covec

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Carbon Price Forecasts

Prepared for

Parliamentary Commissioner for the Environment

economics | research | forecasting | public policy

Authorship
This document was written by Tim Denne and Steven Bond-Smith
tim.denne@covec.co.nz | (09) 916 1960

We help organisations to solve problems and make decisions using our core skills of economics, forecasting, research and public policy.

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Executive Summary

Background

The purpose of this report is to provide the Parliamentary Commissioner for the Environment (PCE) with a set of "best guess" estimates for the carbon price in 2020 and 2030 for three climate policy scenarios that reflect a range of anticipated levels of global ambition in reducing emissions.

The report is based on a review of projected prices in existing literature. The range of prices reflects the differences in approaches to analysis (the different types of model) and input assumptions.

Summary of Projected Prices

Prices in the New Zealand market are determined by the costs of supply and the characteristics of demand. In 2020 and 2030, it would be expected that the New Zealand market would be in net deficit and that demand would be met from the international market. Our "best guess" estimates of the prices in New Zealand, based on international prices, are given in Table ES1, along with possible ranges. The explanations are given below.

Table ES1 Summary of Price Estimates for different Policy Scenarios (NZ$/tonne)

Scenario[1]	2020 Low Estimate	2020 Best guess	2020 High Estimate	2030 Low Estimate	2030 Best guess	2030 High Estimate
Lower ambition	20	**35**	70	20	**50**	100
Medium ambition	25	**50**	85	35	**100**	150
Higher ambition	50	**200**	350	50	**150**	500

[1] Level of global ambition in greenhouse gas emission reduction

Scenarios

The scenarios used in this report are based on assumptions of:

- the extent to which there is a multinational agreement to reduce emissions; and
- the level of ambition in reducing emissions.

The scenarios chosen for analysis, and as recommended by PCE, reflect expectations of possible future developments in climate change policy, particularly the extent to which there is a multinational agreement to reduce emissions and the level of ambition in reducing emissions. The three scenarios are summarised in Table ES2; they are:

1. **Lower Ambition**: there is no effective international emission reduction framework. Individual countries may have their own emission reduction policies on a voluntary basis, and there may be fragmented bi- or multi-lateral agreements. To encourage some adjustment to a low-carbon economy, and for presentation to the outside world, New Zealand has an emission reduction target, but it is relatively unambitious.

2. **Medium Ambition**: The world is on track to stabilise GHG levels in the atmosphere at 550 ppm CO_2-e.[1] There are international agreements but not involving all countries, either as an extended form of the Kyoto Protocol or as a number of regional or multinational agreements to reduce emissions.

3. **Higher Ambition**: The world is on track to stabilise GHG levels in the atmosphere at 450 ppm CO_2-e. New Zealand is part of an international agreement including major emitting countries. There is broad international involvement in reducing GHG emissions.

Table ES2 Possible Prices under Scenario Options

	Levels of International Participation		
Ambition (concentration)	**Limited bi- or multi-lateral agreements**	**International agreements but without all countries**	**International agreements with all countries participating**
Unspecified	1 Lower Ambition		
550 ppm		2 Medium Ambition	
450 ppm			3 Higher Ambition

Price Estimates from Different Sources

To estimate prices, we have summarised the results of estimates from a number of sources. The survey of sources is not comprehensive, but the emphasis has been on the key ones, including the major US and European modelling groups publishing price projections and a number of industry analysts and traders:

1. **Futures markets**—sales of contracts to deliver emission units in the future.
2. **Bottom-up modelling**—estimates using models that incorporate detailed technical information.
3. **Top-down modelling**—estimates from models that are based on historical relationships between prices (typically of energy fuels) and consumption.
4. **Backstop technology cost**—the costs of major technologies that might be used in a widespread way and set a ceiling on price.
5. **Social cost analysis**—estimates of the damage costs of greenhouse gases, on the assumption that the level of international commitments will result broadly in the price of carbon equalling estimates of the social damage cost.[2]
6. **Expert opinion**—using surveys of people with emission market expertise.

The results are shown converted to NZ $ in Table ES3. The range of price estimates increases significantly with the more ambitious levels of emission reduction; the

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[1] CO_2-e = CO_2-equivalents. In this context it refers to the atmospheric concentration of the sum of greenhouse gases that are included in the Kyoto Protocol, ie it excludes water vapour. The concentrations of the individual gases are converted into CO_2-equivalents using global warming potentials (GWPs). GWPs are a measure of the relative contribution of the individual gases to global warming.

[2] By social damage cost, we mean estimates of the net present value of the future impacts of one more tonne of CO_2 emitted to the atmosphere. These are from studies that estimate the physical impacts of climate change on the globe and place a monetary estimate on the damages caused.

estimates of costs for these higher ambition levels depend considerably on levels of technological development.

Table ES3 Summary of Price Estimates (NZ$/tonne)

	2020			2030		
	Lower ambition	Medium ambition	Higher ambition	Lower ambition	Medium ambition	Higher ambition
Current markets	24					
Bottom-up (Annex I only)	0 – 83	0 – 83	33 – 330			
Bottom-up CDM	20	20	40 – 49			
Top-down	8 – 72	17 – 87	167 – 357	100	108 – 117	17 – 833
Back-stop technology			167 - 250			50 – 83
Social costs	10			10		
Expert opinion	0 - 33	33 - 83	83 - >167			

Best Guess Estimates

The "best guess" prices, as shown in Table ES1 are based on the range of published price estimates.

At the lower ambition level, the expected price for 2020 is NZ$35/tonne. This is higher than existing prices and is based on expectations of price changes in competitive markets relative to current prices and the modelled results. Similar approaches are used for 2030.

For the medium and higher ambition prices, we have chosen numbers close to the median of the range of published estimates. For the higher ambition scenario, we assume an early introduction of relatively high emission prices, that this stimulates the development and introduction of low-emissions technologies and fuels, and that the cost of carbon is limited by some backstop technology. We assume that such a technology becomes widespread by 2030, although not by 2020. This means that the assumed best guess higher ambition cost is lower in 2030 than in 2020.

1 Introduction

1.1 Background

The purpose of this report is to provide the Parliamentary Commissioner for the Environment (PCE) with a set of estimates for the carbon price in 2020 and 2030. PCE requires a range and "best" estimates of the international carbon price, and the New Zealand Unit carbon price (if and when it differs from the international carbon price), for three climate policy scenarios that reflect the range of expected levels of ambition in reducing emissions.

The report is based on a review of projected prices in existing literature rather than any new modelling. This is partly because prices in New Zealand markets are expected largely to reflect supply-demand characteristics in international markets, and because price projections reflect the characteristics of the models being used to make those projections. Using the results of a range of models provides a larger spread of price projections, but such a range provides a better understanding of the uncertainties in the projections. The range of prices reflects the differences in approaches to analysis (the different types of model) and input assumptions.

1.2 Scenarios

The scenarios used in this report to summarise the results provide an assessment of the impacts on price of two key assumptions:

- the extent to which there is a multinational agreement to reduce emissions; and
- the level of ambition in reducing emissions.

The issues are related to some extent, as the level of ambition is likely to reflect the level of international concern about the issue which, in turn, is likely to be reflected in the extent of international agreement and cooperation.

The scenarios chosen for analysis, and as recommended by PCE, reflect expectations of future developments in climate change policy and the assumptions used by researchers in producing projections. The three scenarios are summarised in Table 1; they are:

1. **Lower Ambition**: there is no effective international emission reduction framework. Individual countries may have their own emission reduction policies on a voluntary basis, and there may be fragmented bi- or multi-lateral agreements. To encourage some adjustment to a low-carbon economy, and for presentation to the outside world, New Zealand has an emission reduction target, but it is relatively unambitious.

2. **Medium Ambition**: The world is on track to stabilise GHG levels in the atmosphere at 550 ppm CO_2-e.[3] There are international agreements but not

[3] CO_2-e = CO_2-equivalents. In this context it refers to the atmospheric concentration of the sum of greenhouse gases that are included in the Kyoto Protocol, ie it excludes water vapour. The concentrations of the individual gases are converted into CO_2-equivalents using global warming

involving all countries, either as an extended form of the Kyoto Protocol or as a number of regional or multinational agreements to reduce emissions.

3. **Higher Ambition**: The world is on track to stabilise GHG levels in the atmosphere at 450 ppm CO_2-e. New Zealand is part of an international agreement including major emitting countries. There is broad international involvement in reducing GHG emissions.

Table 1 Possible Prices under Scenario Options

	Levels of International Participation		
Ambition (concentration)	**Limited bi- or multi-lateral agreements**	**International agreements but without all countries**	**International agreements with all countries participating**
Unspecified	1 Lower Ambition		
550 ppm		2 Medium Ambition	
450 ppm			3 Higher Ambition

1.3 The Commodity

Scenarios are being used here to reflect the major factors that will affect carbon prices and to provide a useful categorisation for policy analysis purposes. Carbon prices are defined in an international market (or markets) and they reflect the interaction of supply and demand. Before examining the results of analyses, we first explain what is meant by a carbon price in this context; we discuss the carbon market and the factors determining supply and demand.

1.3.1 The Market

The market being examined here is the compliance market. Currently the Kyoto Protocol defines New Zealand's greenhouse gas limitation commitments; it requires New Zealand to hold emission rights equal (or greater) in number to its gross emissions during the commitment period 2008-12. New Zealand has been assigned a target, or assigned amount, and this defines its <u>initial</u> right to emit (in terms of the way the government is treating it). New Zealand's assigned amount for 2008-12 is 307.6 million tonnes of greenhouse gases measured in CO_2 equivalents. Under the Kyoto Protocol, the national assigned amount can be disaggregated into individual assigned amount units (AAUs) that provide a right to emit 1 tonne of CO_2-e. Thus New Zealand has an initial allocation of 307.6 million AAUs. The Kyoto Protocol specifies that AAUs can be traded such that (in theory)[4] New Zealand can sell any surplus that it has (if it emits less than its holding of AAUs) or can purchase if it is in deficit. The Protocol defines other emission rights that are equivalent to AAUs for compliance purposes. These are:[5]

potentials (GWPs). GWPs are a measure of the relative contribution of the individual gases to global warming.

[4] In practice there are limits on trade, as discussed below

[5] http://unfccc.int/kyoto_protocol/mechanisms/emissions_trading/items/2731.php (accessed 11 June 2010)

- removal units (RMUs) created from land use, land-use change and forestry (LULUCF) activities such as reforestation;
- emission reduction units (ERUs) from joint implementation projects; and
- certified emission reductions (CERs) generated from clean development mechanism (CDM) project activities.

The underlying international compliance market is thus specified by:

- a set of commitments that define the demand for carbon emission units;
- the products that can be used for commitment purposes;
- the ways in which supplies can be created; and
- who can supply.

Thus the "price of carbon" is more correctly specified as the price of rights to emit greenhouse gases, measured as CO_2 equivalents, which can be used for compliance purposes with international commitments to limit greenhouse gas emissions.

However, although the market defined by the Kyoto Protocol allows trading in several equivalent products (Kyoto Units), separate markets are being defined by individual countries and country groupings in ways that place some restrictions on trade in Kyoto units. This means that the international market is currently characterised by separate markets with limited interaction between them.

Currently the New Zealand market limits international purchases for compliance purposes to CERs, ERUs and RMUs, however it does not allow imports of CERs or ERUs that result from nuclear projects[6] and it does not allow AAUs from other countries to be used. The EU market similarly does not allow purchase of AAUs, has some limits on ERU purchases (those associated with large hydro developments) and sets an overall limit on the number of units that can be brought into the EU system.

One of the key issues for future prices will be the way in which the international market develops. For New Zealand, the availability on the market of low-price units may not mean that they set the price if there are restrictions to entry that mean marginal demand must be met by higher priced units, whether made available through activity in New Zealand or imported. Scenario definitions will need to take account of these factors.

1.3.2 Demand

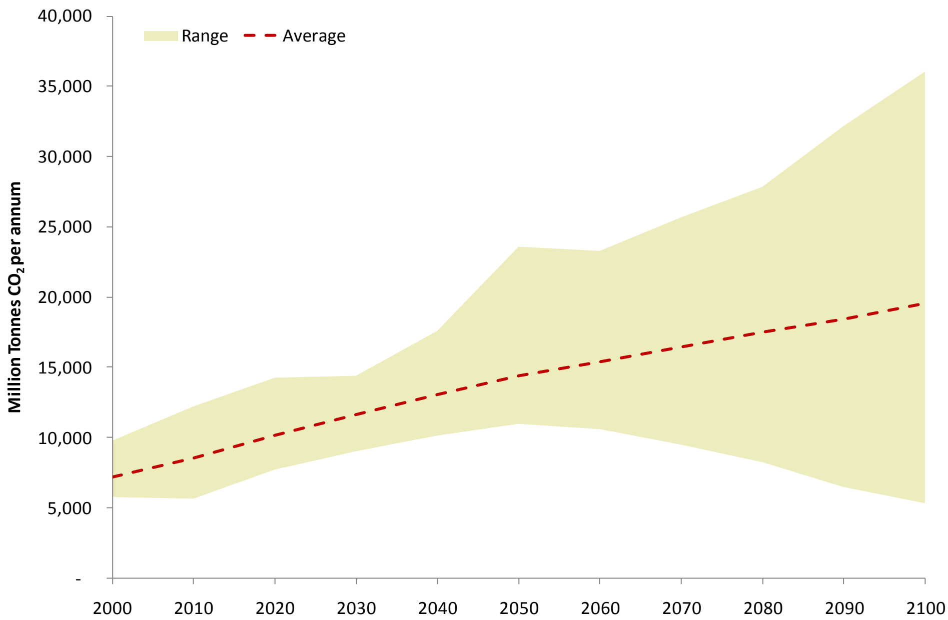
Demand for emission units in New Zealand is unlikely to set price; rather it will be set by overall demand across the countries that have taken on, and intend to be bound by, quantitative emission limits. This includes those that operate a trading market and those that do not; in the absence of a trading market, governments will still be expected to purchase emission units to meet commitments, increasing total levels of demand globally.

There is considerable uncertainty over estimates of total demand for emission units. The uncertainty reflects differences in baseline projections of emissions and the possible stabilisation target adopted. The range of projections of business-as-usual (without

[6] Climate Change (Unit Register) Regulations 2008 (SR 2008/357)

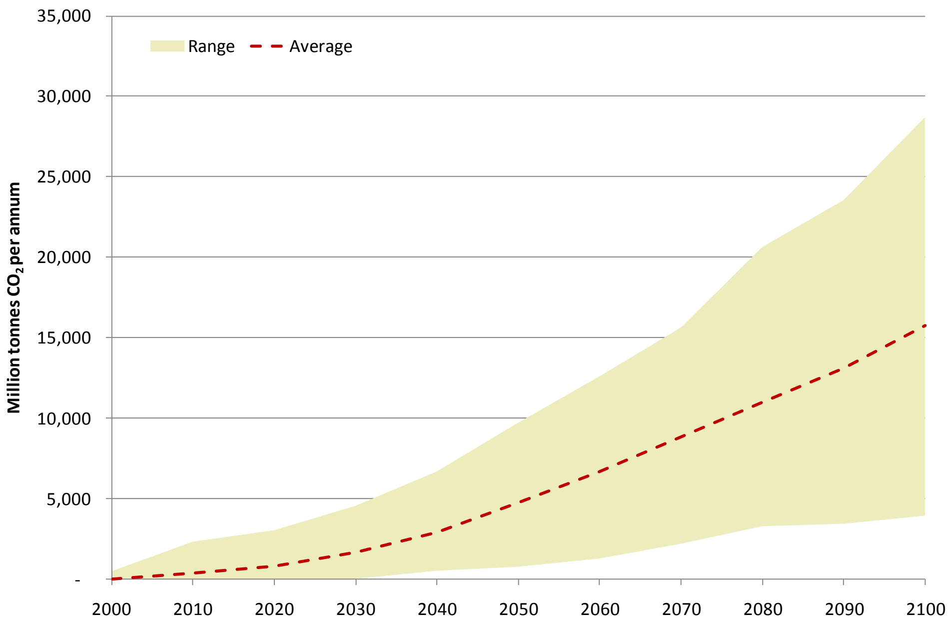
intervention) global emissions through to 2100 from a number of different global models is shown in Figure 1 on the basis of data used as input to the IPCC's Fourth Assessment Report. From this range of business-as-usual (BAU) emissions, modelled estimates of required reductions to achieve a specified stabilisation target (550ppm) differ very widely also, as seen in Figure 2. Given this huge uncertainty, estimates of the costs of meeting stabilisation targets, and thus the costs of carbon, are expected to differ widely also.

