Australian Government

The Treasury

Climate change mitigation policy modelling

SUMMARY OF ASSUMPTIONS AND DATA SOURCES

3 October 2008

Contents

INTRODUCTION

This document provides a summary of the key assumptions used for the modelling of climate change mitigation policy. A comprehensive set of documentation will be released alongside the Government modelling report in late October.

Treasury has engaged widely with industry and other non-government stakeholders on the methodological approach to the modelling and in order to gather information about key input assumptions. These discussions have been very important in determining the modelling framework and in forming model input assumptions. These model input assumptions also draw on research, previous global and Australian studies, and consultation with Government, industry and domestic and international experts. Many of the assumptions used in the modelling exercise are uncertain, especially over the long time horizons being examined. The assumptions outlined in this document have been judged by Treasury to be plausible central estimates within the range of possible values.

The Treasury has employed a suite of economic models including three CGE models: the Global Trade and Environment Model (GTEM); G-Cubed and The Monash Multi Regional Forecasting (MMRF) model. In addition, a complement of bottom-up, sector specific, models that cover the electricity sector, the transport sector and land-use change and forestry sectors have been drawn upon.

Treasury has, where possible, applied a harmonised set of assumptions across the suite of models to ensure that projections have a common basis. However, due to the different model structures and aggregation it has not always been possible to harmonise all assumptions. For example, the MMRF model has more industry disaggregation than GTEM and G-Cubed, and thus requires more industry specific assumptions.

SUITE OF MODELS

The section provides an overview of the suite of models used by Treasury.

GTEM

The Global Trade and Environment Model (GTEM) was developed by the Australian Bureau of Agricultural and Resource Economics (ABARE), and has been used frequently for climate change policy analysis. For this exercise Treasury has worked collaboratively with ABARE to extensively review the structure and assumptions used in the model. GTEM is a global model, and provides insights into what happens to Australia's key international trading partners. However, it has less industry detail than found in the MMRF model. Extensive documentation of GTEM is given by Pant (2007).

G-Cubed

The G-Cubed model, developed by Warwick McKibbin and Peter Wilcoxen, is also a global model. While this model has less regional and industry detail than GTEM, macroeconomic linkages are more developed. For instance, unlike GTEM, G-Cubed can provide estimates of what happens to inflation, and contains elements of forward-looking behaviour. The theoretical structure of G-Cubed is given by McKibbin & Wilcoxen (1998)

MMRF

The Monash Multi Regional Forecasting (MMRF) model, developed by the Centre of Policy Studies (CoPS) at Monash University, is a detailed model of the Australian economy that gives results for all eight States and Territories. MMRF has rich industry detail (with 58 industrial sectors). In this modelling exercise the MMRF model has drawn international assumptions from GTEM. In addition, further disaggregated bottom-up modelling has been used for three key emission sectors: Electricity, Transport and Forestry. Detailed documentation on the MMRF model was provided by Adams et al., 2008.

Electricity sector modelling

Australia's electricity generation sector is being modelled by McLennan Magasanik and Associates (MMA). MMA have models of the National Electricity Market (Victoria, New South Wales, Queensland, Tasmania, and South Australia), the South-West Interconnected System (Western Australia) and the Northern Territory, as well as off-grid electricity generation. MMA provide projections of electricity generation by technology and by state, fuel use, new investments and retirements and electricity prices.

MMA's models are highly detailed and aim to closely represent actual market conditions. The models take account of the economic relationships between individual generating plants in the system, with each power plant divided into generating units, with each unit defined by its technical and cost profiles. A range of fuels and technologies are incorporated, including black coal, brown coal, natural gas, renewables (including hydro, biomass, solar, wind) as well as new technologies, such as carbon capture and storage and geothermal. Electricity demand is modelled on an hourly and monthly basis, to capture the daily and seasonal fluctuations in energy use.

Transportation sector modelling

Transport sector modelling is has been conducted with CSIRO in conjunction with the Bureau of Infrastructure, Transport and Regional Economics (BITRE). CSIRO use a partial equilibrium model, the Energy Sector Model (ESM), of the Australian energy sector which includes detailed transport sector representation. The ESM was co-developed by CSIRO and ABARE in 2006. The model has an economic decision making framework based around the cost of alternative fuels and vehicles. It incorporates detailed information about technical fuel and vehicle technical characterisation.

The model evaluates uptake of different technologies on the basis of cost competitiveness, practical constraints in the of transport markets, current excise and mandated fuel mix legislation, greenhouse gas emission limits, existing plant and vehicle stock in each State, and lead times in the availability of new vehicles or plant. Assumptions and documentation on the ESM were recently published by Graham, Reedman & Poldy (2008)

Land use, land use change and forestry

Modelling of the forestry sector was commissioned from ABARE (for Australia) and from Lawrence Berkeley National Laboratory (for the rest of the world).

ABARE's modelling examines the impact of a carbon price on land use change in the Australian agriculture sector. The framework used is spatially explicit, and involves analysing the opportunities for carbon sequestration provided by land use change and forestry on cleared agricultural land. These opportunities are determined when the net present value (NPV) of returns from forestry investments are compared to the corresponding expected agricultural land value in order to estimate the potential area of clear agricultural land that is competitive for forestry within each spatial grid cell.

The Lawrence Berkeley National Laboratory, use their GCOMAP model. GCOMAP simulates how forest land users respond to changes in prices in forest land and products, and to carbon prices. GCOMAP calculations of net change in carbon stocks associated with land use change and forestry were incorporated into GTEM and G-Cubed. See Sathaye et al., 2005 for details on the GCOMAP model.

Global models — regions and sectors

For this exercise GTEM has been disaggregated into 13 geographic regions and 19 industry sectors. GTEM also models capital goods, private and government consumption, and industrial activities that generate emissions of high global warming potential gases. For this exercise G-Cubed represents 9 geographic regions and 12 industry sectors, together with a capital producing sector. Details are shown in the Table 1.

Table 1: Regional and industry sectoral aggregate in GTEM and G-Cubed

Model / Regions	Industry sectors
GTEM	Coal mining
Australia	Oil mining
United States	Gas mining
European Union	Petroleum and coal products
Japan	Electricity (12 renewable and non-renewable technologies)
China	Iron and steel (2 technologies, electric arc and blast furnace)
India	Non-ferrous metals
Indonesia	Chemical, rubber and plastic products
Other south and east Asia	Other mining
Russia and former soviet union	Non-metallic minerals
OPEC	Manufacturing
Canada	Air transport
South Africa	Water transport
Rest of world	Other transport (5 technologies: rail, internal combustion engine, advanced internal combustion engine, hybrids and non-fossil fuel vehicles)
	Crops
	Livestock
	Fishing and forestry
	Food
	Services
G-Cubed	Coal mining
Australia	Crude oil and gas extraction
United States	Gas utilities
European Union	Petroleum refining
Japan	Electric utilities
China	Mining
Rest of OECD	Durable manufacturing
Former Soviet Union	Non-durable manufacturing
OPEC	Transportation
Other developing countries	Forestry and wood products
	Agriculture, fishing and hunting
	Services

Sectors of the MMRF model

In MMRF, the Australian economy is disaggregated into the six states and two territories, and into 58 industry sectors, as shown in Table 2.

Table 2: Sectoral aggregation in MMRF

Category	Sectors
Agriculture, forestry and fishing	Sheep and beef cattle
	Dairy cattle
	Other animals
	2 sectors: Agriculture services and fishing, forestry
	2 sectors: Grains, other agriculture
Mining	Coal Mining
	Oil Mining
	Gas Mining
	3 sectors: Iron ore mining, Non-ferrous ore mining and other mining
Manufacturing	Meat Products
	Other food, beverages & tobacco
	Textiles, clothing, footwear
	Wood products
	Paper products
	Printing
	Refinery (including petroleum and coal products)
	Rubber & plastic products
	Non-metal construction products
	Cement
	Iron & Steel
	Non-ferrous metals: alumina, aluminium and other non-ferrous
	Other manufacturing: metal products, motor vehicles and other manufacturing
Utilities	Electricity generation (6 sectors: coal; gas; oil; nuclear; hydro; other)
	3 sectors: Electricity supply, gas supply and water supply
Services	Construction services
	Trade services
	Accommodation, hotels, cafes & restaurants
	Communication services
	Finance & insurance services
	Property & business services
	Dwelling services
	Public services
	Other services
Transport	Road transport (2 sectors: passenger; freight)
	Rail transport (2 sectors: passenger; freight)
	Water, pipeline & transport services
	Air transport
Households	Household consumption (3 sectors: electricity services; heating services; transport services)

Linking of models

The suite of models approach used by Treasury requires the linking of models. The sectoral mappings between GTEM and MMRF is outlined in Table 3.

Table 3: Sectoral mappings between MMRF and GTEM

GTEM sector (19 sectors)	MMRF sector (58 sectors)
Livestock	Sheep and beef cattle Dairy cattle Other animals
Crops	3 sectors: Grains, other agriculture
Fishing and forestry	2 sectors: Agriculture services and fishing and forestry
Coal mining	Coal mining
Oil mining	Oil mining
Gas mining	Gas mining
Other mining	3 sectors: Iron ore mining, non-ferrous ore mining and other mining
Food	Meat & meat products Other food, beverages & tobacco
Manufacturing	Textiles, clothing, footwear & leather Wood, pulp and paper products Printing, publishing & recorded media Metal products Motor vehicles Other manufacturing
Petroleum and coal products	Refinery (including petroleum and coal products)
Chemical, rubber and plastic products	2 sectors: Chemicals & rubber & plastic products
Non-metalic minerals	Non-metal construction products Cement
Iron & steel	Iron & steel
Non-ferrous metals	3 sectors: Alumina, aluminium and other non-ferrous
Electricity	Electricity generation (6 sectors: coal; gas; oil; nuclear; hydro; other)
Services	3 sectors: Electricity supply, gas supply and water supply Construction services Trade services Accommodation, hotels, cafes & restaurants Communication services Finance & insurance services Property & business services Dwelling services Public services Other services Household consumption (3 sectors: electricity; heating; transport)
Other transport	Road transport (2 sectors: passenger; freight) Rail transport (2 sectors: passenger; freight)
Air transport	Air transport
Water transport	Water, pipeline & transport services

Economic growth

Gross Domestic Product (GDP) in the reference case, a world without climate change, is a function of assumptions about labour supply and productivity.

