensive than coal or oil, under scenario 1 it is unable to retain its reference case share in total primary energy consumption due to the rapid increase in the use of nonfossil fuels (table 16, figure 6).

16 **structure of global primary energy consumption and electricity generation – scenario 1**

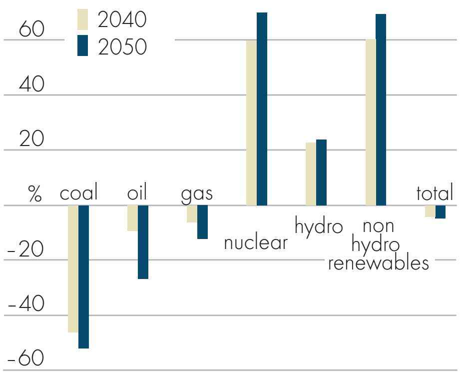
	primary energy consumption	
	2040	2050
	Mtoe	Mtoe
Coal	2 991	3 217
Oil	6 273	6 922
Gas	4 222	4 848
Nuclear	2 344	3 316
Hydro	672	739
Nonhydro renewables	1 003	1 534
Total	17 505	20 576
	electricity generation	
	2040	2050
	TWh	TWh
Coal with no CCS	8 187	3 939
Coal with CCS	79	4 861
Oil	1 416	1 067
Gas with no CCS	11 966	7 680
Gas with CCS	0	7 263
Nuclear	9 065	12 857
Hydroelectric	6 593	7 142
Nonhydro renewables	4 325	6 692
Total	41 630	51 500

impacts on the electricity sector

The introduction of a global carbon tax is projected to lead to a decline in the electricity sector and also to a substantial change in the electricity generation sector in terms of its technology mix (figure 7, table 16). The share of renewables and nuclear power is projected to grow significantly under scenario 1. At 2050, electricity generation from nonhydro renewables and nuclear power is projected to increase by about 70 per cent relative to the reference case. In many regions, expansion into hydroelectricity is limited by known capacity constraints. Given this, electricity generation from hydro is projected to increase by about 24 per cent relative to the reference case at 2050.

As for fossil fuels based electricity generation, the introduction of a carbon tax is projected to result in a substantial uptake of CCS technologies in both coal and gas fired power generation. At 2050, CCS fitted plant accounts for about 24 per cent of total electricity generation capacity with about 55 per cent and 49 per cent of all coal and gas fired electricity generation using CCS options respectively (table 16).

7 **change in global electricity generation, by fuel – scenario 1**
relative to the reference case



projections for Australia

overall impacts

With a globally harmonised carbon tax of A$77 a tonne of CO_2-e at 2050 under scenario 1, the Australian economy is projected to incur a GDP loss of about 1.7 per cent relative to the reference case in that year (table 17). Australia's GDP loss (relative to the reference case) is projected to follow closely the corresponding global average throughout the projection period under the scenario.

Also, total emissions (in CO_2 equivalent terms) in Australia at 2050 are projected to fall by about 36 per cent relative to the reference case, which is slightly higher than the corresponding global average. The projected changes in GDP and emissions under the scenario imply that the emission intensity of the Australian economy would fall from 0.32 Mt CO_2-e/A$b in the reference case to 0.21 Mt CO_2-e/A$b under the scenario at 2050.

17 **emissions abatement and gross domestic product in Australia – scenario 1**

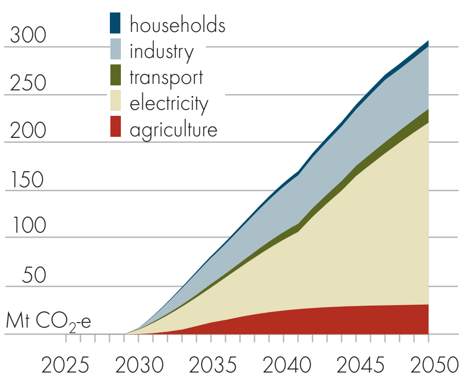
		2040	2050
Carbon tax a	2005A$/t CO_2-e	47	77
Total abatement	Mt CO_2-e	158	307
Gross domestic product a	2005A$b	2 150	2 629
Emission intensity a	Mt CO_2-e/A$b	0.29	0.21
		deviation from the reference case	
		%	%
Greenhouse gas emissions (CO_2-e)		–20.0	–36.2
Gross domestic product		–0.99	–1.75

a Converted at the 2005 exchange rate of A$1 = US$0.76.

sectoral abatement in Australia

In Australia, the electricity sector is projected to account for about 62 per cent of total emissions abatement at 2050 under scenario 1 (figure 8), much higher than the corresponding global average of 49 per cent at 2050 (figure 5). This large contribution of the domestic electricity sector to Australia's total emission abatement is associated with the significant scaling down of electricity output and a high rate of adoption of carbon free electricity generation technologies. Large projected falls in the output of emission intensive industries make the broad 'industry' sector the second largest contributor to Australia's total abatement.

8 emissions abatement in Australia, by sector – scenario 1
relative to the reference case

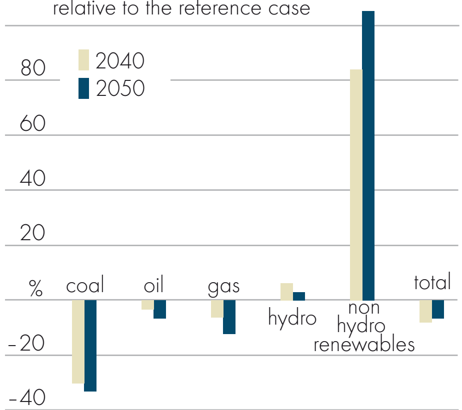


impacts on primary energy consumption in Australia

The projected changes in the structure of Australia's primary energy consumption in terms of the impacts on the use of fossil fuels and renewables are presented in figure 9. As can be seen in figure 9, consumption of emissions intensive fossil fuels such as coal, oil and gas is projected to fall, whereas consumption of nonhydro renewables is projected to rise substantially.

The increase of nonhydro renewables consumption is associated with the substantial increase of electricity generation from nonhydro renewables, which is projected to increase by about 105 per cent relative to the reference case at 2050 (figure 10). It should be noted that the growth of hydroelectricity in Australia is constrained by physical limitations. Under this scenario, output of hydroelectricity is projected to reach 20 terrawatt hours (TWh) at 2040 and is assumed to remain at that level for the rest of the projection period to 2050 (table 18). Overall, Australia's total primary energy consumption is projected to fall by about 7 per cent relative to the reference case at 2050 under scenario 1.

9 change in primary energy consumption in Australia, by fuel – scenario 1
relative to the reference case



impacts on the electricity sector in Australia

Carbon capture and storage (CCS) technology in Australia for electricity generation is projected to become increasingly important over time under scenario 1 (table 18). At 2050, CCS comprises about 38 per cent of total generation capacity, with 58 per cent and 45 per cent of coal and gas fired electricity generation using CCS respectively. The electricity generation from fossil fuels other than coal is projected to increase relative to the reference case (figure 10). However, electricity generation from coal is projected to fall significantly relative to the reference case – falling from 331 TWh in the reference case to 196 TWh under scenario 1 at 2050 (tables 8, 18).

Initially at a low carbon tax, a technology switch away from coal based electricity generation is projected to benefit all less emissions intensive electricity generation using oil and gas as well as the zero emissions electricity generation from renewables. Over time as the carbon tax becomes increasingly high, the projected technology substitution is expected to benefit renewables electricity much more than oil or gas based electricity. By 2050, however, the substantial uptake of CCS is projected to somewhat contain the otherwise large switch away from coal fired electricity generation.

Overall output from the electricity sector is projected to fall by about 14 per cent relative to the reference case in 2050 under scenario 1 (figures 10, 11).

impacts on sectoral output in Australia

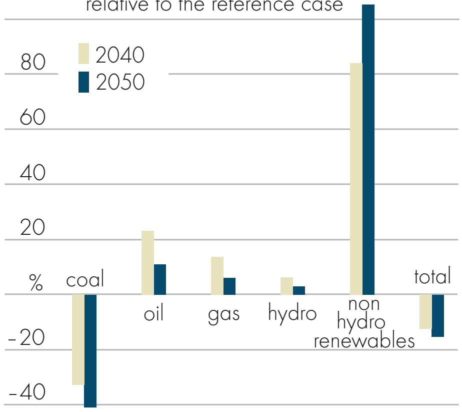
The projected output effects for ten broadly defined sectors of the Australian economy under scenario 1 are presented in figure 11. Outputs from the nonferrous metals and coal sectors are projected to fall the most, by about 22 per cent each relative to the reference case at 2050 under the scenario. The 'other energy' sector (comprising oil and gas) is also projected to fall significantly (relative to the reference case) as well in response to the large decline in global demand for fossil fuels based energy (relative to the reference case)

18 structure of primary energy consumption and electricity generation in Australia – scenario 1

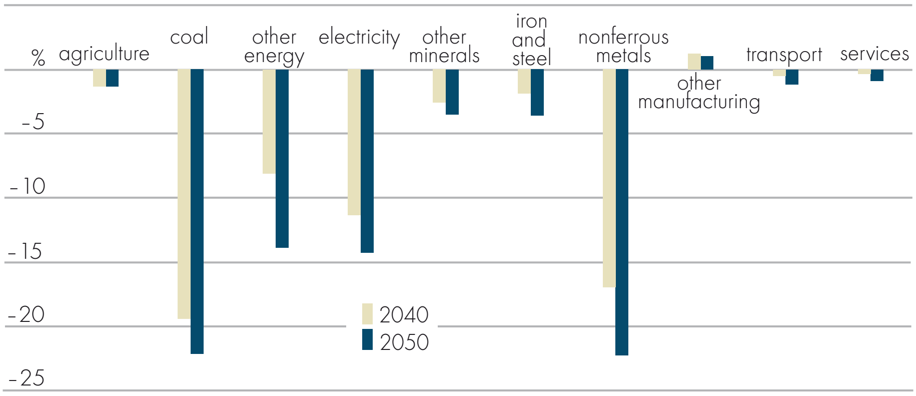
	primary energy consumption	
	2040	2050
	Mtoe	Mtoe
Coal	46	47
Oil	56	59
Gas	36	37
Nuclear	na	na
Hydro	2	2
Nonhydro renewables	22	38
Total	162	183
	electricity generation	
	2040	2050
	TWh	TWh
Coal with no CCS	195	83
Coal with CCS	0	113
Oil	4	3
Gas with no CCS	106	62
Gas with CCS	0	51
Nuclear	na	na
Hydroelectric	20	20
Nonhydro renewables	57	99
Total	381	430

na Not applicable.