Figure 1 Projections of business as usual global CO_2 Emissions



Source: Data from National Institute for Environmental Studies Japan, Greenhouse Gas Emission Scenarios. AR4 (Fourth Assessment Report) (http://www-cger.nies.go.jp/scenario/)

Figure 2 Annual CO_2 Emission Reductions below BAU Required to achieve 550ppm Stabilisation



Source: Covec analysis. Data from National Institute for Environmental Studies Japan, Greenhouse Gas Emission Scenarios. AR4 (Fourth Assessment Report) (http://www-cger.nies.go.jp/scenario/)

By 2100 the size of the estimated reductions are close to the size of total emissions because it is estimated that very significant emission reductions will be required, below what BAU would have been otherwise by that time, to achieve a 550ppm stabilisation target.

The estimates of the emission reductions that might be required to achieve the different stabilisation targets, based on the average values for the different scenarios, are shown in Figure 3. Those for 2020 and 2030 are reproduced in Table 2.

Figure 3 Annual CO_2 Emission Reductions below BAU Required to meet Stabilisation Targets

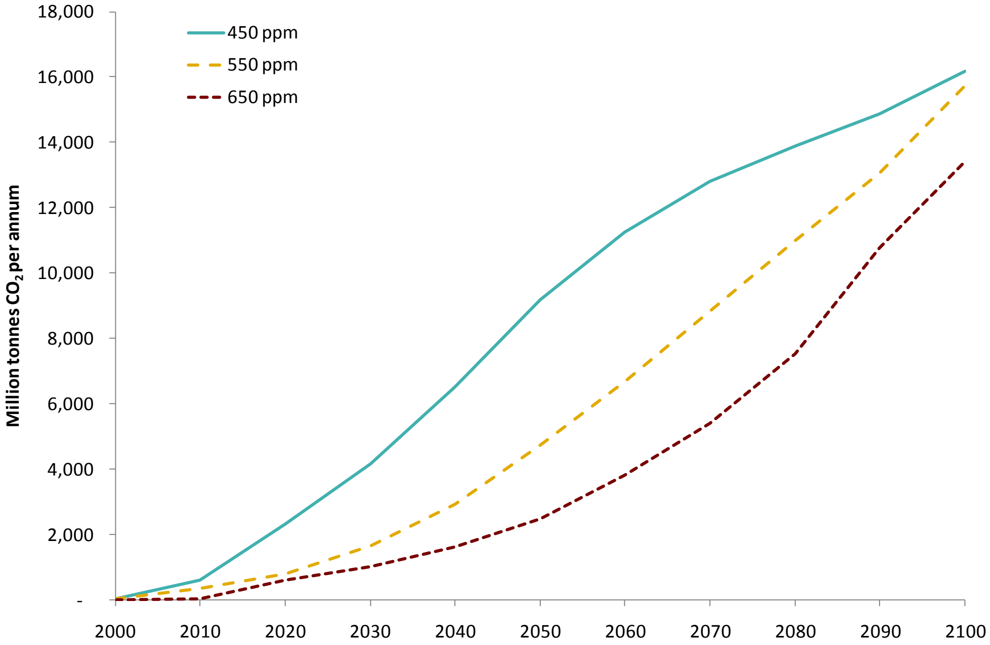


Table 2 Emission Reduction Requirements to Achieve Stabilisation Targets

	CO_2 Only		All GHG	
Target (ppm)	**2020**	**2030**	**2020**	**2030**
450	2,329 1,050 – 4,493)	4,169 (2,060 – 7,136)	3,043	5,354
550	789 (0 – 3,015)	1,634 (0 – 4,534)	968	1,942
650	597 (20 – 1,569)	1,012 (76 – 2,583)	872	1,520

Note: Uncertainty estimates based on ranges from studies

Table 2 also notes the range of estimates of required reductions. This is based simply on the minimum or maximum required emissions compared to the average emissions under BAU. Because there are far fewer studies for non-CO_2 cases, we have included ranges for CO_2 reductions only. For example, there is only one study that examines reductions in CH_4 to achieve 450ppm, and for those studies that do exist, some take simple proportions of CO_2 reductions as way of estimating reductions of other gases.

However, we use these estimates to examine the range in the possible size of the market for reductions in all greenhouse gas emissions. To do so, the range of reduction sis estimated as a percentage of the average and we apply these percentages to the estimated (average) reduction requirements for all greenhouse gases; the results are shown in Table 3. The estimates for 650 ppm are in some instances greater than the estimated reductions for 550ppm, largely because of the more limited number of studies. We have adjusted the results by assuming that the maximum reductions to achieve 650 ppm can never be greater than that required to achieve 550 ppm.

Table 3 Range of Emission Reduction Estimates (Million Tonnes and % below BAU in parentheses)

Stabilisation Target	2020			2030		
	High	Ave	Low	High	Ave	Low
450	5,870 (51%)	3,043 (26%)	1,372 (12%)	9,165 (68%)	5,354 (39%)	2,646 (20%)
550	3,701 (32%)	968 (8%)	0 (0%)	5,389 (40%)	1,942 (14%)	0 (0%)
650	2,291 (32%)	872 (8%)	0 (0%)	3,878 (29%)	1,520 (11%)	0 (0%)

These percentage reductions can also be expressed as percentages below 1990 emission rates, as shown in

Table 4 Range of Emission Reduction Estimates (% below 1990 emission rates)

Stabilisation Target	2020			2030		
	High	Ave	Low	High	Ave	Low
450	59%	31%	14%	92%	54%	27%
550	37%	10%	0%	54%	20%	0%
650	23%	9%	0%	39%	15%	0%

1.3.3 Supply

Levels of supply of carbon units at different prices depend on the initial assigned amounts (or targets) that are established and the costs of emission reduction. However, as noted above, it is also affected by any limitations on trade. If there are low-cost opportunities in one country, this may not affect price if there are restrictions on sales of units from that country.

A complexity, which we discuss further below, is the continued operation of the clean development mechanism as a source of supply.

1.4 Sources of Price Data

To estimate prices, we have summarised the results of estimates from a number of sources:

1. **Futures markets**—sales of contracts to deliver emission units in the future.
2. **Bottom-up modelling**—estimates using models that incorporate detailed technical information.
3. **Top-down modelling**—estimates from models that are based on historical relationships between price (of energy) and consumption.

4. **Backstop technology cost**—the costs of major technologies that might be used in a widespread way and set a ceiling on price.
5. **Social cost analysis**—estimates of the damage costs of greenhouse gases on the assumption that the level of international commitments will result broadly in the price of carbon equalling estimates of the social damage cost.[7]
6. **Expert opinion**—using surveys of people with emission market expertise.

No single approach is perfect as a way to project future prices; each comes with its own analytical approach and set of assumptions, which differ in transparency. For example, futures markets and expert opinions embed the assumptions regarding future levels of ambition and participation, whereas the modelling approaches (bottom-up and top-down) make these explicit. Some make clear the technologies used to reduce emissions (bottom-up modelling and backstop technology costs) whereas for others the technology employed is assumed within some other proxy, eg a sectoral or economy-wide level energy and emissions intensity (top-down modelling). Each approach has advantages and disadvantages and some comments and interpretation are provided here, but it is useful for PCE to consider a wide range of sources in developing its own ideas on future prices. Where there is consistency across the different approaches, this reduces the uncertainties involved in estimating an average, and where the fuller set of approaches widens the range of estimates, this provides a better understanding of the degree of uncertainty involved.

[7] By social damage cost, we mean estimates of the net present value of the future impacts of one more tonne of CO_2 emitted to the atmosphere. These are from studies that estimate the physical impacts of climate change on the globe and place a monetary estimate on the damages caused.

2 Current Markets

Prices in current markets may provide some insights into future prices, particularly because Kyoto Units can be "banked" for use in future commitment periods.[8] Price data are published for the EU ETS and secondary CER markets. This includes futures markets; however, these data provide limited information of use in projecting prices out as far as 2020 or 2030. The New Zealand market is emerging currently and we discuss the linkages to the international market and transparency of data.

2.1 EU ETS

The European Emissions Trading Scheme (EU ETS) has operated since January 2005 and covers CO_2 emissions from industrial installations. The market is for EU allowances (EUAs). It has operated in two phases.

- Phase 1 was a trial phase that ran from 2005 to 2007 during which there was significant over-supply of EUAs and prices fell to close to zero;

- Phase 2 runs from 2008 to 2012. It included additional sources (aviation and three new countries from outside the EU – Norway, Iceland, Lichtenstein) and limited the number of allowances in the scheme to approximately 93% of 2005 emissions.

The relevance of the EU scheme to international prices affecting New Zealand depends on the extent to which the EU ETS links to international emission unit markets. The EU ETS allows the purchase of CERs and ERUs from other countries, although there are limits on this. Specifically, each national allocation plan sets out the percentage of CERs and ERUs that can be used by sectors included in the scheme.[9] The aggregate percentages by Member State are set out in Table 5. In total, the limit is approximately 13% of the total cap for all member states.

Table 5 EU Member State Limits on CERs and ERUs (% of total allowances)

Member State	%	Member State	%	Member State	%
Belgium	8.4	Greece	9	Poland	10
Bulgaria	12.55	Hungary	10	Portugal	10
Cyprus	10	Ireland	10	Romania	10
Czech Rep.	10	Italy	14.99	Slovakia	7
Denmark	17.01	Latvia	10	Slovenia	15.76
Estonia	0	Lithuania	20	Spain	~ 20
Finland	10	Luxembourg	10	Sweden	10
France	13.5	Malta	Tbd	UK	8
Germany	20	Netherlands	10		

European Commission. (2007) Emissions trading: EU-wide cap for 2008-2012 set at 2.08 billion allowances after assessment of national plans for Bulgaria. Press Release. 7 Dec 2007

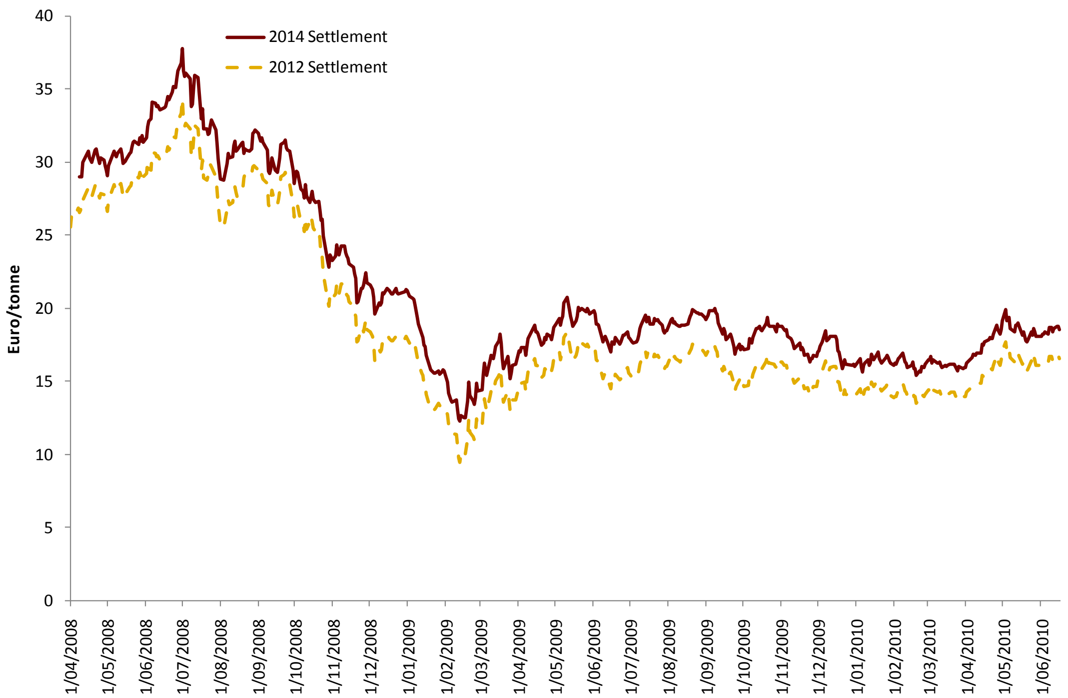
[8] Article 3(13) of the Kyoto Protocol states "If the emissions of a Party included in Annex I in a commitment period are less than its assigned amount …, this difference shall, on request of that Party, be added to the assigned amount for that Party for subsequent commitment periods."

[9] CERs produced from nuclear power or associated with CO_2 sequestration cannot be used either

Despite these limits, the EU ETS has the potential to affect both supply and demand. By establishing a price in the market, based on internal costs of emission reductions, it has encouraged the development of projects in developing countries and thus the supply of CERs. It is also a significant source of demand in the market for CERs.

Published prices for EUAs include spot prices and futures prices. Futures contracts establish rights and obligations to buy or sell EUAs at a certain date in the future. Figure 4 shows prices of EUA Futures with delivery dates of December 2012 and December 2014; the latter is the furthest into the future for which CER Futures contracts are available.

Figure 4 Prices of EUA Futures



Source: European Climate Exchange

There is an expectation of higher prices in the post-2012 period, but currently the market is projecting only a small increase in price to 2014.[10] The most recent data suggest a December 2014 price of €18-19/tonne (NZ$30-31/tonne), approximately €2/tonne higher than December 2012 Futures.

The main way in which the EUA price is likely to affect prices on international markets affecting New Zealand will be via the impacts on the market price of units outside the EU ETS and particularly CERs.

2.2 Clean Development Mechanism

The Clean Development Mechanism (CDM) is the other source of international prices currently. CDM projects result in the creation of certified emission reductions (CERs)

[10] Sales volumes for 2014 futures have been small

which must be verified by a designated operational entity (DOE) appointed by the CDM Executive Board. There are two markets: those for primary and secondary CERs.

Prices in the primary market represent the payments made to project developers for the creation of a CER, but they carry a significant amount of risk at this stage, including: [11]

- Performance risk, eg whether the project will perform as expected;
- Registration risk, eg whether it will be approved by the DOE and the baseline that they use and against which emission reductions will be estimated;
- Country risk, eg uncertain government and legal regimes that affect the release to the market of CERs;
- Contractual risk, including delivery and default risk.

In contrast, secondary CERs have much greater certainty regarding delivery, either because it has been registered and certified, or because there is a contractual arrangement that guarantees delivery (or compensation) with a credible party. CERs are saleable into the EU ETS market, under some limits. Figure 5 shows prices for secondary CER futures with a delivery date of December 2012; this is the most distant futures contracts available as there is no certainty that CERs have a value beyond 2012.