World gross domestic product

Published forecasts for GDP are used where available. Forecasts are imposed for 2006-2009 using outcomes and forecasts from the IMF (2008), OECD (2007) and Consensus Economics (2008a, 2008b). Where country specific forecasts are not available, regional forecasts have been used.

Table 4: World GDP growth rates (GTEM regions)

Country	Average growth rate 2005-2050	Average growth rate 2050-2100
United States	2.0	1.7
European Union	1.3	1.3
China	5.4	1.5
Former Soviet Union	2.8	1.7
Japan	0.5	1.2
India	6.2	2.8
Canada	1.8	1.5
Indonesia	5.1	2.2
South Africa	4.0	2.0
Other south and east Asia	3.7	2.1
OPEC	4.1	2.4
Rest of world	4.9	3.1

Note: See also international population and productivity section.
Source: Treasury, IMF, OCED and Consensus.

Australian gross domestic product

Table 5: Australia's population, productivity and GDP
Annual average growth rates

Decade	Employment growth	Labour productivity growth	Real GDP growth
2000s	2.3	1.1	3.4
2010s	1.1	1.6	2.8
2020s	0.8	1.5	2.3
2030s	0.7	1.5	2.2
2040s	0.6	1.5	2.1
2050s	0.6	1.5	2.1
2060s	0.7	1.5	2.1
2070s	0.7	1.5	2.2
2080s	0.6	1.5	2.1
2090s	0.6	1.5	2.1

Source: Treasury and ABS.

Gross state product

Gross State Product (GSP) is a function of assumptions about the distribution of population and industry across states.

Table 6: Gross state product
Annual average growth rates

Decade	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
2000s*	3.0	3.2	3.8	2.7	4.6	2.9	4.3	2.9
2010s	2.6	2.8	3.2	2.2	3.2	2.0	2.8	2.6
2020s	2.3	2.3	2.7	1.6	2.4	1.7	2.3	2.2
2030s	2.2	2.1	2.6	1.6	2.4	1.7	2.6	2.1
2040s	2.0	2.0	2.4	1.4	2.3	1.5	2.7	1.9
2050s	2.0	2.0	2.3	1.4	2.3	1.5	2.7	1.9
2060s	2.1	2.1	2.3	1.5	2.3	1.6	2.6	2.1
2070s	2.2	2.1	2.2	1.5	2.3	1.6	2.5	2.2
2080s	2.1	2.1	2.2	1.4	2.3	1.6	2.4	2.1
2090s	2.1	2.0	2.2	1.4	2.2	1.6	2.4	2.1

*2000s commence 2005-06, consistent with the base-year in the MMRF model.
Source: Treasury and ABS.

POPULATION/PARTICIPATION

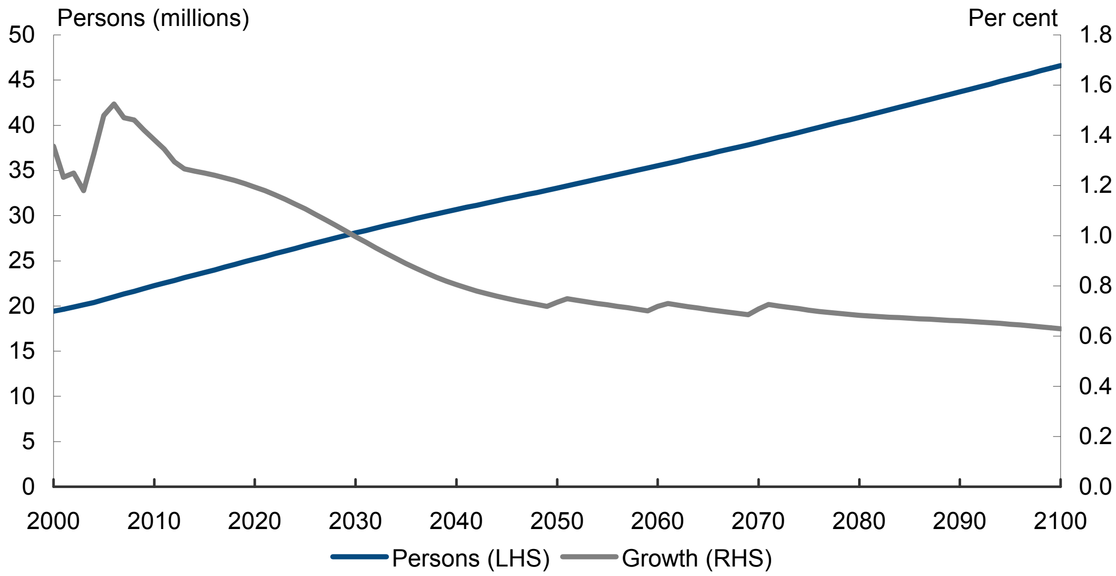
Australian population and labour force participation

Population projections were based on the framework used to develop the Intergenerational Report (IGR) — although input assumptions have been updated since the IGR release in 2007. Since 2007 there has been additional information regarding future immigration trends. As a result, net overseas migration between 2012-13 and 2049-50 is assumed to be 150,000 people per year.

From 2050-51 to 2070-71 net migration is stepped up each decade to reach 200,000 people per annum. Net migration is then kept constant at 200,000 to the end of the century.

- A higher level of net migration beyond 2050 aims to reflect: larger world and Australian populations, and increased requirements for skilled and unskilled workers as a result of the continued ageing of Australia's population.
- Labour force participation assumptions are consistent with the IGR parameters; gender and age specific labour force participation rates remain stable from 2065.
- MMRF requires state population assumptions. State population ratios are taken from ABS projections (ABS Cat. 3222.0 — Population Projections, Australia, 2004 to 2101, released on 14 June 2006) and scaled to be consistent with higher estimated national aggregate population.
- The population estimates for Australia are higher than the United Nations projections for Australia, mainly due to recent changes in net migration assumptions that have not been taken into account in the UN projection.

Chart 1: Australian population



Source: Treasury and ABS.

Table 7: State population

Decade	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
2000s*	1.1	1.4	2.0	1.0	2.1	0.8	1.7	1.5
2010s	1.0	1.2	1.8	0.7	1.8	0.5	1.6	1.2
2020s	0.9	1.0	1.6	0.5	1.4	0.3	1.5	0.8
2030s	0.7	0.8	1.3	0.2	1.1	0.0	1.5	0.7
2040s	0.6	0.6	1.1	0.1	1.0	-0.2	1.4	0.6
2050s	0.7	0.6	1.0	0.1	0.9	-0.2	1.3	0.6
2060s	0.7	0.7	0.9	0.0	0.8	-0.1	1.0	0.7
2070s	0.7	0.7	0.8	0.0	0.8	0.0	0.8	0.7
2080s	0.7	0.7	0.7	0.0	0.7	0.0	0.7	0.7
2090s	0.7	0.7	0.7	0.0	0.7	0.0	0.7	0.7

*2000s commence 2005-06, consistent with the base-year in the MMRF model.
Source: Treasury and ABS.

International population and participation

World population projections to 2050 are taken from the United Nations (2006). This report provides total population and working age (15-64) population for each country in five year intervals from 1950 to 2050. The median projection variant is used.

After 2050 growth rates for population are taken from United Nations (2004). Country-by-country growth rates are used to project population levels over the fifty years to 2100.

Growth rates are interpolated to produce year-by-year projections of population by country (both total and adult). These country projections are then aggregated into the country groups used in GTEM and G-Cubed.

Table 8: Global population level and growth rates (GTEM regions)

	Population level (millions)			Average growth rate	
	2005	2050	2100	2005-2050	2050-2100
United States	300	402	429	0.7	0.1
European Union	461	459	401	0.0	-0.3
China	1320	1418	1202	0.2	-0.3
Former Soviet Union	279	243	200	-0.3	-0.4
Japan	128	103	84	-0.5	-0.4
India	1134	1658	1577	0.8	-0.1
Canada	32	43	40	0.6	-0.1
Indonesia	226	297	275	0.6	-0.2
South Africa	53	62	60	0.4	-0.1
Other south and east Asia	380	513	493	0.7	-0.1
OPEC	219	399	452	1.3	0.2
Rest of world	1961	3564	4056	1.3	0.3

Source: United Nations and Treasury.

International participation rates are assumed to remain constant over the projection period, so the growth of the labour force is projected using the growth of the adult (15-64 years of age) population.

PRODUCTIVITY

Australian labour productivity

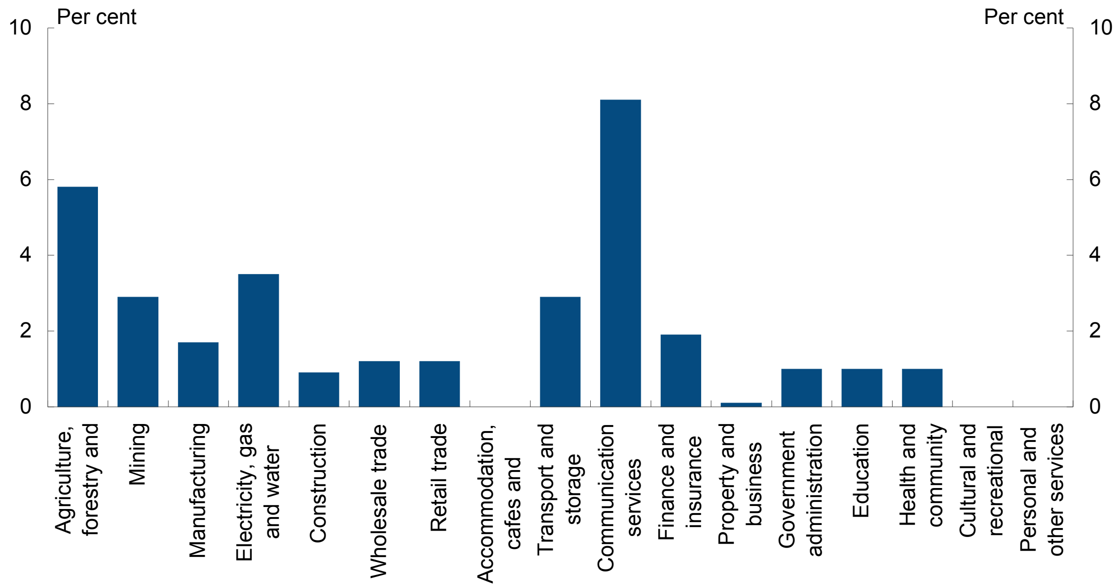
The ABS *National Accounts* indicate that aggregate labour productivity — expressed in terms of GDP per hour worked — for the Australian economy averaged around 1¾ per cent per annum over the period 1975-76 to 2006-07.

