ECONOMIC MODELLING TECHNICAL PAPER 6

GLOBAL CLIMATE CHANGE MITIGATION: IMPLICATIONS FOR AUSTRALIA

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This is the sixth paper in a series of Technical Papers of the Garnaut Climate Change Review's discussion of the methodology and results of Modelling of the Net Costs of Climate Change Mitigation. Other Papers in the series, available on the Review's website **www.garnautreview.org.au** are as follows:

Technical Paper Number 1: Overview and approach to the economic modelling

Technical Paper Number 2: Climate data, methodology and assumptions

Technical Paper Number 3: Assumptions and Data Sources

Technical Paper Number 4: Methodology for modelling climate change impacts

Technical Paper Number 5: Counting the costs of unmitigated climate change

Technical Paper Number 6: Global climate change mitigation: implications for Australia

Technical Paper Number 7: The net costs of global mitigation for Australia

1 The two global mitigation scenarios

This paper analyses the two cooperative global mitigation scenarios, the costs and benefits of which to Australia are analysed in Chapter 11 of the Final Report, and in Technical Paper Number 7. Under the 550 scenario, the world stabilizes the concentration of greenhouse gases in the atmosphere at 550 parts per million CO2-e. Under the more stringent 450 scenario, the concentration of greenhouse gases in the atmosphere initially overshoots but then returns to 450 parts per million CO2-e. Given the current level of greenhouse gas emissions and atmospheric concentrations, temporary overshooting is unavoidable.

While the main focus of the Review is on Australia, Australia's mitigation efforts will inevitably be conditioned by global action. Three outputs from the global modelling of mitigation in particular provide critical inputs to the Australian modelling of mitigation: the global carbon price, Australia's national emissions entitlement, and the global demand and prices for Australia's exports and imports. This paper does not attempt to give a comprehensive summary of the global modelling results, but rather focuses on those aspects of greatest relevance to Australia.

In the global modelling, the world adheres to a global emissions pathway consistent with the 550 and 450-overshooting concentration limits. A single carbon price applies in all countries and across sectors and greenhouse gases. The emissions pathway is generated by assuming that that the global carbon price follows a "Hotelling Rule", i.e. it increases at a fixed rate every year (Box 2). This rule is consistent with an efficient allocation of abatement effort over time, corresponding to an appropriate interest rate. It is a proxy for a system with quantitative targets that allows intertemporal flexibility through banking and borrowing of emissions permits. The starting global carbon price was chosen so that, rising at the fixed rate, it results in a trajectory of global emissions that achieves the stabilisation target.

The burden of action in the two cooperative scenarios is divided between countries as set out in Chapter 9 of the Final Report. This paper provides only some additional background in this area not covered in the Final Report.

The single carbon price arises through international trade in emission permits. Countries can emit more (or less) emissions than their entitlement, and buy (or sell) any excess as permits. In the model, it is assumed that there are no transaction costs and that all nations trade. In the real world, whether to trade or not would be up to each country, and international permit trade might be expected to spread gradually and unevenly with some rather than all countries participating in international trade. To the extent that this is the case, the costs of global mitigation would be higher than modelled here since some countries, to adhere to their quantitative targets, will have to undertake more and more expensive domestic abatement, while relatively low cost options elsewhere go untapped.

Global action in the two mitigation scenarios begins in 2013.

The modeling reported in this chapter has been undertaken in GTEM, the global general equilibrium model used for the global reference case reported in Chapter 3 of the Final Report.

2 National allocations of emissions entitlements: additional background material

Chapter 9 of the Final Report argues that only an explicit distribution of the global abatement burden across countries has any chance of achieving the depth, speed and breadth of action that is now required by all major emitters. A critical output of the global modelling is the derivation of an emissions allocation for Australia which represents its fair share of a global agreement. The assumptions and results are provided in Chapter 9 of the Final Report. Only additional background material is presented in this section.