10 change in electricity generation in Australia, by fuel – scenario 1
relative to the reference case



11 **change in outputs in Australia, by sector – scenario 1**
relative to the reference case



Note: The broad industry sector in figure 8 comprises all sectors in figure 11 except agriculture, electricity and transport.

under the scenario. On the other hand, output from the relatively low emissions intensive industries such as services is projected to contract a little relative to the reference case.

scenario 2a – early action with a full range of abatement technologies

Scenario 2a is the first of a range of scenarios under which the hypothetical global abatement action with the use of a global carbon tax is introduced in 2010. Under this scenario, Australia's current policy of no domestic nuclear power is maintained throughout the projection period. Apart from this, all regions in the world are assumed to have access to all potential abatement technologies specified in GTEM, including the carbon capture and storage option for electricity generation.

global projections

overall impacts

Under scenario 2a the globally harmonised carbon tax is projected to rise from less than US$1 a tonne of carbon dioxide equivalent (CO_2-e) in 2010 to about US$75 a tonne of CO_2-e at 2050 (table 19). It should be noted that the carbon tax is not projected to increase much during the period from around 2030 to about 2040, after which it is projected to grow rather sharply. As discussed later, this reflects the significant projected uptake of CCS technology during the period 2030–40, enabling the global economy to achieve the required abatement at relatively low costs. Beyond this period, with some geophysical limits to CCS binding in some regions, abatement is projected to be more expensive, causing the carbon tax to rise more rapidly.

Under this scenario, total global product is projected to fall by about 2.6 per cent relative to the reference case at 2050 (table 19). Given the reduction in all emissions by 39 per cent

19 global carbon tax, abatement and global product – scenario 2a

		2010	2020	2030	2040	2050
Carbon tax	2005US$/t CO_2-e	1	17	39	45	75
Total abatement	Gt CO_2 -e	0.5	8.4	15.5	23.6	32.8
Total global product a	2005US$b	52 274	70 687	93 318	122 830	160 004
Emission intensity	Mt CO_2-e/US$b	0.79	0.62	0.49	0.40	0.32
		deviation from the reference case				
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–1.2	–16.1	–25.3	–32.7	–39.0
Total global product a		–0.05	–0.75	–1.56	–1.98	–2.56

a Total global product is the global equivalent of gross domestic product (GDP).

relative to the reference case at 2050 under the scenario, global emission intensity is projected to fall to 0.32 CO_2-e/US$b from the reference case level of 0.51 CO_2-e/US$b in 2050.

As can be seen from tables 14 and 19, the carbon tax and the associated economic costs (global as well as for Australia) under scenario 2a ('early action') are projected to be much higher than those projected for the corresponding years under scenario 1. This is because under scenario 2a, compared with scenario 1, some 'capital' in emissions intensive sectors (for example, electricity and nonferrous metals sectors) would be retired early. Also, the assumed abatement task is higher under scenario 2a than under scenario 1.

In table 20, the impacts of the global climate policy action on regional GDPs under scenario 2a are presented for selected years as percentage deviations from the reference case levels.

20 change in gross domestic product, by region – scenario 2a
relative to the reference case

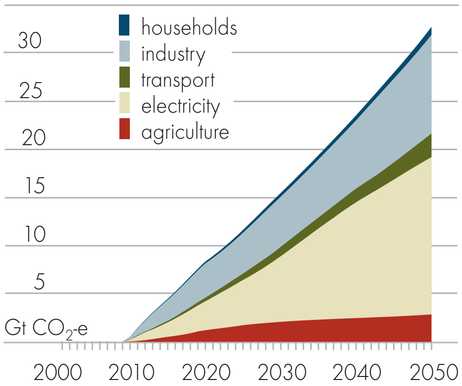
	2010	2020	2030	2040	2050
	%	%	%	%	%
Australia	–0.05	–0.71	–1.51	–2.03	–2.49
Brazil	–0.05	–0.69	–1.31	–1.38	–1.79
Canada	–0.03	–0.48	–0.99	–1.08	–1.31
China	–0.21	–2.65	–4.47	–5.00	–5.55
European Union 25	–0.03	–0.42	–0.84	–0.90	–1.10
India	–0.11	–1.39	–2.88	–3.68	–4.37
Indonesia	–0.07	–0.98	–2.37	–3.32	–4.52
Other ASEAN	–0.04	–0.48	–1.07	–1.48	–1.88
Japan	–0.01	–0.11	–0.12	–0.06	0.06
Mexico	–0.02	–0.19	–0.37	–0.37	–0.48
OPEC	–0.07	–1.16	–2.71	–3.57	–4.94
Korea, Rep. of	–0.04	–0.46	–0.79	–0.80	–1.00
Russian Federation	–0.21	–2.66	–5.03	–7.16	–9.21
Other CIS	–0.18	–2.42	–4.96	–6.60	–8.23
South Africa	–0.10	–1.37	–3.12	–4.30	–4.95
United States	–0.03	–0.42	–0.83	–0.95	–1.14
Rest of world	–0.05	–0.75	–1.59	–2.01	–2.77

Under this scenario, as projected under scenario 1, countries with relatively low emission intensity (for example, Japan) are projected to experience small changes in GDP relative to the corresponding reference case level. On the other hand, countries with significant dependence on fossil fuel consumption and/or exports (for example, the Russian Federation, 'other' CIS and OPEC) are projected to incur substantial declines in GDP relative to the reference case. As shown in table 20, among the OECD member countries, Australia is projected to be the most adversely affected economy in terms of the GDP impact (measured relative to the reference case).

sectoral abatement

Under scenario 2a the electricity sector is projected to account for the largest share in global abatement in carbon dioxide equivalent terms (figure 12). In 2050 the sector is projected to account for about 50 per cent of global abatement in carbon dioxide equivalent terms under scenario 2a. This represents a slightly higher share than in scenario 1, which largely reflects the earlier uptake of CCS technologies under scenario 2a. The global abatement policy induced switching from fossil fuels based to renewables technologies also contributed to the electricity sector's improved ability to abate emissions. Other industries are also projected to offer significant opportunities for abatement, accounting for a 31 per cent share of global abatement in carbon dioxide equivalent terms at 2050.

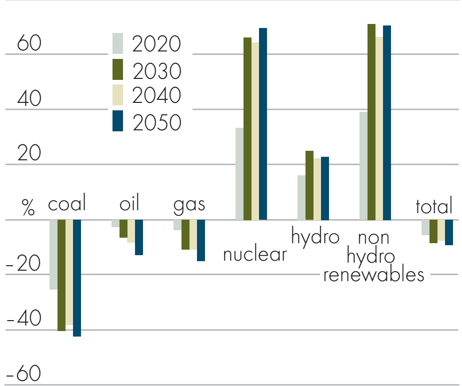
12 global emissions abatement, by sector – scenario 2a
relative to the reference case



impacts on global primary energy consumption

In figure 13 and table 21, projections for global primary energy consumption and its structure in terms of the fuel mix are presented for scenario 2a. The global consumption of primary energy is projected to fall by 6 per cent relative to the reference case in 2020, with a further decline to about 9 per cent below the reference case in 2050. Under this scenario, as in scenario 1, the consumption of all fossil fuels is projected to fall relative to the reference case, with coal consumption falling the most – by about 42 per cent relative to the reference case in 2050 (figure 13). Reflecting improved competitiveness in electricity generation (figure 14, table 21), both nonhydro renewables and nuclear power are projected to grow significantly above their reference case levels – by about 70 per cent

13 change in global primary energy consumption, by fuel – scenario 2a
relative to the reference case

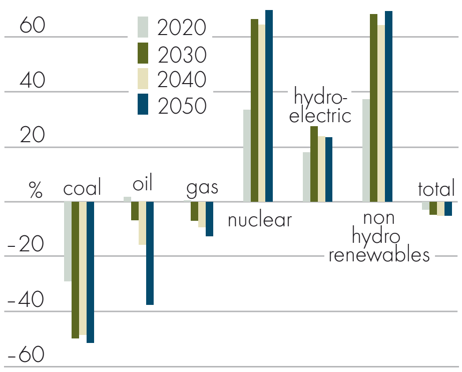


relative to the reference case at 2050 (figure 14).

impacts on the global electricity sector

The importance of using carbon capture and storage (CCS) technologies in electricity generation for achieving the global abatement target can also be seen from table 21. The introduction of a global carbon tax is projected to result in a substantial uptake of CCS technologies in coal and gas fired electricity generation globally. At 2050, CCS is projected to account for about 32 per cent of total generation capacity, compared with about 24 per cent in scenario 1. Renewables (including hydroelectricity) and nuclear power are projected to make up about 52 per cent of total global electricity generation by 2050 under scenario 2a. Overall, electricity output is projected to fall by about 5 per cent relative to the reference case at 2050 under scenario 2a.

14 change in global electricity generation, by fuel – scenario 2a
relative to the reference case



21 structure of global primary energy consumption and electricity generation – scenario 2a

	primary energy consumption				
	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Coal	2 956	2 774	2 512	3 004	3 191
Oil	4 010	4 677	5 374	6 101	6 689
Gas	2 583	3 119	3 450	4 168	4 761
Nuclear	802	1 163	1 815	2 410	3 309
Hydro	345	497	644	678	737
Nonhydro renewables	130	298	695	1 026	1 527
Total	10 827	12 528	14 489	17 387	20 214

	electricity generation				
	2010	2020	2030	2040	2050
	TWh	TWh	TWh	TWh	TWh
Coal with no CCS	8 127	7 463	5 523	3 420	2 417
Coal with CCS	0	0	831	4 531	6 521
Oil	1 113	1 238	1 586	1 316	910
Gas with no CCS	4 447	7 030	8 319	5 976	5 064
Gas with CCS	0	0	248	5 593	9 825
Nuclear	3 082	4 469	6 997	9 308	12 816
Hydroelectric	3 404	4 992	6 408	6 645	7 109
Nonhydro renewables	512	1 227	2 948	4 426	6 673
Total	20 685	26 420	32 859	41 215	51 335

projections for Australia

overall impacts

Under scenario 2a the projected carbon tax of A$99 per tonne of CO_2-e emissions in 2050 would lead to a fall in Australia's GDP of about 2.5 per cent relative to the reference case in the same year (table 22). This represents a slightly lower economywide impact than the corresponding change in global output presented in table 19.

22 emissions abatement and gross domestic product in Australia – scenario 2a

		2010	2020	2030	2040	2050
Carbon tax a	2005A$/t CO_2-e	1	22	51	59	99
Abatement	Mt CO_2-e	4	83	170	281	362
Gross domestic product a	2005A$b	1 076	1 376	1 715	2 129	2 609
Emission intensity a	Mt CO_2-e /A$b	0.52	0.42	0.32	0.24	0.19
				deviation from the reference case		
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–0.7	–12.5	–23.3	–35.6	–42.8
Gross domestic product		–0.05	–0.71	–1.51	–2.03	–2.49

a Converted at the 2005 exchange rate of A$1 = US$0.76.