The climate change mitigation modelling uses Treasury forecasts and Budget projections for aggregate labour productivity growth until 2011-12 (Australian Government 2008). Beyond 2011-12, the composition of the Australian economy is expected to continue to shift toward service industries, which generally have lower levels and rates of growth of measured sector-specific labour productivity than the rest of the economy. As a result, aggregate Australian labour productivity growth gradually slows to 1½ per cent per annum over a ten year period to the mid 2020s. This outcome, of 1½ per cent for long-run aggregate Australian labour productivity growth is consistent with the long-run labour productivity growth assumption for the United States.

The aggregate labour productivity assumption has been implemented in MMRF by adjusting the labour-augmenting technical change variable at an industry level, with the dispersion of technical change across industry based upon historical estimates.

The dispersion of labour-augmenting technical change across industry has not been uniform over the past three decades. Chart 2 shows the different growth rates of labour-augmenting technical change by broad industry group over the period 1975-76 to 2006-07. These growth rates were estimated from ABS *National Accounts* and remove the effect of capital deepening on output. They were calculated by adjusting multifactor productivity (MFP) estimates by industry level labour income shares.

Chart 2: Industry labour-augmenting technical change
Annual average growth from 1975-76 to 2006-07



Source: Treasury and ABS.

Differences in industry growth rates imply changes in the level and composition of the Australian and state economies over time. Agriculture, Manufacturing, Communication, Utilities, Finance & Insurance, Wholesale, Trade, Transport and Storage have historically grown faster than the national average over the last three decades. Conversely, many service industries have grown more slowly than the national average. This pattern is similar across major developed economies.

After 2020, reflecting uncertainty about how persistent historical differences will be over the next century, the labour-augmenting technical change variable in market sector industries converges to a constant rate by 2050. This constant rate is consistent with achieving aggregate labour productivity growth of 1½ per cent per annum.

World productivity

Country-by-country growth in productivity (either output per worker or output per hour worked) is calculated using a conditional convergence framework. If a country has a productivity level below its 'potential', then it will have faster productivity growth as it catches up. Baumol (1986) and Barro & Sala-i-Martin (1992) discuss the economic framework for convergence in detail. Convergence (sometimes called 'catch-up') is a common assumption used for international growth in long-run projections, such as the *Special Report on Emission Scenarios* (IPCC, 2000).

The 'potential' for each country is assumed to be some percentage of the productivity level of the technological leader, assumed to be the United States. Productivity in the US is assumed to adjust towards an assumed long-run growth rate (1½ per cent) in a gradual fashion from the end of history and GDP forecasts. The long-run growth rate assumption was selected after looking at the historical trends of productivity growth by industry, and the likely changes in the industry structure of the US. Official projections of long-run productivity growth are somewhat higher at 1.7 per cent (OASDI Trustees, 2008 and Congressional Budget Office, 2008), but these projections do not take into account the likely shift towards industries with lower average rates of productivity growth.

The other key parameter for the world productivity projections is the rate of convergence. Given the lack of data for many non-OECD countries, trends that are commonly part of the development experience are assumed. The suggested rate in the literature is 2 per cent per annum (Sala-i-Martin, 1996). Many studies using climate change models assumed this rate for example, Bagnoli et al. (1996) and McKibbin et al. (2004).

- OECD productivity is calculated based on the per hour purchasing power parity (PPP) productivity from the Total Economy Database (The Conference Board/Gronningen) January 2008 update. All members of the OECD as of January 2008 are included.
  - The US productivity growth rate is assumed to adjust towards its long-run growth rate of 1½ per in a gradual fashion from the end of history and GDP forecasts. This gives a level of US productivity for all years.
- Non-OECD productivity is calculated based on the per working age population. GDP per capita (in PPP terms) is taken from the December 2007 update of the World Bank International Comparison Project, and adjusted to be per working age population using the population assumptions. Where data on the GDP level is unavailable from the ICP update, the most recent update of the Maddison international PPP data (August 2007) is used. This is done for 50 countries, making up around 4 per cent of world GDP.
- A conditional convergence framework is applied, with the conditional convergence level allowed to differ by country.
  - High-income OECD countries (those with a productivity level greater than 70 per cent of the US level) are assumed to converge to a level of productivity relative to the US equal to the average level over the last 5 years of history (to abstract from cyclical effects). This generally has the effect of causing the country to grow at the same rate as the US.
  - High-income non-OECD countries (those with a productivity level greater than 70 per cent of the US level) are assumed to converge to a level of productivity relative to the US equal to their starting point. This generally has the effect of causing the country to grow at the same rate as the US.
  - Low income countries (those with a productivity level less than 70 per cent of the US level) are assumed to converge to 70 per cent of the US productivity level.
  - Productivity growth is smoothed, so each country takes some time to go from their recent rate of growth to their convergence path.
  - Growth in China up to 2030 has been further adjusted based on judgements by the Garnaut Review of the likely growth path, see Garnaut (2008).

Table 9: Productivity level to the United States level (GTEM regions)

	Productivity level(a)		
	2005	2050	2100
United States	100	100	100
European Union	67	73	75
China	9	50	58
Former Soviet Union	18	39	52
Japan	74	76	76
India	5	24	45
Canada	82	83	84
Indonesia	7	26	47
South Africa	18	41	54
Other south and east Asia	15	30	49
OPEC	24	38	52
Rest of world	11	24	44

(a) GDP per adult population, US=100.
Note: convergence and GDP calculations have been performed at a country, not regional level. OPEC in particular shows seemingly less convergence than other countries — this is a result of OPEC being a mix of countries with high productivity (e.g. Qatar) that do not converge, mid-income countries (e.g. Saudi Arabia) that converge more slowly, and low income countries (e.g. Yemen).

World sectoral labour productivity

The productivity and population assumptions (see above) give the total change in output for the economy. In order to implement these assumptions in the international models (G-Cubed and GTEM) some assumption has to be made about the way that this increase in productivity (or efficiency) is distributed between industries. Since capital stock accumulates endogenously and the supply of other factors are given in the model, and the model calculates the value of a productivity variable to be consistent with the exogenous trajectory of regional outputs.

Aggregate labour productivity has been distributed across industries in each country on the basis of historical performance. Productivity growth rates across sectors are based on historical averages calculated from the Groningen Growth and Development Centre database and the OECD. Table 10 shows the relative growth rates of different sectors within key countries used in the GTEM model.

Table 10: Sectoral labour productivity distribution

Industry	USA	EU25	China	Former Soviet Union	Japan	India	Canada
Coal mining	1.00	1.00	1.30	0.50	0.50	1.50	1.00
Oil mining	1.00	1.00	0.75	0.50	0.50	1.00	1.00
Gas mining	1.00	1.00	0.75	0.50	0.50	1.00	1.00
Petroleum & Coal	1.00	1.00	0.75	0.50	0.50	1.00	1.00
Electricity	1.25	1.00	0.75	0.50	0.50	0.50	1.25
Mining and Chemicals	1.25	1.00	1.00	1.00	1.50	1.00	1.25
Manufacturing	1.25	1.50	1.00	1.00	1.50	1.00	1.25
Road Transport	1.50	2.00	2.00	1.00	2.00	2.00	1.50
Water and Air Transport	0.75	1.00	0.50	0.50	1.00	0.50	0.75
Crops	0.75	1.50	1.00	1.00	0.50	0.50	0.75
Livestock	0.75	1.50	1.00	1.00	0.50	0.50	0.75
Fishing and Forestry	0.75	1.50	1.00	1.00	0.50	0.50	0.75
Food	1.40	1.50	1.00	1.00	1.00	1.00	1.40
Services	1.00	1.00	0.75	0.75	1.00	0.75	1.00

Source: Treasury
Note: GTEM industries have been aggregated where distribution of sectoral productivity is the same.

Industry	Australia	Indonesia	Southern Africa	Other SE Asia	OPEC	Rest of World
Coal mining	1.00	1.40	1.00	1.00	1.00	1.00
Oil mining	1.00	0.75	1.00	0.75	1.00	1.00
Gas mining	1.40	0.75	1.00	0.75	1.00	1.00
Petroleum & Coal	1.40	0.75	1.00	0.75	1.00	1.00
Electricity	1.40	0.75	1.00	0.75	1.00	1.00
Mining and Chemicals	0.80	1.00	1.00	1.00	1.00	1.00
Manufacturing	1.00	1.00	1.00	1.00	1.00	1.00
Road Transport	2.00	2.00	2.00	2.00	2.00	2.00
Water and Air Transport	1.40	0.50	1.00	0.50	1.00	1.00
Crops	1.00	0.75	1.00	0.50	1.00	1.00
Livestock	1.00	0.50	1.00	0.50	1.00	1.00
Fishing and Forestry	2.00	0.50	1.00	0.50	1.00	1.00
Food	1.00	0.50	1.00	0.50	1.00	1.00
Services	1.00	0.75	1.00	0.75	1.00	1.00

Source: Treasury.
Note: GTEM industries have been aggregated where distribution of sectoral productivity is the same.

As an example on how to interpret this data, note that road transport labour productivity in the EU25 will grow twice as fast as the labour productivity in the Coal sector. We are not able to make the same comparison between sectors, for example the mining and chemicals productivity in the EU25 and in China will not be equal — the 'average' (that is, equal to 1.0) growth in each country will be determined by aggregate labour productivity.

Due to structures in the G-Cubed model it was not possible to use differentiated labour productivity growth rates across countries, and so the relative productivity pattern for Australia was used for all regions.