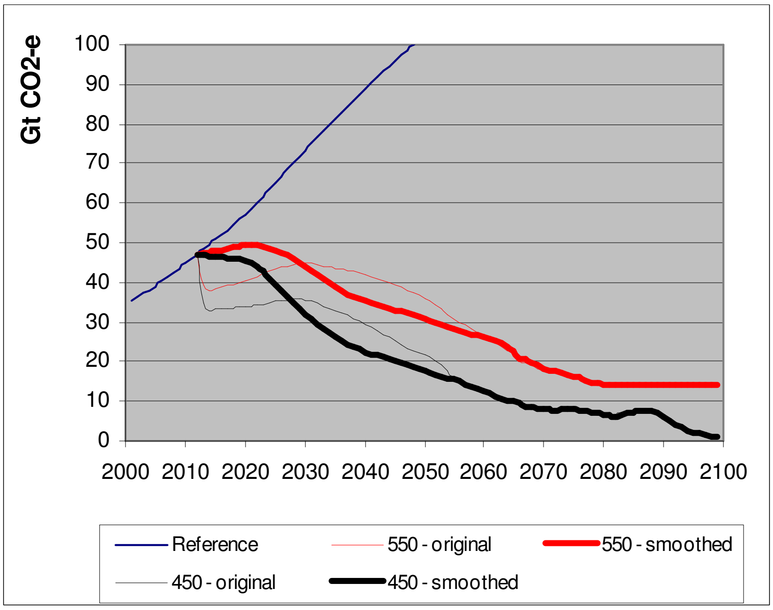
The allocation of emissions entitlements across countries requires the identification of an agreed global emissions trajectory. In the GTEM model, the introduction of a global carbon price in 2013 produces an immediate and large reduction in greenhouse global gas emissions (17 and 26 per cent under 450 and 550 scenarios respectively). On imposing the start-out permit price, the economy moves immediately to its new long-term equilibrium. This is clearly unrealistic. In the real economy, there would be a longer adjustment period. This feature of the modelling has major implications for subsequent emission levels (for example at 2020 and to a lesser degree 2050), first at the global level and, consequently, for individual countries. Because emissions fall so quickly and substantially, emissions in later years do not have to be as low as they would otherwise have to be. While the original trajectories are used for global mitigation cost analysis, smoothed, more realistic global trajectories are required when considering targets for specific points in time, such as for 2020 or 2050.

For the purpose of deriving allocations across countries, the Review therefore considers smoothed trajectories, which result in the same volume of cumulative emissions (the same emissions budget) over the century, but which are constrained in the rate by which the emissions intensity of GDP can fall in the initial years of global mitigation.[1] The smoothed trajectories illustrate what global emissions trajectories could look like in a world of comprehensive mitigation. Smoothing the trajectories in this way had little impact either on long-term global costs or on the achievement of the scenarios' atmospheric concentration and temperature objectives.

The smoothed and the original trajectories are shown in Figure 1. As noted in the Final Report, once smoothed, the trajectory for the 450 scenario at 2050 is close to the 50 per cent reduction in emissions relative to 2000 agreed by the G8 in Japan in July 2008. This level is at one end of the range defined by the IPCC (2007) for the most stringent stabilisation scenario, which is a 50 to 85 per cent reduction over 2000 (on the 15th and 85th percentile of studies). The 550 reduction target for 2050 (a 13 per cent reduction over 2001 levels) lies close to the middle of the relevant IPCC range (a 30 per cent reduction to 5 per cent increase over 2000)

[1] In the 550 (450) scenario, under the smoothed trajectories, global emissions intensity (the ratio of global emissions/GDP) was constrained to fall at 3 (4) per cent per year until 2020. From about 2060, global emissions intensity behaves as per the original trajectories. Between 2020 and about 2060, the original rate of reduction of global emissions intensity under both mitigation scenarios is scaled up to ensure that the smoothed and original trajectories have the same budget over the century.

Figure 1 Global emissions trajectories for the 550 and 450 mitigation scenarios



These smoothed global emissions trajectories now need to be allocated between countries in the form of tradable emissions entitlements. Assumptions used and results obtained are given in Chapter 9 of the Final Report. The resulting allocations for Australia are costed in Chapter 11 of the Final Report and in Technical Paper 7.

Space limitations in the Final Report prevented a detailed account of all the assumptions used to obtain national allocations of emissions entitlements. What follows supplements the material in Chapter 9 (in particular, Box 9.1). Under the "modified contraction and convergence" approach used, countries are divided into two groups: the Annex I countries of the UNFCCC (represented in GTEM as Australia, Canada, the European Union, Japan, the former Soviet Union, and the United States) and others (representing 'developing' countries). Emissions allocations for both groups converge to the global per capita average in 2050 starting in 2013 in at least a linear manner (linear in absolute emissions).[2] For the second group, the developing countries, up to 2020 the additional "headroom" constraint is imposed that emissions entitlements grow at no slower than half the rate of GDP.[3]

Once emission entitlements have been calculated assuming linear convergence (and up to 2020, the "headroom" assumption), they need to be fitted to the non-linear trajectories of Figure 1. The "linear" entitlements are totalled and compared to emissions under the global trajectory. If there is an excess (the global emissions trajectory lies above the sum of the "linear" entitlements), then there is no need for Annex I country emissions entitlements to converge downwards faster than linear, and the excess is proportionately shared among developing countries according to their emissions. If there is a deficiency (the global emissions trajectory lies below the sum of the "linear" entitlements), then to ensure that developing country emissions entitlements converge in at least a linear manner, the shortfall is shared proportionately among Annex I countries according to their emissions.

Special attention needs to be given to developing countries whose per capita emissions would

[2] If a straight line is drawn between initial and 2050 total emissions (for the definition of initial emissions, see Box 9.1) then emissions must lie on or below this line for the first group of countries, and on or above for the second group. Emission entitlements are said to be linear when they are on the line (or up to 2020 growing at half the rate of GDP for developing countries, if this is greater).