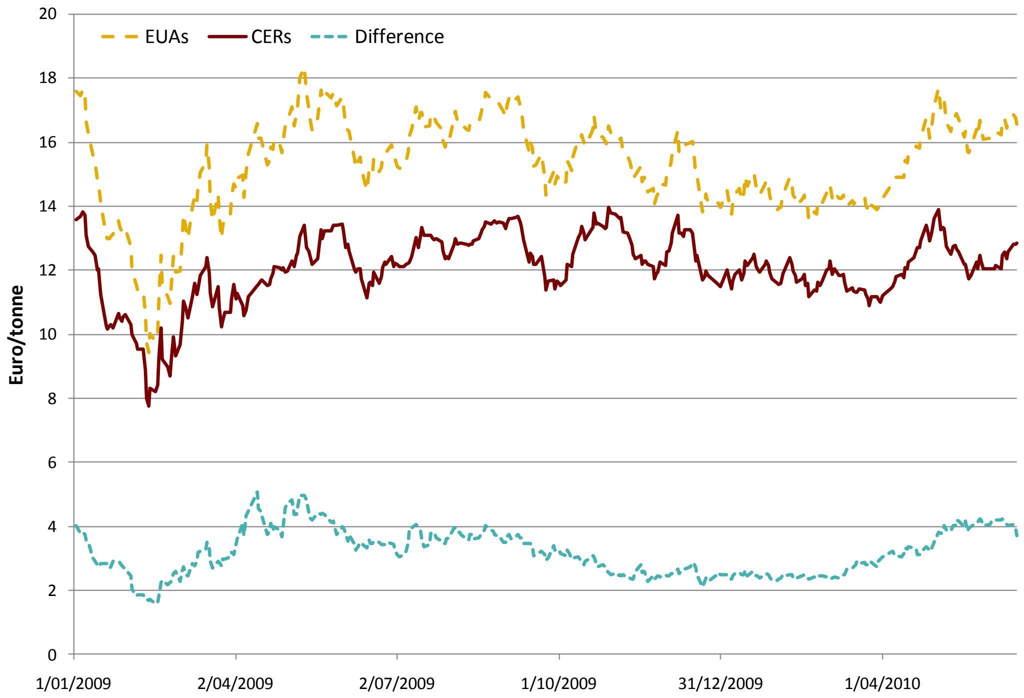
Figure 5 CER Futures (Settlement Dec 2012) Prices

Source: Data from European Carbon Exchange

Figure 6 charts EUA and CER futures for 2012 settlement. The prices follow a very similar path, suggesting that CER price is set by the EU ETS; the relationship is confirmed by regression analysis.[12]

[11] PointCarbon (2007) Issues in the international carbon market, 2008-2012 and beyond. A study by Point Carbon Advisory Services for New Zealand Emissions Trading Group.

Figure 6 Differences in Prices Between CERs and EUAs (Futures - Dec 2012 Settlement)



Source: Data from European Climate Exchange

In the early development of the CDM it was expected by many governments that it would be the source of low cost emission units, as it was anticipated that there would be projects with very low costs of abatement because of the perceived inefficiency of industry. However, the transparency of international market prices allows host governments or developers to obtain the surplus from projects, rather than the purchasers.[13] The surplus available is the difference between the cost of the project and the value of the CERs produced at the market price.

The average difference between EUA price and CER price over this period (from 1/1/2009) is €3.20/tonne; if CERs were to continue, and based on EUA Futures prices, CER prices to 2014 might be €15-16/tonne. However, one of the large uncertainties for the post-2012 period is the level of participation, particularly the entry of the US. Modelling studies have shown very significant differences in prices within and without the US,[14] with its entry leading to upward pressure on prices. Thus current prices may be a poor indicator of future prices if levels of market demand are considerably different from now.

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[12] Regression was undertaken of the daily changes in the individual prices.

[13] Denne,T (2000) Sharing the Benefits: Mechanisms to Ensure the Capture of CDM Project Surpluses. Center for Clean Air Policy CDM Dialogue Series; Muller A and Denne T (2006) How much longer for cheap reductions? Carbon Finance February 2006: 14-15.

[14] See, eg Nordhaus W (2008) A Question of Balance: Weighing the Options on Global Warming Policies

2.3 New Zealand Market

In New Zealand, the market is determined by the dynamics of demand and supply. Ultimately the government has responsibility for ensuring that it holds sufficient Kyoto units to cover its emissions but it has started to pass some of this liability on to industry through the emissions trading system (ETS).

2.3.1 First Commitment Period

The starting place is the overall government position as shown in Table 6. The numbers here are different from those estimated by the Ministry for the Environment at 11.4 million tonnes of CO_2-equivalent.[15] This is because the government numbers were reduced by 2.1 million tonnes reflecting AAUs that had been transferred to private accounts (for foresters wishing to sell internationally in anticipation of removal units earned), 5.1 million units that have been granted under the projects to reduce emissions (PRE) policy[16] and a small difference in stationary energy emissions due to differences in rounding. The numbers in Table 6 are a simple presentation of the net position from an NZ Inc perspective.

Table 6 NZ Net Position (million tonnes of CO_2 equivalent)

	2008	2009	2010	2011	2012	Total
Stationary energy	20.7	18.2	19.4	19.2	19.1	96.5
Liquid fuels and transport	13.6	13.3	13.5	13.6	13.8	67.8
Industrial processes	3.9	4.0	4.2	4.2	4.3	20.6
Agriculture	34.5	34.4	35.7	36.2	36.9	177.7
Waste	1.7	1.6	1.6	1.6	1.6	8.1
Forestry (LULUCF) Emissions	2.4	2.4	1.5	1.5	1.5	9.3
Forestry (LULUCF) Removals	-17.5	-17.6	-17.8	-18.0	-18.3	-89.2
Total (net emissions)	59.2	56.4	58.0	58.3	58.9	290.8
Assigned Amount						309.5
Net Position						18.7

Source: MED (2010) Projected Balance of Emissions for the Energy, Transport and Industrial Processes Sectors for the Kyoto Commitment Period, 2008-2012; MAF (2010) Projections on Land Use, Land-Use Change and Forestry sector (LULUCF) activities under Article 3.3 of the Kyoto Protocol in the first commitment period (2008-2012): Afforestation/Reforestation and Deforestation; MAF (2010) Agricultural sector projected emissions; MfE Projected greenhouse gas emissions from waste

The dynamics of supply and demand within New Zealand have been altered by the creation of the emissions trading system (ETS) that has created a new commodity, a New Zealand Unit (NZU). The basis commitment under the ETS is for participants to surrender one NZU for each whole tonne of emissions of CO_2-equivalents. NZUs can be traded domestically. The market dynamics are determined by supply (who has them, ie the initial allocation) and demand (who needs them for compliance purposes). Forestry, stationary energy and industrial processes, and liquid fossil fuels are included in the ETS in the first commitment period (CP1) (Table 7). Emitters in these industries will be required to surrender NZUs and this determines demand.

[15] http://www.mfe.govt.nz/issues/climate/greenhouse-gas-emissions/net-position/index.html

[16] This was a policy initiative that enabled project developers to earn emission units by implementing projects that were judged to have reduced emissions below business as usual. Tender rounds were held in 2003 and 2004 to identify suitable projects; 34 projects are included in the scheme. No further tender rounds are planned (www.mfe.govt.nz/issues/climate/policies-initiatives/projects/index.html)

Table 7 Sectoral entry to the NZ Emissions Trading System

Sector	Start date
Forestry	1-Jan-2008
Stationary Energy and Industrial Processes	1-Jul-2010
Liquid Fossil Fuels and Transport	1-Jul-2010
Agriculture	1-Jan-2015
Waste and all remaining sectors	1-Jan-2013

Demand for units is affected by the inclusion of a price cap and a limited liability as part of the ETS design for CP1. The two elements are:

- A requirement for participants to surrender one NZU for every two tonnes of emissions of CO_2-equivalents.
- An option for participants to pay the government $25 for each NZU that it is otherwise liable to surrender.

Taken together this effectively sets a price of carbon in New Zealand in CP1 of no more than $12.50/tonne.

Supplies come from the initial government's assigned amount and are supplemented by removal units earned under the Kyoto Protocol; these are allocated to forest land owners that choose to opt into the ETS. The government will also allocate some NZUs to industry that is trade-exposed and competitively at risk because they cannot pass the price of carbon on fully to customers. The overall pattern is set out in Table 8.

Table 8 Expected Supply and Demand in CP1

	Government Position	Market Supply	Market Demand
NZ Supply of Kyoto Units			
NZ Assigned Amount	309.5		
Removal Units Earned	89.2		
Total NZ Government Supply	398.7		
Surrender Liabilities			
Stationary Energy & Industrial Processes (SEIP)	-87.8		-29.3
Liquid Fuels & Transport	-50.7		-17.1
Agriculture	-177.7		
Waste	-8.1		
Pre-1990 forests	-8.7		-0.6
Allocation to Industry			
Allocation for pre-1990 forests	-16.9	16.9	
Allocation for post-1989 removals	-59.2	59.2	
Allocation to SEIP industry	-11.7	11.7	
Allocation to fishing	-0.7	0.7	
Total	-22.8	88.5	-47.0

Source: Table 6 and MfE estimates undertaken for the 2010 Budget.

The first column shows the government's position. In aggregate it is made up of:

- A credit equal to its expected total supply of Kyoto Units from the UN. This comprises the initial NZ Assigned Amount of 309.5 million tonnes and 89.2 million tonnes that the NZ government is expected to earn from removal units resulting from absorption of CO_2 by the forest sector;

- A debit from its liabilities to surrender emission units for emissions from some sectors and for some proportion of the first commitment period, where it has not (fully) passed on these liabilities to emitters.[17] The government will retain liabilities for surrender of emission units for:
  - Energy (both stationary and liquid fuels/transport) and industrial processes for the period 2008 to 30 June 2010 and then for half of the emissions from 1 July 2010 (as industry only faces a liability for 1 tonne in every 2 tonnes emitted);
  - All agriculture and waste emissions in CP1;
  - Some pre-1990 forest emissions.

- An additional debit from the units that it will allocate to industry.

Thus in total, the government is expected to have a deficit of close to 23 million tonnes. The next two columns show expected market supply and demand for NZUs in the ETS.

Supply is made up of the allocations expected to be made to industry. This includes allocations totalling 88.5 million tonnes of emission units to:

- the forest industry to compensate for the additional costs of liabilities associated with land use change;
- owners of post1989 forests that are absorbing emissions, earning RMUs for New Zealand and choose to opt in to the ETS;
- trade-exposed competitive at risk stationary industries; and
- the fishing industry.

Demand for NZUs comes from the surrender liabilities of industry, including stationary energy, industrial processes and liquid fossil fuels/transport that will be required to surrender one NZU for every two tonnes from 1st July 2010. In addition, land use change in the forestry industry will result in additional requirements to surrender emission units. Total demand is estimated to equal 47 million tonnes, which is less than the total quantity expected to be supplied.

The New Zealand ETS market will be in net surplus (by 41.5 million tonnes according to this analysis), although many of the forest land owners allocated NZUs are expected to retain these to cover their future liabilities to surrender units. Excess units in CP1 can be banked for use in future commitment periods. This surplus in the ETS less the government deficit of 22.8 million tonnes, is equal to the New Zealand net position estimated in Table 6 as 18.7 million tonnes.

2.3.2 Post 2012

The position after 2012 has not been clarified at this stage because of the absence of commitments for this period. However, the supply-demand balance will change as a

[17] Strictly speaking the government retains the full liability for all emissions for the full period as the liabilities under the NZ ETS are simply those of a domestic policy instrument, whereas the government retains the international liabilities. However, the effect of the ETS is to pass the liabilities on.

result of the full entry of all sectors, assuming no legislative change. A possible picture is provided in Table 9, with the following assumptions:

- demand in all sectors is based on expected emissions in 2012;
- allocation for pre-1990 forests is based on the assumption that 62% of the available allocation to pre-1990 forests will be made in CP2 and that this will be a five year period.

Table 9 Expected Annual Supply and Demand in CP2

	Market Supply	Market Demand
Stationary Energy & Industrial Processes (SEIP)		-23.4
Liquid Fuels & Transport		-13.8
Agriculture		-36.9
Waste		-1.6
Pre-1990 forests		-1.9
Allocation for pre-1990 forests	5.5	
Allocation for post-1989 removals	11.8	
Allocation to SEIP industry	4.7	
Allocation to fishing	0.3	
Total	22.3	-77.6

The excess supply in CP1 converts into a net shortage in CP2 of an estimated 55.3 million tonnes. Even if the market excess in CP1 (41.5 million tonnes) is banked and used in the New Zealand market in CP2 (rather than sold abroad), there will still be a net deficit.

2.3.3 Price Setting in New Zealand Market

Although the New Zealand market is in surplus in CP1, emission units can be banked and sold in future periods. The current expectation is for the New Zealand market to be in deficit after 2012.

The market dynamics in New Zealand are determined by the options available to buyers and sellers.

Buyers in the market must surrender emission units by May of the year following their emissions. At that stage their options are to:

- purchase NZUs on the market;
- purchase Kyoto Units; or
- pay the NZ$25/tonne price to the government.

It is assumed that the lowest cost option will be chosen. As noted in Section 1.3.1, with some restrictions, the New Zealand market allows unlimited international purchases of CERs, ERUs and RMUs; currently, the major volume sales internationally are of CERs and these would be expected to have the major influence on NZ price, if they are less than $25/tonne. The current spot price for CERs is approximately €12.50/t or NZ$23/tonne at an exchange rate of 0.55. It might be expected to be similar to that in

May 2011. Discounting this to the current time (July 2010) would suggest a current willingness to pay of approximately $21/tonne.

Suppliers of NZUs (forest land owners and those that have been allocated NZUs) have limited opportunities for international sales; there have been some sales of AAUs but this is largely to governments.[18] In addition, there is some risk that there will not be an international agreement after 2012, at which stage the value of NZUs might fall to zero if the ETS is placed on hold following the scheduled review (before the end of 2011). Thus the value of holding on to NZUs for future sale is likely to be less than the current market price.

These dynamics have meant that current prices of NZUs are approximately $18/tonne and have ranged from less than $16/tonne to more than $20/tonne over the last year.[19]

Given the future projections of the New Zealand market being short, and the current intention to remove the price cap after 2012, international carbon prices would be expected to continue to set prices domestically. The only circumstances under which prices would be set domestically would be those in which marginal demand was met by domestic supplies, eg if there were restrictions on international trade, either purchases or sales. For example:

- If international purchases were limited by the government, eg to force more domestic emission reductions,[20] or if there was no international market, marginal supplies might need to come from New Zealand. Assuming competitive supplies within New Zealand (ie many potential suppliers), prices would be based on the higher of
    a) the marginal cost of supply of units required to meet demand, eg the cost of reducing emissions by an obligated firm; and
    b) if there is excess supply, the value of the units in some alternative market, eg sales to other countries with or without emissions trading systems;

- If international sales were limited, eg the New Zealand government restricted sales to other countries, then prices would be set by the lower of:
    a) The costs of emission units from some other market, eg imports of Kyoto units; and
    b) The marginal cost of reducing emissions in New Zealand to balance supply and demand.

- If both imports and sales were restricted then NZ domestic supply and demand would set price.

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[18] Companies have the possibility of exchanging NZUs for AAUs for international transfers, if approved by the NZ government, although there are some limits to this. In CP1 this is limited to forestry companies, and in total this is limited by New Zealand's requirement to hold a Commitment Period Reserve in which its total holding of Kyoto Units in the registry must be no less than 90% of the initial Assigned Amount

[19] OMFinancial Ltd

[20] Some countries have introduced restrictions on imports, as discussed under Section 2.1and Table 5

New Zealand is assumed to have relatively high costs of emission reduction, providing a significant incentive to link the ETS with international markets. High prices in New Zealand are assumed because it has fewer opportunities for fuel switching to low carbon fuels in electricity generation and industrial production than many other countries, largely because of its relatively high baseline consumption of renewable fuels. Emission reductions in the agricultural sector are also assumed to be generally high because of the perceived absence of opportunities beyond herd-size reduction. However, we note that some analysts are suggesting that significant low cost opportunities may exist in this sector.[21] Regardless, economic theory would suggest that New Zealand should open its ETS to the international price because this enables those undertaking emission reductions to obtain a surplus from the sale of emission units.