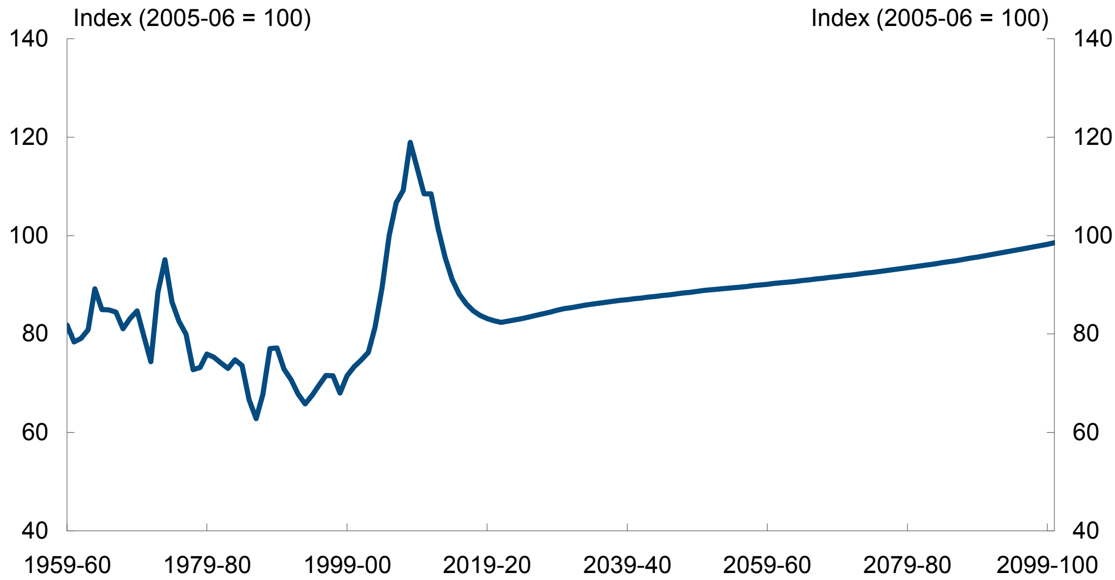
Terms of trade and energy price assumptions

Australia's terms of trade

Australia's terms of trade (the ratio of export prices to import prices) are imposed upon the MMRF model until 2020-21. In the near term, Treasury forecasts are used, and then, in line with the methodology used in recent Budgets, a two-year step down in the terms of trade is imposed. Beyond 2011-12, Australia's terms of trade are assumed to continue to decline gradually over the ten year period to 2021-22, as key commodity prices (coal, oil, gas, iron ore, non-iron ore, other mining, diesel, chemicals, rubber and plastic, steel and other metals) continue to fall towards levels that reflect longer run demand and supply conditions. After 2021-22, Australia's terms of trade are determined within the MMRF model.

In MMRF, export prices reflect the interaction of MMRF's industry supply schedules and the position of the world demand curves for Australia's exports. The position of the world demand curves for Australia's exports, which is exogenous in MMRF, is drawn from GTEM information.

Chart 3: Australia's terms of trade

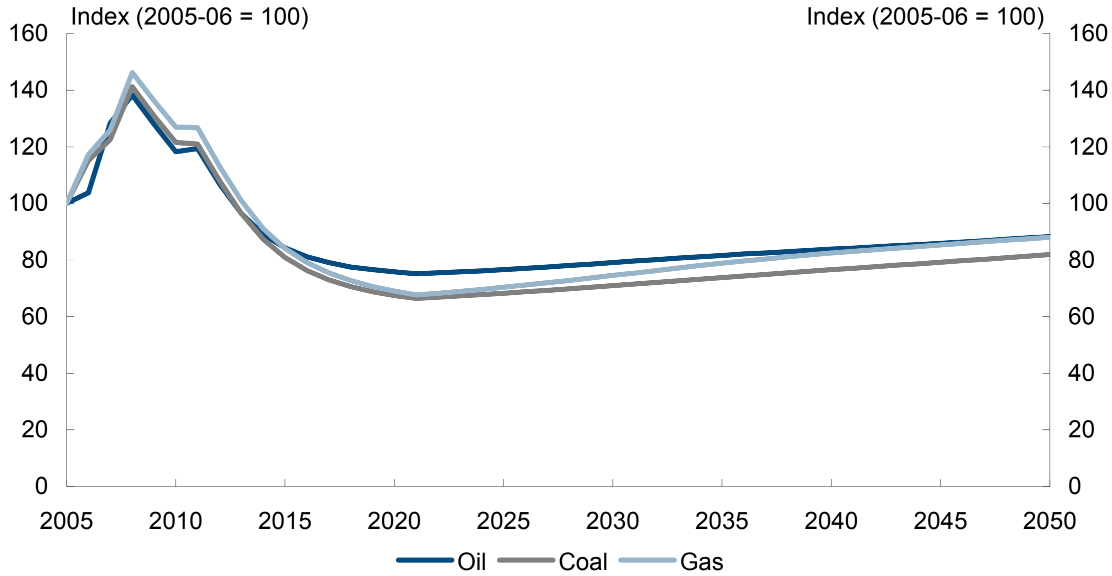


Source: Treasury.

Energy commodity price assumptions

Global energy prices are projected to rise gradually over time, consistent with International Energy Agency (IEA) projections as in the World Energy Outlook 2007. As continued growth in demand forces the exploitation of more marginal resources, the rising marginal cost of extraction for these commodities pushes up their price.

Chart 4: Energy commodity price assumptions
Foreign currency — 2005-06 dollars



Source: Treasury and IEA.

Resource cost curves

In GTEM, movements in the international prices for key energy commodities including oil, coal and gas are assumed to broadly follow movements in International Energy Agency (IEA) projections as in the World Energy Outlook 2007.

The rates of rising extraction costs assumed in GTEM are shown in the Table 11, which gives the percentage change in factor efficiency (labour, capital) in natural resource intensive sectors per doubling of cumulative extraction of the resources (resource depletion effect).

Table 11: Change in factor efficiency per doubling in the level of extraction (Per cent)

	Coal	Oil	Gas	Other Mining
United States	-2.9	-12.8	-10.6	-3.2
EU25	-2.9	-12.8	-13.4	-3.2
China	-4.9	-9.8	-17.8	-3.2
Former Soviet Union	-1.7	-9.8	-17.8	-3.2
Japan	-11.0	-24.0	-46.2	-3.2
India	-4.9	-3.4	-2.6	-3.2
Canada	-5.7	-9.8	-16.2	-3.2
Australia	-5.7	-12.8	-6.4	-3.2
Indonesia	-0.7	-18.6	-25.5	-3.2
South Africa	-0.7	-12.8	-24.0	-3.2
Other SE Asia	-0.7	-11.0	-23.0	-3.2
OPEC	-0.7	-10.4	-14.6	-3.2
Rest of world	-3.3	-6.6	-12.9	-3.2

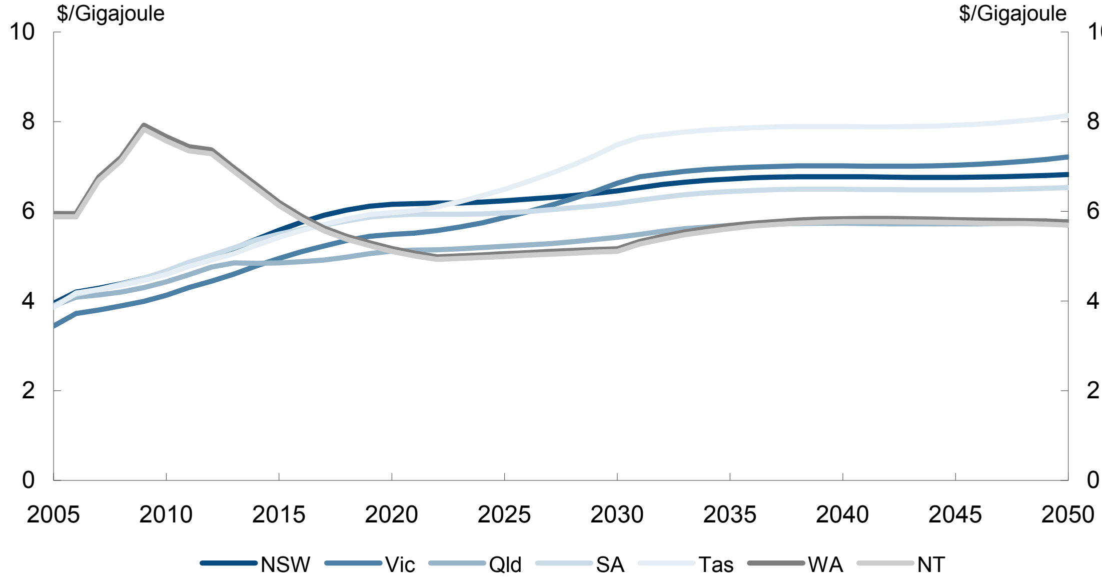
Source: Treasury and GTEM database.

Fuel costs for electricity generation

MMA combined Australian energy price assumptions with electricity industry specific information to determine the fuel prices faced by Australian electricity generators. The MMA approach was as follows:

- Once existing contracts expired for black coal (non-mine mouth) new coal contracts are influenced by world energy prices. Brown coal and mine mouth black coal prices were assumed to be unaffected by world energy price movements.
- South eastern gas supplies are assumed to be gradually depleted over the next two decades, with gas increasingly sourced from Queensland resources. In addition, LNG facilities are assumed to be developed in Queensland, with a moderate degree of LNG penetration assumptions, reaching 10 Mtpa LNG capacity. As a consequence, east coast gas prices are assumed to converge to international gas prices in 2029-30. Differences in gas transmission costs amongst states, reflecting distance from fuel sources, mean that fuel prices are not equalised across states.
  - Domestic average gas prices are modelled by assuming that gas contracts turnover at a rate of 10 per cent of contracts per annum and that new contracts are influenced by world prices.

Chart 5: Domestic Australian gas prices



Source: MMA

STRUCTURAL CHANGE

Intermediate input assumptions

Industry use of intermediate inputs in MMRF and GTEM is assumed to change over time.