[3] This is part of the "transition period" provided to developing countries up to 2020. Deforestation emissions are handled separately, as explained in Box 9.1 of the Final Report.

otherwise under these rules start to exceed the per capita average of Annex I countries. For such countries a rule is imposed that their per capita emissions are constrained so as not to exceed the per capita average of Annex I countries.

3 The global costs of mitigation

3.1 Global costs under standard technology and enhanced technology assumptions

The global costs and benefits of climate change are not directly relevant to a decision as to whether it is in Australia's national interests to mitigate climate change, and to what extent. That will depend on the costs and benefits to Australia. Nevertheless, the global costs as shown by GTEM provide an important benchmark for comparison with other modelling exercises. The discussion in this section focuses only on the cost of reducing greenhouse gases. It does not attempt to analyse the benefits gained at the global level from reducing climate change damages.[4] Comparison to the "no mitigation" scenario is to the reference case of Chapter 3 in the Final Report (without climate change damages).

Modelling deep reductions in greenhouse gas emissions decades into the future is subject to many uncertainties, including how fast future efficiency improvements will occur, what low-emissions technologies will be available, when, at what cost, and how effective they will be. At best, any quantitative estimate of costs over the next century, or even over the next half century, can be illustrative.

Two approaches were taken to estimating the global costs of mitigation. In the first, a standard set of technology assumptions were developed for this modelling exercise. In the second, a number of more optimistic assumptions made about technological progress were adopted. The assumptions made in the enhanced technology scenario are summarized in Box 1 below. The rationale behind the enhanced technology approach is that it is quite likely that, faced with high and rising carbon prices, human ingenuity and financial incentives will combine to deliver climate change solutions that exceed current and projected cost and performance expectations. Note that under the standard technology assumptions the carbon price becomes very high in the second half of the century, rising to $US400 per tonne in real terms by the end of the century in the 550 scenario and $US1000 in the 450 scenario (see section 4). Faced with the prospect of these very high prices, it is possible that technological progress will exceed expectations, and thereby reduce the likelihood that these high prices do actually prevail. Other aspects that could result in lower abatement costs, but have not been explored in the modelling, include larger demand-side responses to sustained price changes, and more extensive changes in consumer tastes as incomes rise well above today's.

[4] Such an indicative analysis was however done in order to translate effects of climate change on Australia's terms of trade. See section 4 below.

Box 1: Enhanced Technology Assumptions

The Garnaut-Treasury modelling work conducted a simulation of an "enhanced technology" scenario in the global general equilibrium model (GTEM) to assess the potential impact of a more optimistic outlook for technology development. This scenario incorporates the combined effects of greater energy efficiency and faster technology learning in the early years, and more effective carbon capture and storage technology as well as the elimination of non-combustion emissions in agriculture above a threshold price.
Specifically, the enhanced scenario implemented within the GTEM model included the following assumptions:

- Faster energy efficiency improvements of 1 per cent annually from 2013 to 2030, an extra 0.5 per cent from 2031 to 2040 and no extra improvements thereafter (in the standard case energy efficiency improvement rate is set at 0.5 per cent per annum).
- Energy efficiency improvements for household consumption at the rate of 1 per cent from 2013 to 2030, 0.5 per cent from 2031 to 2040 and no improvements thereafter. In the standard technology case energy efficiency for household consumption is set at 0. However, households do respond to relative prices by substituting to lower emissions intensive goods.
- More effective carbon capture and storage (CCS) in response to higher carbon prices. The share of combustion CO2 captured increases from 90 per cent to 99 per cent as the permit price rises from zero to $US140/tCO2-e.
- Faster learning by doing for electricity and transport technologies by increasing the parameter for the learning functions by 50 per cent relative to the standard assumptions over the whole simulation period.
- Non-combustion agricultural emissions are eliminated when the carbon price exceeds $US250/tCO2-e.

The global costs of mitigation are summarized in Figure 2 and Table 1 below. For the implications for mitigation costs in Australia, see Chapter 11 of the Final Report.

Figure 2: Global mitigation costs relative to the reference case for the enhanced technology and standard scenarios (percentage of global GDP)