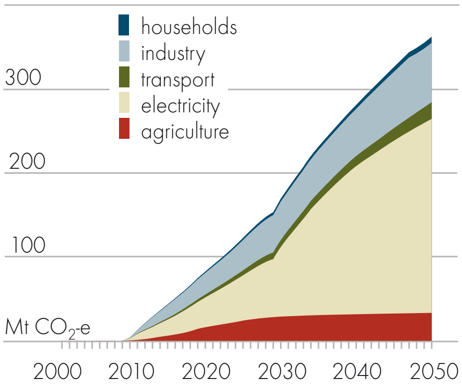
In 2050, all emissions (in CO_2 equivalent terms) in Australia are projected to fall by 43 per cent below the reference case level, slightly higher than the comparable global average. The projected changes in GDP and emissions imply that the emission intensity of the Australian economy would fall from 0.32 Mt CO_2-e/A$ billion in the reference case to 0.19 Mt CO_2-e/A$ billion in scenario 2a by 2050.

sectoral abatement in Australia

As for the sources of emissions abatement in Australia, the electricity sector remains the key source, followed by the 'other industries' sector (figure 15). In 2050 the electricity sector is projected to abate about 231 Mt CO_2-e of emissions from its projected reference case levels. This abatement is expected to result from a combination of a fall in electricity output; policy induced fuel switching from fossil fuels to nonhydro renewables; and a substantial uptake of CCS technologies from around 2030.

Abatement from other industries is projected to be 71 Mt CO_2-e in this scenario at 2050. Large projected falls in the output of emissions intensive sectors, such as nonferrous metals and coal (figure 18), contribute to the total industry abatement.

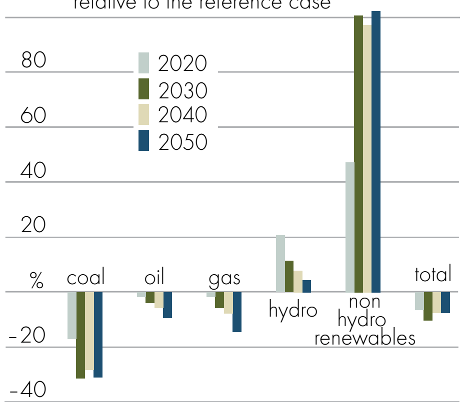
15 emissions abatement in Australia, by sector – scenario 2a
relative to the reference case



impacts on primary energy consumption in Australia

Under scenario 2a, total primary energy consumption is projected to fall by 7 per cent relative to the reference case at 2050 (figure 16). As in scenario 1, the consumption of all fossil fuels is projected to fall relative to the reference case in scenario 2a, with coal consumption falling the most – by about 31 per cent relative to the reference case under scenario 2a in 2050.

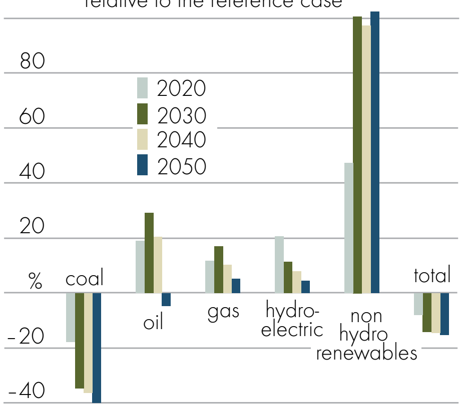
16 **change in primary energy consumption in Australia, by fuel – scenario 2a**
relative to the reference case



impacts on the electricity sector in Australia

Use of nonfossil fuels in electricity generation is projected to grow relative to the reference case, with renewables (nonhydro) energy based electricity output increasing by about 103 per cent relative to the reference case at 2050 (figure 17). The share of nonhydro renewables in total electricity generation is projected to be about 22 per cent in scenario 2a by 2050, slightly lower than in scenario 1 (tables 18, 23). Under this scenario, output of hydroelectricity is projected to reach 20 TWh in 2020 and to remain at this level until the end of the projection period because of the known capacity constraints (table 23).

17 **change in electricity generation in Australia, by fuel – scenario 2a**
relative to the reference case



By 2050, under scenario 2a, CCS technologies operating in both coal and gas fired electricity generation are projected to account for about 56 per cent of total electricity generation, compared with 38 per cent in scenario 1 (tables 18, 23). As a result of significant uptake of CCS technologies from around 2030, the share of fossil fuel fired electricity generation (with and without CCS) in total electricity output is projected to be about 72 per cent in 2050 (the same share as in scenario 1).

Under scenario 2a, as under scenario 1, the introduction of a carbon tax is projected to induce technology switching from coal fired electricity generation to renewables based electricity generation and, to a lesser extent, to other fossil fuels (gas and oil) fired electricity generation. However, the extent of this technology switching is expected to be contained substantially by an uptake of CCS for coal fired electricity generation.

As can seen from figure 17, under scenario 2a, the electricity sector is projected to decline by about 15 per cent relative to the reference case level in 2050 (this is similar to what was projected under scenario 1; see figure 10)

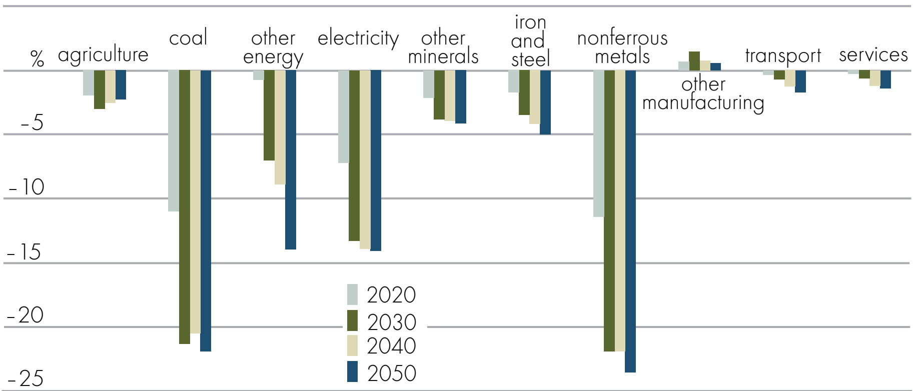
23 structure of primary energy consumption and electricity generation in Australia – scenario 2a

	primary energy consumption				
	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Coal	51	49	42	47	48
Oil	40	46	51	55	57
Gas	26	30	33	36	36
Nuclear	na	na	na	na	na
Hydro	1	2	2	2	2
Nonhydro renewables	3	6	14	24	38
Total	121	132	141	163	181
	electricity generation				
	2010	2020	2030	2040	2050
	TWh	TWh	TWh	TWh	TWh
Coal with no CCS	191	188	148	71	40
Coal with CCS	0	0	17	114	158
Oil	3	4	5	4	2
Gas with no CCS	43	66	95	52	28
Gas with CCS	0	0	0	51	83
Nuclear	na	na	na	na	na
Hydroelectric	17	20	20	20	20
Nonhydro renewables	7	15	35	61	97
Total	261	293	320	372	430

na Not applicable.

18 change in outputs in Australia, by sector – scenario 2a

relative to the reference case



Note: The broad industry sector in figure 15 comprises all sectors in figure 18 except agriculture, electricity and transport.

impacts on sectoral output in Australia

As for the structure and composition of the Australian economy, under scenario 2a it is projected that there will be significant switching toward less emissions intensive activities, with a substantial reduction in the output of fossil fuels and nonferrous minerals processing sectors, relative to the reference case (figure 18). For example, output from emissions intensive industries, such as nonferrous metals, is projected to fall by 24 per cent relative to the reference case by 2050.

Australia's production of fossil fuels is also projected to fall in response to a large decline in global demand for fossil energy. Production of coal in Australia is projected to fall by 22 per cent relative to the reference case by 2050. Output from the low emissions intensive industries are projected to experience little change relative to the reference case.

scenario 2b – early action without carbon capture and storage technologies

Scenario 2b is similar to scenario 2a in that, under both scenarios, the time profile of the chosen global emissions abatement is identical. Also the commencement year for the hypothetical global carbon tax is 2010 in both scenarios. The only feature that distinguishes these two scenarios involves the assumption relating to carbon capture and storage (CCS) technologies. Under scenario 2b it is assumed that no region will be able to introduce any CCS technologies during the projection period to 2050, whereas under scenario 2a it was assumed otherwise. Under scenario 2a, it was projected that CCS technologies would be taken up for electricity generation from around 2030. Clearly, the differences between these two scenarios (scenarios 2a and 2b) beyond 2030 would help identify the likely role of CCS technologies in emissions abatement given the underlying scenario and modeling assumptions.

global projections

overall impacts

The key global results under scenario 2b are presented in table 24. What becomes immediately obvious here is that, beyond 2030, the projected global carbon tax and the associated economic costs are much higher under scenario 2b than under scenario 2a (tables 19, 24). The inability to use CCS technologies for electricity generation under scenario 2b is projected to lead to a carbon tax of US$119 per tonne of CO_2-e at 2050 (compared with the projected carbon tax of US$75 per tonne of CO_2-e at 2050 under scenario 2a, when the CCS technologies were available).

A higher carbon tax under scenario 2b is associated with a greater loss in total global product, compared with scenario 2a. By 2050, total global product is projected to fall by about 3.4 per cent relative to the reference case under scenario 2b. This amounts to a 0.8 percentage point additional loss (measured against the reference case) in global product

24 global carbon tax, abatement and total global product – scenario 2b

		2010	2020	2030	2040	2050
Carbon tax	2005US$/t CO_2-e	1	17	43	71	119
Abatement	Gt CO_2-e	0.5	8.4	15.6	24.0	33.1
Total global product	2005US$b	52 274	70 687	93 253	122 310	158 662
Emission intensity	Mt CO_2-e/US$b	0.79	0.62	0.49	0.39	0.32
		deviation from the reference case				
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–1.2	–16.1	–25.4	–33.2	–39.4
Total global product		–0.05	–0.75	–1.63	–2.40	–3.38

25 change in gross domestic product, by region – scenario 2b

relative to the reference case

	2010	2020	2030	2040	2050
	%	%	%	%	%
Australia	–0.05	–0.71	–1.57	–2.30	–3.17
Brazil	–0.05	–0.69	–1.43	–2.02	–2.82
Canada	–0.03	–0.48	–1.04	–1.41	–1.84
China	–0.21	–2.65	–4.67	–5.79	–6.87
European Union 25	–0.03	–0.42	–0.84	–1.13	–1.50
India	–0.11	–1.39	–2.97	–4.20	–5.39
Indonesia	–0.07	–0.98	–2.42	–4.02	–6.26
Other ASEAN	–0.04	–0.48	–1.10	–1.65	–2.48
Japan	–0.01	–0.11	–0.15	–0.06	0.09
Mexico	–0.02	–0.19	–0.37	–0.47	–0.68
OPEC	–0.07	–1.16	–2.91	–4.80	–7.55
Korea, Rep. of	–0.04	–0.46	–0.85	–1.07	–1.31
Russian Federation	–0.21	–2.66	–5.28	–7.93	–11.26
Other CIS	–0.18	–2.42	–5.24	–7.53	–10.09
South Africa	–0.10	–1.37	–3.11	–4.50	–5.94
United States	–0.03	–0.42	–0.86	–1.15	–1.47
Rest of world	–0.05	–0.75	–1.70	–2.63	–3.93

compared with scenario 2a (tables 19, 24). The GDP projections for the regional economies presented in tables 20 and 25 also reflect the additional economic burden stemming from the lack of the CCS option under scenario 2b, adjusted for any regional differences in the importance of CCS technologies that were modeled under scenario 2a.