In 2020 and 2030 we would expect that New Zealand would be in deficit and that it would allow trade with the international market such that it is international prices that will determine prices in New Zealand.

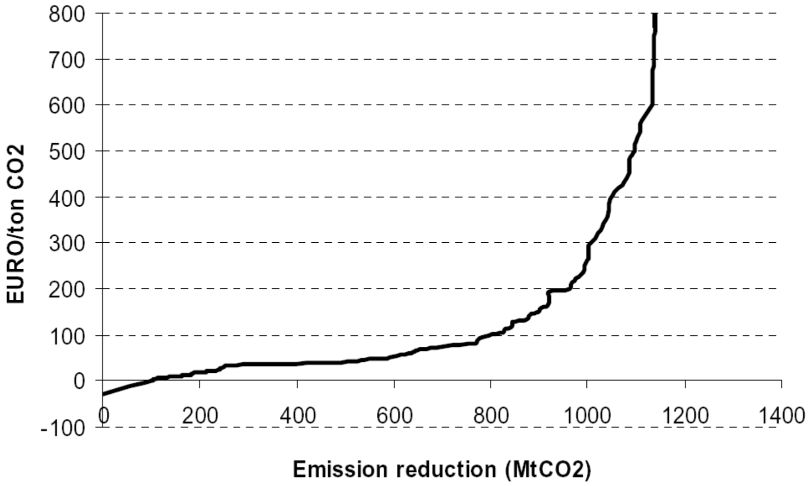
[21] Bertram G and Terry S (2009) The Carbon Challenge. New Zealand's Emission Trading Scheme. Bridget Williams Books.

3 Bottom-Up (Technology) Models

3.1 Modelling Approach

In this section we examine estimates of the costs of carbon on the basis of models that have assessed the costs of reducing emissions. The assumption under this approach is that, in a competitive market with transparent prices, the market price of emission units will be equal the highest per unit cost of reducing emissions. Obtaining carbon prices from this approach requires an estimate of the volume of emission reduction required and the unit costs of the emission reductions that are sufficient to achieve the required level of reductions. An example is shown in Figure 7. Reading this chart it could be estimated that, if emission reductions equal to 800 Mt CO_2 were targeted, the marginal (ie last) emission reduction option used to achieve this objective would cost €100/tonne and this would be the expected market price of carbon.

Figure 7 Marginal costs of Emissions Reduction in Europe (2020)



Source: Klaasen G, Berglund C, Wagner F (2005) The GAINS Model for Greenhouse Gases - Version 1.0: Carbon Dioxide (CO2). IIASA

The costs examined in these models are the costs of reducing a single tonne of CO_2, ie it is an absolute cost per tonne, not a cost per tonne per year. Typically costs are estimated from the net present value of a project to reduce emissions.[22]

[22] To evaluate the costs of measures on a $/tonne basis, account needs to be taken of costs and savings over the duration of the project and its effects. The approach used is to measure the Equivalent Annual Cost or levelised cost of individual interventions where the levelised cost (LC) is defined by the formula:

$$LC = \frac{PV(NetCosts)}{PV(Emissions\ Reductions)} = \frac{\sum C_t/(1+r)^t}{\sum ER_t/(1+r)^t}$$

It is the discounted stream of costs of the project, including capital and operating costs, divided by the discounted stream of emission reductions in tonnes. Although discounting physical volumes may appear unusual, it is equivalent to estimating the $/tonne in each year, weighted by the amount reduced in each year and discounted to the present day.

A number of studies have examined the expected level of emission reductions below business as usual to meet certain climate policy objectives, and the costs of emission reductions at a reasonably detailed level. Bottom up models are described in more detail in Appendix 1.

Bottom-up models are characterised by the level of detail that they include relating to specific fuels and technologies. Typically these models will start with projections of economic activity, eg GDP, which will be used to estimate levels of industrial activity at a sectoral level, including demand for electricity and other energy forms and outputs of key industrial sectors, eg steel, aluminium cement etc. the models will then include data on:

- power plant and industrial boiler capacities, fuels used, and energy efficiency rates;
- options for efficiency improvements and emission reductions at the sectoral level, eg energy efficiency potentials, fuel switching options and so on;
- price data.

The different emission reduction options will then be applied to build up an overall cost curve for emission reductions

3.2 IIASA Meta Analysis

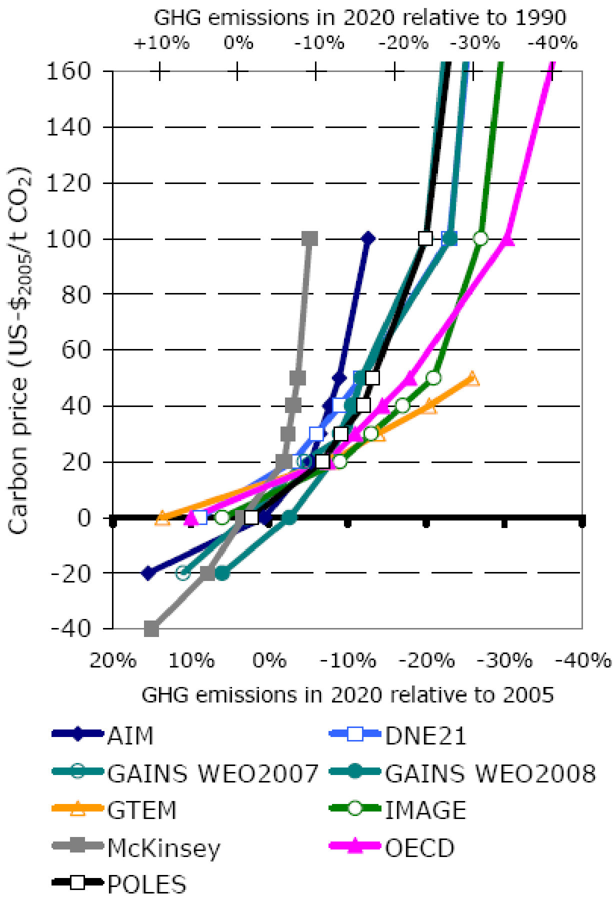
IIASA recently compiled the results of a series of models from different countries to estimate cost curves for emission reductions in different places. The models used are listed in Table 10. The models develop cost curves for individual regions, but the results are aggregated into Annex 1 abatement cost curves as shown in Figure 8; these cost curves are shown for reductions in percentages of 1990 and 2005 emissions.

Table 10 Participating Models

Model	Organisation	Model type
AIM	NIES, Japan	Bottom-up
DNE21+	RITE, Japan	Bottom-up
GAINS	IIASA, Austria	Bottom-up
GTEM	Treasury, Australia	Computable General Equilibrium model
IMAGE	PBL, Netherlands	Bottom-up Integrated Assessment Model
McKinsey	McKinsey	Bottom-up cost curves
OECD	ENVLINKAGES	Computable General Equilibrium model
POLES	IPTS	Linked bottom-up/top-down

Source: Amann M, Rafjal P and Höhne N (2009) GHG Mitigation potential in Annex I countries. Comparison of model estimates for 2020. Interim Report. IIASA. IR-09-034

Figure 8 Marginal cost curves for GHG mitigation in 2020 for Annex I



Source: Amann M, Rafjal P and Höhne N (2009) GHG Mitigation potential in Annex I countries. Comparison of model estimates for 2020. Interim Report. IIASA. IR-09-034, p6

The model results all show a familiar shape, with marginal costs rising rapidly with increases in emission reductions. IIASA noted the following factors as affecting the differences between the models:

- how well models have been calibrated to reproduce base year emission inventories;
- assumptions on the baseline economic development and the implied evolution of energy use, industrial production and agricultural activities up to 2020;
- the time window for implementation of mitigation measures considered by models;
- definitions of which autonomous efficiency improvements are included in the counterfactual baseline against which mitigation costs are evaluated;
- treatment of the costing perspectives of private actors (eg, about expected pay-back period for investments) and of transaction costs;
- different portfolios of mitigation measures that are considered by models,
- assumptions about cost of mitigation measures, especially on the impact of technological progress on future costs; and
- inclusion of macro-economic feedbacks from higher carbon prices on consumer demand and the structure of industrial production, including potential carbon leakage effects.

Using the estimated percentage emission reductions relative to 1990 in Table 4 on page 6, suggests the carbon prices in 2020 as shown in Table 11; the prices range very broadly.

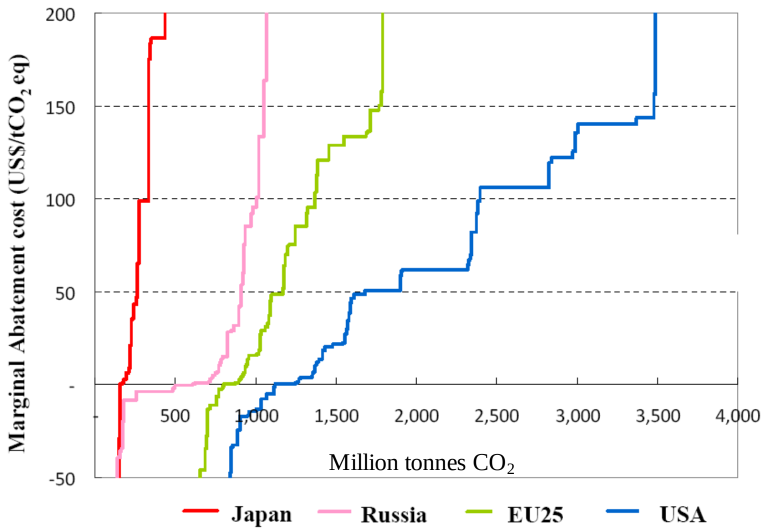
Table 11 Implied Carbon Prices in 2020

Target (ppm)	Price range (US$/t)
450	20 - >160
550	0 – 50
650	0 – 50

3.3 Japan NIES

Hanaoka of the National Institute of Environmental Studies (NIES) in Japan presents data on the wide range of carbon costs in the shape of abatement cost curves between countries (Figure 9). This analysis built up cost curves for different countries using costs for approximately 300 different abatement technologies. The results suggest that the costs will depend critically on how many countries are involved in any international trading system.

Figure 9 Marginal Abatement Cost Curves in 2020



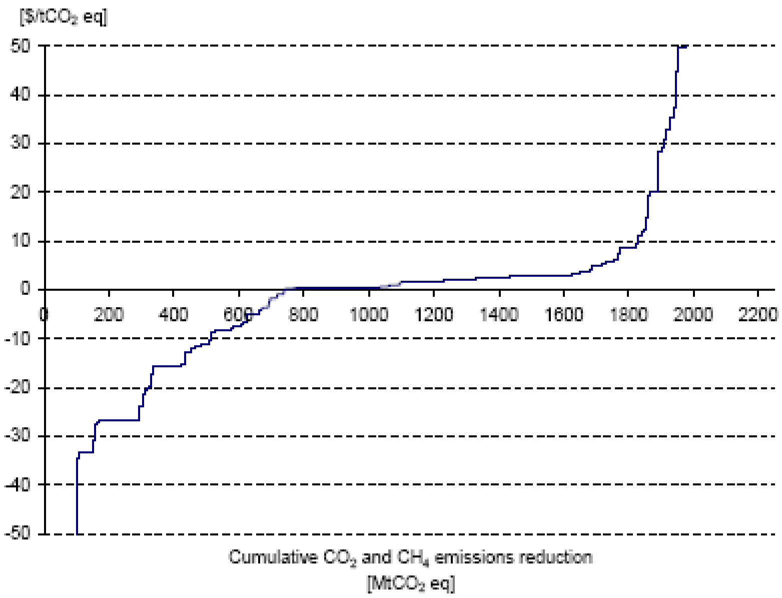
Source: Hanaoka T (2009) Greenhouse Gas Emissions Technical Mitigation Potentials and Costs in 2020. Presentation to Workshop on issues relating to scale of emission reductions to be achieved by Annex I Parties. Bonn Germany, March 27th 2009

3.4 Costs Outside Annex I

The above model results show the costs of emission reduction outside of Annex I. However, many of the low cost emission reductions currently are in developing countries, and mobilised by the CDM.

The Energy Research Centre of the Netherlands developed estimates of the costs of emission reductions in the non-Annex I region. Their cost curve for 2010 is shown in

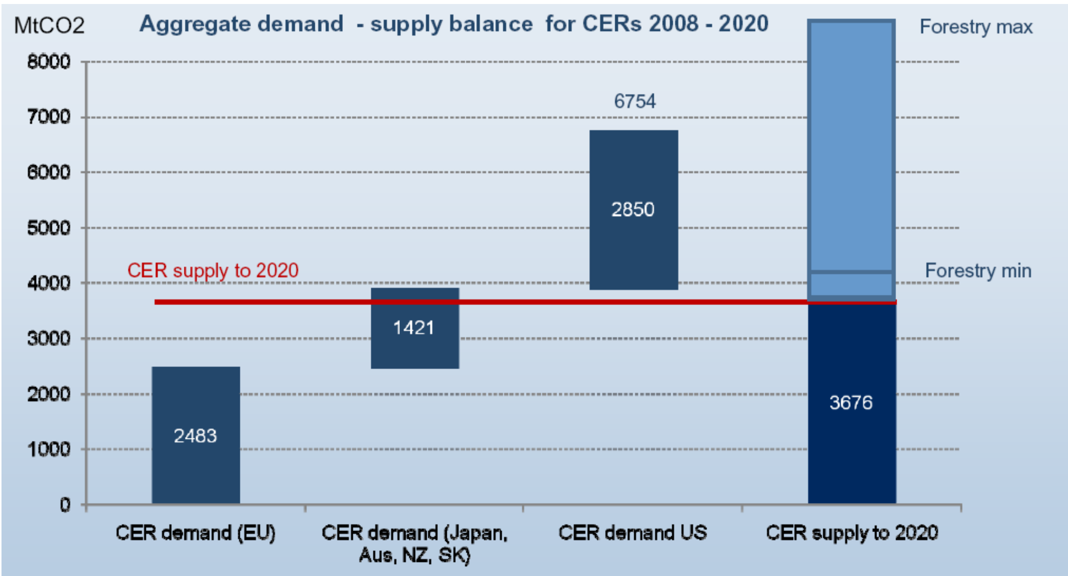
Figure 10 Marginal Abatement Costs for non-Annex I region (2010)



Source: Wetzelaer BJHW, van der Linden NH, Groenenberg H and de Coninck HC (2007) GHG Marginal Abatement Cost curves for the Non-Annex I region. ECN-E-06-060

Bloomberg Finance has analysed the potential supply and demand of CERs and assessed prices with and without forestry CERs (Figure 11); these estimates are based on extrapolation of current trends in CER yields and registration risks. According to these estimates, the inclusion of forestry CERs would enable market demand to be met without requiring higher cost emissions abatement in the US and other Annex I countries themselves.