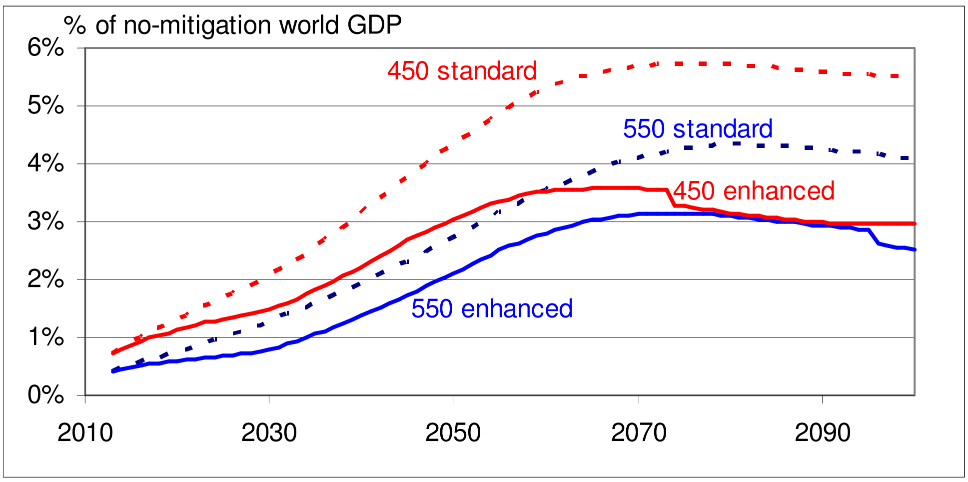


Table 1: Global mitigation costs relative to the reference case for the enhanced technology and standard scenarios (percentage of global GDP)

	2013-20	2013-50	2051-2100	2013-2100	2050
550					
Standard technology	0.6%	1.4%	3.9%	2.9%	2.7%
Enhanced technology	0.5%	1.0%	2.9%	2.1%	2.1%
450					
Standard technology	1.0%	2.4%	5.5%	4.1%	4.3%
Enhanced technology	0.9%	1.8%	3.2%	2.6%	3.0%

Note: These are unweighted averages of annual percentage reductions to global output in the no-mitigation case (except for the 2050 numbers, which are for a single year). Purchasing power parities are used to weight the gross domestic products of different countries and regions.

The global cost (as a percentage of world output) increases over time in all the scenarios, but stabilizes and starts to decline towards the end of the century. In the 450 enhanced technology scenarios, the 2100 cost is similar to the 2050 cost, but in the other scenarios, the global cost at the end of the century is about 20 to 50 per cent higher than at the middle of the century. In all scenarios, average costs in the second half of the century as a share of GDP are much higher than in the first half. The cost of mitigation in the very long term is obviously highly speculative, and many modelling exercises only run out to 2050. Clearly, much more weight can be given to the projections of average costs up to 2050 than in the second half of the century.

The enhanced technology scenarios show significantly lower global mitigation costs than the standard technology ones. The average GDP cost until 2050 is just 1.0 per cent for the 550 scenario under enhanced technology assumptions, compared to 1.4 per cent using the standard technology approach, and similar differences are evident in the 450 scenario. The difference due to technology assumptions is greatest in the 450 scenario in the second half of the century, where average global GDP costs are reduced by 40 per cent compared to the standard scenario, to 3.2 per cent rather than 5.5 per cent.

With the enhanced technology assumptions, the cost differences over the second half of the century are in fact quite small between the 450 and 550 scenarios: only 0.3 percentage points compared to 1.6 percentage points in the standard approach.

The range established by the standard and enhanced technology approaches should not be seen as establishing firm bounds on the likely eventual cost of global mitigation. It is possible that technological progress will proceed much more rapidly than assumed in the enhanced technology case, for reasons set out in the Final Report, Chapters 20-23, especially Chapter 23. Of course, it could also turn out that technological progress and abatement options are more limited than assumed in the standard scenario. In that case, mitigation costs would turn out to be higher. Some of the assumptions embodied in the GTEM standard technology scenario might not eventuate: for example, CCS might never become commercially viable. And while the enhanced technology approach indicates a number of ways in which costs might fall below levels indicated in the standard technology approach, it is also possible that in other areas costs could be higher (for example, the modelling assumes that industrial processes, land use change and forestry emissions are achieved without requiring additional resources). Rather, the standard and enhanced technology scenarios should be seen as two credible efforts to put a cost on a long-term, uncertain, and indeed uncharted journey.

The enhanced technology approach in particular highlights the central importance of the development and deployment of emissions-saving technologies as a key determinant of the economic cost of mitigation. If high emissions prices are expected and sustained over prolonged periods of time, this would very likely lead to the rapid development and deployment of transformative technologies, beyond even the range of options considered in the enhanced technology scenarios. For example, through biosequestration and/or mechanical capture of CO2 from the air, backstop technologies with negative emissions that are currently known could become commercial at some carbon price, which will offset hard-to-reduce emissions from elsewhere. This possibility is investigated in Chapter 11 and Technical Paper 7 in regards to the modelling of mitigation options for Australia.

3.2 Putting the global costs in context

It is important to put the mitigation cost results in context by looking at how far they will force a deviation from the no-mitigation scenario. The answer is not very much. Table 2 provides this analysis for the standard technology approach (the difference would be even less under the enhanced technology approach.) There is a difference of at most 0.2 percentage points in the average annual growth rate up to 2020, up to 0.1 percentage points up to 2050, and less after 2050. The cost of mitigation moves future global GDP levels in the two mitigation scenarios only marginally from the no-mitigation growth path described by the reference case. And importantly, the cost numbers reported here do not take account of the positive economic impacts from avoided climate change damages (see Technical Paper Number 7).