sectoral abatement

The electricity sector is projected to remain the key source of global abatement under scenario 2b, as in the previous scenarios. However, the projected share of the sector in total global abatement falls from 50 per cent in scenario 2a to 42 per cent under scenario 2b in 2050 (figures 12, 19). On the other hand, the relatively high carbon tax projected under scenario 2b with the lack of CCS technologies would lead to additional emissions abatement from other industries under scenario 2b compared with scenario 2a. For example, in 2050, other industries are projected to reduce their reference case emissions by 11.7 Gt CO_2-e in scenario 2b (figure 19). This can be compared with the corresponding emissions reduction of 10.3 Gt CO_2-e by other industries in scenario 2a (figure 12).

impacts on global primary energy consumption

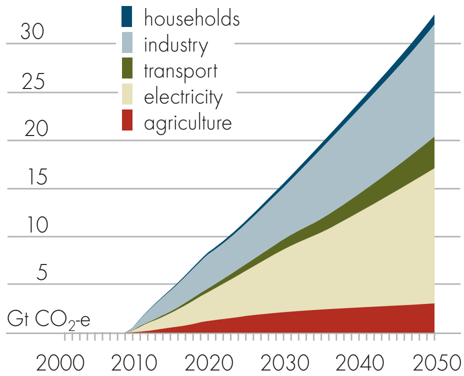
The importance of CCS technologies in global primary energy consumption becomes clear from figure 20 and table 26. The share of coal and gas in total primary energy consumption is expected to fall significantly more under scenario 2b than under scenario 2a (figures 13, 20). For example, in 2050, coal and gas consumption is projected to fall by 64 per cent and 31 per cent (relative to the reference case) respectively under scenario 2b in the absence of CCS technologies (table 26). This can be compared with the corresponding projected declines of 42 per cent and 15 per cent respectively in 2050 under scenario 2a (table 21).

Although the share of renewables and nuclear in total primary energy consumption is projected to increase commensurately under scenario 2b, the increased use of nonfossil fuels fails to fully offset the reduced use of fossil fuels, resulting in a substantial projected fall in total primary energy consumption. In 2050, total global primary energy consumption is projected to fall by 12 per cent (relative to the reference case) under scenario 2b (figure 20) – compared with a 9 per cent decline (relative to the reference case) in scenario 2a (figure 13).

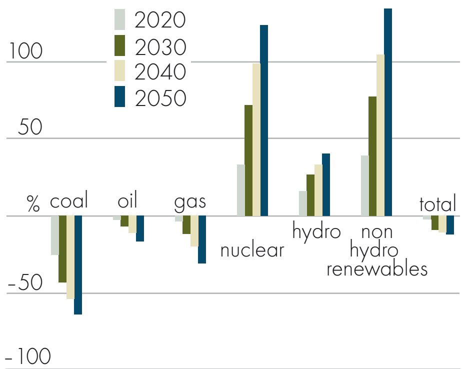
impacts on the electricity sector

The projected change in the composition of primary energy consumption under scenario 2b largely reflects the projected change in the

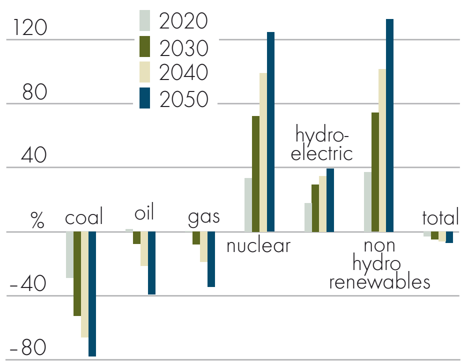
19 global emissions abatement, by sector –scenario 2b
relative to the reference case



20 change in global primary energy consumption, by fuel – scenario 2b
relative to the reference case



21 change in global electricity generation, by fuel – scenario 2b
relative to the reference case



26 structure of global primary energy consumption and electricity generation – scenario 2b

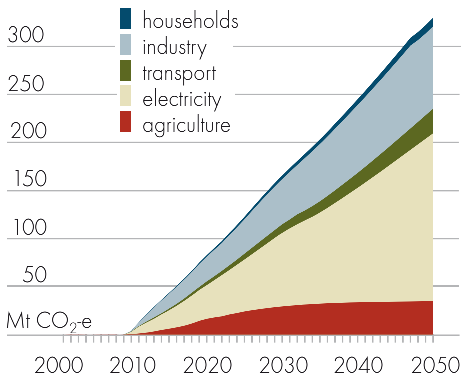
	primary energy consumption				
	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Coal	2 956	2 774	2 385	2 229	1 977
Oil	4 010	4 677	5 345	5 906	6 391
Gas	2 583	3 119	3 404	3 743	3 864
Nuclear	802	1 163	1 879	2 917	4 374
Hydro	345	497	653	738	842
Nonhydro renewables	130	298	720	1 263	2 101
Total	10 827	12 528	14 387	16 796	19 549
	electricity generation				
	2010	2020	2030	2040	2050
	TWh	TWh	TWh	TWh	TWh
Coal	8 127	7 463	5 967	5 237	4 063
Oil	1 113	1 238	1 566	1 225	887
Gas	4 447	7 030	8 461	10 355	11 164
Nuclear	3 082	4 469	7 242	11 275	16 966
Hydroelectric	3 404	4 992	6 508	7 235	8 047
Nonhydro renewables	512	1 227	3 054	5 431	9 177
Total	20 685	26 420	32 797	40 758	50 304

fuel mix in electricity generation under the scenario (figure 21, table 26). Without access to carbon capture and storage technologies, the share of fossil fuels (particularly coal and gas) is projected to fall significantly over the projection period. In 2050 the fossil fuel share of electricity generation is 32 per cent under scenario 2b (table 26), compared with a 48 per cent share in scenario 2a (table 21). Overall, in 2050, electricity output is projected to fall by 7 per cent relative to the reference case under scenario 2b (figure 21). This can be compared with the 5 per cent fall under scenario 2a (figure 14).

projections for Australia

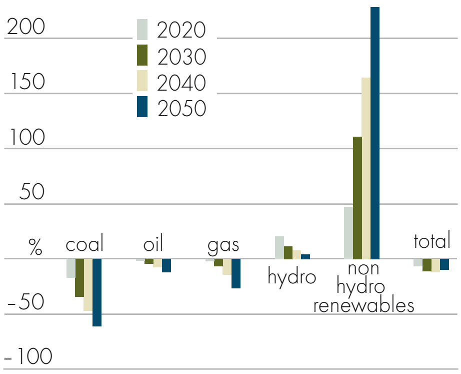
The projections under scenario 2b for Australia are presented in tables 27–28, and in figures 22–25. Compared with scenario 2a, the results largely reflect the additional economic burden that Australia is likely to incur owing to the lack of CCS technologies under scenario 2b, essentially in line with what was discussed earlier in the context of the global economy under the scenario.

22 emissions abatement in Australia, by sector – scenario 2b
relative to the reference case



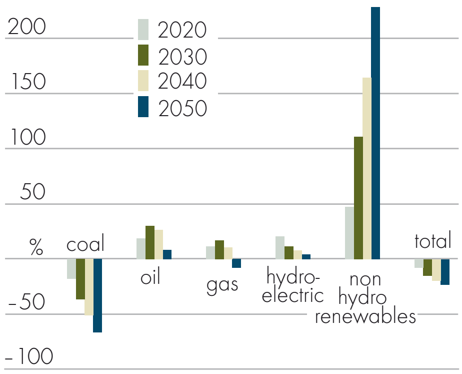
23 change in primary energy consumption in Australia, by fuel – scenario 2b

relative to the reference case



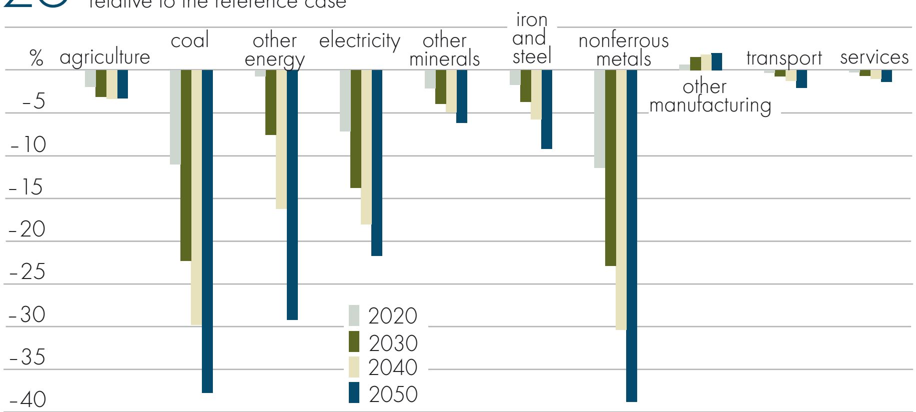
24 change in electricity generation in Australia, by fuel – scenario 2b

relative to the reference case



25 change in outputs in Australia, by sector – scenario 2b

relative to the reference case



Note: The broad industry sector in figure 22 comprises all sectors in figure 25 except agriculture, electricity and transport.

27 emissions abatement and gross domestic product in Australia – scenario 2b

		2010	2020	2030	2040	2050
Carbon tax a	2005A$/t CO_2-e	1	22	57	94	157
Abatement	Mt CO_2 -e	4	83	166	245	330
Gross domestic product a	2005A$b	1 076	1 376	1 714	2 121	2 591
Emission intensity a	Mt CO_2-e/A$b	0.52	0.42	0.33	0.26	0.20
				deviation from the reference case		
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–0.7	–12.5	–22.8	–31.0	–39.0
Gross domestic product		–0.05	–0.71	–1.57	–2.30	–3.17

a Converted at the 2005 exchange rate of A$1 = US$0.76.

28 structure of primary energy consumption and electricity generation in Australia – scenario 2b

	primary energy consumption				
	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Coal	51	49	40	35	27
Oil	40	46	51	54	56
Gas	26	30	33	33	31
Nuclear	na	na	na	na	na
Hydro	1	2	2	2	2
Nonhydro renewables	3	6	14	32	61
Total	121	132	139	155	177

	electricity generation				
	2010	2020	2030	2040	2050
	TWh	TWh	TWh	TWh	TWh
Coal	191	188	160	141	110
Oil	3	4	5	4	3
Gas	43	66	95	103	98
Nuclear	na	na	na	na	na
Hydroelectric	17	20	20	20	20
Nonhydro renewables	7	15	37	82	158
Total	261	293	317	351	389

na Not applicable.