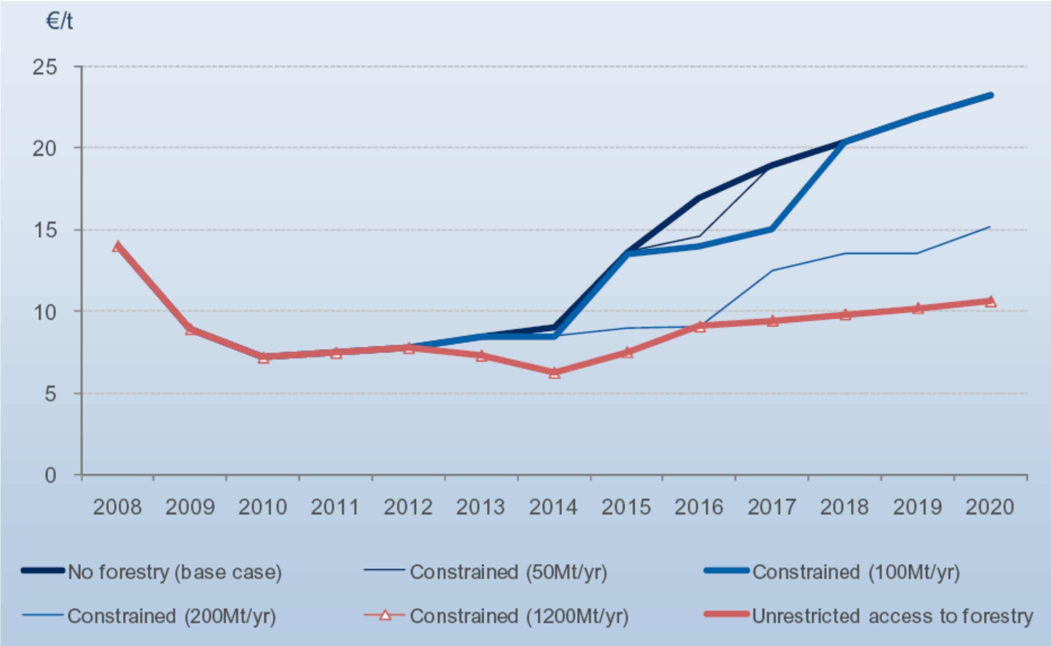
Figure 11 Bloomberg Demand and Supply for CERs



Source: Turner G (2010) Current Carbon Market Fundamentals and Future Prospects. Bloomberg New Energy Finance.

Bloomberg estimates prices using cost curves of specific technologies. Their estimates are made with and without access to forestry projects (Figure 12).

Figure 12 Estimated CER prices with and without access to forestry projects



4 Top-Down Macro-Economic Modelling

4.1 Modelling Approach

Top-down models take a different approach from bottom-up models to estimate costs of emission reductions and the price of carbon. Top-down models are economic models. Typically they estimate the consumption of energy fuels as a factor of activity in the economy (either at sectoral or aggregate level) and the price of fuels. They estimate the cost of carbon required to achieve targeted levels of emission reductions by using a price of carbon to increase fuel costs. The models estimate the required price of carbon to reduce energy consumption or to encourage fuel switching such that emissions are reduced to targeted levels.

In the Appendix we further describe and contrast the top-down and bottom-up approaches to modelling and forecasting carbon prices.

In this section we describe the results of a number of studies that have used these models to estimate prices.

4.2 IPCC

Every five or six years, the Intergovernmental Panel on Climate Change (IPCC) produces comprehensive reports on climate change that assesses the existing scientific, technical and socioeconomic literature. The third volume of the Fourth Assessment Report (FAR) focuses on issues to do with emission reduction, ie mitigation; it provides an analysis of the costs and benefits of different approaches.[23]

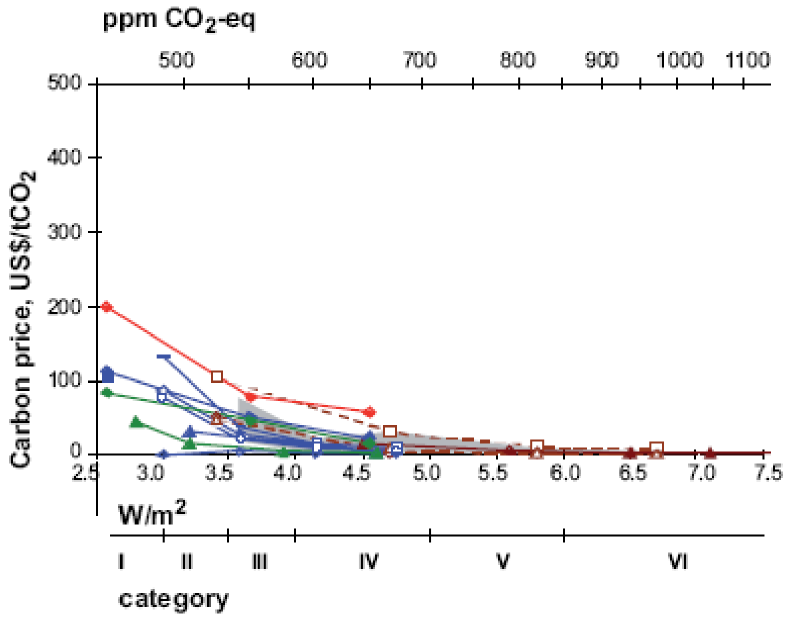
Chapter 3 of the Mitigation report assesses long term issues including the impacts of long-term targets on estimated costs of mitigation and on carbon prices; a number of modelled results are summarised (see Figure 13). At low concentrations there is a very wide range of estimates of the carbon price.

The variation in price estimates is significant, particularly at low concentration outcomes. The IPCC report suggests that the differences between the models reflect differences in assumptions that include:

- baseline emissions and concentrations;
- levels of induced technological change; and
- backstop technologies.

[23] IPCC (2007) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Figure 13 Relationship between Carbon Price (in 2030) and long-term stabilisation targets



Source: Fisher BS, Nakicenovic N et al (2007) Issues related to mitigation in the long-term context. In IPCC (2007) Climate Change 2007: Mitigation,p205

The range of prices for the different concentrations is given in Table 12.

Table 12 Impacts of Stabilisation Concentration on Carbon Price

Category	W/m^2	ppm CO_2 (CO_2-eq)	US$/t CO_2 [1]
I	2.5 – 3.0	350–400 (445–490)	40 – 200
II	3.0 – 3.5	400–440 (490–535)	20 – 150
III	3.5 – 4.0	440–485 (535–590)	18 – 79
IV	4.0 – 5.0	485–570 (590–710)	1 – 24

[1] Prices for Category III and IV are given in the IPCC text; the range of prices for categories I and II here have been estimated from the chart

Chapter 11 of this report includes the results of assessments of the costs of carbon.

Working Group III of the IPCC reports the results of models used to estimate carbon prices under a number of scenarios, particularly those relating to atmospheric concentrations (450 and 550ppm).[24] Mostly this is based on studies (EMF 19 and EMF 21) by the Energy Modeling Forum (see below). The results that they present also include the price impacts of assumptions relating to technological change, although the impacts of these assumptions are much greater in the longer run, ie out to 2100.

4.3 Energy Modeling Forum (EMF)

The Energy Modeling Forum (EMF) was established at Stanford University in 1976 as a forum for expert discussion of important issues in energy and environment that were

[24] Barker T and Bashmakov I et al (2007) Mitigation from a cross-sectoral perspective. Chapter 11 in Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Metz B, Davidson OR, Bosch PR, Dave R and Meyer LA eds] Cambridge University Press.

amenable to modelling. On a number of occasions the group has coordinated international modelling teams to assess the effects on carbon prices of different climate policy scenarios. EMF 22 was a study of the effects of three factors that they described as integral to international climate negotiations:[25]

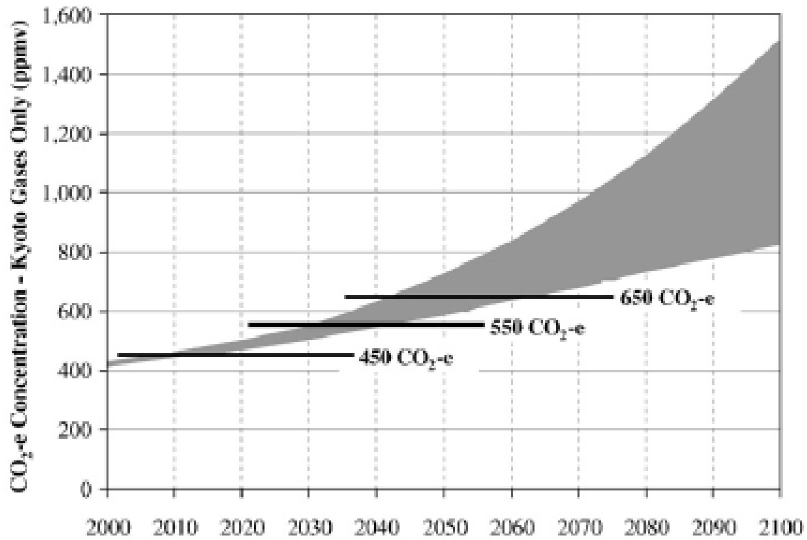
1. The long-term concentration target. Three long-term concentration targets for the Kyoto GHGs are explored:
   a. 450 ppmv CO_2-e [2.6W/m2],
   b. 550 ppmv CO_2-e [3.7W/m2], and
   c. 650 ppmv CO_2-e [4.5W/m2];

2. The option to overshoot the long-term concentration target this century. Two options are explored:
   a. a **not-to-exceed** formulation in which the long-term target cannot be exceeded at any point and
   b. an **overshoot** formulation in which the long-term target must be met by 2100, but in which concentrations can temporarily exceed the target prior to 2100.

3. The time-path of international participation in mitigation. Two assumptions regarding international participation in emissions reduction are explored:
   a. **full initial participation** and
   b. **delayed participation** - an architecture in which many-regions do not engage in climate mitigation until 2030 or beyond.

The scenarios are shown in Figure 14 as ruled lines at the target concentrations, relative to the estimated business as usual projections of the growth in concentration over time (the shaded area).

Figure 14 CO_2-e concentrations of the Kyoto gases and the EMF22 Scenarios



Source: Clarke L, Edmonds J, Krey V, Richels R, Rose S and Tavoni M (2009) International climate policy architectures: Overview of the EMF 22. Energy Economics 31:S64-S81

[25] Clarke L, Edmonds J, Krey V, Richels R, Rose S and Tavoni M (2009) International climate policy architectures: Overview of the EMF 22. Energy Economics 31:S64-S81

Ten scenarios were explored in total as set out in Table 13. If we compare these to the PCE scenarios, two points to note are that the PCE scenarios assume that the concentration limits are not exceeded and the limited ambition target has no concentration limit. Nevertheless:

- lower ambition is closest to scenario 10;
- medium ambition is closest to scenarios 5 or 6; and
- higher ambition is closest to Scenario 1.

Table 13 Scenarios examined in EMF 22

	Pathway	Full participation	Delayed participation
450ppm	Not to exceed	1	2
	Overshoot	3	4
550ppm	Not to exceed	5	6
	Overshoot	7	8
650ppm	Not to exceed	9	10
	Overshoot	X	x

Source: Taken from Clarke et al (2009)

Ten separate models were used in the analysis and undertaken by research groups in the US, Canada, Australia and the EU. No model was able to examine all ten scenarios and scenario 2 could not be modelled (or achieved) by any group. Scenario 1 was only achieved by 2 models.

The results are shown in Table 14, including a calculated average. Those relevant to the scenarios being examined here are in the shaded columns. In all instances we have assumed that the target is not to exceed the targeted concentrations. For the lower and medium ambition scenarios we assume delayed entry of most countries, but for higher ambition we assume early entry of all countries.

Table 14 Carbon Prices in 2020 from EMF22 (2005US$/t CO_2)

	650 CO_2-e		550 CO_2-e				450 CO_2-e			
	Full	Delay	Full		Delay		Full		Delay	
	Not to exceed	Not to exceed	Over-shoot	Not to exceed	Over-shoot	Not to exceed	Over-shoot	Not to exceed	Over-shoot	Not to exceed
ETSAP - TIAM	$3	$5	$8	$10	$13	$24	$77	$214	$1,297	X
FUND	$20	$43	$51	$52	$147	$239	$260	X	X	X
GTEM	$14	$16	$27	$27	$28	X	$48	X	X	X
IMAGE	$1	$1	$11	$16	$12	$92	X	X	X	X
IMAGE-BECS	N/A	N/A	N/A	N/A	N/A	N/A	$62	X	X	X
MERGE Optimistic	$13	$27	$43	$52	X	X	X	X	X	X
MERGE Pessimistic	$9	$13	$29	$35	$154	$256	X	X	X	X
MESSAGE	$6	$35	$7	$26	$35	X	$15	X	X	X
MESSAGE - NoBECS	$6	N/A	$12	$27	N/A	N/A	$70	X	X	X
MiniCAM-Base	$4	$7	$8	$14	$10	X	$20	$101	$53	X
MiniCAM - LoTech	$12	$19	$34	$34	$169	X	$263	X	X	X
POLES	$7	$9	$27	$41	$51	X	X	X	X	X
SGM	$10	$11	$40	$40	$67	$67	X	X	X	X
WITCH	$3	$6	$4	$22	$36	$131	X	X	X	X
Average	$8	$16	$23	$30	$66	$135	$102	$158	$675	

N/A means not attempted

Source: Clarke et al (2009) (Average = Covec calculation)

With delayed participation, the models suggests that it is not possible to avoid exceeding 450ppm; it requires early and full participation of all countries in reducing emissions.

4.4 DICE Model

The Dynamic Integrated model of Climate and the Economy (DICE) model is run by William Nordhaus at Yale University.[26]

Nordhaus notes the differences in his baseline projections from the IPCC Fourth Assessment Report

Nordhaus notes that *the DICE baseline temperature projections are in the lower-middle end of the projections analyzed in the IPCC's Fourth Assessment Report. The IPCC Fourth Assessment Report gives a best estimate of the global mean temperature increase of between 1.8 and 4.0°C from 1980–1999 to 2090–2099. The DICE baseline yields a global mean temperature increase of 2.2°C over this same period.*

Recent analysis using this model has included the following input assumptions:

- levels of ambition specified as:
    - CO_2 concentrations set at 1.5x pre-industrial levels (420ppm), 2x (560ppm) and 2.5x (700ppm);
    - Temperature constraints with increases limited to 1.5°, 2°, 2.5° or 3°C;
- Participation defined as:
    - Original Kyoto Protocol
    - Kyoto Protocol without US participation
    - Strengthened participation

Under strengthened ambition, countries are added gradually over time, beginning with 10 percent emissions reductions and then add further 10 percent emissions reductions every quarter century. Under this case,

- the United States enters the Protocol in 2015 and undertakes 50 percent emissions reductions by 2030;
- China enters in 2020 and has 50 percent emissions reductions by 2045;
- India is a decade behind China.

Every region except sub- Saharan Africa is assumed to undertake significant emissions reductions by the middle of the twenty-first century.

The impacts of the different scenarios on atmospheric concentrations is shown in Figure 15.