Table 2 also makes the same point in a different way by showing the cost to global world product in terms of "months lost". That is, it shows the additional number of months the world would have to wait to achieve the no-mitigation global GDP levels because of the costs imposed by reducing emissions. To achieve 2020 no-mitigation levels in the 550 scenario, the world would have to wait another 2 months, and in the 450 scenario another 4 months. To achieve 2050 reference case output levels the world would have to wait another 10 months in the 550 scenario, and 15 months in the 450 overshooting scenario.

Table 2 Analysis of the deviation of the 550 and 450 scenarios from the reference case.

(a) Global GDP growth rates in the reference case and the two policy cases

	2012-2020	2020-2050	2050-2100
Reference case	3.8%	3.3%	2.3%
550	3.7%	3.3%	2.3%
450	3.6%	3.2%	2.3%

(b) Delay in months in achieving reference case global GDP levels on account of the cost imposed by mitigating climate change.

	2020	2050	2100
550	2	10	18
450	4	15	24

The Review's global mitigation cost estimates can be compared to others published. For stabilisation at 550, IPCC (2007) reports that the median cost estimate in 2050 is 1.3 per cent of GDP with a range from slightly negative to 4 per cent (Ch 3, p.206). The 2050 estimates for the Review's 550 scenario are within the range (2.7 per cent for the standard case, and 2.1 for the enhanced), though above the median. There are fewer cost estimates for the 450 scenario and the IPCC only notes that by 2050 cost estimates for this type of scenario are generally below 5.5 percent, as are the Review's estimates (4.3 per cent for the standard case, and 3.0 for the enhanced).

A widely cited estimate of the cost of mitigation is from the Stern Review. Stern's (2007) central estimate for the cost of global mitigation in a 550 scenario is 1 per cent of GDP by 2050, within a range of+/-3 per cent (p. 267). The Review's GDP global cost of mitigation is also above that of the recent modelling undertaken by the OECD (2008), which estimated the cost of a 450 scenario at 2.5 per cent of global GDP at 2050. It is towards the top of the three-model range of the CCSP (2007) exercise for a 550-class scenario, which gave 2050 global GDP costs of 1.9, 2.0 and 5.4 per cent.

Part of the reason for relatively high cost estimates is that the Review models a larger abatement task. The Review projects faster emissions growth in the absence of action on climate change than other studies. This requires policies which will induce greater abatement: the gap between global business-as-usual and the 550 mitigation case in 2050 is 67 Gt CO2-e, relative to 50 Gt CO2-e in Stern's analysis, for example.

Another issue to consider when comparing results across models is the use of different GDP measures. The Review's modelling uses purchasing power parities to compare the relative size of economies around the globe, whereas many other such exercises and most covered by the IPCC survey use market exchange rates. With market exchange rates, the costs to global GDP in 2050, using the standard GTEM runs, are 1.5 per cent and 2.3 per cent for 550 and 450 respectively, which are similar to Stern and close to the IPCC median for the 550 (no median is given by the IPCC for the 450 case). The reason for the difference in GTEM between global costs using market exchange rates and purchasing power parities is that the model indicates countries which are emissions intensive generally pay a higher cost for mitigation as a percentage of GDP(though not necessarily as a percentage of GNP – this will also be affected by international emissions trading arrangements). Not all emissions-intensive economies are poor (Australia is among them) but on average they are lower income economies. Their relatively higher mitigation costs receive a higher weight in the global cost average when purchasing power parities are used than when market exchange rates are. Note that adjustment costs associated with the redeployment of capital and labour are not captured by GTEM, and these will tend to be higher in developed than developing countries due to their relatively higher pre-existing capital stocks.

3.3 Sensitivity analysis

Higher energy prices, as observed in recent times, exert pressure to economise on energy use and to accelerate the development and deployment of more efficient equipment. Lower energy use in turn would tend to result in lower emissions, easing the task to be fulfilled by mitigation policies. However, substitution between fuels could partially or wholly negate that effect, if a shift takes place to more carbon-intensive energy sources.

In a sensitivity analysis on the 550 scenario, using the standard technology assumptions, a world of higher underlying prices for fossil energy was modelled. It was assumed that the cost of energy extraction is 50 per cent higher than in the standard scenario, in both the reference case and policy scenario.[5] The price effects from higher extraction costs include strong increases in oil prices, moderate increases for gas and small increases for coal prices. The price effects differ between regions depending on cost structures. For Australia, the price increases at 2050 relative to the standard reference case are 16 per cent for coal, 28 per cent for gas and 42 per cent for oil (close to the 45 per cent increase for OPEC, one of the remaining large oil producers). This results in substitution away from fossil fuels, but also a shift toward coal, the most carbon intensive fuel.