In comparison with scenario 2a, under scenario 2b Australia is projected to have:

- a higher GDP loss, with the GDP loss widening over time – both in value terms and in terms of the percentage deviation from the reference case (tables 22, 27)
- a greater decline in electricity output (figures 18, 25)
- a lower share of fossil fuels, particularly coal, and a commensurately higher share of nonhydro renewables in the primary energy consumption (figures 16, 23) as well in electricity generation (tables 23, 28)
- a more severe restructuring of the domestic economy, particularly a deeper decline in the coal, nonferrous metals and electricity sectors (figures 18, 25).

scenario 2c – early action without CCS but with Australia's access to nuclear

Scenario 2c and scenario 2b share a number of key assumptions: the same targeted emissions path for carbon dioxide over the projection period to 2050; the same commencement year for the global carbon tax, 2010; and CCS technology is not available for electricity generation during the projection period. The only feature that separates these two scenarios is the assumption on whether or not nuclear power will be available in Australia. Under scenario 2c, Australia is assumed to have access to nuclear power, while under scenario 2b, Australia was modeled with no nuclear power.

Under scenario 2c, it is estimated that in 2020 one small nuclear plant, with the capacity to produce 4 TWh a year, will operate in Australia. A recent study by the Australian Nuclear Science and Technology Organisation (ANSTO 2006) suggests that nuclear power plants can be cost competitive in Australia without a carbon tax, provided the associated risks are shared among the owner(s) of the plant, government and various other stakeholders. Under scenario 2c, no such risk sharing among different stakeholders was assumed.

In this scenario, it is estimated that by 2020 a nuclear power plant of the abovementioned size can be economically viable given the carbon tax and the domestic growth in electricity demand projected for Australia under scenario 2c. Under scenario 2c, the global carbon tax in 2020 is estimated at US$17 per tonne of CO_2-e (table 29). With a carbon tax of this size, the costs of electricity generation from the existing coal and gas fired technologies are likely to increase substantially in Australia, improving the cost competitiveness of nuclear power. Also, it is estimated that there would be enough growth in electricity demand between now and 2020 in Australia for one small nuclear plant to operate domestically under the changed price circumstances.

global projections

overall impacts

Australia is sufficiently small in terms of its share in both total global product and global emissions that the introduction of nuclear power plants in Australia alone (other things remaining unchanged) is not expected to make much difference to the rest of the world's output and emissions. As such, the carbon tax under scenario 2c and scenario 2b are projected to be identical throughout the projection period (tables 24, 29). The difference in total global product between scenarios 2b and 2c is projected to be about US$4 billion at 2050, which is very small as a proportion of the reference case output at 2050 (rows 3 and 6 in tables

29 global carbon tax, abatement and total global product – scenario 2c

		2010	2020	2030	2040	2050
Carbon tax	2005US$/t CO_2-e	1	17	43	71	119
Abatement	Gt CO_2-e	0.5	8.4	15.6	24.0	33.1
Total global product	2005US$b	52 274	70 687	93 254	122 314	158 666
Emission intensity	Mt CO_2-e/US$b	0.79	0.62	0.49	0.39	0.32
		deviation from the reference case				
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–1.2	–16.1	–25.4	–33.2	–39.4
Total global product		–0.05	–0.75	–1.63	–2.40	–3.38

24 and 29). The regional GDP impacts relative to the reference case under both scenarios 2b and 2c are projected to be very similar for all regions, except for Australia (tables 25, 30). Accordingly, the rest of the analysis of this scenario is focused on the impacts on the Australian economy.

30 change in gross domestic product, by region – scenario 2c
relative to the reference case

	2010	2020	2030	2040	2050
	%	%	%	%	%
Australia	–0.05	–0.71	–1.54	–2.25	–3.08
Brazil	–0.05	–0.69	–1.43	–2.02	–2.82
Canada	–0.03	–0.48	–1.04	–1.41	–1.84
China	–0.21	–2.65	–4.67	–5.79	–6.87
European Union 25	–0.03	–0.42	–0.84	–1.13	–1.50
India	–0.11	–1.39	–2.97	–4.20	–5.39
Indonesia	–0.07	–0.98	–2.42	–4.02	–6.25
Other ASEAN	–0.04	–0.48	–1.10	–1.65	–2.47
Japan	–0.01	–0.11	–0.15	–0.06	0.09
Mexico	–0.02	–0.19	–0.37	–0.47	–0.68
OPEC	–0.07	–1.16	–2.91	–4.80	–7.55
Korea, Rep. of	–0.04	–0.46	–0.85	–1.07	–1.31
Russian Federation	–0.21	–2.66	–5.28	–7.93	–11.26
Other CIS	–0.18	–2.42	–5.24	–7.53	–10.09
South Africa	–0.10	–1.37	–3.11	–4.50	–5.94
United States	–0.03	–0.42	–0.86	–1.15	–1.47
Rest of world	–0.05	–0.75	–1.70	–2.63	–3.93

projections for Australia

overall impacts

Although the carbon tax under scenario 2c is the same as that under scenario 2b, the ability to access nuclear power within Australia under scenario 2c is projected to help reduce

31 emissions abatement and gross domestic product in Australia – scenario 2c

		2010	2020	2030	2040	2050
Carbon tax a	2005A$/t CO_2-e	1	22	57	94	157
Abatement	Mt CO_2-e	4	85	169	249	334
Gross domestic product a	2005A$b	1 076	1 376	1 714	2 122	2 593
Emission intensity a	Mt CO_2-e/A$b	0.52	0.42	0.33	0.26	0.20
		deviation from the reference case				
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–0.7	–12.9	–23.3	–31.5	–39.4
Gross domestic product		–0.05	–0.71	–1.54	–2.25	–3.08

a Converted at the 2005 exchange rate of A$1 = US$0.76.

the loss in Australia's GDP (tables 27, 31). Australia's GDP is estimated at A$2593 billion (in 2005 prices) under scenario 2c in 2050; this is about A$2 billion more than the projected Australia's GDP in scenario 2b at 2050. Also, compared with scenario 2b, the amount of total emissions abatement in Australia under scenario 2c is projected to be more, by about 4 Mt of CO_2-e at 2050.

sectoral abatement in Australia

Because of the assumed access to nuclear power in Australia, abatement from electricity is projected to increase under scenario 2c compared with scenario 2b – in 2050, about 179 Mt of CO_2-e abatement is projected under scenario 2c compared with the projected abatement of 175 Mt of CO_2-e in scenario 2b (figures 22, 26). On the other hand, abatement from the other industry sources is projected to be about the same under scenario 2b and scenario 2c – in 2050, the total abatement from the other industry sources is estimated at 86 Mt of CO_2-e.

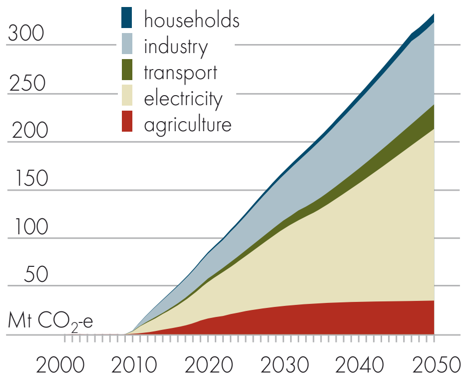
impacts on primary energy consumption in Australia

Compared with scenario 2b, Australia's total primary energy consumption under scenario 2c is projected to be slightly higher, mostly as a result of higher electricity generation under scenario 2b (figures 23, 27). In 2050, Australia's total primary energy consumption under scenario 2c is projected to be about 1.4 Mtoe higher than under scenario 2b.

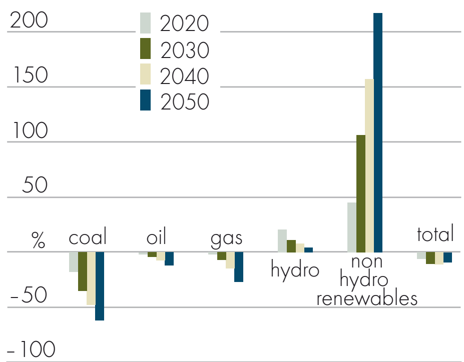
impacts on the electricity sector in Australia

Between 2020 and 2050, nuclear power generation expands from 4 TWh to 17 TWh, accounting for about 4 per cent of electricity generation in 2050 (table 32). This is equivalent to bringing two medium scale nuclear plants on line with an average capacity of about 1.0 gigawatts. To put this in perspec-

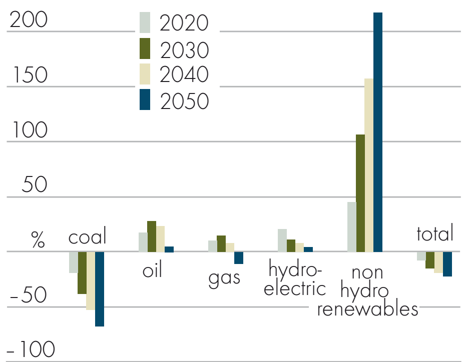
26 emissions abatement in Australia, by sector – scenario 2c
relative to the reference case



27 change in primary energy consumption in Australia, by fuel – scenario 2c
relative to the reference case



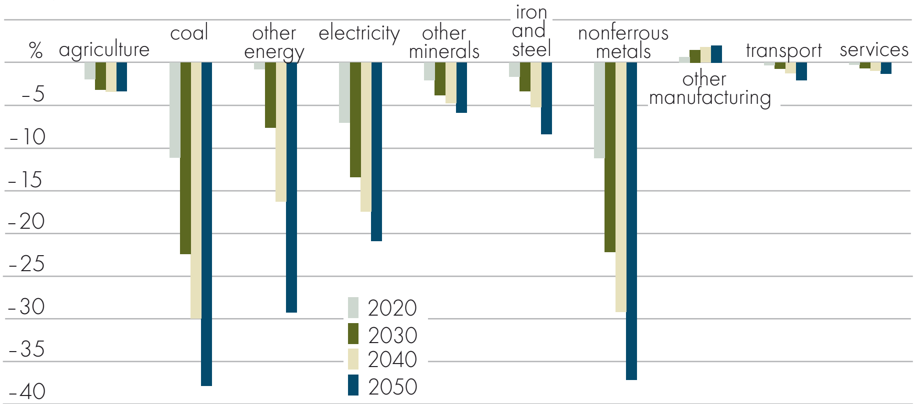
28 change in electricity generation in Australia, by fuel – scenario 2c
relative to the reference case



32 structure of primary energy consumption and electricity generation in Australia – scenario 2c

	primary energy consumption				
	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Coal	51	48	40	34	27
Oil	40	46	50	54	56
Natural gas	26	30	32	33	31
Nuclear	0	1	2	3	4
Hydro	1	2	2	2	2
Renewables	3	6	14	31	59
Total	121	132	140	156	178
	electricity generation				
	2010	2020	2030	2040	2050
	TWh	TWh	TWh	TWh	TWh
Coal	191	186	157	138	107
Oil	3	4	5	4	3
Gas	43	65	93	101	95
Nuclear	0	4	7	11	17
Hydroelectric	17	20	20	20	20
Nonhydro renewables	7	15	36	80	153
Total	261	294	319	353	394

29 change in outputs in Australia, by sector – scenario 2c
relative to the reference case



Note: The broad industry sector in figure 26 comprises all sectors in figure 29 except agriculture, electricity and transport.

tive, under scenario 2c it is estimated that about 240 TWh of electricity will be produced in 2050 from power plants that are projected to be installed between 2020 and 2050.