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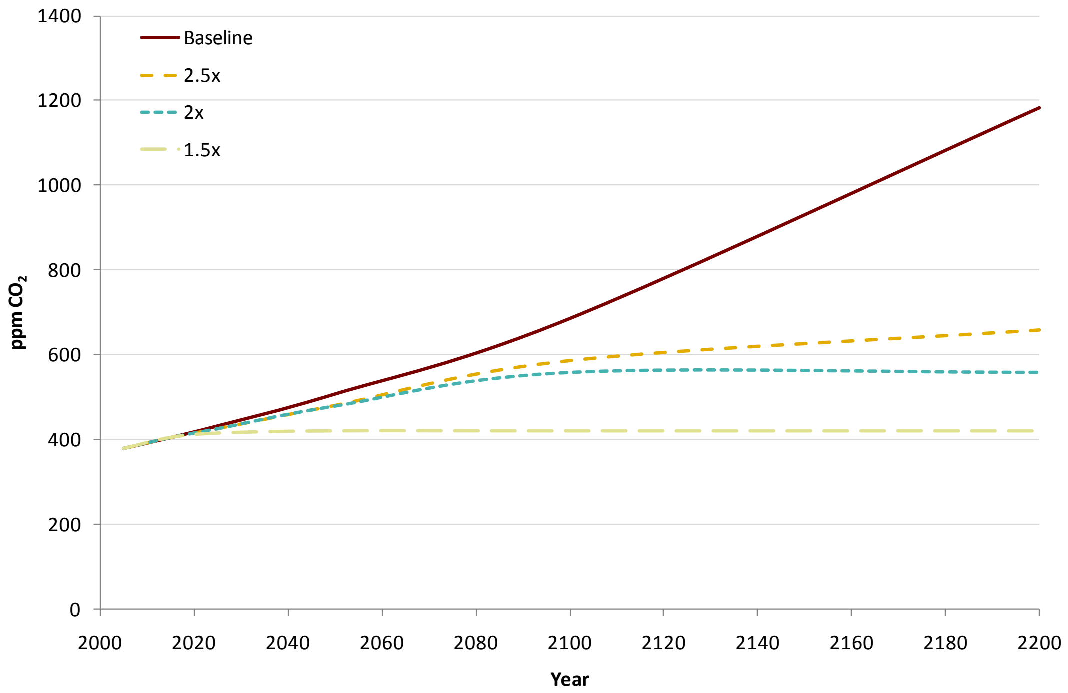
[26] Nordhaus W (2008) A Question of Balance: Weighing the Options on Global Warming Policies.

Figure 15 Concentrations under Different Nordhaus Scenarios



The carbon price results for the different policy scenarios are shown in Table 15.

Table 15 Carbon Price (US$/tonne) for Different Policy Scenarios

Scenario	2015	2025	2035
1.5x CO_2 (420ppm)	248	423	610
2x CO_2 (560ppm)	45	59	75
2.5x CO_2 (700ppm)	42	53	66

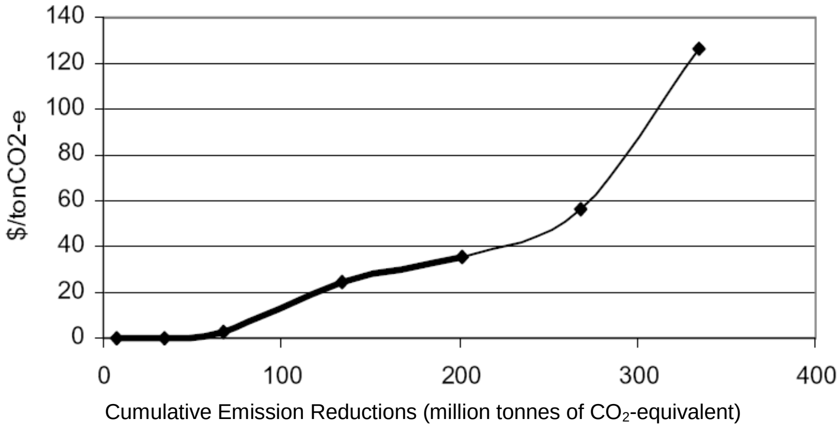
Source: Nordhaus W (2008) A Question of Balance: Weighing the Options on Global Warming Policies

4.5 EPPA Model

The EPPA Model has been used to develop regional marginal abatement cost (MAC) curves.[27] It includes estimates of MACs for Australia and New Zealand combined (Figure 16) and other regions, eg

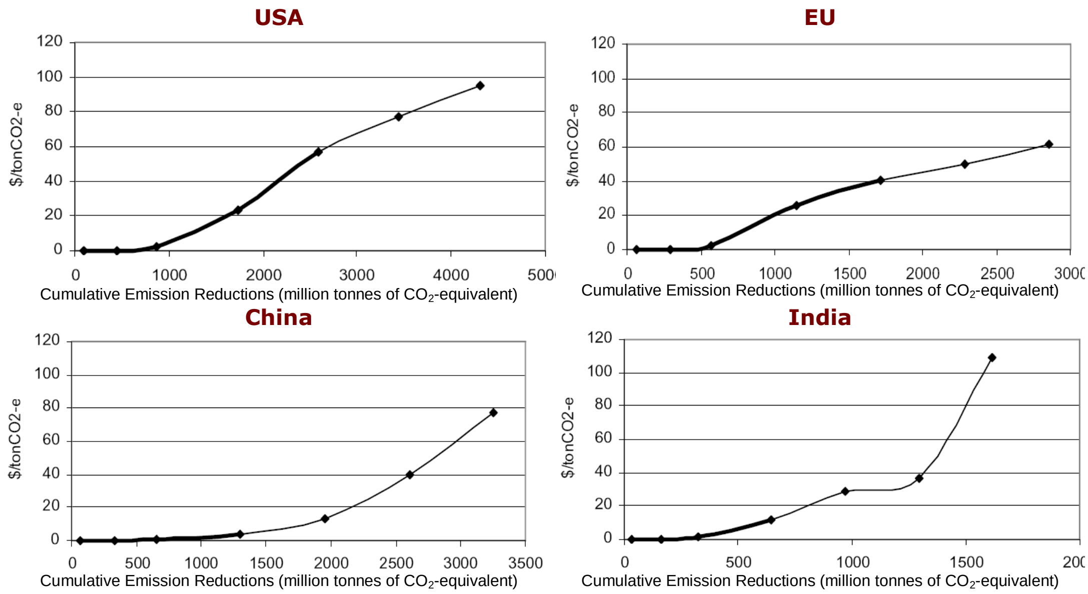
[27] Morris J, Paltsev S and Reilly J (2008) Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: Results from the EPPA Model. MIT Joint Program on the Science and Policy of Global Change.

Figure 16 Marginal Abatement Costs (2020) for Australia and New Zealand



Source: Morris et al (op cit)

Figure 17 Marginal Abatement Costs (2020) for a Selection of Other Countries



Source: Morris et al (op cit)

4.6 European Studies

Studies undertaken in the EU have identified the critical impact of assumptions about the continuing use of project-based mechanisms. Estimates of the expected marginal abatement costs using two models (POLES and GEM-E3) are shown in Table 16 for five different scenarios.

Table 16 Estimates of marginal abatement costs

Scenario Description		ERUs/CERs available	POLES €/tonne	GEM-E3 €/tonne
1a	Annex 1 Kyoto targets retained to 2025	✓	7.22	1.79
2a	EU reduces by 8% by 2025. No other countries participate.	✓	1.39	0.35
2b	As above		23.08	33.6
3a	EU reduces by 8% by 2025. No other countries participate.	✓	2	0.70
3b	As above		54.43	91.16

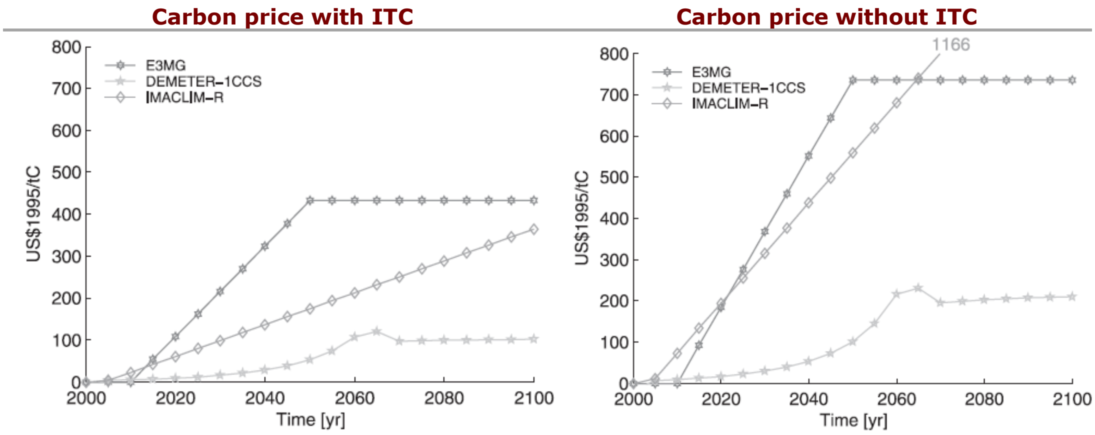
Source: Russ P, Ciscar JC and Szabo (2005) Analysis of Post-2012 Climate Policy Scenarios with Limited Participation. Institute for Prospective Technological Studies.

The assumption in this modelling is that significant volumes of low cost emission abatement opportunities are available in developing countries. However, the prices projected are very different from, and significantly smaller than, market prices of CERs currently and expected future prices. This may reflect expectations that low cost projects will result in low priced CERs, rather than developing country governments and project developers earning significant rents based on the expected value of CERs.

4.7 Modelling Endogenous Technological Change

A recent special edition of *The Energy Journal* examined the implications of building endogenous or induced technological change (ITC) into economic models of carbon stabilisation. The studies looked at the effects on stabilisation at 450ppm. The results of three models are summarised in Figure 18.

Figure 18 Impacts of Induced Technological Change on Carbon Price Required to Achieve Stabilisation at 450ppm



Source: Edenhofer O, Lessmann K, Kemfert C, Grubb M and Köhler J (2006) Induced Technological Change: Exploring its Implications for the Economics of Atmospheric Stabilization. Synthesis Report from the Innovation Modeling Comparison Project. *The Energy Journal* Special Issue Induced Technological Change and the Economics of Atmospheric Stabilization, p57-107

5 Backstop Technology Costs

Backstop technologies are considered by a number of analysts as the basis for projections of future prices. These are technologies that could displace a significant quantity of current emission sources, thus setting the marginal cost of emission reductions.

5.1 Carbon Capture and Storage

Carbon capture and storage (CCS) technologies capture CO_2 emissions from industrial sources, transport it and store it

Ecofys/TNO lists four main CO_2 capture processes:[28]

1. Pre-combustion processes. The fossil fuel is converted to a hydrogen-rich stream and a carbon-rich stream.
2. Post-combustion processes. Carbon dioxide is recovered from a flue gas.
3. Denitrogenation processes. A concentrated CO_2 stream can be produced by the exclusion of N_2 before or during the combustion/conversion process.
4. Pure streams of CO_2. Some industrial processes produce pure CO_2.

Studies that have examined this option have looked at the costs of capture from large point-sources, eg electricity generation and steel plants. Costs for transport and storage will vary significantly, depending on the distance to suitable storage sites, either underground, eg in abandoned mines, or underwater where the pressure of the water keeps the CO_2 in liquid form and in suspension.

A range of costs of capture is provided in Table 17.

The Harvard Kennedy School study estimated initial costs for the technology when first employed, at $100-150/t falling by approximately 65% by 2030 as the technology matured.

In addition to capture costs, Ecofys estimates compression costs of €6-10/t of CO_2. Transport costs vary by distance. Pöyry estimate costs for a number of specific sites in the UK varying from £0.3-15/t. Ecofys estimates the costs of transport by distance (Table 18).

Pöyry estimates storage costs at one aquifer as £1-2/t.

[28] Hendriks C, Graus W, van Bergen F (2004) Global Carbon Dioxide Storage Potential and Costs. By Ecofys in cooperation with TNO.

Table 17 Estimated costs for Carbon Capture

Study	Capture costs
Harvard Kennedy School of Government[29] 2008$ values	US$100-150/t (first of kind) US$30-50/t (nth of kind)
IPCC 2005[30] 2002$ values	US$13-37 (IGCC plant) US$29-51 (PC Plant) US$37-74/t (NGCC)
Carnegie Mellon[31]	US$4.5 – 44.4/t
Pöyry[32] 2006£ values	£22-28/t
Ecofys/TNO[33] 2004(?)	€26-43/t (electricity) €3-42/t (industrial)
Batelle[34]	US$25-60/t

Note: IGCC = Integrated gasification combined cycle (gasified coal); PC = pulverised coal; NGCC = natural gas combined cycle, or CCGT

Table 18 Estimated Transport Costs for CO_2

Distance (Source to Storage Reservoir)	Average distance (km)	Average costs (€/tonne)
Short	<50	1
Medium	50 – 200	3
Long	200 – 500	5
Very Long	500 – 2000	10
Extremely Long	>2000	30

Source: Hendriks C, Graus W, van Bergen F (2004) Global Carbon Dioxide Storage Potential and Costs. By Ecofys in cooperation with TNO

5.2 Other Technologies

A range of technologies are built into a number of modelling exercises and this is the reason for the horizontal price estimates in the curves in Figure 18 on page 31, for example. These suggest much higher costs for backstop technologies than assumed for CCS.

[29] Al-Juaied M and Whitmore A (2009) Realistic costs of Carbon Capture. Harvard Kennedy School Discussion Paper 2009-08.

[30] IPCC, 2005. In: Metz B, Davidson O, de Coninck HC, Loos M, Meyer LA (Eds.), IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, New York, NY

[31] Rubin ES, Chen C and Rao AB (2007) Cost and Performance of Fossil Fuel Power Plants with CO_2 Capture and Storage. *Energy Policy* 35: 4444-4454

[32] Pöyry (2007) Analysis of Carbon Capture and Storage Cost-Supply Curves for the UK. DTI

[33] Hendriks C, Graus W, van Bergen F (2004) Global Carbon Dioxide Storage Potential and Costs. By Ecofys in cooperation with TNO.

[34] Battelle Memorial Institute (2006) Carbon Dioxide Capture and Geologic Storage. A Core Element of a Global Energy Technology Strategy to Address Climate Change

6 Social Cost of Carbon

Estimates have been made of the full global cost of an incremental unit of CO_2 or its equivalent, if emitted now. This might provide some insights into the level of carbon price that might be acceptable to governments.

Most of the damage estimates come from Integrated Assessment Models (IAMs) that combine scenarios of climate change and its damage effects with an economic model of activity and output. These models have been used to estimate total and marginal damage costs of climate scenarios. There have been a number of reviews of the damage cost estimates resulting from IAMs, and a useful review of reviews for the UK government-sponsored international seminar on the social costs of carbon.[35] There are a number of key parameters that affect the results including[36] discount rates—greenhouse gases, particularly CO_2, are very long lived and many of the effects will have substantial time-lags. Thus discount rates matter. There is a substantial literature growing on the use of low and declining discount rates[37]; time varying discount rates could roughly double damage estimates. Declining discount rates have been adopted for policy purposes in the UK but not in New Zealand.

The Stern review[38] provides an additional summary of previous estimates of the social cost of carbon and cites others to note that the estimates in the literature span three orders of magnitude from 0 to over £1,000/tC (c.NZ$700/t CO_2). Similarly Covec had previously summarised some of the recent literature in this area.[39] The conclusions rested significantly on a working paper by Richard Tol[40] that summarised the literature. After weighting the various estimates, Tol concludes that "[…] for all practical purposes, climate change impacts may be very uncertain but it is unlikely that the marginal costs of carbon dioxide emissions exceed [US]$50/tC and are likely to be substantially smaller than that." Note that $50/t C is equivalent to US$13.6/t CO_2.

The Stern review also notes that the SCC is not a single value but depends on the concentrations in the atmosphere, and that at high concentrations, the damage associated with additional emissions is greater than at low concentrations. Stern suggests that, under business as usual, the damage cost will be approximately US$85/t

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35 Department for Environment, Food and Rural Affairs (2003) The Social Cost of Carbon Review. Background Paper.

36 Taken from: Pearce D (2003) International Seminar on the Social Cost of Carbon: Rapporteur's Summary

37 When there is uncertainty about future state of the economy/levels of relative consumption or of changes in time preference, it can be demonstrated that discount rates should decline over time. See: OXERA (2002) A social time preference rate for use in long-term discounting. The Office of the Deputy Prime Minister, Department for Transport, and the Department of Environment, Food and Rural Affairs.