The net effect is a small reduction in global emissions in the reference case, 5 per cent lower at 2050. As a result, achieving atmospheric stabilisation requires somewhat lesser policy effort. The GDP costs of the mitigation policy are lower, but only start to diverge significantly in the 2040s. The average global GDP cost over the second half of the century is reduced from 3.9 to 3.4 per cent. The permit price is very close to that in the standard scenario for most of the century.

Turning land-use change and forestry from a net carbon source to a net sink provides a significant share of global abatement effort, around 10 per cent of total reductions relative to the reference case at

[5] The policy scenario was then re-run with a new Hotelling price trajectory, to approximate the same atmospheric concentration outcome. The high energy price scenario has no 'plateau' in emissions at the end of the century, limiting comparability after around 2080.

2050 in both the 550 and the 450 scenario. In another sensitivity analysis, the effect of taking out the land-use change and forestry sector as an abatement option was examined. The same overall reduction target now needs to be achieved using a narrower base. The result is higher permit prices for the rest of the global economy by around 25 and 30 per cent at 2050 in the 450 and 550 scenarios respectively, and an increase in the cost in terms of global GDP in the same year, by around one fifth and one quarter respectively. This analysis illustrates the importance of bringing land-use change and forestry emissions into the global mitigation regime.

4 The evolution of global carbon prices

Under the two cooperative scenarios, the global carbon price determines the marginal cost Australia will face for its greenhouse gas emissions. It is thus a key outcome of the modelling.

In the standard technology approach to the modelling, the global carbon price in the 450 and 550 scenarios follow a 'Hotelling rule' (Box 2) under which it increases at a fixed rate of 4 per cent per year, in real terms. In these scenarios, the starting price emerges as the lowest price which limits the concentration of greenhouse gas emissions to 550 ppm CO2-e and 450 ppm, respectively (since the 450 scenario allows for overshooting, concentration levels are allowed to exceed this level temporarily). The permit price in the 550 trajectory tails off towards the end of the century, because the Hotelling Rule is turned off to prevent a reduction in concentration levels below 550 ppm, and annual emissions are held constant.

Box 2 The Hotelling rule

The concept of a resource price rising with the interest rate comes from resource economics. Hotelling (1931) demonstrated that profit from the optimal extraction of a finite mineral resource will increase over time at the rate of interest. Since only a finite amount of greenhouse gases can be released into the atmosphere prior to the stabilisation of the concentration of greenhouse gases, the optimal release of greenhouse gases into the atmosphere over time is a problem similar to the optimal extraction of a finite resource (Peck and Wan, 1996).

The interest rate assumed in the modelling is 4 per cent, comprising a real interest rate of 2 per cent, and a 2 per cent risk premium. Other climate policy modelling exercises have used similar Hotelling interest rates (see, for example, CCSP (2007) Ch 4, p. 89).

In the enhanced technology approach, the emissions trajectory derived under the standard technology approach is adhered to, and the carbon price which is consistent with this trajectory derived. Given the more optimistic assumptions about technology, this price will lie below the standard technology price.

Table 3 summarizes the carbon prices thus derived for the two stabilisation scenarios and sets of technology assumptions, at different points in time. The 550 scenarios start out with carbon prices around $US20/t, rising to roughly $US70 to $US90 by 2050, and then to over $US400 under standard technology assumptions. The price remains at a more modest level under the enhanced technology scenario (which, to recall, does not follow a Hotelling price path but achieves the same emissions trajectory through time). The 450 scenario starts out at $US35/t, and crosses the $US100 threshold in the 2030s under standard technology assumptions and just before 2050 under the enhanced technology scenario. The carbon price under standard assumptions is over $US1000/t by the end of the century, and half that under the more optimistic technology assumptions. The threshold for elimination of agricultural emissions under enhanced technology assumptions is passed in the 2070s for 450, and the 2090s for 550.

Table 3: International carbon price, standard and enhanced technology scenarios

	2013	2020	2030	2050	2100
	$US(2005) / tCO2-e				
550					
Standard technology	20	26	39	86	432
Enhanced technology	20	22	30	67	144
450					
Standard technology	35	46	67	149	1042
Enhanced technology	34	40	53	107	540

Note: This table shows the average of the carbon prices faced by the various countries of the world. The carbon price in different countries may differ from the average (measured in fixed 2001 exchange rates) due to exchange rate variations.

These prices are within the range reported by the IPCC (2007) for the first half of the century. The IPCC reports that for 450-type stabilisation scenarios by 2030 carbon price estimates from various models are clustered in the range of $US100, above the results obtained here. The Review's 550 prices are within the IPCC range at 2030 ($US18-79) as well as at 2050 prices ($US30-155), but the 550 carbon price in this analysis derived under the standard technology approach is above the IPCC range for 2100 ($US35-350) (IPCC, 2007, Ch 3, p.206). The three models used in the recent CCSP (2007) exercise all have higher carbon prices for their 530 ppm stabilisation scenario though. No 2050 or 2100 carbon prices are reported by the IPCC for a 450-type scenario.