At 2050, the additional 17 TWh of electricity generated by nuclear power is projected to cause electricity output from nonhydro renewables to decline to 153 TWh under scenario 2c from 158 TWh projected under scenario 2b (tables 28, 32). Overall electricity output is projected to increase to 394 TWh under scenario 2c from the estimated 389 TWh under scenario 2b at 2050.

impacts on sectoral output in Australia

Under scenario 2c it is projected that there would be significant switching toward the less emissions intensive activities, with a substantial reduction in the output of fossil fuels and minerals processing sectors, relative to the reference case (figure 29). However, compared with scenario 2b, output of electricity and nonferrous metals is projected to fall slightly less than under scenario 2c by 2050 (figures 25, 29).

scenario 2d – early action with a deep cut in Australia's emissions

Scenario 2d is similar to scenario 2a in that, under both scenarios, a carbon tax is assumed to be introduced from 2010 to achieve the same amount of carbon dioxide abatement globally up to 2050 and carbon capture and storage technologies are assumed to be accessible. The key distinctive assumption of scenario 2d is that greenhouse gas emissions in Australia are reduced to 50 per cent below their 1990 levels by 2050 under the scenario. To put this in perspective, under scenario 2a, Australia's emissions of all greenhouse gases (in CO_2-e terms) are projected to decline by 39 per cent below the reference case at 2050 (table 19) and its carbon dioxide emissions at 2050 are projected to be about 46 per cent below the reference case at 2050. On the other hand, under scenario 2d, Australia's total greenhouse gas emissions are set to be reduced by 68 per cent from their projected reference case levels at 2050. The corresponding reduction in carbon dioxide emissions under the scenario are projected to fall by 71 per cent below the reference case at 2050. However, the targeted global (including Australia's) abatement of carbon dioxide at 2050 under both scenarios remained at 40 per cent below the reference case. Under scenario 2d, however, Australia is assumed to use nuclear power from 2020 onwards.

global projections

overall impacts

In 2050, the carbon tax required to achieve the global abatement task of 32.8 Gt CO_2-e is estimated at US$74 per tonne of CO_2-e (table 33), which is only US$1 less than the corresponding carbon tax projected in scenario 2a (tables 19, 33). As in scenario 2a, the carbon intensity of the global economy is projected to fall to 0.32 Mt CO_2-e/US$b by 2050 under scenario 2d.

Global GDP is projected to fall by 2.6 per cent relative to the reference case by 2050. GDP is slightly higher in most regions than in scenario 2a (tables 20, 34). This is a result of the marginally lower carbon tax (table 33) and improved competitiveness compared with Australian industries.

33 global carbon tax, abatement and total global product – scenario 2d

		2010	2020	2030	2040	2050
Carbon tax	2005US$/t CO_2-e	1	16	38	44	74
Abatement	Gt CO_2-e	0.5	8.3	15.5	23.6	32.8
Total global product	2005US$b	52 274	70 680	93 305	122 770	159 889
Emission intensity	Mt CO_2-e/US$b	0.79	0.62	0.49	0.40	0.32
		deviation from the reference case				
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		−1.2	−16.0	−25.3	−32.7	−39.0
Total global product		−0.05	−0.76	−1.57	−2.03	−2.63

34 change in gross domestic product, by region – scenario 2d

relative to the reference case

	2010	2020	2030	2040	2050
	%	%	%	%	%
Australia	−0.27	−2.47	−4.36	−7.18	−10.69
Brazil	−0.05	−0.67	−1.28	−1.35	−1.74
Canada	−0.03	−0.46	−0.96	−1.04	−1.26
China	−0.21	−2.60	−4.41	−4.96	−5.50
Chinese Taipei	−0.03	−0.38	−0.65	−0.60	−0.69
European Union 25	−0.03	−0.41	−0.82	−0.88	−1.08
India	−0.10	−1.37	−2.86	−3.70	−4.39
Indonesia	−0.06	−0.97	−2.36	−3.39	−4.65
Other ASEAN	−0.04	−0.47	−1.06	−1.49	−1.90
Japan	−0.01	−0.11	−0.12	−0.05	0.07
Mexico	−0.02	−0.18	−0.35	−0.36	−0.44
OPEC	−0.07	−1.13	−2.65	−3.52	−4.85
Korea, Rep. of	−0.04	−0.45	−0.77	−0.79	−0.97
Russian Federation	−0.21	−2.61	−4.96	−7.12	−9.17
Other CIS	−0.17	−2.36	−4.86	−6.52	−8.12
South Africa	−0.10	−1.33	−3.06	−4.26	−4.88
United States	−0.03	−0.41	−0.82	−0.93	−1.11
Rest of world	−0.05	−0.73	−1.56	−1.99	−2.73

projections for Australia

overall impacts

An imposition of a carbon tax of A$623 a tonne of CO_2-e on the Australian economy is projected to reduce Australia's GDP by 10.7 per cent relative to the reference case level in 2050 under scenario 2d (table 35). Under this scenario, emissions of greenhouse gases (in CO_2-e terms) in Australia are projected to fall by about 68 per cent relative to the reference case at 2050, compared with only 43 per cent relative to the reference case under scenario 2a (tables 22, 35). The projected changes in GDP and emissions result in the emission intensity of the Australian economy in 2050 falling from 0.32 (Mt CO_2-e/A$b) in the reference case to 0.11 (Mt CO_2-e/A$b) in this scenario.

35 emissions abatement and gross domestic product in Australia – scenario 2d

		2010	2020	2030	2040	2050
Carbon tax a	2005A$/t CO_2-e	7	60	136	323	623
Abatement	Mt CO_2-e	18	207	343	467	573
Gross domestic product a	2005A$b	1 074	1 351	1 665	2 015	2 389
Emission intensity a	Mt CO_2-e/A$b	0.50	0.34	0.23	0.16	0.11
				deviation from the reference case		
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–3.3	–31.3	–47.2	–59.1	–67.7
Gross domestic product		–0.27	–2.47	–4.36	–7.18	–10.69

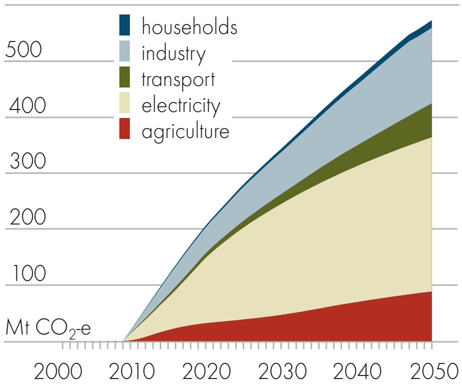
a Converted at the 2005 exchange rate of A$1 = US$0.76.

sectoral abatement in Australia

The electricity sector provides the single largest contribution to Australia's abatement task. Abatement from electricity increases from 231 Mt of CO_2-e in scenario 2a to 275 Mt of CO_2-e in scenario 2d as a result of a decline in electricity output, switching to less emission intensive fuels and technologies and the availability of nuclear power from 2020 onwards.

The electricity sector, however, contributes only 48 per cent of Australia's abatement task under this scenario, compared with 64 per cent in scenario 2a. In emission intensive industries, large declines in output along with substitution away from energy in the input mix contribute to a significant portion of the abatement task. In agriculture, large declines in output result in the abatement of 89 Mt of CO_2-e or 15 per cent of the total abatement task by 2050 (figure 30).

30 emissions abatement in Australia, by sector – scenario 2d
relative to the reference case



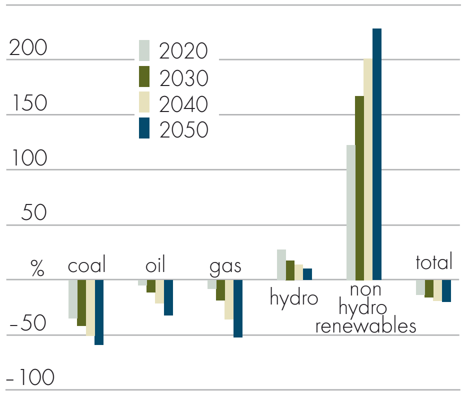
impacts on primary energy consumption in Australia

Energy consumption falls by 20 per cent compared with reference case levels at 2050 (figure 31). Consumption of fossil fuels falls by 48 per cent relative to the reference case by 2050, with consumption of coal falling by 59 per cent.

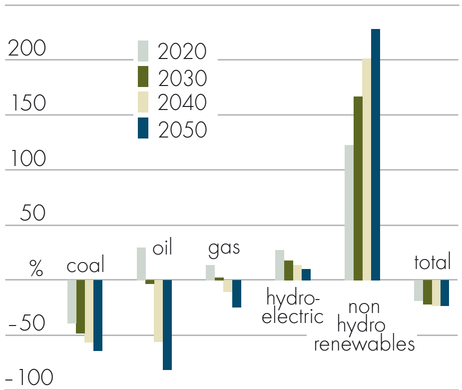
impacts on the electricity sector in Australia

Carbon capture and storage technology is very important under this scenario in electricity generation. By 2050, CCS technologies operating in both coal and gas generation make up 48 per cent of total electricity generation. CCS technology is used in 96 per cent of all coal fired generation and 91 per cent of all gas fired generation. Electricity generation by nonhydro renewables expands by 228 per cent relative to the reference case at 2050 (figure 32). Electricity generation from nuclear power increases to 11 TWh by 2050, contributing to 3 per cent of electricity generation (table 36). When compared with scenario 2c (17 TWh by 2050), the uptake of nuclear power is lower (11 TWh by 2050) in this scenario because the availability of carbon capture and storage improves the competitiveness of coal and gas fired electricity generation.