The assumed changes in industry use of intermediate inputs in MMRF are based on a historical decomposition analysis by Giesecke (2004). The intermediate input usage estimates in MMRF have also been validated within Treasury using a data set provided by the Centre for Integrated Sustainability Analysis at University of Sydney. Reflecting uncertainty about how persistent historical trends will be over the next century, the intermediate input change assumptions are assumed to decline linearly to zero between 2020 and 2050. The change in the intermediate input usage is implemented in MMRF in a cost-neutral manner, such that total factor productivity remains unchanged.

As shown in Table 12, the use of energy intensive commodities is assumed to decline. This autonomous energy efficiency improvement (AEEI) reflects historical trends and analysis by the IEA and ABARE. In contrast, the intermediate use of services by business is assumed to continue to increase. For example, the demand for business services is assumed to increase by 1.5 per cent per annum over the next ten years.

Table 12: Intermediate input usage in MMRF [(a)]
Annual average growth rates

Commodities	2006 to 2010	2011 to 2020	2021 to 2030	2031 to 2040	2041 to 2050	2051 to 2100
Sheep and Cattle	-0.3	-0.2	-0.2	-0.1	0.0	0.0
Dairy cattle	-0.3	-0.2	-0.2	-0.1	0.0	0.0
Other Animals	-0.3	-0.2	-0.2	-0.1	0.0	0.0
Forestry	-0.5	-0.5	-0.4	-0.2	-0.1	0.0
Coal mining(b)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Gas mining (b)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Other Mining	-1.5	-1.5	-1.2	-0.7	-0.2	0.0
Meat Products	0.5	0.5	0.4	0.2	0.1	0.0
Textiles, Clothing and Footwear	-2.0	-2.0	-1.5	-0.9	-0.3	0.0
Wood Products	-0.2	-0.2	-0.2	-0.1	0.0	0.0
Paper Products	-0.2	-0.2	-0.2	-0.1	0.0	0.0
Printing	-0.4	-0.4	-0.3	-0.2	-0.1	0.0
Gasoline (b)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Diesel (b)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
LPG (b)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Air Fuel	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Other Fuel (b)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Chemicals	-0.7	-0.7	-0.5	-0.3	-0.1	0.0
Rubber & plastic products	0.5	0.5	0.4	0.2	0.1	0.0
Non-metal construction products	-0.5	-0.5	-0.4	-0.2	-0.1	0.0
Cement	-0.3	-0.3	-0.2	-0.1	0.0	0.0
Iron & Steel	-1.0	-1.0	-0.8	-0.5	-0.1	0.0
Aluminium	-1.0	-1.0	-0.8	-0.5	-0.1	0.0
Other Metals Manufacturing	-0.1	-0.1	-0.1	0.0	0.0	0.0
Metal Products	-0.1	-0.1	-0.1	0.0	0.0	0.0
Other Manufacturing	-0.5	-0.5	-0.4	-0.2	-0.1	0.0
Electricity Supply (b)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Water Supply	-1.0	-1.0	-0.8	-0.5	-0.1	0.0
Construction	0.5	0.5	0.4	0.2	0.1	0.0
Trade	0.5	0.5	0.4	0.2	0.1	0.0
Accomodation and Hotels	-1.5	-1.5	-1.2	-0.7	-0.2	0.0
Road Transport: Passenger	0.7	0.7	0.5	0.3	0.1	0.0
Road Transport: Freight	0.7	0.7	0.5	0.3	0.1	0.0
Rail Transport: Passenger	0.4	0.4	0.3	0.2	0.1	0.0
Rail Transport: Freight	0.4	0.4	0.3	0.2	0.1	0.0
Air Transport	0.5	0.5	0.4	0.2	0.1	0.0
Communication Services	1.0	1.0	0.8	0.5	0.1	0.0
Financial Services	0.5	0.5	0.4	0.2	0.1	0.0
Business Services	1.5	1.5	1.2	0.7	0.2	0.0

(a) Annual rate of change of use of the commodity identified per unit of output of all industries.
(b) Energy commodities have economy wide energy efficiency term applied. See energy efficiency section
Source: Treasury and Centre of Policy Studies
Note: Excluded commodities have no intermediate input efficiency shocks applied.

Table 13: Intermediate input efficiency in GTEM, annual average growth rates (2002 to 2100)

Country	Annual average
United States	0.3
EU25	0.3
China	0.5
Former Soviet Union	0.6
Japan	0.3
India	0.7
Canada	0.2
Australia	0.4
Indonesia	0.3
South Africa	0.6
Other SE Asia	0.3
OPEC	0.4
Rest of world	0.7

Source: Treasury

Table 13 shows the average annual efficiency improvement across all intermediate inputs from 2002 to 2100. For example, in the United States, intermediate input efficiency improves by around 0.31 per cent per annum from 2002 to 2100. As mentioned above, these efficiency improvements are differentiated by commodity inputs.

Household taste shifts

Household taste shifts account for any additional change in consumption after accounting for changes in incomes and relative prices. Projection assumptions are based on historical decomposition analysis by the Centre of Policy Studies (Adams et al. 1994, Dixon and Rimmer 2002, Giesecke 2004). In addition, Treasury has undertaken a decomposition analysis in the MMRF model based on consumption categories in the National Accounts.

The projected household taste shifts suggest a continuation of the long-run trends towards services commodities and away from basic commodities. Reflecting uncertainty about how persistent household trends will be over the next century, the taste shifts terms are assumed to decline to zero in a linear fashion between 2020 and 2050.

Table 14: Household taste shocks in MMRF
Annual average growth rates

Commodities	2006 to 2010	2011 to 2020	2021 to 2030	2031 to 2040	2041 to 2050	2051 to 2100
Biofuels	1.0	1.0	0.8	0.5	0.1	0.0
Forestry	-1.5	-1.5	-1.2	-0.7	-0.2	0.0
Coal mining	-0.6	-0.6	-0.5	-0.3	-0.1	0.0
Paper Products	-1.0	-1.0	-0.8	-0.5	-0.1	0.0
Printing	-1.0	-1.0	-0.8	-0.5	-0.1	0.0
Chemicals	0.8	0.8	0.6	0.4	0.1	0.0
Water Supply	-0.5	-0.5	-0.4	-0.2	-0.1	0.0
Trade	0.5	0.5	0.4	0.2	0.1	0.0
Accomodation and Hotels	0.5	0.5	0.4	0.2	0.1	0.0
Air Transport	1.5	1.5	1.2	0.7	0.2	0.0
Communication Services	3.0	3.0	2.3	1.4	0.4	0.0
Financial Services	0.5	0.5	0.4	0.2	0.1	0.0
Business Services	1.0	1.0	0.8	0.5	0.1	0.0
Public Services	2.3	2.3	1.8	1.0	0.3	0.0
Other Services	1.0	1.0	0.8	0.5	0.1	0.0
Private Transport	-0.5	-0.1	0.0	0.0	0.0	0.0
Private Electricity	0.5	0.5	0.4	0.2	0.1	0.0

Source: Treasury and Centre of Policy Studies
Note: Excluded commodities have no taste shocks applied.

Energy Efficiency

Energy efficiency improves when less energy is required to produce the same amount of output. Energy efficiency can improve when the price of energy rises relative to other inputs or from technological improvements, including: better use of existing technologies; the replacement of existing technologies with newer technologies; or improvements in new technology through research and development and learning by doing.

Assumed energy efficiency improvements in the modelling will affect the level of energy use and hence emissions. The three CGE models used by Treasury, GTEM, G-Cubed and MMRF have differing treatment of energy efficiency depending on the structure of the particular model.

Economy wide energy efficiency

While CGE models can capture price induced improvement in energy efficiency internally if they allow for substitution in consumption and production choices, where these substitution opportunities are not fully captured then underlying energy efficiency improvements are incorporated using a simple autonomous energy efficiency improvement (AEEI) parameter. The AEEI parameter specifies the rate of annual energy efficiency improvement, but not the source.

Arriving at estimates for the value of the AEEI is difficult given the uncertainty in the evolution of energy efficiency over very long time frames. While history provides a guide, available data is often aggregated which obscures trends in energy efficiency with other factors such as structural changes in the economy. In the reference scenario for Australia, a constant economy wide AEEI parameter of 0.5 per cent for all sectors outside the electricity and transport sectors has been assumed, reflecting available estimates of historical energy efficiency by ABARE (2003) and the IEA (2004 and 2007a). For other regions, GTEM uses 0.5 per cent per year, except for some specific sectors such as: Transport iron and steel; non-metallic minerals; non-ferrous metals; and chemicals, rubber and plastics. These assumptions are outlined in Tables 15, 17 to 20. Fuel efficiency assumptions have also been made by CSIRO in their modelling of the Australian transport sector (Table 15).

Sector specific energy efficiency

Transport energy efficiency improvements

World transport efficiency assumptions

Assumptions are made in the reference scenario regarding transport energy efficiency improvements in the 'other transport' sector in GTEM are based on ABARE (2006). The other transport sector includes rail and road transport technologies.

Table 15: Transport sector energy efficiency assumptions

Annual average increase from 2005 to 2100

	Rail	ICE	Advanced ICE	Hybrid	Non-fossil fuel
United States	0.6	0.3	0.5	0.6	0.6
European Union	0.6	0.4	0.4	0.7	0.7
China	0.6	0.5	0.7	1.0	1.0
Former Soviet Union	0.6	0.5	0.7	0.7	0.7
Japan	0.6	0.3	0.4	0.6	0.6
India	0.6	0.8	0.9	1.2	1.2
Canada	0.6	0.3	0.5	0.6	0.6
Australia	0.6	0.7	0.8	0.9	0.9
Indonesia	0.6	0.6	0.8	0.7	0.7
South Africa	0.6	0.8	0.6	0.9	0.9
Other south and east Asia	0.6	0.9	1.2	1.1	1.1
OPEC	0.6	0.8	0.8	1.1	1.1
Rest of world	0.6	1.0	0.8	1.0	1.0

Source: ABARE and Treasury.
Note: ICE refers to internal combustion engines and non-fossil fuel vehicles includes electric and hydrogen cars.