5 Terms of trade

Carbon pricing changes the demand for different commodities, and with it global trade flows and volumes. The expected impacts of climate change further affect world demand. The changes in external demand facing Australia under the different scenarios are modelled in GTEM, and further in the GIAM module to GTEM (see Technical Paper Number 1, and Harman, et al 2008) which incorporates the economic effects of climate change impacts. These modelled effects on the demand for Australia's exports are then used as an input to the domestic economic modelling.

A simple if partial summary measure of the world demand impacts on Australia is the terms of trade, the ratio of export prices to import prices. Australia's terms of trade increase through time in all scenarios. In the reference case, by 2100, they are 1.6 times the level in the starting year 2001. However, the increase in terms of trade is slightly slower when factoring in climate change impacts, essentially because climate change induced reductions in growth rates elsewhere in the world also reduce demand for Australia's export commodities (first row of Table 4).

Global mitigation efforts could play out positively or negatively for Australia's terms of trade, depending on how other countries go about reducing greenhouse gas emissions, and in particular the role of fossil fuels in a carbon-constrained world. In the standard technology scenarios, which feature strong reductions in global use of all fossil fuels and in particular coal, Australia's terms of trade by the end of the century decline relative to the reference case. In the enhanced technology scenario, however, global mitigation itself has a positive, or at least not a negative, effect on Australia's terms of trade, compared to the reference case. The main reason for the divergence between the two scenarios is the ability of carbon capture and storage of fossil fuel electricity to reduce emissions virtually to zero, thus supporting the continued use of Australian fossil fuels in world electricity generation.

Table 4 Australia's terms of trade in 2100, percentage change relative to the reference case

	No mitigation scenario	550	450
Standard technology, with climate impacts*	-3.0	-4.3	-7.7
Standard technology, no climate impacts^	0.	-4.2	-7.8
Enhanced technology, no climate impacts^	0	2.0	0

Note:.The enhanced technology scenario was not modelled incorporating global climate change impacts.

* Source: GIAM

^ Source: GTEM

6 Decarbonising the world economy

How are the large modelled global emissions reductions achieved? Lowering emissions requires either cutting back economic activity, or delinking economic activity and greenhouse gas emissions. In fact, Section 3 has already shown that the impact on overall economic activity is marginal. Instead, the link between economic activity and greenhouse gas emissions is effectively broken: the global economy is decarbonized.

Decarbonisation is achieved mainly through a transformation of the energy and transport sectors, direct mitigation of emissions from agriculture and industrial processes, the creation of forestry sinks, and more efficient use of inputs, both energy and non-energy. Together these changes drastically reduce the emissions intensity of production of most goods and services.

Taking a snapshot at 2050 as Table 5 does, using the standard technology 550 scenario to illustrate, there is a small total reduction in global economic activity, of about 3 per cent. This is the global cost of mitigation, discussed in Section 3.

There are also changes in the composition of the economy. Low-energy and low-emissions intensive activities such as services gain relative to emissions intensive industries such as mining, manufacturing and agriculture. Changes in output relative to the no-mitigation case, however, are in most cases very small when compared to the underlying expansion of all of these industries, which sees them several times larger in 2050 than today. Note though that a finer level of disaggregation would bring out greater changes, for example, within the manufacturing sector.

Large changes in output do occur in the energy industries. A shift away from fossil fuels reduces the level of activity in coal mining and oil and gas extraction and processing to less than half of what would have been the case without greenhouse gas policies, though this group of sectors still grows relative to current levels. Mitigation also leads to rapid expansion of the electricity sector as it comes to be based on low- and zero-emissions technologies, and starts to replace fossil fuels in transport, industrial applications, and residential uses like heating.

Overall, changes in both aggregate output and the composition of output are dwarfed by reductions in the emissions intensity of output, as all sectors decarbonize (Table 5, final column). In the 550 scenario under standard technology assumptions by 2050, global emissions reduce by 65 per cent relative to the no-mitigation case, and the overall emissions intensity of output by 64 per cent. This decarbonization is, however, an uneven process. Again under the standard technology 550 scenario, by 2050, electricity generation decarbonizes by 82 per cent (as measured by the reduction in emissions intensity relative to the no-mitigation case), but agriculture decarbonizes only by 43 per cent, and transport by 28 per cent. This reflects the relatively higher marginal abatement costs in agriculture and transport, and the greater potential for lower cost abatement in electricity generation.