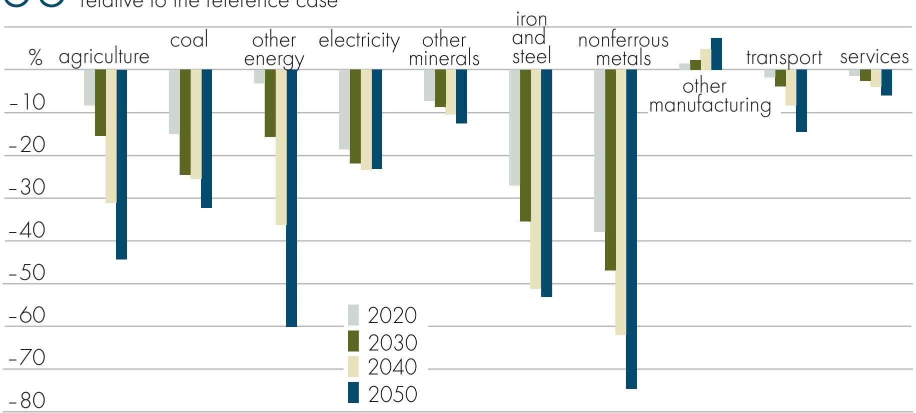
31 change in primary energy consumption in Australia, by fuel – scenario 2d
relative to the reference case



32 change in electricity generation in Australia, by fuel – scenario 2d
relative to the reference case



33 change in outputs in Australia, by sector – scenario 2d
relative to the reference case



Note: The broad industry sector in figure 30 comprises all sectors in figure 33 except agriculture, electricity and transport.

36 structure of primary energy consumption and electricity generation in Australia – scenario 2d

	primary energy consumption				
	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Coal	48	38	36	32	29
Oil	40	44	47	46	43
Natural gas	26	28	29	25	20
Nuclear	0	1	2	2	3
Hydro	1	2	2	2	2
Renewables	3	9	18	36	61
Total	118	122	133	143	158
	electricity generation				
	2010	2020	2030	2040	2050
	TWh	TWh	TWh	TWh	TWh
Coal with no CCS	181	92	32	14	5
Coal with CCS	0	47	99	112	113
Oil	3	5	4	1	0
Gas with no CCS	45	60	32	15	7
Gas with CCS	0	7	51	69	73
Nuclear	0	4	6	8	11
Hydroelectric	17	21	21	21	21
Non hydro renewables	7	23	47	93	158
Total	254	259	291	334	389

impacts on sectoral output in Australia

Output from most energy intensive industries fall by more the 50 per cent relative to the reference case at 2050. The nonferrous metals and energy (gas and oil) industry experience the largest declines, with output falling by 75 per cent and 60 per cent respectively. The agriculture industry also experiences a significant decline in output – falling 44 per cent relative to the reference case at 2050.

Output from the electricity industry and coal industry falls by 23 per cent and 32 per cent respectively compared with the reference case as a result of coal fired electricity generation having access to CCS and exports making up a significant portion of coal production.

scenario 3 – an international coalition for greenhouse gas abatement

Under scenario 3, an international coalition comprising all OECD countries, the Russian Federation and other economies in the CIS plus China and India is assumed to meet the chosen global emissions target for carbon dioxide. The emissions target is the same as considered under the scenario 2 group.

Under scenario 3, the OECD member countries plus the Russian Federation and other economies of the CIS are assumed to implement a harmonised carbon tax from 2010, with China and India joining in 2020 with the introduction of a small carbon tax domestically. These two carbon taxes are assumed to converge over time such that by around 2070 the size of the carbon tax applied in all coalition member countries becomes the same. Under this scenario, it is assumed that all coalition members have access to CCS technologies, and that Australia has no access to nuclear energy during the projection period to 2050. In terms of the assumed technology options (for Australia as well as globally), scenario 3 is therefore similar to scenarios 1 and 2a.

To identify the likely impacts of the availability of nuclear power in Australia under scenario 3, a sensitivity analysis on Australia's nuclear power assumption was carried out (see box 1 at the end of this chapter). As such, this variant of scenario 3 – with Australia having access to nuclear power – fully conforms with the technology assumptions made for scenario 2d.

global results

overall impacts

Under scenario 3, the carbon tax in the OECD economies, the Russian Federation and other economies of the CIS is projected to increase from US$3 per tonne of CO_2-e in 2010 to US$399 per tonne of CO_2-e in 2050, whereas for China and India the carbon tax is

37 global carbon tax, abatement and total global product – scenario 3

		2010	2020	2030	2040	2050
Carbon tax						
– China and India	2005US$/t CO_2-e	0	0	21	77	347
– other members	2005US$/t CO_2-e	3	54	74	130	399
Abatement, global	Gt CO_2 -e	0.5	7.0	14.1	22.2	30.9
Total global product	2005US$b	52 260	70 470	93 327	122 465	157 219
Emission intensity, global	Mt CO_2-e/US$b	0.79	0.64	0.51	0.41	0.34
		deviation from the reference case				
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–1.2	–13.5	–23.0	–30.7	–36.7
Total global product		–0.08	–1.06	–1.55	–2.27	–4.26

estimated to increase from US$21 per tonne of CO_2-e in 2030 to US$347 per tonne of CO_2-e in 2050 (table 37). The estimated penalties under scenario 3 are significantly higher than the global penalty estimated under all previous scenarios. At 2050, the carbon tax under scenario 3 is projected to be about five times as large as the estimated carbon tax under scenario 2a. The significantly higher estimates for global carbon tax under scenario 3 (compared with all other scenarios) result from the limited ability under the scenario to exploit all the cheap abatement opportunities that are available globally and carbon leakage.

Since the carbon taxes are only implemented in a small group of countries in order to meet the global abatement target under scenario 3, almost all countries outside the hypothetical coalition have the opportunity to grow even beyond their projected reference case levels (table 38). As would be expected, the coalition economies that impose a carbon tax lose international competitiveness to the noncoalition economies and incur considerable GDP losses relative to the reference case (table 38).

In 2050, total global product is projected to fall by 4.3 per cent relative to the reference case (table 37). It is estimated that the broader economic costs per unit of abatement (that is, direct plus 'flow-on' costs measured in terms of the potential global output lost per unit of emissions abated) under scenario 3 will be about twice as much the 'global coalition' equivalent under scenario 2a, at 2050.

As mentioned above, many countries outside the coalition grow at levels above the reference case and there is a tendency for carbon intensive industries to move away from coalition countries to noncoalition countries. This process, known as carbon leakage, would

38 change in gross domestic product, by region – scenario 3
relative to the reference case

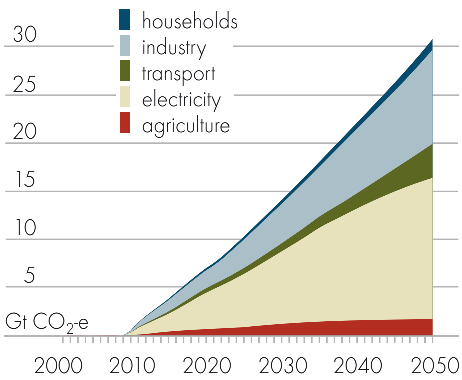
	2010	2020	2030	2040	2050
	%	%	%	%	%
Australia	–0.16	–2.67	–3.57	–4.66	–8.27
Brazil	0.01	0.21	0.46	0.83	1.62
Canada	–0.10	–1.66	–2.18	–3.01	–6.08
China	0.00	0.13	–1.93	–4.59	–9.69
European Union 25	–0.10	–1.41	–1.83	–2.49	–4.76
India	0.00	0.10	–1.01	–3.45	–7.83
Indonesia	0.00	0.19	0.43	0.71	1.02
Other ASEAN	–0.01	0.05	0.26	0.57	1.17
Japan	–0.05	–0.61	–0.71	–0.81	–1.49
Korea, Rep. of	–0.10	–1.25	–1.56	–2.09	–3.60
Mexico	–0.05	–0.83	–1.25	–1.83	–3.82
OPEC	–0.01	0.09	0.54	1.18	2.34
Russian Federation	–0.57	–7.23	–10.65	–13.92	–20.83
Other CIS	–0.51	–7.99	–11.46	–14.71	–22.18
South Africa	0.03	0.46	0.80	1.30	2.36
United States	–0.09	–1.40	–1.85	–2.43	–4.38
Rest of world	0.00	0.15	0.40	0.76	1.43

cause emissions in noncoalition economies to increase under this scenario by about 13 per cent relative to their reference case levels.

sectoral abatement

As in all other scenarios, the electricity sector is projected to make the largest contribution to global abatement. In 2050, the share of the sector in global abatement is projected to be about 48 per cent in carbon dioxide equivalent terms (figure 34) under scenario 2a, slightly below the corresponding share in scenario 3. Emissions from other industries ('industry' in figure 34) also provide a significant source of abatement, accounting for about 32 per cent of the global abatement in carbon dioxide equivalent terms. The technology option for switching from fossil fuels to nonfossil energy, particularly in the coalition countries, plays an important part in reaching the global abatement target. The uptake of CCS technologies in the coalition countries is also projected to contribute substantially to reducing their emissions from the electricity sector.

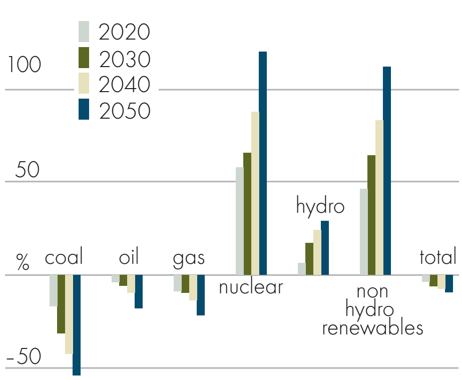
34 global emissions abatement, by sector – scenario 3
relative to the reference case



impacts on global primary energy consumption

Total global primary energy consumption under scenario 3 is projected to fall by 9 per cent at 2050 relative to the reference case, almost the same percentage change projected under scenario 2a. As in previous scenarios, the consumption of all fossil fuels is projected to fall relative to the reference case, with coal consumption falling the most. In 2050, coal consumption is projected to fall by about 55 per cent relative to the reference case (figure 35). On the other hand, because of their increased use in electricity generation, renewable energy and nuclear power are projected to increase by 115 per cent and 123 per cent respectively, relative to the reference case at 2050.