Australian transport energy efficiency assumptions

CSIRO assume that vehicles equipped with petrol engines will improve in efficiency by 25 per cent and diesel engines by 14 per cent from 2006 to 2050 independently of changes related to fuel type and hybrid drivetrain, Graham et al., 2008.

Table 16: CSIRO fuel efficiency improvements from 2006 to 2050

Average annual growth

	Petrol	Diesel	LPG	NG	B100	B20	E85	E10	H2	GTLD	CTLD
Passenger											
Light	0.7	0.3	0.8	0.8	0.5	0.3	0.9	0.7	1.0	0.3	0.3
Medium	0.7	0.3	0.8	0.8	0.4	0.3	0.9	0.7	1.0	0.3	0.3
Heavy	0.7	0.4	0.8	0.8	0.4	0.3	0.9	0.7	1.0	0.3	0.3
LCVs											
Light	0.7	0.3	0.8	0.9	0.5	0.3	0.9	0.7	1.0	0.3	0.3
Medium	0.7	0.3	0.8	0.9	0.4	0.3	0.9	0.7	1.0	0.3	0.3
Heavy	0.7	0.4	0.8	0.9	0.5	0.3	0.9	0.7	1.0	0.3	0.3
Trucks											
Rigid	0.7	0.3	0.8	0.8	0.5	0.3	0.9	0.7	1.0	0.3	0.3
Articul'd	0.7	0.3	0.5	0.5	0.5	0.3	0.6	0.7	0.6	0.3	0.3
Buses	0.7	0.3	0.8	0.9	0.5	0.3	0.9	0.7	1.0	0.3	0.3

Source: Graham (2008) Note: NG refers to compressed natural gas, B100 and B20 are differing blends of biodiesel, E85 and E10 are differing ethanol blends, H2 is hydrogen, GTLD is gas to liquid fuels and CTLD are coal to liquid fuels.

Other sector energy efficiency assumptions

Table 17: Non-ferrous metals energy efficiency shocks

Annual average per cent improvement in energy efficiency

Countries	2005 to 2100
United States	1.7
European Union	1.7
China	1.1
Former Soviet Union	0.7
Japan	0.6
India	0.8
Canada	0.7
Australia	0.5
Indonesia	1.5
South Africa	0.8
Other south and east Asia	0.7
OPEC	0.7
Rest of world	0.8

Source: ABARE and Treasury

Table 18: Chemical, rubber and plastics energy efficiency shocks

Annual average per cent improvement in energy efficiency

Countries	2005 to 2010	2010 to 2020	2020 to 2030	2030 to 2100
United States	0.5	0.5	0.5	0.6
European Union	0.5	0.5	0.5	0.5
China	0.5	0.5	0.5	0.5
Former Soviet Union	0.4	0.4	0.4	0.5
Japan	0.5	0.5	0.5	0.5
India	0.6	0.6	0.5	0.5
Canada	0.4	0.5	0.5	0.5
Australia	0.4	0.4	0.5	0.5
Indonesia	0.4	0.4	0.5	0.5
South Africa	0.4	0.5	0.5	0.5
Other south and east Asia	0.4	0.4	0.5	0.6
OPEC	0.4	0.4	0.5	0.5
Rest of world	0.5	0.5	0.5	0.6

Source: ABARE and Treasury.

Iron and steel energy efficiency (GTEM)

As part of the modelling in GTEM assumptions have been made on improvements in energy efficiency in the iron and steel industry. Annual average efficiency improvements are based on the US Energy Information Administration National Energy Modelling System (NEMS), which underlies the EIA's Annual Energy Outlook. Note that in GTEM, iron and steel is a technology bundle industry with two discrete technologies — blast furnace and electric arc furnace (recycled steel from scrap steel). The assumed improvements in energy efficiency for blast furnace and electric arc furnace processes are outlined in Tables 19 and 20 respectively.

Table 19: Blast furnace
Annual average per cent improvement in energy efficiency

Countries	2005 to 2010	2010 to 2020	2020 to 2030	2030 to 2100
United States	0.5	0.3	0.3	0.8
European Union	0.4	0.3	0.3	0.4
China	0.9	1.0	1.0	0.7
Former Soviet Union	0.5	0.9	0.9	0.7
Japan	0.3	0.3	0.3	0.5
India	1.1	0.9	0.8	1.0
Canada	0.2	0.3	0.3	0.5
Australia	0.4	0.3	0.3	0.7
Indonesia	0.0	0.0	0.0	0.5
South Africa	0.6	0.8	0.8	1.2
Other south and east Asia	0.3	0.5	0.5	0.4
OPEC	0.5	0.3	0.3	0.9
Rest of world	0.6	0.8	0.8	0.9

Source: ABARE and Treasury

Table 20: Electric Arc
Annual average per cent improvement in energy efficiency

Countries	2005 to 2010	2010 to 2020	2020 to 2030	2030 to 2100
United States	0.9	0.7	0.7	0.9
European Union	0.8	0.6	0.6	0.7
China	1.0	1.3	1.3	1.0
Former Soviet Union	0.6	1.3	1.4	0.8
Japan	0.5	0.6	0.6	0.8
India	1.3	1.3	1.3	1.3
Canada	0.4	0.7	0.7	0.6
Australia	0.7	0.7	0.7	0.9
Indonesia	1.2	1.2	1.2	1.4
South Africa	0.7	1.3	1.3	1.5
Other south and east Asia	0.5	0.7	0.8	1.2
OPEC	1.0	0.9	0.9	1.0
Rest of world	0.6	1.2	1.3	1.2

Source: ABARE and Treasury.

EXISTING ELECTRICITY POLICY MEASURES

Modelling of the reference scenario included pre-existing policy measures, including the 9,500GWh a year Mandatory Renewable Energy Target (MRET), the Victorian Renewable Energy Target (VRET), the NSW and ACT Greenhouse Gas Abatement Scheme, and the Queensland 15 per cent Gas Scheme. However, major new mitigation policies such as the planned increase in MRET to 45,000GWh a year, the Carbon Pollution Reduction Scheme and the Australian Government's target to reduce emissions by 60 per cent from 2000 levels by 2050 have not been included.

TECHNOLOGY ASSUMPTIONS

Electricity technology assumptions

Table 21 describes the key electricity sector input assumptions used by MMA.

Table 21: Technology characteristics, MMA

	Thermal efficiency		Capital costs	Capital cost de-escalator	
	2010	2011 to 2050	2010	2010 to 2020	2021 to 2050
Fuel/technology	%	% p.a.	$/kW s.o.	% p.a.	% p.a.
Black Coal					
Supercritical coal (dry-cooling)	38	0.48	1,879	0.5	0.5
Ultrasupercritical coal (US)	41	0.48	2,255	0.5	0.5
Integrated gasification combined cycle (IGCC)	39	1.20	2,673	1.5	1.0
IGCC with carbon capture (CC)	32	1.30	3,688	1.5	1.0
Ultrasupercritical with CC and oxyfiring	30	0.58	2,997	1.0	0.5
USC with post-combustion capture	28	0.58	2,482	1.5	0.5
Brown Coal					
Supercritical coal with drying	35	0.48	1,972	0.5	0.5
Supercritical coal	33	0.48	2,289	0.5	0.5
Ultra supercritical coal with drying	37	0.48	2,366	1.0	0.5
IGCC with drying	37	1.20	2,788	1.0	1.0
Integrated drying gasification combined cycle (IDGCC)	37	1.20	2,732	1.5	0.5
IGCC with CC and drying	30	1.30	3,886	1.5	0.5
IDGCC with CC	32	1.30	3,026	1.5	0.5
Co-firing with biomass or gas in supercritical plant	35	0.48	2,169	0.5	0.5
Post-combustion capture without drying	28	0.58	2,761	1.5	0.5
Post-combustion capture with drying	26	0.58	2,575	1.5	0.5
Natural gas					
Combined cycle gas turbined (CCGT) - small	49	0.60	1,467	0.5	0.5
CCGT - large	53	0.60	1,334	0.5	0.5
Cogeneration	72	0.60	1,740	0.5	0.5
CCGT with CC	46	0.70	2,001	1.0	0.5
Renewables					
Wind			2,134	0.5	0.5
Biomass - Steam			2,598	0.5	0.5
Biomass - Gasification			2,784	1.5	1.0
Concentrated solar thermal plant			4,176	1.5	1.0
Geothermal - Hydrothermal			2,227	1.0	1.0
Geothermal - Hot Dry Rocks			2,413	1.5	0.5
Concentrating PV			4,640	1.0	1.0
Hydro			2,320	1.0	0.5

Source: MMA.

Thermal efficiency

The thermal efficiency of a fossil fuel power plant is the ratio of electricity generated to energy input. Assumptions on thermal efficiency improvements for Australia were provided by MMA. Table 22 shows the thermal efficiencies when the plants are operating at maximum capacity. As plants do not always operate at maximum capacity, the average thermal efficiency is typically lower than those shown in the table. Post 2050, thermal efficiencies were assumed to slightly increase for coal and gas, reflecting a continuation of efficiency improvements in the 2030-2050 period.

Assumptions on electricity generation efficiencies are based on information received from ACIL Tasman and MMA. It is assumed that the thermal efficiency of new fossil fuel electricity and heat generation plants improves over time. These assumptions apply to new power plants. The thermal efficiency of the average plant in the capital stock improves as a combination of the advancement of the technology frontier and the replacement of old capital with new, frontier capital.