38 Stern N (2006) The Economics of Climate Change. The Stern Review. Cabinet Office - HM Treasury

39 Covec (2006) Enabling Biofuels: Biofuel Economics. Final Report to the Ministry of Transport

40 Tol, RSJ (2003) The Marginal Costs of Carbon Dioxide Emissions: an Assessment of the Uncertainties. Working Paper FNU-19, Hamburg University, Germany. http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/margcostunc.pdf

CO_2 but that if concentrations are limited to 450-550 ppm, then the marginal damage costs of additional emissions are approximately US$25-30/t CO_2.

Recently, the UK government has adopted the results of the Stern review as the basis for defining a SCC of US$30/tonne (£19/t CO_2) that they subsequently uprate to £25/tonne.[41]

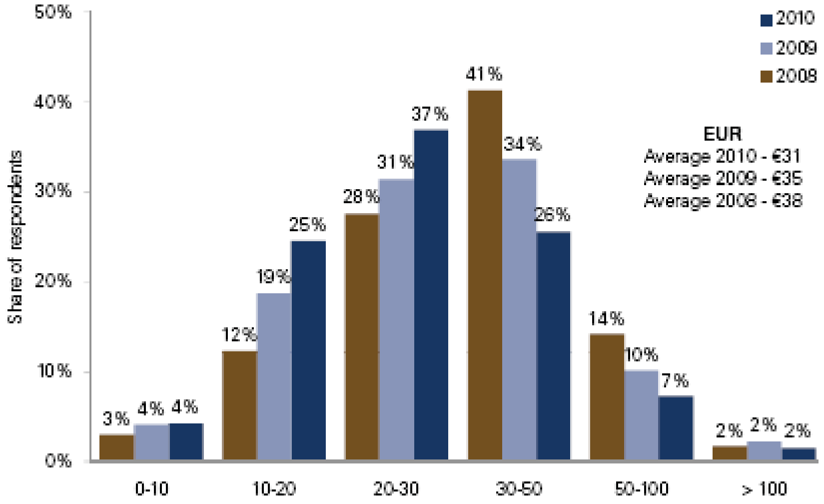
More recently still, Tol has updated his meta-analysis to include 211 studies of the SCC.[42] He notes that there has been a downward trend in the estimates and that the Stern review is a high cost outlier. He also notes that the uncertainty about the social cost of carbon is so large that the tails of the distribution may dominate the conclusions. Tol notes that the mean amongst these studies is equal to US$23/tonne of Carbon (US$6/tonne of CO_2).

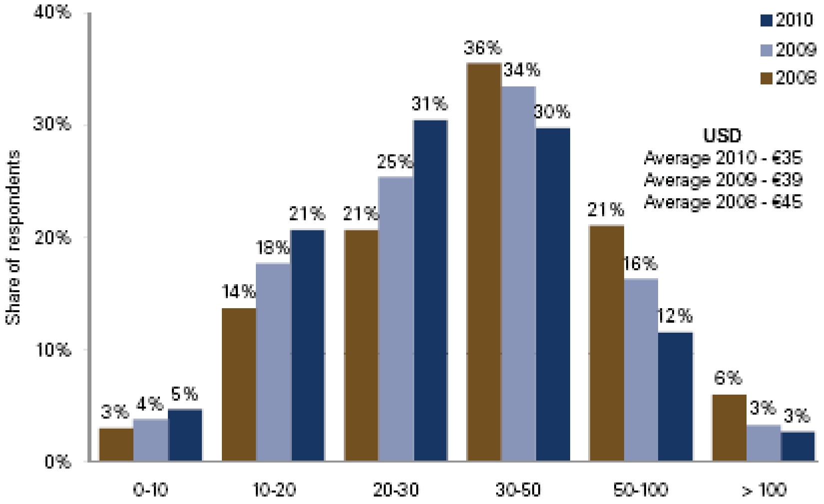
[41] Economics Group, Defra (2007) The Social Cost of Carbon and the Shadow Price of Carbon: What they are,and how to use them in economic appraisal in the UK.
[42] Tol RSJ (2008) The Social Cost of Carbon: Trends, Outliers and Catastrophes. Economics 2: 2008-25

7 Expert Opinions

A number of surveys have been undertaken of price expectations by traders and others. For example, Point Carbon undertakes a regular (annual) market survey. The 2010 survey ran from 20 January to 4 February 2010 and had 4,767 respondents in total including carbon traders, CDM project developers, companies with emissions regulated under the EU ETS, banks and other financial institutions, other companies and government staff. Expectations of carbon prices in 2020 are shown in Figure 19 in €/tonne (top figure) and US$/tonne (bottom figure).

Figure 19 Carbon Price Expectations, 2020 (€/tonne and US$/tonne) (N=2,612)[43]





Source: Point Carbon (2010). Carbon 2010 – Return of the sovereign. Tvinnereim E and Røine K (eds)

The most frequent response in 2010 was for a price of €20-30/tonne and US$30-50/tonne; average prices are €31/tonne and US$35/tonne. Point Carbon notes that both of these estimates are down on the previous year's estimates.

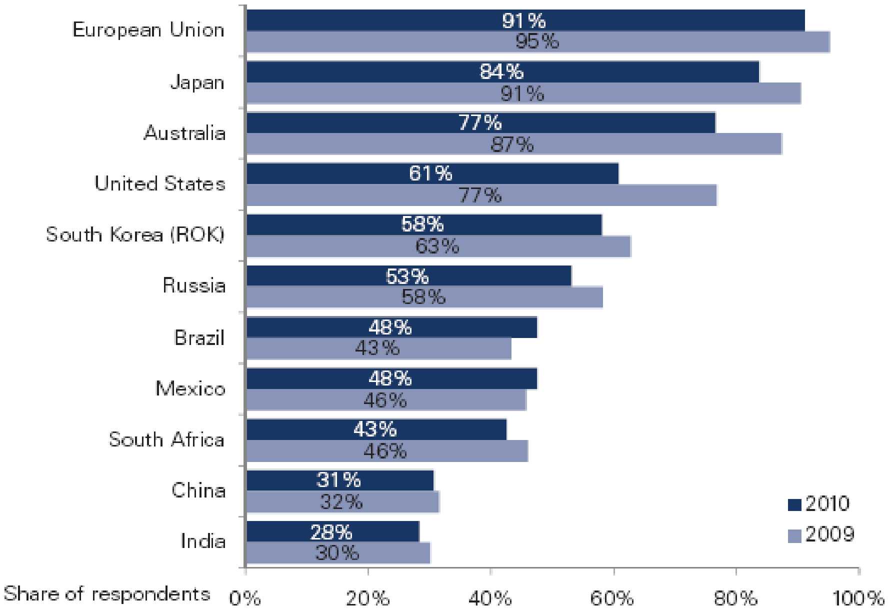
[43] ie 2,612 respondents to this question

These need to be interpreted in terms of the levels of international ambition assumed by the respondents for the periods of the projections. However, this was not asked in the Point Carbon survey; rather it asked respondents:

- Which countries they thought would participate in a post-2012 agreement with quantified commitments. The results are shown in Figure 21 and suggest increased levels of participation compared with today, eg some expectation of developing countries taking on commitments, and a majority expecting the participation of the US.

- Whether mandatory cap and trade would be introduced to a number of specified countries by 2015; the results are shown in Figure 21. In addition, 80% of 49 Japanese respondents thought that there would be a post-2012 ETS in Japan and 56% of 4,052 non-Japanese respondents thought that there would be.

Figure 20 Expectations for participants in a post-2012 global agreement (N=1,523)

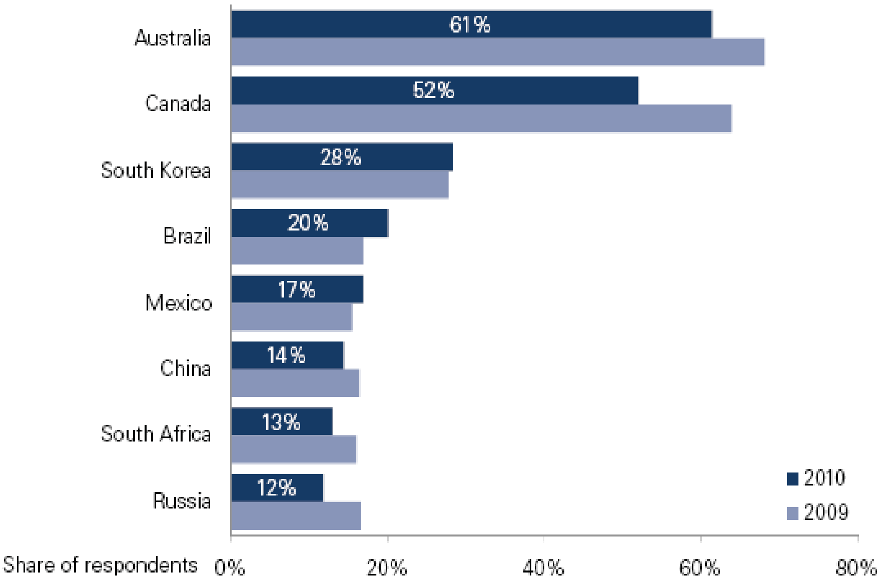


Source: Point Carbon (2010). Carbon 2010 – Return of the sovereign. Tvinnereim E and Røine K (eds)

While questions were not asked about the level of commitment, we can glean from this that there is a majority view that quantified commitments will continue and will expand from where they are currently. In addition an increasing number of countries will introduce emissions trading systems leading to an increase in global demand for emission units; there will be some corresponding increase in supply also, but this would be expected to be less than the demand effect.

However, we might assume that the price expectations of respondents reflect, to a considerable extent, their expectations over levels of participation and levels of ambition in international agreements, in the same way as this report is examining these issues. We speculate that the estimates that are equivalent to the scenarios examined in this report produce the results shown in Table 19.

Figure 21 Expectations for mandatory ETS (N=4,131)



Source: Point Carbon (2010). Carbon 2010 – Return of the sovereign. Tvinnereim E and Røine K (eds)

Table 19 Assumed Price Expectations of Survey Respondents

Scenario	Price expectation (US$/tonne)
Lower Ambition	0 - 20
Medium Ambition	20 - 50
Higher Ambition	50 - >100

8 Conclusions

8.1 Summary of Results

In this section we bring together the estimates from the wide range of different sources to provide some guidance on potential prices. We have provided estimates in original currencies (Table 20) and then converted to NZ $ using exchange rates of US$0.6:NZ$1 and €0.51:NZ$1 (Table 21). The US$ exchange rate is that used by the Ministry of Economic Development (MED) in its long run projections of energy demand;[44] the Euro rate is the average rate over the last 10 years.[45]

Table 20 Summary of Price Estimates (Original Currency)

	2020			2030		
	Lower ambition	Medium ambition	Higher ambition	Lower ambition	Medium ambition	Higher ambition
Current markets	€12/t					
Bottom-up (Annex I only)	US$0-50	US$0 – 50	US$20 – 200			
Bottom-up CDM	€10/t	€10/t	€20-25/t			
Top-down	US$5-43	US$10-52	US$100-214	US$60	$US65-70	US$10-500
Back-stop technology			US$100-150			US$30-50
Social costs	US$6			US$6		
Expert opinion	US$0-20	US$20-50	US$50- >100			

Table 21 Summary of Price Estimates (NZ$/tonne)

	2020			2030		
	Lower ambition	Medium ambition	Higher ambition	Lower ambition	Medium ambition	Higher ambition
Current markets	24					
Bottom-up (Annex I only)	0 – 83	0 – 83	33 – 330			
Bottom-up CDM	20	20	40 – 49			
Top-down	8 – 72	17 – 87	167 – 357	100	108 – 117	17 – 833
Back-stop technology			167 - 250			50 – 83
Social costs	10			10		
Expert opinion	0 - 33	33 - 83	83 - >167			

The same information is provided graphically in Figure 22. As might be expected the range increases significantly with the more ambitious levels of emission reduction.

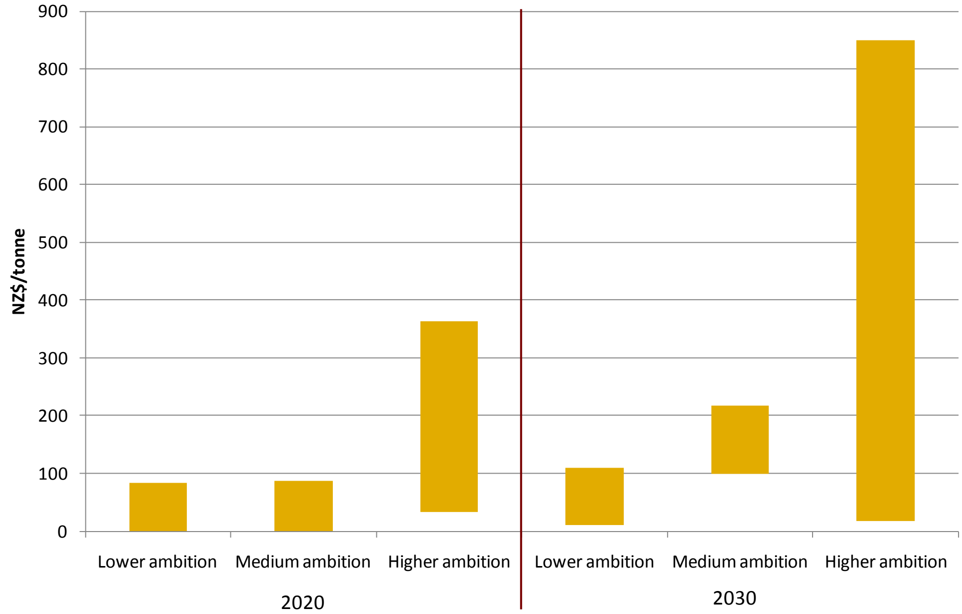
8.1.1 2020

For 2020 there is a relatively small range of prices at the lower ambition levels, and the extension into the future of current prices is within the range of estimates from models. We include the estimates from the social costs of carbon, which suggests that levels of

[44] The assumptions are set out in MED (2007) New Zealand's Energy Outlook to 2030. The same assumptions have been used for more recent updates.
[45] www.oanda.com

ambition will be kept at this low level. The expert opinion numbers involve our interpretation of the suggestions of survey respondents; they appear to be reasonable estimates of prices based on the range of data presented here.

Figure 22 Range of estimated carbon prices under different scenarios



Compared with lower ambition levels, there are fewer studies that provide estimates for the achievement of medium ambition targets. From the studies available, the top end of the range of price estimates is slightly higher than that for lower ambition levels.

At higher levels of ambition there is a large range of potential costs of carbon, reflecting different modelling assumptions. The lower estimates of the range of prices are based on the results of the bottom-up studies, whereas the top-end results originate from the top-down studies. Our view is that, because they reflect actual behavioural responses to prices, rather than based on theoretical responses, the top-down studies will be providing more accurate estimates.

8.1.2 2030

There are far fewer studies that extend out to 2030 and this affects the uncertainties around the numbers presented. In particular the range of prices estimated for the higher ambition levels is very broad.

8.2 Best Guess Estimates

Our best guess estimates of prices are given in Table 22, along with possible ranges.

Table 22 Summary of Price Estimates under different Policy Scenarios (NZ$/tonne)

Scenario	2020 Low Estimate	2020 Best guess	2020 High Estimate	2030 Low Estimate	2030 Best guess	2030 High Estimate
Lower ambition	20	**35**	70	20	**50**	100
Medium ambition	25	**50**	85	35	**100**	150
Higher ambition	50	**200**	350	50	**150**	500

[1] Level of global ambition in greenhouse gas emission reduction

In all cases we assume that New Zealand links its ETS to international markets and that international prices are what sets prices in New Zealand.