35 change in global primary energy consumption, by fuel – scenario 3
relative to the reference case



impacts on the electricity sector

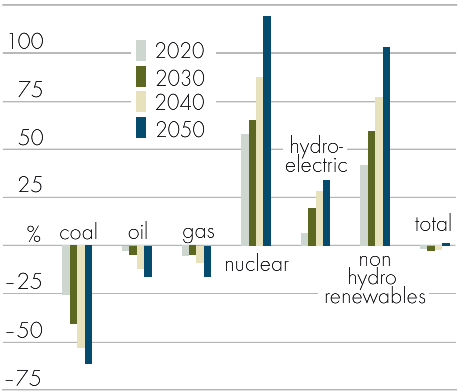
Renewables (including hydroelectricity) and nuclear power are projected to account for about 59 per cent of total global electricity generation in 2050 under scenario 3 (table 39), a much higher share than under scenario 2a. Although the introduction of a carbon tax is expected to cause a decline in fossil fuel based electricity generation relative to the refer-

39 structure of global primary energy consumption and electricity generation – scenario 3

	primary energy consumption				
	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Coal	2 965	3 083	2 886	2 784	2 530
Oil	4 006	4 609	5 403	6 006	6 285
Natural gas	2 577	2 954	3 488	4 028	4 371
Nuclear	822	1 378	1 809	2 756	4 302
Hydro	343	455	603	688	774
Renewables	132	314	668	1 132	1 901
Total	10 845	12 791	14 857	17 395	20 164
	electricity generation				
	2010	2020	2030	2040	2050
	TWh	TWh	TWh	TWh	TWh
Coal with no CCS	8 053	7 093	5 614	3 778	3 230
Coal with CCS	0	700	1 834	3 395	3 837
Oil	1 110	1 186	1 615	1 369	1 217
Gas with no CCS	4 454	5 796	6 160	7 807	9 886
Gas with CCS	0	835	2 601	3 820	4 364
Nuclear	3 159	5 288	6 965	10 621	16 592
Hydroelectric	3 380	4 518	6 023	6 893	7 738
Nonhydro renewables	518	1 266	2 795	4 782	8 017
Total	20 674	26 682	33 608	42 464	54 880

ence case (figure 36), there will be considerable uptake of CCS technologies in coal and gas fired electricity generation. At 2050, CCS is projected to account for about 15 per cent of total generation capacity under scenario 3, considerably lower than under scenario 2a.

36 change in global electricity generation, by fuel – scenario 3
relative to the reference case



results for Australia

overall impacts

Under scenario 3, the projected carbon tax for the OECD member countries applies to Australia. In 2050, a carbon tax of A$525 per tonne of CO_2-e in Australia is projected to reduce GDP by 8.3 per cent relative to the reference case (table 40). In the same year, Australia's emissions in carbon dioxide equivalent terms are projected to fall by 64 per cent relative to the reference case. The projected change in GDP and emissions will imply an emissions intensity of 0.13 Mt CO_2-e/A$b in Australia by 2050 under the scenario.

40 emissions abatement and gross domestic product in Australia – scenario 3

		2010	2020	2030	2040	2050
Carbon tax a	2005A$/t CO_2-e	4	71	98	171	525
Abatement	Mt CO_2-e	11	210	312	397	538
Gross domestic product a	2005A$b	1 075	1 348	1 679	2 070	2 454
Emission intensity a	Mt CO_2-e/A$b	0.51	0.33	0.25	0.19	0.13
		deviation from the reference case				
		%	%	%	%	%
Greenhouse gas emissions (CO_2-e)		–2.1	–31.7	–43.0	–50.2	–63.6
Gross domestic product		–0.16	–2.67	–3.57	–4.66	–8.27

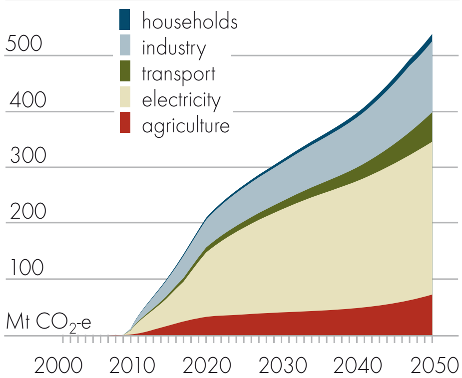
a Converted at the 2005 exchange rate of A$1 = US$0.76.

It is important to note that, in 2050, the size of Australia's abatement task (measured in terms of both carbon dioxide and all greenhouse gases considered in this analysis) as well as the carbon tax are projected to be slightly lower under scenario 3 than under scenario 2d. In 2050 the GDP loss is smaller under scenario 3 than under scenario 2d, by over 2 per cent of the reference case GDP level.

sectoral abatement in Australia

Abatement from the electricity sector is estimated at 273 Mt CO_2-e under scenario 3 (figure 37). This can be compared with the corresponding projection of 275 Mt CO_2-e under scenario 2d (figure 30). As in all other scenarios, the abatement from the electricity sector is projected to arise from the likely decline in electricity output, fuel switching from fossil fuels to nonfossil fuels as well as CCS uptake following the introduction of a carbon tax.

37 emissions abatement in Australia, by sector – scenario 3
relative to the reference case



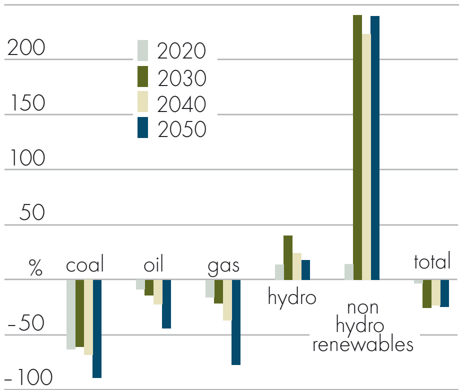
Under the scenario, abatement in the 'industry' sector is projected to be about 127 Mt CO_2-e at 2050. Large projected falls in the output of emissions intensive commodities, such as nonferrous metals and coal (figure 40), contribute to the abatement achieved by industry.

impacts on primary energy consumption in Australia

Energy consumption under this scenario is projected to fall 18 per cent below the reference case level at 2050 (figure 38), slightly less than under scenario 2d (figure 31, tables 36, 41). The consumption of all fossil fuels is projected to fall relative to the reference case, with coal consumption falling the most – by about 53 per cent relative to the reference case in 2050. The fall in fossil fuel consumption is projected to be slightly less under scenario 3 than under scenario 2d (figures 31, 38, tables 36, 41).

Switching toward nonfossil fuel fired power generation, however, is still significant, with renewable energy sources rising by 206 per cent relative to the reference case at 2050 (figure 38). In recognition of Australia's physical constraints, once the output of hydroelectricity is projected to reach 20 TWh in 2020 it is maintained at that level until the end of the projection period. This represents a 7 per cent increase in hydroelectricity generation relative to the reference case in 2050.

38 change in primary energy consumption in Australia, by fuel – scenario 3
relative to the reference case



impacts on the electricity sector in Australia

In 2050, CCS technologies operating in both coal and gas fired power generation are pro-jected to account for about 54 per cent of total electricity generation under scenario

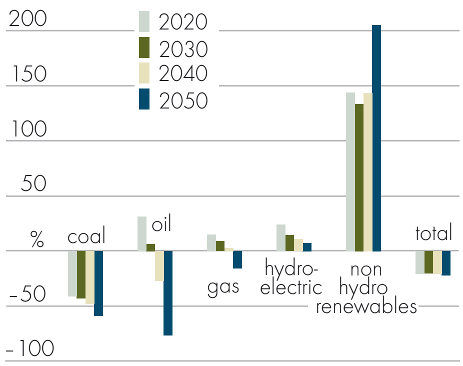
41 structure of primary energy consumption and electricity generation in Australia – scenario 3

	primary energy consumption				
	2010	2020	2030	2040	2050
	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Coal	50	36	39	39	33
Oil	40	44	48	50	47
Natural gas	26	27	30	30	23
Nuclear	na	na	na	na	na
Hydro	2	2	2	2	2
Renewables	3	10	16	29	57
Total	120	120	135	150	161
	electricity generation				
	2010	2020	2030	2040	2050
	TWh	TWh	TWh	TWh	TWh
Coal with no CCS	186	98	45	26	5
Coal with CCS	0	37	99	125	131
Oil	3	5	4	2	1
Gas with no CCS	44	55	34	20	7
Gas with CCS	0	12	55	76	83
Nuclear	na	na	na	na	na
Hydroelectric	18	20	20	20	20
Nonhydro renewables	7	25	41	75	147
Total	258	252	298	345	394

na Not applicable.

3 (table 41), compared with the 48 per cent estimated for scenario 2d (table 36). As a result of significant uptake of CCS technologies, the share of fossil fuel fired electricity generation in total generation is projected to be about 58 per cent in 2050. The corresponding share of nonhydro renewables in total electricity generation is estimated at 37 per cent in scenario 3 at 2050.

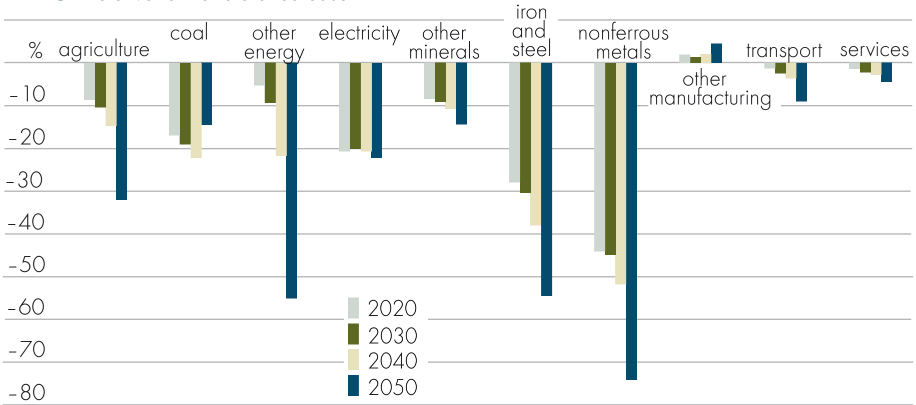
39 change in electricity generation in Australia, by fuel – scenario 3
relative to the reference case



impacts on sectoral output in Australia

Under scenario 3, as is the case under scenario 2d, the nonferrous metals sector is projected to be the most adversely affected among emissions intensive sectors. In 2050, the output of the nonferrous metals sector is projected to fall to about 74 per cent below the reference case level (figure 40). Australia's production of all fossil fuels is projected to fall in response to a large decline in global demand for fossil energy. In 2050, Australia's production of other energy (oil and gas) is projected to fall by about 55 per cent relative to the reference case, whereas Australia's coal production is estimated to fall by less (about 15 per cent relative to the reference case). The other sector that is expected to decline significantly is agriculture, with a projected fall of about 32 per cent below the reference case level in 2050.

40 change in outputs in Australia, by sector – scenario 3
relative to the reference case



Note: The broad industry sector in figure 37 comprises all sectors in figure 40 except agriculture, electricity and transport.

box 1: an international coalition with Australia having access to nuclear power: a sensitivity analysis

To further investigate the likely impacts of the availability of nuclear power in Australia under a hypothetical international coalition, a modified scenario 3 was simulated assuming Australia has access to nuclear power. All other assumptions underlying scenario 3 are maintained. The modified version of scenario 3 fully conforms with the technology assumptions made for scenario 2d.

It is projected that the carbon tax required under the hypothetical international coalition would not change whether or not Australia has access to nuclear power domestically. This is because Australia's contribution to global emissions is very small.

Nonetheless, in 2050, the ability to use nuclear power within Australia under the hypothetical international coalition is projected to enable the Australian economy, compared with the case where Australia does not have access to nuclear power, to

- abate an additional 1 Mt of CO2-e emissions
- reduce the potential decline in electricity output by about 2 TWh and
- moderate the potential loss of gross domestic product by about A$1.2 billion.

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