Table 22: Thermal efficiency of new power plants in electricity generation in GTEM

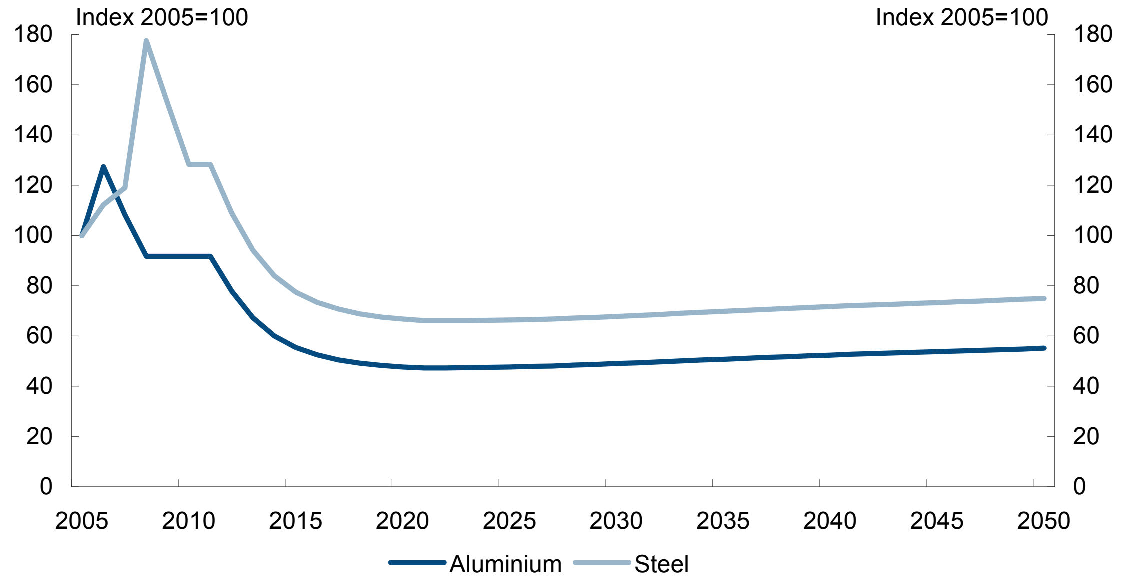
Country	Coal			Gas		
	2002	2050	2100	2002	2050	2100
United States	35.6	47.0	54.6	40.3	61.3	65.7
European Union	35.1	41.2	44.6	48.1	55.2	58.0
China	31.6	43.3	50.3	46.5	63.1	69.8
Former Soviet Union	31.3	33.3	35.4	38.1	41.1	42.3
Japan	37.1	45.5	50.3	45.1	60.1	65.8
India	27.7	47.5	56.8	41.6	64.5	69.9
Canada	38.2	44.9	48.6	46.2	57.9	60.2
Indonesia	27.8	47.2	57.6	32.9	63.1	69.7
South Africa	38.5	46.8	54.3	39.4	65.0	70.4
Other south and east Asia	33.8	46.3	54.8	37.3	61.7	68.1
OPEC	39.0	49.0	58.6	31.9	63.4	70.1
Rest of world	32.7	47.1	56.3	41.5	60.9	65.3

Source: ABARE, ACIL Tasman, MMA.

Capital costs

There are two main factors that drive capital costs over time in MMA: metal prices and technological progress. MMA assume that 25 per cent of capital costs reflect commodity costs. Treasury provided cost indices for key metals (steel, aluminium) for the reference and policy cases, consistent with the terms of trade assumption, which MMA used to construct capital costs. Metal prices are higher in the policy scenarios due to the cost of carbon from emissions associated with metal production. Reference case metal prices are shown in Chart 6.

Chart 6: Index of metal prices in reference case (2006 $AUD)



Source: Treasury.

MMA assume that capital costs decline over time for all technologies due to technological progress. Table 21 shows the annual rate of capital cost de-escalation.

GTEM assumes projects that additional global deployment of renewable technologies leads to faster rates of cost decline for these technologies. To capture the impact of global deployment on Australia, additional capital cost reductions were applied on Australian renewable technology capital costs. These were developed by comparing renewable cost declines in GTEM and applying the *additional* rate of cost decline to MMA modelling.

Learning rates

Non-renewable and biomass technologies use feedstock, labour and capital to produce electricity, while renewable, including hydro, technologies use only labour and capital as inputs. The efficiency with which new technology uses capital and labour was assumed to increase over time as the scale of these technologies increase.

The GTEM parameters of the learning function were calibrated, given the pathways of the fossil fuel prices and the possibility of substitution between the technologies, to produce shares of each technology that were broadly in line with the MMA analysis and other published results. Learning rates for GTEM were only assumed for new technologies and were broadly constant across all regions. The learning rates for GTEM based on the doubling of the cumulative global output are shown below.[1]

- Wind — 1.9 per cent
- Solar — 3.3-4 per cent
- Other renewables — 2.5 per cent
- Coal CCS — 0.7 per cent
- Gas CCS — 1.5 per cent

It is worth noting that in addition to these learning effects, the renewable technologies also benefit disproportionately from overall sector specific factor productivity growth because primary factors are the only input to these technologies, while for non-renewable technologies costs of feed stocks, such as coal, are significant.

Constraints

Exogenous assumptions and constraints in the MMA modelling include:

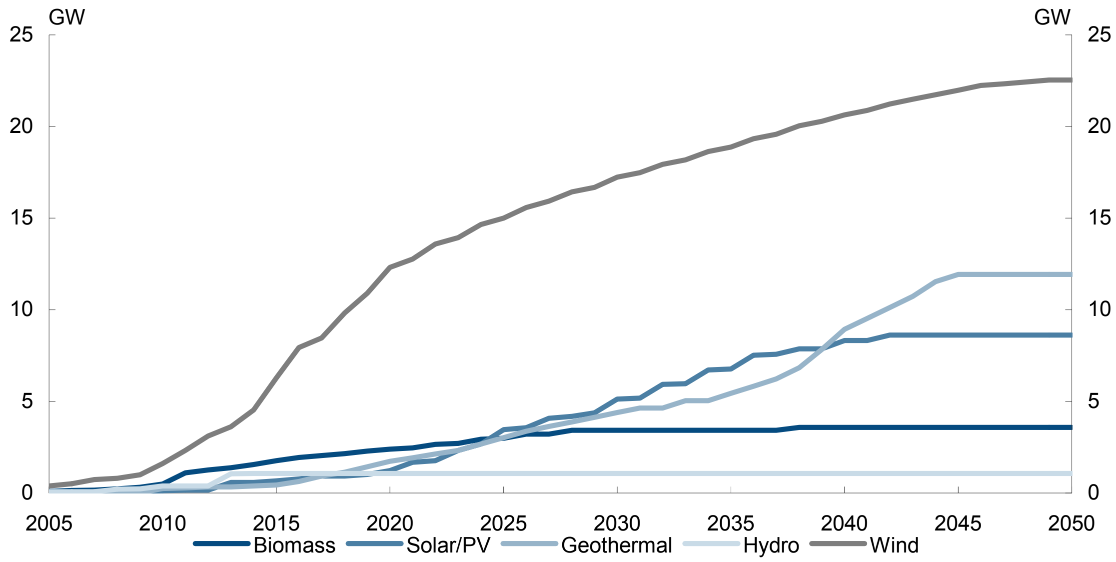
- The impact of the 2006-07 drought is assumed to disappear by 2012 - for instance, hydro dam levels are assumed to be replenished.
- New entry of power plants that are currently not planned were constrained until 2011 for peaking gas, 2012 for baseload gas, and 2013 for coal.
- Limits were placed on the rate of take up and total take up of renewable energy capacity reflecting resource availability and engineering and technical constraints (including that wind capacity was constrained to be no more than 25 per cent of a region's peak demand).

[1] Under the GTEM formulation of learning rates, cost reductions depend on cumulative global *output* of electricity from a specific technology. This is different to the more common formulation where cost reductions depend on cumulative global installed *capacity*. Accordingly, the GTEM learning rates are not directly comparable with many estimates in the literature.

Chart 7 shows the assumed cumulative limits on wind, solar/PV, hydro, biomass and geothermal take up.

- Checks were applied to ensure that the amount of carbon projected to be geo-sequestered by carbon capture and storage did not exceed estimates of available storage space (Bradshaw 2005 and Langford 2005).

Chart 7: Cumulative renewable capacity constraints — MMA



(a) The charts shows the maximum additional post-2005 capacity that can be installed by each year, if it is economical.
Source: MMA.

Exogenous assumptions and constraints in the GTEM modelling are:

- The expansion of hydroelectricity is constrained to reflect remaining unexploited hydropower resources. For China, India, Indonesia, Other Asia and the Rest of World hydro electric uptake is unconstrained to 2020 and fixed thereafter. For other regions (except Australia) hydro electric production is assumed to be fixed (based on the assumption that all profitable hydro resources have already been utilised) from 2001. For Australia, however, hydro electric production is exogenously shocked based on MMA analysis

- Generation of wind electricity by region is constrained based on estimates of wind resources (IEA 2000 and de Vries 2007).

- Checks are applied to ensure that the amount of carbon projected to be geo sequestered by carbon capture and storage did not exceed estimates of available storage space (IPCC 2005).

Carbon capture and storage

Carbon capture and storage (CCS) technology combined with coal and gas electricity generation is assumed to be available on a commercial scale from 2020 in both Australia and the world. The approach to modelling CCS in MMA and GTEM differed, reflecting the level of detail in the respective models and the inherent uncertainty surrounding a technology that has yet to be demonstrated on a commercial scale.

In MMA modelling, CCS was assumed to be available for various black coal, brown coal and gas technologies. Power plants can be either purpose built CCS or built 'capture ready', with CCS installed when the carbon price is sufficiently high. Retrofitting existing power plants with CCS was also an option available. In contrast, GTEM only models purpose built CCS operations and has a single technology for coal and gas. However, the rates of CCS take up in GTEM were cross checked in light of the possibility for retrofitting.

The timing of CCS technology deployment depends on current and expected future electricity demand and the carbon price. Coal CCS technology is generally deployed at a carbon price of $45 per tonne of CO2-e while gas CCS technology is generally deployed at a carbon price of around $100 per tonne of CO2-e. This result is a function of other factors.

- MMA assumed that CCS technologies capture 85 per cent of emissions prior to 2050, with this capture efficiency stepped-up to 90 per cent in the post 2050 period. In GTEM, a constant 90 per cent capture efficiency was assumed throughout the period.

- In MMA modelling, CCS capital costs are assumed to be around 30 to 40 per cent higher for coal and 50 per cent higher for gas compared to non-CCS options. Capturing and compressing carbon requires energy use and, as a result, the sent out efficiency of a power plant with CCS is assumed to be around 20 per cent lower for CCS coal generation and 14 per cent lower for CCS gas generation.