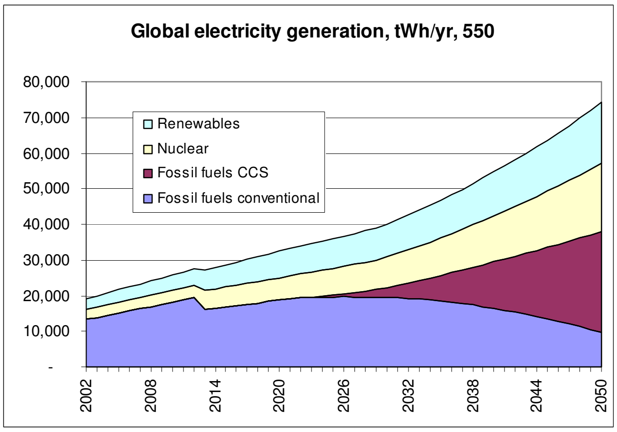
Table 5: Change in emissions and output by industry in the standard technology 550 scenario relative to the reference case, at 2050

	Share in global emissions reductions, %	Change in emissions, relative to reference case, %	Change in output, relative to reference case, %	Change in emissions intensity of output, relative to the reference case, %
Coal, oil and gas	6	-60	-53	-15
Electricity generation	34	-75	36	-82
Minerals and metals	16	-55	-4	-53
Manufacturing	7	-75	-4	-74
Transport	5	-32	-6	-28
Agriculture	8	-46	-4	-43
Services	6	-65	-2	-64
Land-use change and forestry net emissions	10	-272	n.a.	n.a.
Household energy use	9	-58	n.a.	n.a.
Total	100	-65	-3	-64

Notes: Coal/oil/gas and minerals/metals includes mining, extraction and processing. Agriculture includes emissions from fuel use in fishing and forestry. Emissions from land-use change and forestry and the domestic sector have no economic activity accounted for. Emissions embodied in electricity use are attributed to electricity generation, not to the sector which uses them.

The electricity sector contributes the most to global decarbonisation, accounting for around one-third of absolute global emissions reductions achieved at 2050 under the 450 and 550 scenarios, and slightly more cumulatively over the century. The large reduction in the emissions intensity of electricity reflects major shifts in the generating mix (Figure 3). At 2050 global electricity generation is composed of roughly one quarter renewables, one quarter nuclear, 38 per cent fossil fuels with carbon capture and storage (CCS) and 13 per cent conventional (non-CCS) fossil fuel. The share of conventional fossil fuel generation continues declining in the second half of the century. The transition in the technology mix is more rapid in the 450 scenarios.

Figure 3 Global electricity generation in the standard technology 550 scenario up to 2050



The longer-term technology mix is strongly influenced by assumptions about the features and costs of the different low-emissions technologies. The alternative assumptions on CCS in the enhanced technology scenarios have a big effect on the composition of power generation in the policy scenarios (Table 6). In the standard technology scenarios, the share of electricity generated globally from fossil fuels using CCS increases at first, but then decreases again, dropping to almost zero at the end of the century. This is because at very high permit prices, the assumption that with CCS 10 per cent of fossil fuel generation emissions are not captured places CCS at a strong disadvantage compared to zero-emissions renewable and nuclear technologies. By contrast, when assuming that CCS efficiency can reach 99 per cent at sufficiently high permit prices, the share of CCS is almost 40 per cent by the end of the century for 450, and over 50 per cent for the 550 scenario. CCS expands more slowly at first under the high technology scenarios, because the assumed faster learning rates and efficiency improvements elsewhere keep the permit price lower, delaying the deployment of CCS.

Clearly, whether and to what extent CCS becomes and remains viable in a carbon constrained world will be the key determinant of coal use (and so of Australia's coal production and exports), in a world committed to climate change mitigation. This in turn will depend on the relative progress of CCS and renewable technologies, about which there is much uncertainty. [6]

Table 6: Shares of electricity generated globally using CCS technology, in the enhanced technology and standard technology scenarios

	2050	2100
550		
Enhanced technology	31%	53%
Standard technology	38%	19%
450		
Enhanced technology	39%	38%
Standard technology	32%	3%

The transport sector also experiences transformative technological change, though in the 550 case (under standard technology assumptions) this is far from complete in 2050 when 45 per cent of total transport is undertaken using hybrids and electric vehicles, and internal combustion engine powered

[6] The modelling results for technology shares in electricity shown here depend strongly on assumptions about the availability, effectiveness and relative future costs of CCS and renewables. Thus the future generating mix could differ strongly from the scenarios shown here, depending on technology development.

vehicles continue to meet 11 per cent of demand. Changes occur more rapidly in the 450 scenario, and in the enhanced technology scenario where there is faster learning in the new technologies. By the end of the century, road transport in all scenarios relies almost exclusively on advanced technology vehicles.

The manufacturing and services sectors also contribute to lower aggregate emissions, mostly by substituting (low-carbon) electricity for fossil fuels and by reducing process emissions for example from chemical industries, cement and aluminium production.

Agriculture is partially decarbonized, both through lower fossil fuel use and reductions in non-combustion emissions such as methane from enteric fermentation, and nitrous oxide from fertilizer application.

Finally, land-use change and forestry plays an important role in reducing global emissions, changing from a net source of emissions in aggregate to a net sink, as deforestation is slowed and new forests are planted. By 2050, net sequestration offsets 18 per cent of global emissions in the 550 scenario, and contributes 10 per cent of absolute emissions reductions relative to the reference case.

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