The best guess price for 2020 is NZ$35/tonne at the lower ambition levels. This is higher than existing prices and reflects factors that include:

- The CER price for 2012 (c€12/tonne = NZ$24/tonne at 0.5 exchange rate) escalated at a real compound interest rate of 5%. This is based on an assumption that the price of exhaustible resources would grow at a rate equal to the discount rate.[46]

- It is less than the median point of expected prices from the various modelling exercises. This reflects an assumption that, with the use of market-based instruments, actual (ex-post) costs tend to be less than predicted costs (ex-ante).[47]

For 2030, escalating the price at 5% real would result in a price of approximately $57/tonne at the lower ambition level; this has been rounded down, partly to reflect expectations of technological development, consistent with the findings of lower ex-post costs.

For the medium and higher ambition prices, we have chosen numbers closer to the median of the range of estimates.

For the higher ambition scenario, we assume that the scenario is consistent with an earlier introduction of higher emission prices, that this stimulates the development and introduction of new low-emissions technologies and fuels and that the cost of carbon is limited by some backstop technology. We assume that such a technology becomes widespread by 2030, although not by 2020. This means that the assumed best guess higher ambition cost is lower in 2030 than in 2020.

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[46] The theoretical basis for this is Harold Hotelling's work on the economics of exhaustible resources (Hotelling H (1931) The Economics of Exhaustible Resources. Journal of Political Economy 39:137-175). The theory is that if the price went up at faster than this rate, holders of emission units would hold on to them as they will be more valuable next year than this; as a result firms will cut emissions more. But if prices are estimated to rise at a rate lower than the discount rate, firms will do less to reduce emissions, more will be consumed in the current period. As a result prices will change across all periods such that prices rise consistently with the "Hotelling rule."

[47] See for example Winston Harrington, Richard D. Morgenstern, and Peter Nelson (1999) On the Accuracy of Regulatory Cost Estimates. Resources for the Future Discussion Paper 99-18.

Appendix 1 – Approaches to Modelling

There are a number of different approaches to modelling and forecasting carbon prices. These different approaches can typically be classified as Bottom-up or Top-down approaches. Top-down and bottom-up models differ in the extent to which they specify technologies and in the way that changes in demand are calculated in response to changes in price and other variables.[48]

Bottom-Up Models

Bottom-up models are project or technology specific. They may contain databases of information about individual technologies either as sources of energy supply or of energy demand. Combined with an exogenously produced projection of economic activity, eg GDP, these models assess the energy requirements, and the technologies that will be used. They can respond to price or technology regulations by replacing one set of technologies with another. The subsequent changes in total energy consumption and the fuels used results in changes in emissions. However this limits the focus to technical mitigation measures and typically keeps the structure of demand and volumes fixed.[49]

Bottom-Up cost curves represent the ranked costs of mitigation measures with the assumption that mitigation measures are adopted in order from least to highest cost. Bottom-up models will often estimate low costs of emission reduction because they include assessments of emission reductions at low or negative cost, eg energy efficiency measures. In contrast, top-down models assume that all actions that are different from existing activities come at a cost.

Top-Down Models

Top-down models specify demand as a set of relationships which represent the way that some aggregation of demand responds to energy prices and other factors such as GDP and population growth. They contain very little information about any individual economic sector or the nature of demand. Typically they correlate historical demand data with driver variables, via regression analysis, to establish econometric equations that are used to project future demand. Projections of the explanatory variables, eg GDP, population and input fuel prices, are exogenous inputs to the models. Outputs include variables such as demand, energy supplies by fuel and final prices.

Top-down models include general equilibrium (GE) and other macro-economic models that are partial equilibrium (PE) models. The fundamental distinction between PE and GE models is with regard to the breadth of coverage of the economy. GE models attempt to describe the entire economy, including the relevant market (energy) and the relationship to other areas of the economy and feedback effects from these to the original (energy) market. GE models find solutions that achieve equilibrium between supply and demand simultaneously in all markets (capital, labour, resources), allowing

[48] See, for example Covec and Infometrics (2005) Review of MED Energy Modelling Capability. Report for Ministry of Economic Development

[49] Amann M, Rafjal P and Höhne N (2009) GHG Mitigation potential in Annex I countries. Comparison of model estimates for 2020. Interim Report. IIASA. IR-09-034

for feedback effects between separate markets. In contrast, PE models concentrate on a particular sector of the economy, with all others being treated as irrelevant to the model, in the sense that what goes on in the sectors covered by the PE model does not materially affect what goes on in the excluded sectors, and vice versa.

There are also differences in the mix of exogenous/endogenous variables in PE and GE models. Values for endogenous variables are generated by the models, whereas values for exogenous variables need to set by the user. Exogenous variables are of three types:

1. determined outside the model system (such as world oil prices in a GE model);
2. set by policy (such as the fiscal deficit/surplus); or
3. stand in for situations where a reliable equation is not readily apparent (such as in wage setting behaviour).

The characteristics of the different models are given in Table 23.

Table 23 Characteristics of Top-Down and Bottom-Up Models

Top-down	Bottom-up
Use an "economic approach"	Use an "engineering approach"
Can not easily represent technologies	Allow for detailed description of technologies
Reflect available technologies adopted by the market, but usually allow for non-specific technological progress	Reflect currently known technological potential
The most efficient technologies are given by the production frontier (which is set by the market), but the frontier may be shifted out by non-specific technological progress	Efficient technologies, if known, can lie beyond the economic production frontier suggested by market behaviour
Use relatively aggregated data for predictive and analytical purposes	Use disaggregated data for exploratory purposes
Are based on observed market behaviour	Are independent of observed market behaviour
May disregard the technically most efficient technologies available, thus underestimate known potential for efficiency improvements	Disregard market thresholds (hidden costs and other constraints), thus overestimate the potential for efficiency improvements
Determine energy demand through aggregate economic indices (GNP, price elasticities), but vary in addressing energy supply	Represent supply technologies in detail using disaggregated data, but vary in addressing energy consumption
Endogenise behavioural relationships	Assess costs of known technological options directly

Source: Based on van Beeck N (1999) Classification of Energy Models. Tilburg University & Eindhoven University of Technology. In: Covec and Infometrics (2005) Review of MED Energy Modelling Capability. Report for Ministry of Economic Development

Linked Bottom-up/Top-Down Models combine elements of both top-down and bottom up models.

Integrated Assessment Models

Integrated Assessment Models (IAMs) are another class of models that combine elements of different disciplines. Typically they include a bottom-up or top-down model **plus** some representation of the effects of emissions. For example they might relate emissions to atmospheric concentrations, thus allowing models to be run to estimate the costs of achieving a given atmospheric concentration or temperature increase, or to undertake cost benefit analyses that include costs of damage avoided with costs of mitigation.

Different Purposes

These approaches each serve different purposes. Top-down models have the advantage of fully considering all the "costs" of carbon mitigation, as well as feedback mechanisms and changes in demand and supply with a carbon price. Bottom-up models are effective for considering the impact of specific technologies or policies for carbon mitigation and carbon prices. The type of model used should reflect the policy and technology under consideration.

Table 24 Comparison of Models

Model	Model type	Key Assumptions						Carbon Price[50]
		Brief Description	Energy	Regions	Economic Activity and Land use	Technological Change	Green House Gasses and Abatement	
AIM	Bottom-up	3 main models; Greenhouse Gas Emission model, Global Climate Change model, Climate Change Impact Model.		Contains country and global modules and information from a detailed GIS.	GDP growth of 32% from 2005 to 2020 (Market exchange rate)	Partially endogenous technology module. Baseline has frozen mitigation technology	Implementation 2005-2020	Relatively high
DNE21+	Bottom-up	Technological change partially endogenous.	Energy Systems model minimises world total costs of energy systems.	World divided in 50 regions.	GDP growth of 34% from 2005 to 2020 (market exchange rate)	Baseline mitigation technology includes measures with cost savings and mitigation portfolio includes only technology that requires a positive carbon price.	Model also includes energy-unrelated CO2 and 5 types of non-CO2 Green House Gasses. Implementation 2006-2020	Mid-high
GAINS	Bottom-up	Quantifies GHG mitigation potentials and costs for Annex I countries.			Uses exogenous activity projections. GDP growth of 43-45% from 2005 to 2020 (PPP)	Baseline technology based on historical trends.	Implementation 2010-2020	WEO2007 Mid WEO2008 Mid

[50] Ranking of Carbon price is based on relative price of achieving a specific reduction target from the graph shown in Figure 8

Model	Model type	Key Assumptions						Carbon Price[50]
		Brief Description	**Energy**	**Regions**	**Economic Activity and Land use**	**Technological Change**	**Green House Gasses and Abatement**	
GTEM	Computable General Equilibrium model	Detailed model of the Australian economy		Australia only	Recursive mechanism to explain investment and sluggish adjustment in factor markets. GDP growth of 34% from 2005 to 2020 (PPP)		Model produces abatement curves which represent the level of abatement at different prices, rather than the cost of abatement. Implementation 2013-2020	Low
IMAGE	Bottom-up Integrated Assessment Model	Modules describe long term dynamics of global environmental change including air pollution, climate change and land-use change.	Includes global energy model TIMER which describes primary and secondary energy production and related GHGs.		Land and climate modules describe dynamics of agriculture, natural vegetation and climate change. GDP growth of 42% from 2005 to 2020.	Baseline mitigation technology includes measures with cost savings and mitigation portfolio includes only technology that requires a positive carbon price.	Includes FAIR-SiMCaP 2.0 model that combines abatement costs from two models. Implementation 2000-2020	Low
McKinsey	Bottom-up cost curves	Based on abatement potential and cost		21 world regions.	GDP growth of 39% from 2005 to 2020 (Market exchange rate)		Over 200 abatement levers. Implementation 2010-2020	Highest

Model	Model type	Key Assumptions						Carbon Price[50]
		Brief Description	Energy	Regions	Economic Activity and Land use	Technological Change	Green House Gasses and Abatement	
OECD	Computable General Equilibrium model		8 energy sectors in each region/country. Energy efficiency is partly exogenous.	Built on a database of national economies; 12 countries/regions. International trade prices and flows are fully endogenous.	25 sectors in each region/country, 3 rep agents. Production under cost minimisation, perfect markets and constant returns to scale. Production technology - nested constant elasticity of substitution. Land use change emissions not included. GDP growth 44% from 2005 to 2020. (Market exchange rate)	Capital accumulation included as in neoclassical growth models. Technological change is exogenous. Baseline technology based on historical trends.	6 GHG's included Revenues of carbon tax are indirectly rebated to the household. Implementation 2013-2020	Mid-low

Model	Model type	Key Assumptions						Carbon Price[50]
		Brief Description	Energy	Regions	Economic Activity and Land use	Technological Change	Green House Gasses and Abatement	
POLES	Linked bottom-up/top-down		Global simulation of the energy system. Recursive simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through the international energy price. Energy prices determined endogenously. Oil price depends on relative scarcity of oil reserves.	Hierarchical structure of interconnected modules at the international, regional and national levels. World is separated into 47 regions.	Technology detailed moduels for energy-intensive sectors including power generation, iron and steel, the chemical sector, aluminium production, cement, non-ferrous minerals and modal transportsectors. GDP growth of 35% from 2005 to 2020.	Baseline mitigation technology includes measures with cost savings and mitigation portfolio includes only technology that requires a positive carbon price.	Implementation 2010-2020	Mid

Glossary

Annex B	An annex of the Kyoto Protocol that sets out the countries (or parties) with quantified emission limitation or reduction commitments, and what those commitments are. Countries listed in Annex B are allowed to participate in emissions trading under the Kyoto Protocol
Annex I Party	A developed country or Economy in Transition listed in Annex I of the United Nations Framework Convention on Climate Change. These parties aim to return their emissions to their 1990 level by 2000
Assigned Amount	The initial quantity of emission units assigned to an Annex B party under the Kyoto Protocol which, in the absence of any trading or the addition of removal units, define the maximum quantity of emissions that a party can emit during a commitment period. During the first commitment period under the Kyoto Protocol (2008-12) the assigned amount is equal to the quantified emission limitation or reduction commitment as a percentage, times it base year (1990) emissions times five. For New Zealand this is equal to 309.5 million tonnes of CO_2-e.
Assigned Amount Unit (AAU)	The emission units allocated to the Annex B countries under the Kyoto Protocol on the basis of their quantified emission target for the first commitment period, 2008 to 2012. One AAU is equal to one tonne of carbon dioxide equivalent.
Carbon dioxide equivalent (CO_2-e)	The quantity of a given greenhouse gas multiplied by its global warming potential (GWP), which equates its global warming impact relative to carbon dioxide (CO_2). This is the standard unit for comparing the degree of warming that can be caused by emissions of different greenhouse gases.
Certified Emission Reduction (CER)	A credit produced by a project approved under the Clean Development Mechanism (CDM). Each CER is equivalent to an allowance to emit one tonne of CO_2, and surrendering a CER can be counted towards meeting Kyoto targets.
Clean Development Mechanism (CDM)	A Kyoto Protocol mechanism that allows emission reduction and afforestation/reforestation projects with sustainable development benefits to be implemented in developing countries that have ratified the Kyoto Protocol. CDM projects earn particular Kyoto units, which can be used by Annex B parties to help meet their quantified emission limitation and reduction commitments under the Kyoto Protocol.
Commitment Period Reserve	A rule within the Kyoto Protocol that requires each party with binding targets to hold a minimum number of Kyoto units in its national registry. In New Zealand's case this means that Kyoto units covering 90 per cent of our assigned amount (under the

	Kyoto Protocol) must be held in the registry at any point in time throughout the first commitment period (2008–2012). If this limit is reached, the registry would effectively close to outgoing international transfers until more Kyoto units (AAUs, CERs, ERUs or RMUs) were transferred into the registry.
Emission Reduction Unit (ERU)	A credit produced by an emission reduction or emission removals from a Joint Implementation (JI) project. Each ERU is equivalent to an allowance to emit one tonne of CO_2, and surrendering an ERU can be counted towards meeting Kyoto targets.
Emissions Trading System (ETS)	A system in which emissions are regulated through tradable rights to emit. Typically under an ETS, emitters must hold, or surrender to the government, an emissions allowance (or emissions unit) that provides them with a legal right to emit. Each emissions allowance is specified as a certain quantity of emissions (eg 1 tonne) and an emitter must hold or surrender at least as many allowances to emit as its total level of emissions within a specified time period.
Joint Implementation (JI)	A system established under Article 6 of the Kyoto Protocol that allows a country in Annex B to produce emission reduction units (ERUs) from a project that reduces emissions or removes greenhouse gases from the atmosphere. A JI project must have effects that are additional to what would otherwise have occurred. Projects must have approval of the host Party and participants have to be authorized to participate by a Party involved in the project.
Kyoto Protocol	A protocol to the United Nations Framework Convention on Climate Change that includes emissions limitation or reduction commitments for parties listed in Annex B.
Kyoto Unit	The collective name given to the different units that can be used to meet commitments under the Kyoto Protocol. Each Kyoto Unit provides the holder with the right to emit 1 tonne of CO_2-equivalents during a commitment period. The Kyoto Units are Assigned amount Units (AAUs), Emission Reduction Units (ERUs), Certified Emission Reductions (CERs) and Removal Units (RMUs).
Land Use, Land Use Change and Forestry (LULUCF)	A greenhouse gas inventory category that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities.
New Zealand Unit (NZU)	The emissions allowance that is defined under the New Zealand Emissions Trading System (NZ ETS). A participant in the NZ ETS must surrender 1 NZU for each tonne of emissions from each activity that is included in the ETS.
Removal Unit (RMU)	A Kyoto Protocol unit generated in an Annex B Party by LULUCF activities that absorb CO_2. One RMU is equal to an allowance to emit 1 tonne of CO_2 equivalent.

United Nations Framework Convention on Climate Change (UNFCCC)	An international treaty on climate change that came into force in 1992. It aims to stabilise greenhouse gas concentrations at a level that avoids dangerous human interference with the climate system.