- MMA modelled the storage of captured carbon by state. Depending on the location of sequestration relative to the point of emission, extensive pipelines may be required. It is possible that existing gas distribution infrastructure could be employed to facilitate this. However, to the extent that new pipes are required to transport CCS, the fixed cost of building those pipes is not assumed to be paid for by generators in the modelling. The variable cost of transporting and storing carbon is $10-$20 a tonne in MMA modelling, depending on the state.

Nuclear

Nuclear was assumed to continue to be available in regions where it is currently deployed (and not available elsewhere, including in Australia). No specific constraints were imposed on the basis that nuclear resources and emerging technology were assumed to be able to meet demand for nuclear electricity.

Marginal abatement cost (MAC) curves

The introduction of a price on carbon induces industries to reduce the emissions intensity of their production — that is, they attempt to reduce the volume of greenhouse gasses emitted for each unit of production. One common way to represent and model this reduction, especially when the models do not allow for substitution between intermediate inputs of production, is with marginal abatement cost (MAC) curves. This is the method that has been used in the GTEM and MMRF models.

For the purposes of the current modelling exercise MAC curves for both the GTEM and MMRF models have the functional form:

$$\Lambda = \begin{cases} e^{-\alpha (t+1)^{\gamma}} & \textbf{if } \Lambda > \textbf{min}\,\Lambda, \\ \textbf{min}\,\Lambda; & \end{cases}$$

where Λ is an index of the emissions factor relative to the reference year, t is the carbon price, α is set to 0.03 unless otherwise noted, and the parameters γ and min Λ are selected to model the selected industry as best as possible based on sector specific information on technology and production possibilities. 'Min Λ' is the minimum emissions intensity of output possible, and γ sets the speed of adjustment of emissions intensity in response to a carbon price, a higher γ represents a faster adjustment.

Marginal abatement cost curves in GTEM

The MAC curves used in GTEM were derived to fit the functional form listed above to the global level data from the EMF-21 data set by Weyant and Chesnaye (2006). The MAC curves in GTEM are applied only to fugitive emissions, that is, only to emissions that are not the consequence of combustion of energy.

Table 23: GTEM fugitive emission MAC curve parameters

Sector	γ	minΛ
Coal	0.90	0.1
Gas	0.80	0.1
Oil	0.75	0.1
Landfill/solid waste	0.85	0.1
Livestock	0.60	0.1
Crops	0.45	0.1
Fertilizer use	0.45	0.1
Non ferrous metals	0.80	0.1
Non metallic minerals	0.60	0.1

Source: Treasury and EMF 21 (2006).

Marginal abatement cost curves in MMRF

Fugitive MAC curves

The MAC curves for fugitive emissions used in MMRF have been constructed using a combination of the EMF-21 data set by Weyant and Chesnaye (2006), consultation with McLennan Magasanik Associates and consultation with industry stakeholders. The combination of the EMF-21 data set and the information obtained through the consultation process has yielded a set of MAC curves tailored to Australian industries.

Table 24: MMRF fugitive emission MAC curve parameters

Sector	γ	minΛ
Livestock	0.50	0.1
Crops	0.56	0.1
Coal	0.70	0.1
Oil	0.55	0.1
Gas	0.63	0.1
Non-Ferrous Ore Mining	0.50	0.1
Paper Products	0.50	0.1
Refinery	0.55	0.1
Chemicals	0.90	0.1
Non-Metal Construction	0.50	0.1
Cement	0.89	0.1
Steel	0.90	0.1
Aluminium	0.90	0.1
Gas Supply	0.64	0.1
Trade	0.99	0.1
Accomodation and Hotels	0.99	0.1
Road Transport: Passenger	0.99	0.1
Other Services	0.99	0.1
Private Transport	0.99	0.1
Private Electricity	0.99	0.1

Source: Treasury, EMF21, MMA and Industry consultation.

Combustion MAC curves in MMRF

The MMRF model does not currently capture the potential for fuel switching, that is, substitution between say coal and gas within each sector. Fuel switching is a feature of the GTEM and G-Cubed models. In the MMRF model, to capture the notion that industrial combustion emissions will fall in response to rising carbon prices MAC curves were applied to combustion emissions in the industrial (non-transport) sectors.

The MAC curve for each type of fuel was calibrated to reflect the possibility of using carbon capture and storage technology similar to the electricity generation sector or to reflect the decarbonisation of the transport sector through the electrification of transport.

Table 25: MMRF combustion emission MAC curve parameters

Fuel	α	γ	minΛ
Coal	0.000001	2.75	0.1
Gas	0.000001	2.33	0.1
Gasoline	0.000006	2.05	0.1
Diesel	0.000007	2.05	0.1
LPG	0.000006	2.07	0.1
Air Fuels	0.000007	2.05	0.1
Other Fuels	0.000007	2.05	0.1

Source: Treasury

LAND-USE AND FORESTRY ASSUMPTIONS

Forestry

Detailed modelling of the forestry sector can be problematic within CGE models. Due to the importance of this sector to both Australia's and the worlds response to a carbon price more detailed bottom-up modelling of the forestry sector was commissioned from ABARE (for Australia) and from Lawrence Berkeley National Laboratory (for the rest of the world).

The Australian estimates are based on the Kyoto Protocol Article 3.3 emissions accounting framework. Specifically, rules for Article 3.3 include:

- only new forests established on land that was not forested in 1990 are included;
- all greenhouse gases are to be reported;
- harvest wood products are excluded; and
- the 'short rotation' harvest sub-rule, which protects individual stands from returning a negative outcome, is included up to the end of the Kyoto period.

The global emission estimates are more consistent with the United Nations Framework Convention on Climate Change (UNFCCC). These differences largely reflect the availability of data. The main differences between the carbon accounting in the international forestry modelling and Kyoto reporting adopted for Australia are:

- all identified managed native forests and plantations (even if cleared after 1990);
- all carbon is reported including harvested wood products; and
- no sub-rule mechanism is included.

Australia

For Australia, the supply of land available for use in the agricultural and forestry sectors is assumed to be fixed. The allocation of land between the forestry and agricultural sectors is modelled by ABARE using a spatial modelling framework.

ABARE's modelling examines the impact of a carbon price on land use change in the Australian agriculture sector. The framework used is spatially explicit, and involves analysing the opportunities for carbon sequestration provided by land use change and forestry on cleared agricultural land. These opportunities are determined when the net present value (NPV) of returns from forestry investments are compared to the corresponding expected agricultural land value in order to estimate the potential area of clear agricultural land that is competitive for forestry within each spatial grid cell.

The assumed percentage changes each year to the returns to agriculture and timber over the period 2007-2100 are based on MMRF reference case projections. These changes are applied to both agricultural land values; and the returns and costs associated with timber plantations.

Three types of forestry activity were assumed to be available — softwood and hardwood timber plantations and environmental (carbon sequestration) plantations. All types have establishment costs, but environmental plantings do not have transport or harvesting costs and are assumed not to incur ongoing management costs. These costs are presented in Table 26.

The cost assumptions relating to the establishment, harvesting and transport of timber plantations and environmental plantings are based on data from NSW Department of Primary Industry (Roberts 2007) and ABARE estimates. These costs are assumed to remain constant in the analysis, but are discounted at a rate of 7 per cent each year. Further, the cost assumptions are based on large-scale investments and may differ considerably from small-scale operations.

Table 26: Cost assumptions, 2007 prices

		Timber plantations	Environmental plantings
Establishment	$/ha	2,500	2,000
Management	$/ha	180	0
Harvesting	$/m3	22	0
Transport	$/m3.km	0.123	0

Source: ABARE estimates; Roberts (2007)

The assumed return from traditional timber production is calculated using the average mill-door log price receivable in each state. These mill-door log prices are assumed to range from $42/m^3$ to $71.5/m^3$ in 2007 (Table 27). The variation in the mill-door log price is attributed to the differences in the demand and supply of softwood and hardwood timber across states. Only one price is estimated for hardwood (broadleaved) and softwood (coniferous) logs. However, these prices are a good approximation of the expected return from native and forest plantations in Australia between 2000-2001 and 2006-2007 (ABARE 2008). Mill-door log prices by state and species are derived from ABARE forest industry survey data.

The ABARE analysis uses a broad definition of available agricultural land and assumes a 100 per cent take up of sequestration opportunities. Factors other than economic viability, including water availability or environmental restrictions, may make the some land unsuitable for afforestation and therefore reduce the sequestration potential.

Table 27: Assumed mill-door price by type in the reference case, 2007 prices

		Hardwood	Softwood
New South Wales	$/m3	54.5	52
Victoria	$/m3	62.8	59.6
Queensland	$/m3	54.5	66.8
South Australia	$/m3	62.8	61.9
Western Australia	$/m3	71.5	59.6
Tasmania	$/m3	60.6	61
Northern Territory	$/m3	67.3	42

Source: ABARE (2008).

The ABARE modelling is supplemented by estimates of net carbon sequestration for plantations occurring between 1990 and 2006 provided by the Department of Climate Change, and adjustments to account for the 'short rotation' harvest sub-rule over the Kyoto period.

Australian land-use, land use change emissions

There is no economic modelling of Australian land-use and land-use change emissions. Emissions from this sector are exogenously imposed in the models. Land use emissions for Australia, largely represent emissions from clearing of regrowth as part of agricultural management — rather than clearing for new land. In the reference scenario, emissions from land clearing were assumed to remain at 44 Mt CO_2-e per year throughout the modelling period, based on a simple extrapolation from projections in the most recent national emission projections (DCC, 2007). Under the policy scenarios clearing emissions are assumed to decline linearly in response to the carbon price, reaching zero by 2100.

World

International land use and forestry estimates were commissioned from the Lawrence Berkeley National Laboratory, and are based on their GCOMAP model - see Sathaye et al., 2005 for details on the GCOMAP model.

The GCOMAP model establishes a reference case level of land use, absent carbon prices, for 2000 to 2100. It then simulates the response of forest land users (farmers) to changes in prices in forest land and products, and prices emerging in carbon markets. The objective is to estimate the land area that land users would plant above the reference case level, or prevent from being deforested, in response to carbon prices. The model then estimates the net changes in carbon stocks while meeting the annual demand for timber and non-timber products.

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